ENVIRONMENTALLY SUSTAINABLE INDUSTRIAL DEVELOPMENT

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Environmentally sustainable industrial development

Recommended for publishing by the Academic Council of the National Metallurgical Academy of Ukraine
(protocol №7 of 06.07.2017)

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This book was developed in the frames of TEMPUS project “Higher engineering training for environmentally sustainable industrial development” (543966-TEMPUS-1-2013-1-BE-TEMPUS-JPCR; http://hetes.com.ua/) and aims to bring together under single cover interdisciplinary aspects related to environmentally sustainable development of important industrial sectors such as mining, oil & gas exploration and processing, energy, iron & steelmaking and machinery manufacturing. This book also embraces general aspects of climate science, climatic change observations, international climate agenda and international mitigation mechanisms. It also delivers the notion of eco-innovation. The book is written by the international group of authors representing Belgium, United Kingdom and Ukraine. It might be used as a textbook to support teaching relevant disciplines on Master and PhD levels. The book will be also useful for the industry professionals and authorities engaged with implementation of sustainable development goals into practice.
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Recommended as a textbook for teaching the disciplines related to environmentally sustainable industrial development on Master and PhD levels of study


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**Introduction**

Environmental sustainability becomes increasingly important issue embracing all aspects of socio-economic development in the modern world. Unbeatable evidence of climate change and reinforcement of climate policies have triggered paradigmal shift of driving vectors influencing the industrial development and, thus, reshaping the trajectories of technological innovation.

The EU-funded TEMPUS project “Higher engineering training for environmentally sustainable industrial development” (543966-TEMPUS-1-2013-1-BE-TEMPUS-JPCR; http://hetes.com.ua/), performed during 2013-2017 by the consortium of partners from Belgium, Spain, Sweden, United Kingdom and Ukraine, aimed to improve the relevance of higher engineering education in Ukraine towards the challenges of current and future industrial transformation, sustainable development and climate stabilization.

This book is one of the HETES project deliverables. It brings together under single cover interdisciplinary topics related to environmentally sustainable development of important industrial sectors such as mining, oil & gas exploration and processing, energy, iron & steelmaking and machinery manufacturing. This book also embraces general aspects of climate science, climatic change observations, international climate agenda and international mitigation mechanisms. It also delivers the notion of eco-innovation.

The book is written by the international group of authors representing Katholieke Universiteit Leuven (Belgium), Buckinghamshire New University (UK), four Ukrainian higher education institutions (National Metallurgical Academy of Ukraine, Donetsk National Technical University, Ivano-Frankivsk National Technical University of Oil and Gas, Kryvyi Rih National University) and leading Ukrainian R&D organization in a field - State Enterprise «Ukrainian research & technology center of metallurgy industry «Energostal»».

The book intends to support the teaching of relevant disciplines on the Master and the PhD levels. Authors also hope that the book will be useful reference for industry professionals and authorities engaged with implementation of sustainable development goals into practice.

On behalf of the Editorial Board

Volodymyr Shatokha
1. Introduction to Earth climate system and climate change factors

V. Shatokha

1.1. Atmospheric energy balance and greenhouse effect

Climate of the Earth is constantly changing throughout the history of our planet being exposed to complex interaction of the large scale processes occurring within our atmosphere and in outer space.

Fig.1.1 schematically illustrates the flows of energy among the outer space, the atmosphere and the Earth's surface and shows how the combination of these flows retains heat, creating a greenhouse effect. Sun provides almost the entire energy the Earth receives from the outside. The energy budget diagram shown in Fig 1.1 shows the most updated understanding of energy flows into and away from the Earth. Provided by NASA [1] it is based on the work of many scientists over more than 100 years, with the most recent measurements from the Clouds and the Earth’s Radiant Energy System (CERES) [2] satellite instrument providing high accuracy data of the radiation components (reflected solar and emitted infrared radiation fluxes).

The source of energy for the Earth system is the Sun. This energy comes primarily in the form of visible sunlight. Taking into account night and day and seasonal changes, on average 340.4 W/m² of energy enters the Earth system. About 30% of sunlight is reflected directly back to space: 77 W/m² by clouds and 22.9 W/m² by the Earth surface (notably by its bright regions covered by ice and snow). This percentage is called albedo. The rest 70% of the sunlight energy is absorbed by the Earth system – surface and atmosphere – and heats it up.

In case if all the energy obtained by our planet would be limited to this amount, not considering Earth’s reflectivity, its surface would have a temperature of about -18°C. Instead, the Earth's atmosphere absorbs part of the radiation heat, recirculated through the so-called greenhouse effect, which gives an additional 324 W/m² and provides the average temperature of the Earth's surface about +14 °C [3].

The most common greenhouse gas (i.e. gas that absorbs thermal radiation, contributing the greenhouse effect) is water vapour. Like any other gas, water vapour has the ability to absorb infrared (i.e. - thermal) radiation only within certain wavelength ranges, while within the rest of ranges it is "transparent" to radiation. These ranges - the so-called "steam windows" - have the highest transparency for the wavelength of 10 microns. Existing gas composition in the atmosphere and its transparency in infrared spectrum controls certain balance of energy, when the Earth is neither too cooled nor overheated by solar radiation, because certain fraction of infrared radiation penetrates to outer space.

However, the infrared radiation absorption wavelengths vary from one gas to another. In particular, CO₂ absorbs infrared radiation in the wavelength range of more than 12-13 microns, partially overlapping the "steam window", and therefore increasing the concentration of this gas alters energy balance and enhancing greenhouse effect. Graphically this phenomenon is illustrated in Fig.1.2, according to NASA [4].
In addition to CO2, the other gases causing greenhouse effect (referred to as greenhouse gases, GHG) are: methane, CH4; nitrous oxide, N2O; hydrofluorocarbons compounds; perfluorocarbon compounds; sulphur hexafluoride, SF6.

These gases absorb the infrared radiation much more actively than CO2, however, given the quantitative concentration and average life expectancy of the molecule in the atmosphere, the biggest contribution to the greenhouse effect brings carbon dioxide. The second most important gas is methane. To simplify the quantitative assessment of the GHG emissions, conversion coefficients to the carbon dioxide equivalent - the so-called global warming potential (GWP, global warming potential) values - are used. GWP estimates the infrared-absorbing ability of a gas in relation to carbon dioxide, for which GWP is equal to 1. GWP values are time depended: some of them can have a big impact but decompose faster than others. It should be noted that the GWP values are not fully defined and various sources give different data. Table 1.1 provides data on greenhouse gases according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (hereinafter - IPCC) data [5].
Table 1.1: Lifetime and global warming potential of various greenhouse gases

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>Lifetime of the molecule in the atmosphere (years)</th>
<th>GWP for the period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20 years</td>
</tr>
<tr>
<td>CO₂</td>
<td>30-95¹</td>
<td>1</td>
</tr>
<tr>
<td>CH₄</td>
<td>12</td>
<td>72</td>
</tr>
<tr>
<td>N₂O</td>
<td>114</td>
<td>289</td>
</tr>
<tr>
<td>CHF₃</td>
<td>270</td>
<td>12000</td>
</tr>
<tr>
<td>CH₂ FCF₃</td>
<td>14</td>
<td>3830</td>
</tr>
<tr>
<td>SF₆</td>
<td>3200</td>
<td>16300</td>
</tr>
<tr>
<td>CF₄</td>
<td>50000</td>
<td>5210</td>
</tr>
</tbody>
</table>

1.2. Climate system observations

The phenomenon of global warming caused by human activity, the presence of which was actively discussed over the last two decades and has been unquestionably confirmed in the 5th Assessment Report of the IPCC [6] - the result of 6 years' work by more than 800 researchers from 70 countries. New evidences of the ongoing climate change and the climate change forecast are based on the results of independent research that includes observation of the climate system, studying paleoclimatic data, theoretical studies and modelling of the climate processes. Application of these methods allowed for obtaining a complete picture of the variable and long-term changes in the atmosphere, ocean, cryosphere and the Earth's surface. The results of observations might be briefly summarised as follows:

- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (Fig. 1.3, 1.4).
- Earth’s surface in each of the last 3 decades has been successively warmer than in any preceding decade since 1850 (Fig.1.5). In the Northern Hemisphere, 1983–2012 was the warmest 30-year period of the last 1400 years.
- The globally averaged combined land and ocean surface temperature data show a warming of 0.85 °C from 1880 to 2012. The total increase between the average of the 1850–1900 and the 2003–2012 periods is 0.78 °C (Fig. 1.3).
- For the longest period when data on regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming.

¹ Lifetime of molecules in the atmosphere is very difficult to determine due to many processes a substance is involved in – ocean’s absorption, photosynthesis and others.
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. It is certain that the upper ocean (0–700 m) warmed from 1971 to 2010. 
- On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 °C per decade from 1971 to 2010.
- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (Fig.1.4).
- The average rate of ice loss from glaciers around the world, excluding glaciers on the periphery of the ice sheets, was 226 Gt per year from 1971 to 1993, and 275 Gt per year from 1993 to 2009.
- Permafrost temperatures have increased in most regions since the early 1980s. Observed warming was up to 3°C in parts of Northern Alaska (early 1980s to mid-2000s) and up to 2°C in parts of the Russian European North (1971 to 2010). In the latter region, a considerable reduction in permafrost thickness and areal extent has been observed from 1975 to 2005.
- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. From 1901 to 2010, global mean sea level rose by 0.19 m (Fig.1.4).
- The atmospheric concentrations of greenhouse gases - CO₂, CH₄ and N₂O - have increased to levels unprecedented in at least the last 800,000 years. CO₂ concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic CO₂, causing ocean acidification (Fig. 1.5).
- The atmospheric GHG concentration has been increasing since 1750 due to human activity. In 2011 the concentrations of CO₂, CH₄ and N₂O were 391 ppm, 1803 ppb², and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively.
- From 1750 to 2011, CO₂ emissions from fossil fuel combustion and cement production have released 375 GtC³ to the atmosphere, while deforestation and other land use change are estimated to have released 180 GtC. This results in cumulative anthropogenic emissions of 555 GtC.
- Of these cumulative anthropogenic CO₂ emissions, 240 GtC have accumulated in the atmosphere, 155 GtC have been taken up by the ocean and 160 GtC have accumulated in natural terrestrial ecosystems.

² ppm - parts per million; ppb - parts per billion
³ Gigatonne of carbon
- The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era, corresponding to a 26% increase in hydrogen ion concentration.

Fig. 1.3. Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

Fig. 1.4. Change of the Northern Hemisphere snow cover, Arctic summer sea ice extent and global average sea level

Fig. 1.5. Change of CO₂ in the atmosphere (red), partial pressure of CO₂ dissolved at the ocean surface (blue) and surface ocean acidity (green)

1.3. The factors of climate change

The climate change is a result of an imbalance of natural and anthropogenic factors that cause change in the energy system of the Earth. A key to understand and
to evaluate quantitatively these factors is the concept of radiative forcing. In climatology radiative forcing is a difference between the radiation energy that the Earth receives from the Sun, and the energy radiated by the Earth into outer space. As shown previously (Fig.1.1), an important factor in this balance is the presence in the atmosphere of greenhouse gases, including CO₂.

IPCC gives the following definition: "Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism" [7].

Fig.1.6 illustrates the relationship between the radiative forcing and other aspects of climate change. Anthropogenic factors and natural processes directly or indirectly cause a change of the factors that influence the climate. In general, these processes are not only followed by specific - positive or negative - changes in radiative forcing: they also incur secondary effects, such as a change in evaporation. Some biogeochemical processes may feed the consequences of climate change back to the factors that cause climate change (e.g. global warming increases the emission of methane from wetlands, which being a greenhouse gas causes further warming). Therefore radiative forcing and the subsequent radiative effects lead to climate perturbations and responses. The potential opportunity to mitigate climate change by influencing the human activity is depicted in Fig.1.6 by the dashed line.

![Components of the Climate Change Process](image)

Fig.1.6. Illustration of radiative forcing due to other factors of climate change (according to [8])

The 5th assessment report uses the values of radiative forcing that took place in 2011 relative to pre-industrial conditions (before 1750), expressed in W/m². Positive radiative forcing values indicate heating, whereas negative values are indicative of cooling of the earth's surface. Radiative forcing is estimated based on direct (in-situ)
measurements, remote observations, studies of the properties of greenhouse gases and aerosols, and quantitative modelling of the processes observed.

The most important conclusions of the 5th IPCC Assessment Report about the impacts of climate change are [6]:
- Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO₂ since 1750.
- The total natural radiative forcing from solar irradiance changes and stratospheric volcanic aerosols made only a small contribution to the net radiative forcing throughout the last century, except for brief periods after large volcanic eruptions.

1.4. Climate change forecast

The change of a climate system might be forecasted based on a number of climate models of various complexity that simulate the climate system, using certain scenarios of anthropogenic factors change. IPCC uses four scenarios, called Representative Concentration Pathways (RCP). These scenarios describe four options of the future, different by the quantity of GHG emitted into the atmosphere in the coming years and the dynamics by which these quantities can be achieved. These scenarios are abbreviated as RCP2.6, RCP4.5, RCP6 and RCP8.5, referring to possible radiative forcing level to be achieved by 2100 relative to pre-industrial era (+2.6, +4.5, +6.0 and +8.5 W/m², respectively).

Scenarios take into account huge number of factors including policies and legislation to limit anthropogenic effect on climate, population growth, GDP growth, the use of new technologies and materials, and the structure of energy balance, fossil fuels depletion dynamics and many others (some of these factors are taken into account both globally and for different regions of the planet). Models developed cover an extremely wide range of issues - from changing the structure of human nutrition (that causes relevant changes in agriculture) to forecasting the economic feasibility of using hydrogen as a fuel for transport over the next century.

Table 1.2 shows the results of the forecast for the change of the global mean surface temperature for the middle and end of the XXI century relative to the period of 1986-2005 under different RCP scenarios by the IPPC [9]. Some simulation results on the primary energy use under different scenarios are shown in Fig.1.8.

The most optimistic RCP2.6 scenario is aimed at limiting the average global temperature growth within 2°C (radiative forcing increases to 2.6 W/m²) compared to pre-industrial era. Fig.1.9 presents the modelling results for primary energy consumption according to the baseline scenario and RCP2.6 [10]. The baseline scenario projects the modern technological trends into the future without application of political and legal mechanisms to limit GHG emissions. RCP2.6 scenario employs
strict legal limitations for the GHG emissions and implements the carbon capture and storage (CCS) technology, enabling capture of CO₂ from the emissions and its storage in a manner that will prevent it from entering the atmosphere.

It should be noted that, although RCP2.6 scenario optimistically depicts our future, its social, political, technological and economic viability is not evident today.

Table 1.2: Projections for the average global surface temperature change for the middle and end of the XXI century relative to the period of 1986-2005 under different RCP scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2046-2065</th>
<th>2081-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP2.6</td>
<td>1.0 (0.4 to 1.6)</td>
<td>1.0 (0.3 to 1.7)</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>1.4 (0.9 to 2.0)</td>
<td>1.8 (1.1 to 2.6)</td>
</tr>
<tr>
<td>RCP6.0</td>
<td>1.3 (0.8 to 1.8)</td>
<td>2.2 (1.4 to 3.1)</td>
</tr>
<tr>
<td>RCP8.5</td>
<td>2.0 (1.4 to 2.6)</td>
<td>3.7 (2.6 to 4.8)</td>
</tr>
</tbody>
</table>

Fig.1.8. Forecast and structure of the primary energy use for different scenarios (EJ = 10¹⁸J) [11]

Fig.1.9. Forecast for the primary energy use in the baseline scenario (a) and RCP2.6 (b)
More details on the RCP scenarios, presented in a popular form, can be found in the work [12]. Database of the RCP scenarios is available at an open online resource RCP Database [13], which allows the user to simulate the changes of GHG emissions on a global scale and for certain regions.

In all of the RCP scenarios CO₂ atmospheric concentration is higher than the current level due to the increase of total CO₂ emissions in the XXI century. Fig.1.10 shows CO₂ equivalent atmospheric concentration change under the four scenarios, where the influence of various substances affecting radiative power (CH₄, NO₂, aerosols, etc.) is adjusted to CO₂ equivalent.

![Graph showing CO₂ equivalent concentration during the XXI century under various RCP scenarios](image)

**Fig.1.10. CO₂ equivalent concentration during the XXI century under various RCP scenarios**

Projections for future global and regional climate change, developed in the IPCC 5th Assessment Report might be summarised as follows⁴:

- Continued GHG emissions will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained GHG emissions reduction.
- Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 in all scenarios except RCP2.6. It is likely to exceed 2°C in RCP6.0 and RCP8.5, and more likely than not to exceed 2°C in RCP4.5. Warming will continue beyond 2100 in all scenarios except RCP2.6. It will exhibit interannual-to-decadal variability and will not be regionally uniform (Fig.1.11).
- Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry

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⁴ Text below is a very brief summary of the AR5 conclusions. It is highly recommended to refer to the original text [9] for more exhaustive information.
regions and between wet and dry seasons will increase, although there may be regional exceptions.
- The global oceans will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation.
- The Arctic sea ice cover will continue to shrink and thin and the Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease.
- Global mean sea level will continue to rise during the 21st century (Fig.1.12). Under all scenarios, the rate of sea level rise will exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.
- Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO2 in the atmosphere. Further uptake of carbon by the ocean will increase ocean acidification.
- Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if GHG emissions are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO2.
- Limiting the warming caused by anthropogenic CO2 emissions alone to less than 2°C will require cumulative CO2 emissions from all anthropogenic sources to stay between 0 and about 1000 GtC (3670 GtCO2) since that period. An amount of 515 GtC (1890 GtCO2), was already emitted by 2011.
- Anthropogenic climate change resulting from CO2 emissions is largely irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO2 from the atmosphere over a sustained period. Surface temperatures will remain approximately constant at elevated levels for many centuries even after a complete cessation of net anthropogenic CO2 emissions. Due to slow heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40% of emitted CO2 will remain in the atmosphere longer than 1000 years.
- Methods that aim to deliberately alter the climate system to counter climate change, termed geoengineering, have been proposed. Limited knowledge precludes a comprehensive assessment of both Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) and their impact on the climate system. CDR methods have biogeochemical and technological limitations to their potential on a global scale. Modelling indicates that SRM methods, if realizable, have the potential to substantially offset a global temperature rise, but they would also modify the global water cycle, and would not reduce
ocean acidification. CDR and SRM methods carry side effects and long-term consequences on a global scale.

Fig.1.11. Projections of average surface temperature of the Earth for 2081-2100 compared to 1986-2005

The summary above shows that urgent action is needed to significantly reduce the GHG emissions and to mitigate climate change in the XXI century and in the more distant future.

Some pathways to mitigate climate change, the implementation of which can ensure the maintenance of global warming within the limits of 2 °C relative to pre-industrial level are highlighted in the Headline statements from the Summary for Policymakers by IPCC [14]. These pathways require significant emission reductions over several decades notably achieved through the technological advancement aimed at zero GHG emissions by the end of the century. To achieve sustainable development targets many technological, economic, social and organizational problems shall be solved. The gravity of the challenge will rise significantly if problem solving is delayed. Setting environmental objectives less ambitious than the aforementioned 2°C target does not tackle the problem, but just delays it's solving with evidently worse final result.

Fig.1.12. Projections of global mean sea level rise over the 21st century relative to 1986–2005 for RCP2.6 (blue) and RCP8.5 (pink).

Efficient mitigation of climate change requires an integrated approach at all levels of activity including governance, development of eco-innovations, attraction of
investment, infrastructural improvements, changes in human lifestyle and behaviour etc. Appropriate policies shall be implemented at the international, national and regional levels. Nevertheless, today it is still possible to link the measures to prevent climate change with reaching the social targets.

References
2. "Greenhouse Effect" by Robert A. Rohde
1.5. Energy Outlook

*M.Karpash*

Global demand shows no signs of slowing, increasing another 2 million B/D in 2011 and still increasing even during the continuous price drop starting from 2014. Both international and national oil companies are anticipating continued strong energy demand and sustained reliance on fossil fuels as the energy product of choice.

Two new long-term outlooks agree that global population growth and rising incomes will propel energy demand, primarily in developing countries. The most significant shift in the energy mix going forward is increasing reliance on natural gas and a decline in coal use for electricity.

BP’s Energy Outlook 2030 predicts that world energy consumptions will grow 1.6% a year from 2010 to 2030, although energy efficiency will improve sharply, restraining overall growth in energy consumption. Almost all of the growth will come from non-OECD countries. Use of natural gas and no fossil fuels will gain at the expense of coal, with gas expected to meet 31% of the growth in global consumption. Although heavy reliance on fossil fuels will continue, gas consumption also will take market share away from oil. The report forecasts that oil demand growth will come largely from China, India, and the Middle East. Supply for meeting that expected growth in demand will come primarily from OPEC countries, with production increases in natural gas liquids and conventional crude from Saudi Arabia and Iraq.

ExxonMobil recently extended its long-term energy forecast to 2040 for the first time. The Outlook for Energy: A View to 2040 predicts that global demand will be about 30% higher in 2040 compared with today, with demand in developing countries rising about 60%. “Less carbon-intensive fuels, particularly natural gas, gain market share, while coal peaks and begins a decline for the first time in modern history,” the report says. The shale revolution continues, as the report predicts that natural gas from shale and similar sources will make up roughly a third of total global gas production by 2040.

Fossil fuels will remain the dominant fuel choice for years to come, but their development will require increased technical capability and efficiency to meet global demand, panellists at the conference executive plenary session concluded. The industry must give assurances that it can develop resources to meet world demand and must make a commitment to introducing new technologies that increase recovery factors. Additionally, the industry must confirm that it can operate in more efficient ways to mitigate greenhouse gas emissions. Several game-changing technical opportunities exist, among them increasing recovery factors through enhanced oil recovery, carbon capture and sequestration, Arctic exploration, and the development of biofuels.
Over the last decade energy markets changed totally and definitely the 2014 became the no-return point. Critically, it is surprising or alarming - indeed, to energy industry stakeholders for long period of time the volatility and uncertainty that characterised last decade felt like a return to more normal conditions. Consideration shall be given to broader shifting in some of the tectonic plates that make up the energy landscape, with significant developments in both the supply of energy and its demand. Those developments had profound implications for prices, for the fuel mix, and for carbon emissions.

In the flow of those fundamental changes and minor fluctuations we need timely and reliable data in order to understand those developments and consider their likely implications.

The most significant development on the supply side since 2000s was undoubtedly the continuing revolution in US shale. The US recorded the largest increase in oil production in the world, becoming the first country ever to increase average annual production by at least 1 million barrels per day for three consecutive years [1]. The US replaced Saudi Arabia as the world’s largest oil producer – a prospect unthinkable a decade ago. The growth in US shale gas in recent years has been just as startling, with the US overtaking Russia as the world’s largest producer of oil and gas.

The developments on the demand side were no less striking as the growth in energy demand slowed sharply. Global primary energy consumption increased by just 0.9% in 2014, its slowest rate of growth since the late 1990s, other than immediately after the financial crisis. This slowing was driven in part by the rebalancing of the Chinese economy away from energy intensive sectors causing the growth of energy consumption in China to slow to its lowest rate since 1998. Even so, China remained the world’s largest growth market for energy.

As we have seen, these shifts in supply and demand had major effects on energy prices, particularly oil prices. The fall in oil prices looks to have been largely driven by the strength of supply as non-OPEC production grew by a record amount and OPEC maintained its production levels in order to protect its market share.

These developments also had important implications for the fuel mix. The slowing pace of Chinese industrialisation caused the growth in Chinese coal consumption to stall and the growth in global consumption of coal to be unusually weak. Global growth in natural gas was also weak, held back by the mild European winter triggering a sharp fall in European gas consumption. Renewables were again the fastest growing form of energy and, in a year when global consumption growth slowed sharply, they accounted for one-third of the increase in total primary energy use. Renewables provided around 3% of the world’s energy needs.

The deceleration in global energy demand and shift in the fuel mix had a marked impact on carbon emissions. BP’s calculations suggest that global CO2
emissions from energy use grew by just 0.5% in 2014, the weakest since 1998, other than in the immediate aftermath of the financial crisis.

Figure 1.13 illustrates global consumption in 2014 [1]: growth was below average in all regions except North America and Africa. All fuels except nuclear grew at below-average rates. Oil remains the world’s dominant fuel. Hydroelectric and other renewables in power generation both reached record shares of global primary energy consumption (6.8% and 2.5%, respectively). The Asia Pacific region once again accounted for the largest increment to global primary energy consumption and continues to account for the largest share (41.3% of the global total). The region accounted for over 71% of global coal consumption for the first time in 2014, and coal remains the region’s dominant fuel. Gas is the dominant fuel in Europe & Eurasia and the Middle East, while oil is the largest source of energy in the Americas and Africa.
The future of energy sustainable growth seems to be quite unclear in term of reliable prognosis. Earlier economists - Fig.1.14.

Leading energy multinational companies describe plausible developments in the socio-political-economic spheres and then push to explore longer-term energy and related boundaries. These boundaries reflect possible consequences of each scenario but are not mechanistically linked to them.

Over the century, cumulative CO2 emissions raise severe concerns about ongoing climate turbulence and highlighting the need for directing attention and resources to adaptation. Thus we understand that current trends in economic and social development represent a significant challenge to long-term environmental sustainability. The build-up of greenhouse gases in the atmosphere still exceeds current targets for limiting atmospheric temperature increases to 2°C.

This is the case even with lower economic trajectories, rapid displacement of coal by gas, advances in energy efficient compact urban development, and accelerated deployment of CCS and other technologies. These challenging conclusions highlight the significance not only of the scenarios themselves, but also of the wider dialogue they must contribute to and the choices made as a result.

Economic growth is generally positive in itself, even though it naturally increases pressure on resources. From one point of view this contain a paradox – economic growth itself based on resource use holds is in contractions with climate change which eventually limits the growth.

It will place severe stress on resource economics and the environment, not just in CO2 terms but also for fresh water and food resources. If unsustainable outcomes
are to be avoided, the key lesson is the need to accelerate proactive and integrated policy implementation – and emphatically not to argue that poor economic outcomes for the developing world would constrain greenhouse gas emissions. In fact, vibrant economies may well be a necessary catalyst for smart resource policies because environmental concerns tend to fall down the agenda when economies are sluggish.

Assuming the above provided information we can state our entry into an era of volatility and of multiple transitions – economically, politically, socially, and within the energy and environmental systems:

- Intensified economic cycles as the conditions have changed that underpinned the period from the mid-1980s to the mid-2000s, referred to as the ‘great moderation’ in the advanced industrial economies.
- Heightened political and social instability, stimulated in part by economic volatility.
- Tensions in the international order, as multilateral institutions struggle to adjust to shifts in economic power, and other arrangements proliferate.
- Significant demographic transitions, involving ageing populations in some places, youth bulges in others, and relentless urbanisation in both fast-emerging and less-developed economies.
- Surging energy demands driven by growing populations and prosperity, with new energy supplies emerging while others struggle to keep pace, and greenhouse gas emissions increasing, particularly from growth in coal consumption.
- The deployment of technological advances enabling rapid growth in resources plays such as shale gas and liquid-rich shales in, for example, North America, with ripples across the globe, but uncertain prospects elsewhere. The technology for utilising renewable resources, such as solar photovoltaic, also advances, with rapidly growing supply from a small but established base.
- Better defined and significantly challenged ecological boundaries, including pressures arising from the water-energy-food Stress Nexus, as each component experiences supply/demand tightness. Because of their linkages, these components feed off each other and accelerate the combined growth in stress.

1.5.1. The global outlook for economic growth and energy demand

Slow growth in the global economy against the backdrop of the post crisis processes reduces to some extent the demand for energy. In addition, production and energy supply policy contributes to "unblock" the available resources, and, accordingly, is beneficial for relatively optimistic forecasts to come true concerning the recoverable resources. This section briefly presents the excerpts with commentary from an authoritative forecast [2].

Gas production in dense rocks, production of shale gas and coal bed methane has been steadily increasing all around the world, creating a "gas foundation" for
Global Energy. Strategic urban planning based on the concept of sustainable development is focused on the construction of more compact cities and the electrification of transport. In the long-term perspective hydrogen energy infrastructure is going to be created, providing storage and transportation of energy from the irregularly used or remote renewable resources.

Demand for liquid fuels is growing slowly, but oil prices remain moderate on average. Natural gas prices have stabilised at a low level, due to the low-cost deposits development, particularly of shale gas. Moderate energy prices lead to the fact that expensive development is not carried out, which adversely affects the holders of certain resources, which depend entirely on income from energy sales.

Partial replacement of coal by gas and material incentives for the widespread introduction of capture and CO2 underground storage technologies lead to the fact that after the 2030 greenhouse gas emissions will start to decline rapidly. Nevertheless, the emission reduction dynamics is not to limit the global temperature increase of 2 C.

In case of further economic slowdown in certain regions and the big disappointments in economic growth and trade, the world's financial turmoil of the early twentieth century will lead to a long period when the rate of growth in energy demand is slowing.

In the years 2020-2030 certain countries previously developed rapidly with economies in transition; have to overcome the political and social barriers for the implementation of structural changes in the field of finance and industry, which could accelerate the pace of economic development. Despite the increase in world population, it will reduce the growth in demand for resources.

However, by mid-century, a number of states with powerful economy began to get out of the "middle income trap", and a new economic recovery began in the world. However, since the long-term impact effect of previous measures displayed itself, such as compact urban development and electrification, this economic recovery would not lead to a sharp rise in demand for energy, in particular, because by that time a significant part of development fell on the service sector where power consumption was relatively low. This difference in dynamics violates the correlation between economic growth and increasing demand for energy, which was tracked before.

In the first decade of the XXI century the recoverable gas reserves will be able to more than double. The most important factor in the growth of the resource base will be gas production from dense rocks, production of shale gas and coalbed methane, using modern drilling technologies and hydraulic fracturing.

Development of new resources will run successfully, so that it will increase the demand and supply. This will also help to stimulate product offerings measures.
Although there remains some uncertainty as to the volume of still undiscovered
gas, gas production of from dense rocks/shale gas activities was increasingly taking
place in the overall volume, and this growth will continue in the second half of this
century. In an even more distant future research and development support will lead to
the development of the methane hydrates reserves, which will result in a further
increase in supply.

Eight countries, which in 2012 accounted for 60% of global gas production,
will continue to increase its share in the next three decades, but the emergence of new
resources creates a new world's gas production industry. The expected drop in
production in North America gave a way to growth, and China is one of the biggest
earners, allowing energy consumers to reduce their demand for coal and oil.

The relatively slack economic growth and gas excess in the world lead to the
fact that at times the price of primary energy resources fall down and many of their
producers are increasingly difficult to obtain the desired benefits. This results in
lower investment and therefore offers a new fall - so the market is balanced.
Moderate oil prices create pressure on technically complex and expensive cost
projects in remote and inaccessible areas, implemented mainly outside OPEC.

1.5.2. Energy system of Ukraine and its gas sector characteristics

The energy sector of Ukraine faces the unforeseen tasks of significant
accounting for value import of energy resources to inefficient infrastructure and
markets. However, Ukraine has the opportunity to experience the energy revolution
that would promote employment, economic growth and energy security.
Modernisation of Ukraine energy sector just begun and will require significant
investment, along with fundamental reforms of the business environment. A
significant dependence on oil and gas import and often inefficient sectors of
generating, transportation and supply implies that the highest priority should be the
need to reduce energy dependence. The main advantage is the ability to achieve
energy efficiency in public services, heating and industrial sectors. With large
reserves of traditional energy sources, Ukraine could increase the potential for
increasing the production of own resources [3].

Identification of this potential will require deep regulatory reforms and full
implementation of the international agreements terms. Effective competition, together
with the progressive movement to market prices, will also help Ukraine to attract
investments into the market. Project energy strategy that defines a series of measures
to stimulate economic growth was published in 2012. Expansion and implementation
of traditional energy strategy, which is based on more measures to stimulate demand,
could significantly increase the progress in the medium term.

Faced with unprecedented challenges of the energy sector, but with significant
untapped potential, Ukraine remained at a crossroads in the energy sector. The
country has a unique opportunity to start an energy revolution to modernise its energy sector, reform energy markets, create jobs and promote economic growth, which was not a priority along the 1990s and 2000s. Each of these possibilities in turn will strengthen energy security, diversify the economy and accelerate sustainable development. Thus, there will be a need for rapid and radical changes in energy policy and for demand stimulation.

In terms of stimulating economic growth, it is found that Ukraine can minimise its dependence on natural gas imports in the near future by a significant increase in domestic production, both traditional and non-traditional, by developing biomass opportunities and increasing the benefits of energy efficiency.

On the demand side, energy efficiency and energy saving potential is significant, particularly in the industrial and municipal sectors. However, this potential remains largely unresolved and concerns hardly applicable framework of Ukraine’s energy policy. Defining the priorities for energy policy, Ukraine could save significant reserves of resources, especially gas. This requires a framework that will dismiss from private and public funding, while removing subsidies on gas consumption in the domestic system and central heating, which are unstable and impede investment. Moreover, later Ukraine will have overall beneficial result of the reallocation of resources, which are intended for current subsidies, for financing mechanisms that can realise the country energy efficiency potential.

The transition should be based on the traditional strategy, which involves the use of natural energy resources, infrastructure upgrading, forced approaches to improve energy efficiency, rapid progress against relatively efficient market reform and appropriate governance. It implies direct administrative procedures, transparent use of public funds, effective competition protected by independent governing and competition authorities as well as effective measures to combat corruption and conflicts of interest. Large-scale improvements of the economic conditions are necessary to maintain significant levels of investment required.

Energy policy of Ukraine indicates changes to promoting the further development of domestic resources and strengthening the foundations of the energy market to EU levels. The adoption and full implementation of the Agreement on Energy Community allow Ukraine to provide competitive, transparent and predictable market framework that will help to attract investment and reinforce improving efficiency in the energy sector. While some steps have already been implemented, it still remains a space for improvement and reforms.

**Ukrainian energy policy overview**

The overall level of dependence on imports is 39%. In combination of energy use in Ukraine, natural gas is dominated, which made up about 40% of OES in 2010 that is less than 47% in 2004 (Fig.1.15). Coal takes 31% in 2010, as compared to 23.6% in 2004. Nuclear energy takes 17% of the total energy supply in 2010.
Hydropower takes only 2% of the OES only with marginal amounts of supply from other renewable energy sources. Despite the fact that it is difficult to collect reliable data on heat production from renewable energy sources and official statistics may underestimate the actual level of consumption of biomass, the distribution of renewable energy from the primary energy mix may be slightly higher.

![Energy balance of Ukraine in 2010](image)

Energy Community Treaty entered into force in 2006. It brings together EU and Balkan countries and Ukraine and Moldova to promote energy security, stability, development and solidarity by integrating energy market, bonds, harmonisation of regulations, rules and policies at the level of the European Union, and coordinate policy.

**Ukraine's gas sector overview**

On 2011 Ukraine was 67% dependent on external supplies of natural gas, importing 44.8 billion m³. In the same year, industry consumed 24.6 billion m³, the percentage of households connected to gas networks was 77%. Underground gas storage system has a total capacity to 31 billion m³ at 11 storage facilities and the volume of gas transported to Europe is up to 104 billion m³.

The share of natural gas in the energy balance of Ukraine decreased last decade from 47% in 2000 to 40% in 2010. The same trend has continued in recent years. The demand for natural gas has fallen from 76.4 billion m³ in 2005 to 59.3 billion m³ in 2010. Domestic production of natural gas in recent years virtually unchanged in volume, it accounted for 20 bln. m³.

**Public Sector**

The need for natural gas in the public sector decreased by 20% from 34 billion m³ in 2003 to about 27 billion m³ in 2010. In Ukraine, the public sector includes households, district heating companies, schools and hospitals, and state-owned companies. Such a reduction (up to 2 billion m³ per year) has been achieved by reducing the district heating consumption in combination with modernisation,
transition to coal as fuel of "Kyivenergo", which combines heating and power (CHP) and the increased use of individual gas heating in homes (which is in a different statistical category). In the segment of district heating 13 billion. m³ were consumed in 2011, including 1.9 billion. m³ of the "Kyivenergo" CHP. Household consumption decreased from 18 bln. m³ per year in the early 2000s, to about 17.4 billion. m³ in 2011, as minor investments were made to improve energy efficiency in the residential sector and upgrading heating systems. It should be noted that the total number of residential buildings increased by 7% during 2007-2011, but there is no data available on whether they use gas (apparently that is the case). Among 17.5 million. Ukraine households, 13.43 million are the apartments and houses connected to the gas system, representing 78.1% of the urban population and 38.2% of rural households, according to NSC "Naftogaz of Ukraine". By early 2012 it was established nearly 8.24 million individual gas meters in homes that is just over half of all consumers. The data show that from 2008 till 2009, 500 000 gas meters were installed, but there is still a large part of consumers who use gas without meter.

The public sector has great potential to reduce gas consumption, especially in the central heating. However, the trend of the transition to individual heating gas boilers and gasification policy of NSC "Naftogaz of Ukraine" can slow this downward trend in gas demand in the public sector, along with delays in establishing individual gas meters for households and raising tariffs. The updated Energy strategy of Ukraine till 2030 provides that natural gas consumption by households will decrease by 30% by 2030 to 12 billion. m³/year, after energy efficiency upgrading, increasing gas prices and the construction of new buildings that are not connected to the gas infrastructure.

**Industrial Sector**

Gas consumption in industry decreased significantly from 35 bln. M³ in 2004 to 30.5 billion. M³ in 2008 to a record low of 18.4 billion. M³ in 2009 and bln. M³ in 2011. In addition, the impact of the economic crisis, there is a relationship between the variable annual prices of imported gas and lower demand for gas in the industrial sector, where gas prices reflect the cost of imports (Fig. 1.16). Over the past three years, GDP growth is less correlated with the demand of the industrial sector of gas, as GDP grew much faster, reflecting the trend of structural changes in the Ukrainian economy, developing the service sector, decreased industrial production and higher gas prices encouraged reduce consumption or investment in energy efficiency. The relationship between changes in industrial production, gas consumption by sector and GDP are shown in Fig.1.17.
Sub-sectors of the chemical industry are the largest consumer of gas in Ukraine. There are six major plants producing fertilisers, which mainly produce ammonia, four of them are controlled by Osthem Holding Limited (Stirol, Rivneazot, Cherkasy Azot, Severodonetsk Azot); one – by Privat Group (Dniproazot); and one is state-owned (Odessa port plant, which itself consumes 1.3 billion m³ of gas). After a sharp drop in demand in 2009, the chemical industry has greatly increased their gas consumption to reach pre-crisis level (8.5 bln. m³ of gas in 2007 to 6 bln. m³ of gas in
2011), regardless of changes in gas prices for industry (Figure 1.5), which increased production costs.

Chemical industry benefited from certain reductions in gas prices by abolishing value added tax (VAT) in 2009 and 2010. Expenses on natural gas now account for 80% of fertilizers production costs, so the industry has sustained an incentive to reduce gas consumption, if it is not possible to lower gas expenses in the distant future, or raise product prices. Yet achieving efficiency can be changed by larger production volumes, leaving total consumption unchanged.

Metallurgy is very important for the economy of Ukraine, because it reflects 50% of exports. In 2011 Ukraine ranked eighth in the world in the production of steel casting (35.3 million tons). Metallurgy sector significantly reduced its demand after increasing import prices. In anticipation of growing international competition and rising gas prices, there have been taken energy efficiency measures and replaced outdated smelting technologies. Production was reduced because of the economic crisis in 2009, and was not resumed by mid-2012. From 2008 many investments were made for the transition to alternative fuels, often replacing gas with coal. While the steel industry consumes about 10 bln. m³ of natural gas in 2004, then in 2011 the amount was reduced by a third to about 1 bln. m³.

**Future projections**

Due to a new round of confrontation between Ukraine and Russia, which unfolded in 2014 as a result of the processes after the Revolution of dignity in Ukraine in November 2013 and February 2014, the domestic energy sector is undergoing significant changes. Especially significant changes should be expected in the gas sector, as natural gas imports from Russia are the subject of dispute between the two countries in recent years.

We can assume that the following trends are most likely in the gas sector of Ukraine:
- further reducing of the dependence on gas imports from Russia to the overall decrease in consumption;
- maintaining the current level or increase the volume of gas production from own deposits;
- maintaining the existing level or slight decline in gas transit through Ukraine from Russia to Europe.

The expectation proofs of the suggested hypothesis are the dynamics of the information published by the Centre of Energy Studies (http://naftogaz-europe.com/article/en/GasConsumptioninUkraineeng) – Fig.1.18.
Fig. 1.18  Dynamics of changes in Ukraine's gas sector

References to Chapter 1.5
1. BP Statistical Review 2015
2. International agenda for climate change mitigation

V. Shatokha

2.1. Kyoto Protocol

The magnitude of anthropogenic factors causing climate change and the global nature of the challenge require coordinated efforts of the international community. The need to mitigate climate change through the international mechanisms was recognised at the United Nations Conference on Environment and Development held in 1992 in Rio de Janeiro. By adhering to the UN Framework Convention on Climate Change (hereinafter - UNFCCC)\(^1\) governments of 154 countries have committed to reduce GHG emissions in order to ensure "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The Convention itself neither restricts GHG emissions for individual countries, nor employs any implementation mechanisms. Instead, it established the basic principles for the future international agreements, under which the legally binding obligations could be set up.

The basic UNFCCC principles (Article 4, cl.1) are that to protect the climate system, stating that the parties shall have "common but differentiated responsibilities", and that the developed countries have to be leaders in this process. Article 4 (cl.7) states that "The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties". This approach is fully consistent with the basic concepts of sustainable development.

Developed countries (including Ukraine) belong to the so-called Annex I to the UNFCCC. For these countries, the targets to stabilise GHG emissions were set at a certain level determined individually for each country relatively to a level of emissions, occurred during certain year in the range from 1990 to 2000. However, just three years after the Rio - at the 1\textsuperscript{st} conference of the UNFCCC parties in 1995 in Berlin - this target was recognised inadequate, - mainly because with the technologies applied emissions stabilisation would mean to limit the industrial development and economic growth. Further discussion of this issue led to development of the Kyoto Protocol, adopted in 1997. Unlike previous UNFCCC documents, the Kyoto Protocol has a force of a legally binding international law, establishing for the developed countries commitments to reduce GHG emissions.
Article 25 of the Kyoto Protocol stipulated its entering into force after the following two conditions are accomplished:

1) It shall be ratified by at least 55 countries listed in Annex I (i.e. developed);
2) Ratified countries shall stand for at least 55% of the global GHG emissions.

The first condition was reached in May 2002 (Iceland was 55th), and the second on February 16, 2004 - after ratification by Russia (in 1990 Russia was responsible for 17.4% of GHG emissions). Ukraine ratified the Protocol on February 4, 2004. The Protocol has been ratified by 191 countries. It was not ratified by the United States (36% of GHG emissions in 1990). Canada withdrew from the Protocol in 2012.

Kyoto Protocol had two periods of implementation.

The first period lasted from 2008 to 2012. During this period, the participating countries have taken certain obligations to limit GHG emissions compared to 1990 (with the exception for several former Eastern European socialist bloc countries, for which emissions levels as of 1985-1989 were taken as a baseline). Commitments have not been set the same for all countries. Formally, the most stringent commitments were pledged by Luxembourg (reduction by 28%), whereas the easiest - for Greece (ceiling to increase emissions by 25%). However, the austerity of commitments for a certain country cannot be judged just from these figures without considering the dynamics of industrial development, population growth, etc.

The Kyoto Protocol has repeatedly been the subject of criticism - especially given the reasoning in setting the commitments for individual countries. E.g. D. M. Lieverman 2 considers "zero" commitment in relation to 1990 level for Russia, with respect to decline in industrial production, de facto was equivalent to investment to its economy up to US $10 billion - the benefits which can be realised through financial mechanisms of the Kyoto Protocol (will be discussed below). For Ukraine zero commitments (1990 level) to reduce the GHG emissions were also established, being very favourable condition.

Generally, commitments pledged in the 1st period of implementation had had to ensure the reduction of GHG emissions in Annex I countries in 2012 by 5% compared to 1990. These countries were entitled to meet their obligations by reducing emissions either domestically or through so-called "flexible mechanisms" (discussed below) by deploying carbon cutting technologies in developing countries.

The efficiency of the first period of the Kyoto Protocol implementation has been widely discussed. Fig.2.1 demonstrated the change of GHG emissions in Annex I countries (with and without the US and Canada). At first glance, one can conclude that the goal has been achieved. However, in fact the amounts of GHG emissions
have been substantially affected by the industrial production decline in the countries of former Soviet Union and East Europe in 1990s and the financial crisis and global recession of 2008.

The gaps between GHG emissions target and the result achieved for some Annex I countries are shown in Fig.2.1 (if a nation had a -10% target but its emissions increased by 10% it scores -20, or if it had a 5% target but cut by 15% it scores 10). Analysis of these data confirms that many countries where the targets were overreached represent the former soviet union or its East Europe’s satellites, hence achievement observed had happened mostly not due introduction of advanced technologies but owing to other socio-economic reasons.

Fig.2.1. Change of GHG emissions CO₂ equivalent in Annex I countries

![Fig.2.1](image-url)

Fig.2.2 Gaps between the Kyoto protocol target and the results achieved in 2012 for some Annex I countries (without adjustment by "flexibility mechanisms"; red – failure, blue – success; source – The Guardian [3]).

![Fig.2.2](image-url)
The second commitment period under the Kyoto Protocol covers the years from 2013 to 2020. However, amendments to the Protocol relating to the obligations to reduce emissions (so called Doha Amendments) in this period, has not entered into legal force. As of 7 March 2016, 61 country has ratified the Doha Amendment whereas a total of 144 countries are required for its entry into force.

Although most of EU countries have not ratified the Doha Amendment, in order to bridge the gap between the end of the 1st Kyoto period and the start of the new global agreement in 2020, the EU countries (together with Iceland) have agreed to meet – jointly – a 20% reduction target compared to 1990 by 2020.

2.2. The flexible mechanisms of the Kyoto Protocol

In order to lower the economic cost of achieving the GHG emissions reductions targets, the Kyoto Protocol introduced three so-called "flexibility mechanisms" – clean development mechanism (CDM), emissions trading and joint implementation. These mechanisms enable Parties to access cost-effective opportunities to reduce emissions, or to remove carbon from the atmosphere, in other countries.

Typically, in developing countries there is a significant potential for improving energy efficiency and cutting CO₂ emissions with the help of proven cost-effective technologies, whereas in many developed countries industry often performs at the “best that you can” level when opportunities to further reduce the emission levels are already limited and cost too much. Therefore, the basic idea behind flexibility mechanisms is that while the cost of emissions reduction varies considerably from region to region, the effect for the atmosphere is the same, irrespectively of where the action is taken.

All three mechanisms are based on the Protocol’s system for accounting of the targets: the amount to which an Annex I Party must reduce its emissions over the five year commitment period (known as its “assigned amount”) is divided into units each equal to one tonne of CO₂ equivalent. Based on these assigned amount units (AAUs), and other units defined by the Protocol, certain country may gain credit from action taken in some other country that may be counted towards its own emissions target. These flexibility mechanisms are discussed in more detail below.

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5 This is consistent with scenarios of global development, analysed in detail in Chapter 6
2.2.1. Clean Development Mechanism

Clean Development Mechanism (Clean Development Mechanism, CDM), set under the UNFCCC, provides for cooperation between the countries, which develops and industrialised countries.

The essence of the CDM is that Annex I country of the Kyoto Protocol, which has quantified commitments to reduce greenhouse gas emissions, acts as an investor and implements a project to reduce emissions in a country that is not included in Annex I. Under CDM scheme Annex I country gets possibility to reach the mitigation commitments in equivalent to emissions reduced as a result of the project CDM. A developing country has a direct benefit from the project and also benefits from an inflow of investment, infrastructure development and access to new technologies.

CDM works as follow. Industrialised countries wishing to obtain credits under the CDM scheme must receive confirmation of developing the country that the project will contribute to its sustainable development. Then, using a methodology agreed by the Executive Board (EB) of the CDM, the applicant (developed country) must demonstrate that the proposed project would not have occurred anyway (so-called criterion of "additionality"), and to establish the baseline by assessing what would be the amount of emissions in the future without the project. Then an independent agency has to evaluate the project to confirm that it may result in real, measurable and long-term emission reductions. On this basis, EB decides whether to start the project. After the project is registered and implemented, EB offers participants the project credits - so-called CER (Certified Emission Reductions). One CER is equivalent to one ton of CO₂ (or other greenhouse gas equivalent). Number of CER is calculated as the difference between baseline and actual emissions based on monitoring data. It should be noted that CER is a kind of marketable commodity sellable on a specialised stock exchange. A CDM scheme is depicted in Fig.2.4.

As of September 14, 2012 the number of issued CER has reached one billion in 4626 registered projects under the scheme CDM, with 60% CER units came from projects implemented in China.

The effectiveness of the market component of CDM, as a mechanism for promoting a limit on greenhouse gas emissions by stimulating investment, has not stood the test of practice. As shown in Fig 2.5 market value of CER, which were mostly auctioned using the European emissions trading scheme (European Union Emissions Trading Scheme), has fallen from over 20 Euros per unit in 2008 to almost zero by the end of 2012.
The reason for the fall of the CER market value was an excess of supply over demand due to a number of factors, a detailed analysis of which is beyond the scope of this publication. This decline was unexpected because of the trust provided by involvement of UN with its own financial resources, and threatened a number of investment projects under the CDM, as the opportunity to refund investors through emissions trading mechanism was questionable. Currently CDM Executive Committee is looking for ways restoration motivation investors about the use of "clean development mechanism".

2.2.2. Emissions trading and joint implementation

Emissions trading (International Emission Trading, IET) - is the market mechanism used to limit emissions, providing economic incentives to reduce emissions. Under the IET scheme, the governmental agency sets limits of emissions for enterprises. Companies that wish to increase emissions above the limit can buy
extra permits from those companies that emit fewer pollutants into the atmosphere than they are allowed. In fact, under the scheme the "buyer" pays for excess emissions, while the "seller" gets rewarded for emission reductions. In English literature scheme is called as cap and trade. The fact that emission allowances under this scheme are gaining market value motivates producers to the cost-effective emission reductions - through energy conservation, production optimisation, innovation etc. Cap and trade scheme is often considered as more flexible and cost-effective mechanism to reduce emissions and to motivate modernisation compared with taxation.

There are several trade schemes for various air pollutants. Major scheme for greenhouse gases is European Union Emission Trading Scheme. In the US domestic emission trading schemes are used to prevent acid rain along with several regional schemes for nitrogen oxides and other greenhouse gasses.

Joint Implementation (JI) - this is more flexible mechanism of the Kyoto Protocol, designed to help developed countries (Annex I) to fulfil their commitment to reducing greenhouse gas emissions. Under JI scheme any Annex I country of the Kyoto Protocol can invest in a project related to the reduction of greenhouse gas emissions, implemented in another Annex I country, instead of reducing these emissions in their own country. Thus certain countries may reduce the cost of the tasks to cut emissions by investing to projects carried out in countries where emission reductions can be achieved more cheaply. Emission Reduction Units (ERU), equal to 1 ton of greenhouse gas emissions in CO₂ equivalent, are used as credit units.

Typical JI projects under the scheme are the modernisation of coal fired power plants that through the introduction of a combined cycle as well as the projects using renewable energy (wind, solar, biomass) sources etc.

Mostly JI projects are carried out in the so-called transition countries. In particular, Russia and Ukraine were "receiving party" to the greatest number of such projects. Details of the projects in JI, where Ukraine to part can be retrieved from the Ukrainian registry of carbon units¹², which operates under the auspices of the State Environmental Investment Agency.

In summary, the flexible mechanisms had to fulfil the following three objectives:

- reduce the burden of obligations on climate change mitigation in developed countries (IPCC forecast loss of GDP of developed European countries using CDM and JI, should be within 0,13-0,81%, while in case if reductions would take place in their own country, these losses would amount to 0,3-1,50%¹³);
– reduce the "leakage" of emissions from developed countries to developing countries, through the transfer of dirty industries in these countries;
– ensure transfer of advanced technologies to developing countries.

Although not all mechanisms have proven to be effective, experience, acquired in the implementation of the Kyoto Protocol is very important and approaches developed during this period will likely be further developed in the future.

References

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5 http://edgar.jrc.ec.europa.eu/overview.php
6 Obama and Xi in emissions pledge: bbc.co.uk, 12 November 2014, last updated at 08:12 GMT
11 http://www.epa.gov/airmarkets/
12 http://www.carbonunitsregistry.gov.ua/ua/261.htm
13 Climate Change 2001 - Synthesis report. Figure SPM-8, IPCC, 2001
If people managed to do something in a proper way they tend to make it possible again and standardization is all about. Many standardisation organisations across the globe work actively in the areas more or less covering sustainable development (SD). In this chapter we will briefly go through achievements of ISO, CEN, Ukraine and some very impressive specific initiatives which became widespread.

**International standardisation organisation (ISO)**

ISO is the International Organisation for Standardisation. It has a membership of 160 national standards institutes from countries large and small, industrialised, developing and in transition, in all regions of the world. ISO’s portfolio of more than 18 000 standards provides practical tools for all three dimensions of sustainable development: economic, environmental and societal.

ISO standards for business, government and society as a whole make a positive contribution to the world we live in. They ensure vital features such as quality, ecology, safety, economy, reliability, compatibility, interoperability, conformity, efficiency and effectiveness. They facilitate trade, spread knowledge, and share technological advances and good management practice.

ISO in recent decade developed several series of standards on SD-related issues:

- ISO 14001 - Environmental management
- ISO 26000 - Social responsibility
- ISO 50001 - Energy management

**ISO 14001 - Environmental management**

Like all ISO management system standards, ISO 14001 includes the need for continual improvement of an organisation’s systems and approach to environmental concerns.

The standard has recently been revised, with key improvements such as the increased prominence of environmental management within the organisation’s strategic planning processes, greater input from leadership and a stronger commitment to proactive initiatives that boost environmental performance.

There are many reasons why an organisation should take a strategic approach to improving its environmental performance. Users of the standard have reported that ISO 14001 helps:

- Demonstrate compliance with current and future statutory and regulatory requirements
- Increase leadership involvement and engagement of employees
- Improve company reputation and the confidence of stakeholders through strategic communication
• Achieve strategic business aims by incorporating environmental issues into business management

• Provide a competitive and financial advantage through improved efficiencies and reduced costs

• Encourage better environmental performance of suppliers by integrating them into the organisation’s business systems

Standards of ISO 14000 family:

ISO 14001 is the world’s most recognised framework for environmental management systems (EMS) – implemented from Argentina to Zimbabwe – that helps organisations both to manage better the impact of their activities on the environment and to demonstrate sound environmental management. ISO 14001 has been adopted as a national standard by more than half of the 160 national members of ISO and its use is encouraged by governments around the world. Although certification of conformity to the standard is not a requirement of ISO 14001, at the end of 2015, at least 300 000 certificates had been issued in 170 countries and economies.

ISO 14004, which complements ISO 14001 by providing additional guidance and useful explanations.

Environmental audits are important tools for assessing whether an EMS is properly implemented and maintained. The auditing standard, ISO 19011, is equally useful for EMS and quality management system audits. It provides guidance on principles of auditing, managing audit programs, the conduct of audits and on the competence of auditors.

ISO 14031 provides guidance on how an organisation can evaluate its environmental performance. The standard also addresses the selection of suitable performance indicators, so that performance can be assessed against criteria set by management. This information can be used as a basis for internal and external reporting on environmental performance. Communication on the environmental aspects of products and services is an important way to use market forces to influence environmental improvement. Truthful and accurate information provides the basis on which consumers can make informed purchasing decisions.

The ISO 14020 series of standards addresses a range of different approaches to environmental labels and declarations, including eco-labels (seals of approval), self-declared environmental claims, and quantified environmental information about products and services.

ISO 14001 addresses not only the environmental aspects of an organisation’s processes, but also those of its products and services. Therefore, ISO has developed additional tools to assist in addressing such aspects. Life-cycle assessment (LCA) is a tool for identifying and evaluating the environmental aspects of products and services from the “cradle to the grave”: from the extraction of resource inputs to the eventual
disposal of the product or its waste. The *ISO 14040* standards give guidelines on the principles and conduct of LCA studies that provide an organisation with information on how to reduce the overall environmental impact of its products and services.

*ISO 14064 parts 1, 2 and 3* are international greenhouse gas (GHG) accounting and verification standards which provide a set of clear and verifiable requirements to support organisations and proponents of GHG emission reduction projects.

*ISO 14065* complements *ISO 14064* by specifying requirements to accredit or recognise organisational bodies that undertake GHG validation or verification using *ISO 14064* or other relevant standards or specifications.

*ISO 14063*, on environmental communication guidelines and examples, helps companies to make the important link to external stakeholders.

*ISO Guide 64* provides guidance for addressing environmental aspects in product standards. Although primarily aimed at standards developers, its guidance is also useful for designers and manufacturers. *ISO 14045* provides principles and requirements for eco-efficiency assessment. Eco-efficiency relates environmental performance to value created. The standard establishes an internationally standardised methodological framework for eco-efficiency assessment, thus supporting a comprehensive, understandable and transparent presentation of eco-efficiency measures.

*ISO 14051* provides guidelines for general principles and framework of material flow cost accounting (MFCA). MFCA is a management tool to promote effective resource utilisation, mainly in manufacturing and distribution processes, in order to reduce the relative consumption of resources and material costs. MFCA measures the flow and stock of materials and energy within an organisation based on physical unit (weight, capacity, volume and so on) and evaluates them according to manufacturing costs, a factor which is generally overlooked by conventional cost accounting. MFCA is one of the major tools of environmental management accounting (EMA) and is oriented to internal use within an organisation.

*ISO 14067* on the carbon footprint of products provides requirements for the quantification and communication of greenhouse gases (GHGs) associated with products. The purpose of each part will be to: quantify the carbon footprint (Part 1) and harmonise methodologies for communicating the carbon footprint information and also provide guidance for this communication (Part 2).

*ISO 14069* provides guidance for organisations to calculate the carbon footprint of their products, services and supply chain.

*ISO 14005* provides guidelines for the phased implementation of an EMS to facilitate the take-up of EMS by small and medium-sized enterprises. It includes the use of environmental performance evaluation.
ISO 14006 provides guidelines on eco-design while ISO 14033 provides guidelines and examples for compiling and communicating quantitative environmental information.

Finally, ISO 14066 specifies competency requirements for greenhouse gas validators and verifiers.

For more information: http://www.iso.org/iso/home/standards/management-standards/iso14000.htm

**ISO 26000 - Social responsibility**

Organisations around the world, and their stakeholders, are becoming increasingly aware of the need for, and benefits of, socially responsible behaviour. The objective of social responsibility is to contribute to sustainable development.

An organisation’s commitment to the welfare of society and the environment has become a central criterion in measuring its overall performance and its ability to continue operating effectively. This, in part, is a reflection of the growing recognition that we need to ensure healthy ecosystems, social equity and good organisational governance. Ultimately, an organisation’s activities depend on the health of the world’s ecosystems. These days, organisations are subject to greater scrutiny by their various stakeholders.

ISO 26000 is intended to assist organisations in contributing to sustainable development. It encourages them to go beyond legal compliance, recognising that compliance with the law is a fundamental duty of any organisation and an essential part of their social responsibility programme. The standard seeks to promote a common understanding of social responsibility while complementing – but not replacing – other existing tools and initiatives.

An organisation’s performance on social responsibility can influence, among other things:

- Competitive advantage
- Reputation
- The ability to attract and retain workers or members, customers, clients and users
- The maintenance of employee morale, commitment and productivity
- The perception of investors, owners, donors, sponsors and the financial community
- Relationships with companies, governments, the media, suppliers, peers, customers and the community in which it operates

When applying ISO 26000, organisations should consider societal, environmental, legal, cultural, political and organisational diversity as well as differences in economic conditions, while being consistent with international norms of behaviour.
ISO 50001 - Energy management

ISO 50001:2011, Energy management systems – Requirements with guidance for use, is a voluntary International Standard developed by ISO. ISO 50001 gives organisations the requirements for energy management systems (EnMS). ISO 50001 provides benefits for organisations large and small, in both public and private sectors, in manufacturing and services, in all regions of the world. ISO 50001 establishes a framework for industrial plants; commercial, institutional, and governmental facilities; and entire organisations to manage energy.

ISO 50001 is based on the ISO management system model familiar to more than a million organisations worldwide who implement standards such as ISO 9001 (quality management), ISO 14001 (environmental management), ISO 22000 (food safety), ISO/IEC 27001 (information security). In particular, ISO 50001 follows the Plan-Do-Check-Act process for continual improvement of the energy management system.

These characteristics enable organisations to integrate energy management now with their overall efforts to improve quality, environmental management and other challenges addressed by their management systems.

ISO 50001 provides a framework of requirements enabling organisations to:
- Develop a policy for more efficient use of energy
- Fix targets and objectives to meet the policy
- Use data to better understand and make decisions concerning energy use and consumption
- Measure the results

For more information: [http://www.iso.org/iso/home/standards/iso26000.htm](http://www.iso.org/iso/home/standards/iso26000.htm)
• Review the effectiveness of the policy
• Continually improve energy management.

ISO 50001 can be implemented individually or integrated with other management system standards.

ISO 50001 is based on the Plan-Do-Check-Act continual improvement framework and incorporates energy management into everyday organisational practices. This approach can be briefly described as follows.

- Plan: conduct the energy review and establish the baseline, energy performance indicators (EnPIs), objectives, targets and action plans necessary to deliver results in accordance with opportunities to improve energy performance and the organisation’s energy policy.
- Do: implement the energy management action plans.
- Check: monitor and measure processes and the key characteristics of its operations that determine energy performance against the energy policy and objectives and report the results.
- Act: take actions to continually improve energy performance and the EnMS. The basis of this approach is shown in Fig. 2.7.

For more information: [http://www.iso.org/iso/home/standards/management-standards/iso50001.htm](http://www.iso.org/iso/home/standards/management-standards/iso50001.htm)
EITI – Successful case of collaborative standards initiatives

One of the most compelling institutional innovations of the last several decades, Collaborative Standards Initiatives (CSIs) are becoming an increasingly prominent tool of global governance. CSIs can be defined as cross sector partnerships created with a rule-setting purpose, to design and steward standards for the regulation of market and non-market actors. CSIs are designed to address shortfalls in the provision of social and environmental safeguards, equity, and justice considered inadequately addressed by existing market systems and regulatory regimes – and to do so in a participatory, inclusive way, designed to build consensus. Both ‘what CSIs do’ and ‘how CSIs do it’ make them potentially valuable building blocks in the effort to make globalisation inclusive and sustainable.

At the root of CSIs are several core design principles. First among them is the principle of inclusiveness that strives to ensure all affected parties can participate in shaping the rules that CSIs form. While many CSIs successfully engage representatives of the private, civil, and (where relevant) public sectors, many struggle to manage processes that include broad-based participation.

CSIs generally include the principle of voluntary consent by which ‘signatories’ agree to abide by the rules and standards established by CSIs. The principle of voluntary consent proves in practice to be a tricky concept: whether participants truly experience engagement in CSIs as ‘voluntary’ is questionable and context dependent. In some instances, participants perceive ‘voluntary’ CSIs as regulation by a different name. In other cases, the principle of voluntary consent leads to loose and modest application, or even free riding, by targeted signatories.

Transparency and accountability represent other central principles of CSIs. These ensure that CSI decisions are subject to the light of day and that the governance system builds mechanisms to respond to challenges and disputes. However, CSIs struggle to manage an extended accountability system that is responsive to stakeholder interests without creating excessive and stifling organisational burdens.

Finally, CSIs rest on a bedrock principle of partnership that enables representatives of multiple sectors and interested parties to collaboratively design and govern the initiative. While other principles exist, these represent particularly central features of CSIs [1].

Many CSIs take on either broad or specific development concerns, from health and labour practices, to human rights and a variety of others issues. However, despite their best efforts to balance the concerns of market, environmental, and social interests, CSIs are often perceived to unfairly weigh one interest above others. For example, critics charge that certain environmental standards initiatives inadequately consider their impact on indigenous communities that depend on ecosystems for their livelihoods.
From the Forest Stewardship Council (www.fsc.org), to the Equator Principles for financial institutions (www.equator-principles.com), to the Extractive Industry Transparency Initiative (http://eiti.org), CSIs have created a new set of challenges as well as opportunities for global development.

The EITI is a multi-stakeholder initiative that brings together public, private and non-governmental actors to improve the revenue transparency from extractive industries and their host governments. International development agencies – particularly international financial institutions and bilateral donors -- have played a key role in the inception of the EITI, which was housed at the UK’s Department for International Development (DFID). Informally, the role of international development agencies as early catalysts provided key inputs from individual staff experts, critical country data and their convening brands to bring stakeholders to the table.

However, as the initiative gained momentum, the role of the international development agencies evolved from informal roles to more formalised engagements. In the case of the World Bank Group (WBG) its role has become one of a supporter for country implementation. Based on its core assets (its fiduciary capacity, country-operations structures, and reputation) today the WBG manages a multi-donor trust fund to support in-country activities that can strengthen the EITI’s implementation.

In the case of the WBG, this new role as supporter has enabled strong synergies between its headquarters and country teams. Furthermore, it has streamlined EITI transparency provisions and principles into the World Bank’s mining policies and provided a solid ground from which country teams discuss governance improvements in their engagement with respective governments [2-3].

EITI’s move to a more independent governance system, improving representation and country reporting of progress is seen as one to increase the legitimacy and traction. A new Board includes constituent groups from implementing countries, supporting countries, civil society, industry, and investment companies. The EITI’s Secretariat, originally hosted by the UK’s DFID, is now independently established in Oslo, Norway.

Challenges ahead point to improving country implementation as well as bringing key outsiders to the table (e.g. China’s energy companies). The international development agencies, in a supporter role, can do much to strengthen the EITI model, especially on country implementation, with a more focused outreach into BRIC countries, strengthen incentives for companies to comply and leading recipient governments to streamline EITI principles.

As for end of 2015 the key data on EITI are available:

- 51 implementing countries
- 31 countries are fully compliant with EITI requirements
- 48 counties have published revenues
- 289 year covered in EITI reports
stated 1.909 trillion USD of government revenues from oil, gas and mining.

Publications:


Annex

Table A.1: Adopted International and EU standards on sustainable development

<table>
<thead>
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<th>№</th>
<th>Standard</th>
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<td>3</td>
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<td>Managing for the sustained success of an organisation -- A quality management approach</td>
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<td>4</td>
<td>ISO/TR 37150:2014</td>
<td>Smart community infrastructures -- Review of existing activities relevant to metrics</td>
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<td>5</td>
<td>ISO/TS 37151:2015</td>
<td>Smart community infrastructures -- Principles and requirements for performance metrics</td>
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<td>6</td>
<td>IWA 9:2011</td>
<td>Framework for managing sustainable development in business districts</td>
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<td>8</td>
<td>ISO 15392:2008</td>
<td>Sustainability in building construction -- General principles</td>
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<td>9</td>
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<td>Sustainability in buildings and civil engineering works -- A review of terminology</td>
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<td>16</td>
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<td>Event sustainability management systems -- Requirements with guidance for use</td>
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<td>ISO 18459:2015</td>
<td>Biomimetics -- Biomimetic structural optimisation</td>
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<td>19</td>
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<td>Language resource management -- Persistent identification and sustainable access (PISA)</td>
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<td>20</td>
<td>ISO/IEC 24700:2005</td>
<td>Quality and performance of office equipment that contains reused components</td>
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<td>21</td>
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<td>Ships and marine technology -- Ship recycling management systems -- Specifications for management systems for safe and environmentally sound ship recycling facilities</td>
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<td>22</td>
<td>ISO 13065:2015</td>
<td>Sustainability criteria for bioenergy</td>
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<td>23</td>
<td>CWA 16267:2011</td>
<td>Guidelines for Sustainable Development of Historic and Cultural Cities - Qualities</td>
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<td>24</td>
<td>CWA 16768:2014</td>
<td>Framework for Sustainable Value Creation in Manufacturing Network</td>
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<td>25</td>
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<td>28</td>
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<td>Bio-based products - Sustainability criteria</td>
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<td>Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products</td>
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Table A.2: Adopted International and EU standards on sustainable development

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<td>2</td>
<td>ISO/DTR 37121</td>
<td>Sustainable development in communities -- Inventory and review of existing indicators on sustainable development and resilience in cities</td>
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<td>3</td>
<td>ISO/AWI 19565</td>
<td>Minimum requirements for the certification of products from sustainable marine fishery</td>
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<td>Sustainable development of communities -- Indicators for city services and quality of life</td>
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<td>Sustainable and traceable cocoa beans -- Part 1: Requirements for sustainability management systems</td>
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<td>Sustainable and traceable cocoa beans -- Part 2: Requirements for performance (profit, people and planet related)</td>
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<td>Sustainable development in communities -- Indicators for Smart Cities</td>
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<td>ISO/DIS 18504</td>
<td>Soil quality -- Guidance on sustainable remediation</td>
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<td>Sustainable procurement -- Guidance</td>
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<td>ISO/AWI 37104</td>
<td>Sustainable development in communities -- Guide to establishing strategies for smart cities and communities</td>
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<td>ISO/DIS 37102</td>
<td>Sustainable development and resilience of communities -- Vocabulary</td>
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<td>CEN/WS 079</td>
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<td>prEN 15643-5</td>
<td>Sustainability of construction works - Sustainability assessment of buildings and civil engineering works - Part 5: Framework for the assessment of sustainability performance of civil engineering works</td>
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</table>

References to Chapter 2
2. www.worldbank.org/mining
3. The new paradigm of innovation and the concept of eco-innovation

Shatokha V., Petrenko A.

Technological basis for the sustainable development should ensure systemic innovation aimed primarily at reducing the consumption of fossil fuels. It will not be possible to cope with the environmental challenges facing humanity, relying only on existing technologies. The only scenario of social and technological development, involving the introduction of revolutionary technologies (see. RCP scenarios in Section 2), can keep the climate system in balance and prevent it from the disastrous events in the future.

The need for radical eco-innovation (eco-innovations challenge), capable of reducing consumption of materials by 2050 is illustrated in Fig.3.1 based on the data by OECD (Organisation for Economic Co-operation and Development) [1]. *Business as usual* scenario describes inputs using existing technologies, *Factor 2* scenario aims to reduce consumption of materials per capita twice, and the scenario *Factor 5* - reduces consumption of materials per capita by 80% (current consumption is 120% relative to 1970). Other scenarios shall also be noted. E.g. *Factor 4* describes a scenario where living standards rise twice, while the materials consumption reduces twice as well (2x2 = 4); in *Factor 10* living standards rise twice while consumption reduces fivefold (2x5 = 10) [2].

Fig.3.1.Demonstration of eco-innovation challenge (on the vertical axis – consumption in relationship to 1970)

Below we briefly review the typology eco-innovations based on the terminology by OECD [3].

In the past, the problems of pollution, including dust and gas emissions, were the typically solved by dispersion of emissions in the atmosphere, aimed at reducing the concentration of harmful substances. The popular motto declared “solution to pollution is dilution”. Dilution can be achieved either by using the chimneys with
certain height, or with the help of specially designed factory roof. This approach, while remaining important today, it can be not helpful under certain atmospheric conditions - such as calm and inversion (atypical temperature change in the vertical direction, which prevents convection of hot contaminated gas). Obviously in this case, local pollution problem transforms to a regional or even global one.

The introduction of more stringent environmental requirement caused the development and implementation of numerous innovations aimed at reducing the amount of pollutants entering the environment. Usually these innovations were not accompanied by significant changes in existing production technologies. This approach is sometimes called "end-of-pipe" as it relates to the final stage of production, when efforts are directed to the removal of contaminants that are already formed during production. According to OECD, the concept of "end-of-pipe" is schematically illustrated in Fig.3.2

Fig.3.2. Schematic illustration of the "end of pipe" concept

Although this approach improves the environmental performance, production cost increases; therefore improvement of the environmental performance has usually been seen as a barrier to economic growth. However, in some cases "end-of-pipe" innovations are coupled with technology optimisation. For example in the blast furnace ironmaking the dust catching systems has been dramatically improved over decades currently providing more than 95% dust catching efficiency. Most of the apparatuses were deployed well before the stringent environmental legislation has been put in. This was primarily due to the requirements to the dust content in the blast furnace top gas, a low calorific by-product fuel used to heat stoves and to generate electricity. However, this had a positive effect on the environment. Later on, the introduction of top gas turbines, converting the compression energy directly into electricity, has required an even lower dust content in the gas, which resulted in various innovative solutions, including the dry dust catching systems with a total efficiency of dust removal over 98%.

Generally, the “end of pipe” concept remains important in many cases. However, in order to move the centre of gravity to the environmental management arena, in 1989 the United Nations Environmental Programme (UNEP) implemented the Cleaner Production (CP) Programme. In fact, this program, which had resulted in
the creation of several national centres around the world, was already apparent in the reflection of the trend for preventing the formation of harmful emissions instead of combating emissions that are already formed. "Cleaner production" model aims at the optimisation of manufacturing processes, energy saving technologies, development of new materials and products, the use of secondary resources, etc. - to a more integrated approach for achieving environmental standards and time improving economic efficiency at the same time. The implementation of this model is associated with certain risks and limitations both technological and organisational. However, a study conducted in 2007, covering more than 4,000 manufacturing plants in Canada, Germany, Norway, the United States, Hungary, France and Japan showed that over 75% of investments are focussed on cleaner production [4].

The next stage of eco-innovation evolution can be considered an eco-efficiency model. Moving from emissions capturing to prevention concept, some companies have found that not everything that is good for the environment is bad for business. Optimisation of production processes and reducing the consumption of raw materials can improve competitiveness. Therefore, in order to help the businesses to contribute to sustainable development, while remaining competitive in the 1992 World Business Council for Sustainable Development) introduced the concept of eco-efficiency by defining it as "the delivery of competitively priced goods and services that satisfy human needs while progressively reducing environmental impacts of goods and resource intensity throughout the entire lifecycle to a level at least in line with the Earth’s estimated carrying capacity" However, recently the concept of eco-efficiency gained wider meaning, which can be formulated as "doing more with less", and is also a key of the Environmental Management System (EMS).

Solving the environmental problems gained a more integrated approach in the "lifecycle" concept (Fig.3.3). Life-cycle assessment (LCA) tool, based on this concept today is one of the main instruments for environmental impact assessment and for decision-making in developing new products and technologies. As evident from the name, the approach involves reducing the use of resources and environmental impacts throughout the life-cycle of products and services. The concept of LCA is more ambitious, compared to CP, stimulating look beyond traditional organisational boundaries. It covers the environmental impact and responsibility from the minerals extraction through production processes and consumption to the final stage, when the used product is returned back to the environment as waste. Therefore, LCA analysis is often called "cradle-to-grave” Analysis.

The life-cycle philosophy is the basis for the new business models and management approaches. At the political level it is reflected in the initiative of Extended Producer Responsibility and Integrated Product Policy, introduced by the
European Union in order to extend producer responsibility for the entire product life cycle.

Practical application of LCA has resulted, in particular, in emergence of the "green supply chain management" concept, that involves the consideration of environmental aspects throughout the entire chain, from raw material sources, including various organisations and companies involved in the production, processing of product supply, consumption and final disposal.

On this basis and in response to the factors of social and political pressure the concept of corporate social responsibility (CSR) has emerged as a new business model according to which the companies on a voluntary basis declare obligations, sometimes even exceeding legislative requirements, to include ecological aspects to all types of business activity and to report on the ethical, social and environmental risks resulting from this activity. In the sense of marketing, it is one of levers to impact the consumer’s behaviour towards considering not only price and technical parameters of goods but also how production, use and final utilisation of goods influences the environment.

![Fig. 3.3 Schematic illustration of the "life-cycle" concept](image)

The closed loop production concept (Fig. 3.4) is similar to "lifecycle" with the difference that all components of system are subject to reuse, processing or utilisation. It assumes more systemic approach according to which all products and processes are developed, recognising that at a certain stage they have to receive new life thus significantly reducing the need for non-renewable natural materials. The closed cycle marks transition from the "cradle-to-grave" to "cradle-to-cradle" concept. For example, in heavy machinery the design of cars and mechanisms can be improved not only to reduce the use of potentially dangerous materials and to increase of power efficiency, but also considering possibility to simplify dismantling, estimation of the parts’ condition, their restoration or replacement and so on. It goes beyond the maintainability concept. Today the industrial companies create the new
models of interaction with users, concerning return of the equipment and replacement of components including sale of restored (remanufactured) units at a discount price and provision of guarantees. Thus the consumer receives rather service than goods. For example, the US company Caterpillar which operates in heavy mining machinery manufacturing, thanks to cradle-to-cradle approach significantly reduced the use of non-renewable materials while expanding its sales market and increasing the profit.

The next step of eco-innovations’ evolution is introduction of the closed cycle concept beyond the separate production enterprises and even beyond the industrial branches. This approach received the name of Industrial Ecology. Industrial production in this concept is considered as an ecosystem element which has to be not in isolation but in harmony with an ecosystem.

From the analysis given above, it is possible to define a certain typology of eco-innovations. In the analytical materials of OECD the concept of eco-innovation is based on three dimensions - the purpose, the mechanism and influence.

The of eco-innovations might be:
- products - goods or services;
- processes - production methods and procedures;
- marketing methods;
- management structure;
- the organisations, including stakeholders outside the company, social and cultural values.

Four mechanisms thanks to which change of object of eco-innovation is achieved might be defined:
- a modification - rather limited improvements of a product and processes;
- a redesign that includes essential changes in the existing processes, products, organisational structures, etc.
- an alternative - introduction of new goods and services which can satisfy already existing functional requirements and be used as substitute of other products;
- a creation, including development and deployment of essentially new products, technologies, procedures, structures and organisations.

Influence is understood as the impact of eco-innovations on the state of the environment including in the life cycle context. Influence depends on a combination of object and the mechanism and consequently can vary from certain improvements of an environmental state to full elimination of environmental damage. In particular, influence can be considered within the concepts of Factor 2, 4, 5 or 10 as described above.

Fig. 3.4 illustrates relationship between mechanisms and objects of eco-innovations with respect to evolutionary phases of environmentally sustainable industrial production.

![Diagram](image)

**Fig. 3.4. Relationship between mechanisms and objects of eco-innovations in the context of the environmentally sustainable production evolution**

In a prominent work [5] industrial experts have come to a conclusion that, today the advanced huge integrated metallurgical enterprises reached such level of technological perfection that the space for further progress to be achieved in this arena does not exist. Therefore such enterprises - especially those in the developed countries - have not really have many chances to adapt to the future economic context which will impose essential restrictions on emissions of greenhouse gases. By analogy with the evolutionary theory of Darwin, authors call such enterprises a deadlock branch - an equivalent to dinosaurs where changes in the economic environment will lead to extinction. Thus the steel industry has come to the level after which so-called "disruptive innovation" has to take place, which has to change techno-economic infrastructure in a root. The main reasons for this are [6]:

- achievement of limits of perfection within the boundaries of existing technologies (so called "technology saturation");
- change of an economic context in sense of environmental requirements, quality of raw materials, and emergence of alternative and breakthrough technologies;
- insufficient flexibility of production, in particular considerable duration of term of implementation of the order for production (as a rule, more than one month) while specialised products for various applications more often are required for the consumer;
- huge capital investment costs.

In the following chapters, the potential of innovative technologies for achieving the sustainable development targets will be analysed in detail. It should be noted that, innovative development of steel production can affect not only technologies, but also can become the reason for transformation of the entire industry:

- some technological processes (for example agglomeration of iron ore materials, coal coking, etc.) can become unnecessary;
- the optimum size of the enterprise can change;
- new types of products might be required;
- ferrous metallurgy can become rather a part of service of the existing industrial infrastructure, than production of a semi-product from which it is possible to make anything.

Today there are too many uncertainties - both on rates of introduction of innovative technologies, and concerning "rules of the game" in future conditions of economy with legislative restrictions of emissions of greenhouse gases.

References


4. Trends and factors of sustainable development

4.1. Iron and Steelmaking

V. Shatokha, S. Tymoshenko, S. Semenko

4.1.1. Development trends

Iron and steel industry is one of the most energy-intensive industrial sectors in the world. Usage of coal as the main primary energy carrier makes this industry one of the major sources of carbon dioxide emissions. Data of the International Energy Agency (IEA) in Fig. 4.1 show that share of ferrous metallurgy in the world’s CO₂ emissions by the industrial sources comprises 30%. In the total world’s anthropogenic emissions of CO₂, share of ferrous metallurgy makes about 9%. Therefore, the climate change mitigation worldwide is impossible without essential reduction of greenhouse gases emissions from metallurgical enterprises.

![Fig. 4.1. World’s CO₂ direct emissions by sector](image)

The target established by the IPCC on the basis of the fourth assessment report in 2007 on reduction of global emissions by 50% in 2050 compared to the level of 2000, in order to keep the level of global temperature increase within 2 °C, became part of the legislation in some countries. In particular, in European Union the target "20-20-20" was established, meaning greenhouse gases emissions reduction by 2020 from 1990 levels unless by 20%, cut in expenditure of energy by 20% and increase a share of energy production from renewable sources to 20%. In February, 2011 the Council of Europe confirmed the purpose to reduce the total greenhouse gases emissions by 80% by 2050 in comparison with 1990. In October 2014, the Council of Europe
accepted the 2030 framework for climate and energy policies, establishing the following tasks by 2030:

- to reduce greenhouse gases emissions at least by 40% relatively to 1990;
- to increase the energy share from renewable sources, at least by 27% on average for the European Union;
- to increase energy efficiency at least by 27% (might be reconsidered in 2020, meaning possibility of achievement an indicator of 30% by 2030).

For the industry EU Low-carbon Roadmap defines reduction of CO₂ emissions by 34-40% in 2030 (depending on sector) and by 83-87% in 2050.

By 2050 the population of Earth will inevitably significantly increase and economic development will demand more steel, than made today. Increased production will complicate achievement of environmental targets on a global scale. Forecasting of the future emissions of greenhouse gases is very complex task and it has to consider a big number of factors which are difficult to predict. The methodological approaches to forecasting, and results of forecasts on growth of population and steel demand, change of specific consumption of energy and structure of energy balance, availability of the steel scrap and other resources, etc. – with respect to peculiarities of the certain countries and regions - vary in rather wide range.

In relationship to production of steel, sustainable development concept implies solving the economic and social problems of industrial regions in the framework of global environmental constraints, associated with the negative effects of anthropogenic impact on the environment, mainly the emission of carbon dioxide into the atmosphere. Owing to exceptional energy consumption in production of steel, environmental security is linked to energy efficiency through the environmental component, which accompanies the production of energy. The ecological "purity" of the energy used at the enterprise, depending on the ratio of its production methods: the burning of coal or natural gas, nuclear reaction, solar, wind. Therefore, enhancing of energy efficiency of the steel production is seen as a positive factor of sustainable development concept.
Data of World Steel Association on world production of steel within the XX century are shown given in Fig. 4.2 (World Steel Association 2016). The long period of growth observed after World War II, had ceased after two oil crises of 1973 and 1980 followed by the stagnation period. However, only in 12 years of the XXI century, world production of steel doubled, having exceeded 1.6 billion ton in 2013 (fig. 4.3) with 6% growth year on year within six years in a row - result unprecedented in the history of this industry. This was mainly caused by economic growth in China which share in world’s steel production increased from 15% in 2000 to 48.5% in 2013.

As can be seen from the diagram in Fig.4.4, now almost all the steel is smelted in oxygen converters (BOF) and electric arc furnaces (EAF), whereas the share of open-hearth production (OHF) shrinks to almost zero.

The ratio between BOF and EAF is a result of historical processes of the industry’s emergence and/or restructuring and differs significantly across countries and economic regions (Fig.4.5). The BOF method is usually associated with primary steel production using blast furnaces (BF), although scrap is also used in this route.
Among European countries Greece and Portugal produce 100% of steel in the EAF, while in Netherlands, Czech Republic, and Austria more than 90% of steel production is made via BOF method.

Data on steel output in Ukraine for the last hundred years are shown in Fig. 4.4. Reaching the maximum production at the level of almost 60 million tons per year during the period since the end of the 70-s to the middle of the 80s, after collapse of the Soviet Union, production of steel fell lower than 16 million tons, having restored to the level nearly 43 million tons on the eve of world crisis of 2008 - 2009.

After essential production drop during the crisis, production in 2013 was stabilized at the level of about 33 million tons that corresponded to outputs which took place half a century ago - in 1963. However, owing to the political events and military conflict in the east of Ukraine in 2015, production of steel fell to 22.9 Mt although slightly recovered to 24.2 Mt in 2016.

The data shown in Fig. 4.2-4.4 confirm the difficulty of steel production forecasting – whether it is as for single country, or globally - in particular, owing to
unpredictable socio-political events greatly influencing the economic realities. Nevertheless, the further growth of world’s steel production is doubtless, in particular, in the developing countries (see more in section 6). Data on the steel output in the world’s top ten steel producing countries shown in Table 4.1 testify high potential for increasing the world’s steel production, in particular, considering rather low level of production per capita in India. Production increase in this country only to present average world’s level of 225 kg per capita, will mean additional production of nearly 200 million tons of steel per year - even without considering growth of population. However, usually country shall produce unless 400 kg per capita for ensuring requirements of dynamic economical development. Moreover, according to some forecasts steel production in China may continue to grow at least till 2030.

As shown in Table 4.1, Ukraine has one of the highest levels of steel production per capita in the world. In the Soviet Union, share of Ukraine in the general industrial production was extremely high (Table 4.2). Considering that the territory of Ukraine in the USSR made only 2.7%, and population 18%, and also that fact that iron & steel industry is concentrated in four Ukraine’s regions out of 26, industrialization level, and respectively an environmental pressure in these areas, in particular from the already performed economic activity (pits, dumps of wastes etc) was and remains very high.

Table 4.1
Steel production in the world's top ten producing countries

<table>
<thead>
<tr>
<th>№</th>
<th>Country</th>
<th>2016, Mt</th>
<th>2015, Mt</th>
<th>2016/2015, %</th>
<th>kg per capita (2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>808.4</td>
<td>802.8</td>
<td>+0.7</td>
<td>581</td>
</tr>
<tr>
<td>2</td>
<td>Japan</td>
<td>104.8</td>
<td>105.2</td>
<td>-0.4</td>
<td>833</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>95.7</td>
<td>89.4</td>
<td>+6.6</td>
<td>67</td>
</tr>
<tr>
<td>4</td>
<td>United States</td>
<td>78.6</td>
<td>78.8</td>
<td>-0.3</td>
<td>243</td>
</tr>
<tr>
<td>5</td>
<td>Russia</td>
<td>70.8</td>
<td>70.9</td>
<td>-0.1</td>
<td>494</td>
</tr>
<tr>
<td>6</td>
<td>South Korea</td>
<td>68.6</td>
<td>69.7</td>
<td>-1.6</td>
<td>1380</td>
</tr>
<tr>
<td>7</td>
<td>Germany</td>
<td>42.1</td>
<td>42.7</td>
<td>-1.4</td>
<td>529</td>
</tr>
<tr>
<td>8</td>
<td>Turkey</td>
<td>33.2</td>
<td>34.7</td>
<td>-4.5</td>
<td>436</td>
</tr>
<tr>
<td>9</td>
<td>Brazil</td>
<td>30.2</td>
<td>33.3</td>
<td>-10.3</td>
<td>159</td>
</tr>
<tr>
<td>10</td>
<td>Ukraine</td>
<td>24.2</td>
<td>23.0</td>
<td>+5.0</td>
<td>515</td>
</tr>
</tbody>
</table>

Table 4.2
Ukraine’s share in production of ferrous commodities in the Soviet Union (%)
<table>
<thead>
<tr>
<th>Products</th>
<th>Share in production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1940</td>
</tr>
<tr>
<td>Crude steel</td>
<td>48.8</td>
</tr>
<tr>
<td>Rolled products</td>
<td>49.7</td>
</tr>
<tr>
<td>Iron ore</td>
<td>67.7</td>
</tr>
<tr>
<td>Coal</td>
<td>50.5</td>
</tr>
</tbody>
</table>

### 4.1.2. Sustainable development factors for iron and steel industry

As described above, the concept of sustainable development is very complex. Both words - "sustainable" and "development" are equally important. Production of steel is business and consequently by definition aims at receiving profit. Taking into account modern socioeconomic conditions, in particular globalization of economy, environmental constraints and experience of an economic crisis of 2008-09, the Boston Consulting Group (USA) defined some fundamental problems the steel producers’ face, which we summarize as follows:

1) ensuring competitiveness under conditions of increased cost of energy and raw materials, simultaneously with enforcement of environmental requirements;

2) improvement of technology performance indicators such as energy consumption and environmental pollution;

3) ability to take advantage of the instruments of sustainable development strategy.

Herewith we are applying these three factors for the case of iron and steel industry of Ukraine.

#### 4.1.2.1. Competitiveness

Situation with fuel and raw materials prices in the world’s market is illustrated in Fig. 4.5 on the example of the price change on the iron ore concentrate of Vale (FOB Brazil for the Asian markets) and the coking coal Peak Downs (FOB Australia for the Asian markets) according to Delphica (2013) data during the periods before, during and after global economic crisis. The cost of the iron ore concentrate at the beginning of 2011 in comparison with 1998 grew by 7 times, at the same time the cost of coking coal grew by 10 times that is connected, first of all with the increase of demand for these resources in China which share in world’s import of coal increased from almost
zero level in 2001 to 18% in 2010. China’s share in import of iron ore raw materials reached almost 50% by the same year. The price increase became possible as a result of very considerable level of monopolization in the relevant markets: 88% of export of the coking coal is covered by three countries (Australia - 58%, the USA - 20% and Canada - 10%), and more than 70% of sea trade of iron ore are controlled by three companies.

In 2013, the world’s iron ore prices were increasing. In particular, the price on Australian’s ore grew before to US$ 120 per ton. In 2014, as a result of decrease of demand in China the price plummeted. In April 2014, the price on iron ore was US$ 47 per ton.

Fig. 4.7. Evolution prices for iron ore (a) and coke (b), US$ per tonne

Under conditions of considerable fluctuation in prices of mineral resources availability of considerable own natural resources, in particular iron ore and the coking coal has to be essential advantage for Ukraine. Below we provide brief analysis of raw materials market in Ukraine.

Iron ore

Calculated to pure iron, the estimated global reserves of iron ore comprise 79 billion t, or 12 t per capita. The greatest deposits are in Brazil (16 billion t), Russia (14 billion t), Ukraine (9 billion t), Australia (9 billion t) and China (7 billion t). Leaders in reserves per capita are Australia (440 t), Sweden (240 t), Kazakhstan (220 t).
t) and Ukraine (190 t). Thus, the available ore reserves in Ukraine are abundant, which allows to predict further development of ferrous metallurgy in our country.

The largest in Ukraine is the Kryvyi Rih deposit. Firstly the presence of iron ores here was reported in 1781. In 1866 high-quality iron ore deposits were discovered. After numerous geological expeditions these fields were commercialized, which triggered the steelmaking boom in the Dnipro region. Today Kryvyi Rih has both – shaft and open pit - mining of iron ore with the pits with the depth down to 400 m and in mines at a depth of 1200 m and more.

The general reserves of iron ore are estimated over 30 billion t with the following distribution on the main geological deposits:

- 18.7 billion t in Kryvyi Rih;
- 4.5 billion t in Kremenchug;
- 2.5 billion t in Belozersk;
- 1.4 billion t in Kerch (doesn’t operated since 1992).

The industrial stocks available to production at the mining enterprises by type are as follows:

- 1394.1 Mt of rich hematite ore;
- 15521.8 Mt of magnetite quartzite;
- 1027.8 Mt of the oxidized magnetite quartzite.

Thus, the essential part of deposit consists of quartzite that is a hard to beneficiate mineral. Considerable part of ores in Kryvyi Rih features very dispersed character of iron oxides’ minerals. Generally, taking into account the available equipment and technological capabilities, the quality of raw materials is lower than world’s standards. In particular, the content of iron in a concentrate - on average is about 65% while, for example, high-quality concentrate of LKAB (Sweden) contains 71% of iron.
As shown in Fig 4.8, production of iron ore in Ukraine grows steadily, now exceeding the pre-independence level. Having an opportunity to completely satisfy own requirements, Ukraine is the 4th world’s largest iron ore exporter. In 2013, out of 82.4 Mt of ore produced, nearly a half - 40.8 Mt was exported, mainly to China (46.3%), and also in the Czech Republic (12.2%), Poland (10.4%) and other countries. A subject of export is not only a concentrate, but also pellets: in particular, the Ferrexpo company (the Poltava GOK) exported in 2013 more than 10 million tons of iron ore pellets - mainly to the European Union countries, China, India and Japan.

**Coal**

Ukraine possesses the biggest in Europe coal resource - over 55 billion t of confirmed and 120 billion t of exploitable reserve, 97% from which are in Donetsk’s coal deposit. From this resource only 12-15% is of coking grades. The main part of mining is conducted by the shaft method, and the majority of mines are with a depth of 400 - 800 m. Some mines reach the depth of 1000-1300 m. The deposit is in operation since the end of the 18th century. The maximum production in 177.8 Mt was reached in 1970. The historical maximum of production of the coking coal was 88.4 t in 1980. In 2013 was 24.1 Mt of coking coal was mined, the lowest indicator for the last 20 years, while 10.9 Mt of coking coal was imported. The reason is in not
just a deficit of coking coal but also a high content of sulphur in Ukrainian’s coal (up to 3.5% of total sulphur). The export of coal in 2013 was 6.1 Mt.

Currently the majority of mines, notably those producing coking grades, and nearly a half of total coke production capacity (five out of twelve coke-making factories) are on the territory out of governmental control. At least three coke-makers are stopped into a “hot conservation”. The domestic coking coal supply in 2015 was down by 61% year on year and the share of imported (mostly from the USA) coal in coking mix during January-May 2016 was as high as 67%.

From this analysis following summary might be concluded:

1) Ukraine has abundant raw material resources for ensuring steady and long-term functioning of iron and steel industry;

2) In a view of low content of iron in iron ore materials, competitiveness of the domestic metallurgical enterprises will depend on introduction of modern technologies of ore beneficiation;

3) Under conditions of using domestic coal with the high content of sulphur, competitiveness of the domestic metallurgical enterprises demands definition of optimum energy-efficient technological schemes to produce pig iron and steel, including an external desulphurization.

Under the conditions of market economy existence of resources in the country does not mean automatically their availability to all producers. In particular, currently in Ukraine out of nine integrated steelworks only five belonging to Metinvest and ArcelorMittal companies have own iron ore resources. These holdings proved to be most competitive under the condition of fluctuated prices. Data of cost to produce steel for those Ukrainian companies without their own iron ore resource are shown in Fig. 4.9 (a) according to Delphica (2013) against fluctuations of market price during the period from 2003 to the 2nd quarter of 2011. In post-crisis years, profitability was considerably reduced and sometimes price of production taking into account transportation of products even exceeds market price.

Ensuring competitiveness requires systemic renovation of fixed assets and introduction of advanced technologies. In the conditions of narrowing profit margins, the possibilities of investment in modernization of equipment are significantly
reduced that it is visible from the Fig. 4.9 (b) showing the data on the general investments in modernization of the equipment at the enterprises covered by Metallurgprom Association during 2001-2014.

Ukraine’s steel companies weren’t active in investing to capital assets: maximum investments peaked in 2007 at the level of US$ 47 per tonne of crude steel with the average level of about US$ 25 per tonne of crude steel. In 2015 specific investments comprised just 372 UAH (ca US$ 15). Of course, such levels of investments are very far from being sufficient to modernise the industry towards the sustainable development standards. Possibilities of radical modernization, existed during the
period before 2009 when the level of profitability was much higher, in Ukrainian’s iron and steel industry were considerably missed. The shares of capacities with complete depreciation are (% data for 2009):

- coke batteries - 54;
- blast furnaces - 89;
- open hearth furnaces - 87;
- blast oxygen furnaces - 26;
- rolling mills - 90.

It should be noted that a situation with depreciation of fixed assets in other industries and in municipal sector of Ukraine is similar. The total need for the replacement of the worn-out equipment makes more than 300 million tons of steel, which has to be produced and consumed at the domestic market to satisfy the requirements of housing construction, municipal services, transport infrastructure, industrial constructions, pipelines and so forth (Амоша 2013). It is very important factor of future sustainable development of ferrous metallurgy in Ukraine which has to be capable to satisfy requirements of the domestic market and less depend on export.

About the 80% of products of the Ukrainian’s enterprises of ferrous metallurgy exported. Reliance on export is one of the serious problems in view of excess of capacity worldwide. In January, 2015 the average level of capacity utilisation in the world reached the lowest level in the last two years at 72, 5% (in Ukraine in 2013 - 74, 9%) that is a consequence of reduced demand for steel products. It is generally considered that the level of capacity utilisation below 80% negatively affects profitability of production, and the increase of this indicator over 85% is a positive signal for the industry. Existence of excess capacities means essential increase of the competition in the global market as almost each steel-producing country has considerable reserves of capacities to satisfy not only own demand but also requirements arising in other places. For example, only reserve capacity in China is nearly equal to production of steel in Russia and Japan taken together.

As shown in Table 4.3, Ukraine is the 6th world’s largest steel exporter, and 4th net steel exporter (total exports minus import). Export and the share of steel exported
continues to grow (Fig. 4.10). More than 40% of export consists of ingots and semi-products and this figure despite fluctuations tends to grow (Fig. 4.11). Hence Ukraine tends to export rather raw materials than value-added products. In contrast to this e.g. Poland has managed to develop more economically viable, technologically flexible and more environmentally clean model where value-added finishing dominates over energy-intensive and polluting manufacturing of semi-product, and domestic steel consumption is robust: Fig. 4.12 shows that indirect steel export (i.e. export of steel-made products) from Poland steadily grow. Poland even became 8th worlds’ biggest indirect steel exporter, whereas for Ukraine figures of indirect steel export are quite low.

Table 4.3

<table>
<thead>
<tr>
<th>№</th>
<th>Country</th>
<th>Export, mln t (2015 year)</th>
<th>Net (Export-Import)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>111.6</td>
<td>98.4</td>
</tr>
<tr>
<td>2</td>
<td>Japan</td>
<td>40.8</td>
<td>34.9</td>
</tr>
<tr>
<td>3</td>
<td>South Korea</td>
<td>31.2</td>
<td>9.5</td>
</tr>
<tr>
<td>4</td>
<td>Russian Federation</td>
<td>29.7</td>
<td>25.3</td>
</tr>
<tr>
<td>5</td>
<td>Germany</td>
<td>25.1</td>
<td>n.a.</td>
</tr>
<tr>
<td>6</td>
<td>Ukraine</td>
<td>17.7</td>
<td>16.9</td>
</tr>
<tr>
<td>7</td>
<td>Italy</td>
<td>16.5</td>
<td>n.a.</td>
</tr>
<tr>
<td>8</td>
<td>Belgium</td>
<td>15.2</td>
<td>3.1</td>
</tr>
<tr>
<td>9</td>
<td>Turkey</td>
<td>15.0</td>
<td>n.a.</td>
</tr>
<tr>
<td>10</td>
<td>France</td>
<td>14.0</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Fig. 4.10 Share of export in total crude steel production in Ukraine

Fig. 4.11 Share of ingots and semi-products in Ukraine’s export
4.1.2.2. Energy efficiency

Energy efficiency in iron and steel industry is determined by conditions of the equipment, the technologies used and quality of raw materials. Depending on the cost of energy carriers, structure of an energy balance, the used technologies, share of energy in production cost of an iron and steel plant makes from 20 to 40%. On average in the world 95% power costs at an integrated enterprise is the share of solid fuel (mostly - coal), 3-4% - natural gas, 1-2% oil. Approximately 75 % of the energy, primarily in the form of coal, is consumed in blast furnace production, while blast-furnace top gas it is used on various downstream steel production technologies as low calorific fuel.

Below we give brief overview of various technological routes of steel production from raw materials to semi-product - billets, slab, and bloom (often referred to as “crude steel” or to more value-added rolled products.

In the "large-scale" metallurgy that predominant is a two-stage steel production route (Seetharaman et al 2014), in which the BOF or the EAF is used for smelting of steel. Obtaining a given steel grade with necessary chemical composition and temperature is carried out by means of secondary metallurgy: in the ladle furnace (LF) and, for certain grades, also in the vacuum degassing unit (VD) or vacuum oxygen decarburization unit (VOD). Secondary metallurgy allows to separate in space and to combine in time two mutually exclusive technological process of oxidation refining (in BOF, EAF, VOD) and reduction refining (in LF, VD), needed to produce high-quality steel before casting on the continuous casting machine (CCM).
Steel production and, consequently, technological routes in the "large-scale" industry might be performed at integrated mills or mini-mills.

Integrated mills have a full cycle production (Fig. 4.14): agglomeration of iron ore → smelting of pig iron in BF → re-melting of iron into the crude steel in the BOF → ladle refinement to the desired grade of steel in LF, VD, and VOD → casting on the CCM to produce a marketable product. In some integrated mills (in SAR and in India) alternative to BF Corex technology (Hu et al 2009) is used, which allows to partially replace the deficient coke by low-grade coal. However, the position of the blast furnace in pig iron production remains sufficiently strong.

Another alternative of the BF production is solid-phase reduction of iron ore in the shaft furnace (SF) by gaseous reducing agents, which is carried out mainly by Midrex and HYL technologies (World Direct Reduction Statistics 2013). The initial material for the shaft units are iron ore pellets and the product is metalized pellets (direct reduced iron, DRI), or briquettes (hot briquetted iron, HBI), obtained from DRI in a roller press. For smelting of crude steel in this case the EAF is used being universal unit for all types of charge. Secondary metallurgy complements crude steel production as shown in Fig. 4.15. Typically in DRI production natural gas is used as a source to obtain reducing agent, although coal-based technologies are also available.
As an alternative to Midrex and HYL, recently a process of iron ore reduction in a rotary hearth furnace (RHF) is being actively developed. In particular ITmk3 technology (Kikuchi 2010) uses self-reducing ore-coal pellets to produce molten «nuggets» of metal, similar in composition to the pig iron. Technological scheme of the route is shown in Fig. 4.16. Its advantage is relatively low investment cost compared to previously discussed routes, making the process cost-effective for low-volume production, typical for modern mini-mills (under 1 Mt of steel per year), as well as the possibility of utilising fine ferrous wastes of a steel mill such as sludge and dust from dust catching apparatus.

![Fig. 4.16. Steel production route with alternative ironmaking using ITmk3 technology](abbreviations– in the text)

Mini-mills concept implies production of steel in the EAF usually from scrap and has much lower energy and environmental costs (Fig.4.17). However, DRI or, more often HBI (being better transportable material, DRI is susceptible to ignition), can be used as additive to scrap or even as the main source of iron. Recently a micro-mills (up to 100 kt of steel per year) concept has emerged.

![Fig. 4.17. Technological route of the mini - mill. Abbreviations – in the text.](abbreviations– in the text)

Summarised data on the technologies used to produce steel and related to them CO2 emissions intensity as well as share in the global market in 2014 is shown in Fig.4.18. In this summary some production route with cumulative share in the global market of less than 1% are neglected.
The theoretical minimum energy (net energy) to produce steel from ore-based technological route BF-BOF is 8.62 GJ/t LS, and for re-melting scrap in the EAF – 1.27 GJ/t LS (Fruehan et al 2000). However in practice energy consumption is much higher and depends upon the technologies used and quality of raw materials. According to Worldsteel data it varies in the range from 19.8 to 31.2 GJ/t for BF-BOF, from 28.3 to 30.9 for DRI-EAF and from 9.1 to 12.5 for scrap-EAF (World Steel Association 2012).

Taking into account, the depreciation level of the equipment and the problems with quality of raw materials no wonder that the Ukrainian ferrous metallurgy significantly lags on indexes of energy efficiency behind the best world analogues. Fig. 4.19 demonstrate’s data about the energy consumption in different sections of metallurgical production for the different countries. For the EU and Ukraine average data are provided, for China and India data for the advanced manufactures are provided. It is visible that the Ukrainian vendors significantly ahead other countries on energy expenses. It is especially noticeable for production of steel in Ukraine, where open-hearth furnaces are still used.
Fig. 4.19. Specific energy consumption per tonne of steel in different countries

Fig. 4.20 demonstrates the energy saving potential of the steel industries for some countries achievable through implementation of the best available technologies (IEA 2014). Ukraine has the highest specific figure and, therefore, the achievable energy saving potential value for Ukraine is nearly equal to those of Japan, South Korea and Canada taken together. Major effect might be achieved by further substitution of the OHF by BOF and improvements of the blast furnace operation. Taking into account that over 95% of CO\textsubscript{2} emissions in iron and steel industry originate from fossil fuels, energy saving potential is proportional to carbon dioxide reduction value.

![Energy saving potential chart]

Fig. 4.20. Energy saving potential (in GJ/t of crude steel and EJ per year) due to introduction the best available technologies for the world’s major steel producers

Apparently, production of pig iron is the main consumer of energy; therefore its radical modernization is indispensable for transition to sustainable development.

In 2013 Ukraine was the 9\textsuperscript{th} world’s biggest producer of pig iron. The statistics demonstrated in Fig.4.21 shows that after plummeting by 30% in 2009 compared to
2007 pig iron production has recovered in 2011 by 15% and then fluctuated at around 29 Mt per year. However, military conflict in the East dropped production to 21.8 Mt.

Pig iron to crude steel production ratio is a macroeconomic indicator reflecting steel sector’s infrastructure. In Ukraine this ratio was extremely stable for two decades, then, however, it grew, reaching the world’s highest level of 0.95 in 2015. To some extent it reflects reluctance of steel companies for stopping blast furnaces under conditions when steel production decreases.

![Fig. 4.21 Pig iron production in Ukraine](image1)

![Fig. 4.22 Pig iron to crude steel production ratio in Ukraine](image2)

Structure of steel production by method (Fig. 4.23 a) shows that most rapid decrease of the share produced by more energy efficient BOF method is observed during financial crisis of 2008 and coincides with steel production plunge. Hence positive infrastructural change is associated not with investments but rather with closure of obsolete OHF facilities. From 2008 to 2013 steel production capacity in Ukraine decreased by almost 10% from 47.8 to 43.8 Mt per year with average capacity utilisation of 75.9 %. Currently process of modernisation stagnates and the share of OHFs in steel production in Ukraine is the worlds’ highest level of 20.5%. Now very few OHF operate in the world – besides Ukraine only in Russia and India. The worlds’ average OHF steel production is as small as 0.6% in 2014.
Situation with deployment of continuous casting in Ukraine has been slightly better: fivefold growth of this technology’s share is observed from 1992 to 2010 (Fig. 4.23 b), than, however it stagnates at relatively low level of ca 54%, whereas the world’s average level in 2014 was 95.8%.

More thorough analysis exceeds the scope of current book; however, even from this superficial overview it is obvious that owing to the technologies used Ukraine’s iron and steel industry cannot world’s reach best standards in energy efficiency.

![Fig. 4.23. The structure of steel production in Ukraine by methods of smelting (a) and casting (b)](image)

In the context of sustainable development, it is important to emphasise that enhancing energy has the following positive effects:

- even though it requires significant investment, in the long term, the cost of production will decrease thus increasing competitiveness;
- it reduces dependency on energy imports and vulnerability to external economic and political factors;
- being largely associated with solid fuel, energy efficiency is proportional to environmental safety.
4.1.2.3. The environmental impact

The topic of hazardous emissions of iron and steel industry was raised in a number of publications. In this book we do not focus this issue, providing instead, the information about the greenhouse gases emissions, given its importance for sustainable development and the lack of coverage in the literature.

Fig. 4.24, according International Energy Agency Clean Coal Centre (IEA 2012), summarises data about the balance of CO₂ at an advanced integrated enterprise working with a fairly high technological performance including utilization of converter and coke oven gases. Total CO₂ emissions to the atmosphere comprise 1815 kg per ton of final product. The main sources of carbon dioxide are coal (94.2%) and limestone (case when hydrocarbon fuels are not analysed). The largest part of CO₂ emissions associated with pig iron production. Top gas is almost completely utilized for producing hot blast as well as for heating coke batteries and other furnaces, for generating steam and electricity. The most part of by-product gases (blast furnace top gas, coke oven gas and BOF gas) is utilized to generate steam and electricity, the largest source of emissions is power plant. Therefore, as will be shown below, in a short term modernization of power plant is one of the most promising measures for boosting energy efficiency and cutting greenhouse gas emissions. Distribution of GHG emissions by the main sources of iron and steel industry according to Energostal data is shown in Fig.4.25.

![Figure 4.24: Balance of carbon dioxide on a typical advanced steel plant](image)

Indicators of air pollution from iron and steel industry in Ukraine, according to government’s statistic (Ukrstat 2015), are shown in Table 4.6. The level of air pollution decreased slightly over the past six years - mainly due to the
decommissioning of OHF. However, CO₂ emissions have increased, resulting from a significant reduction of the use of natural gas: from 9.5 billion m³ in 2007 to 2.72 billion m³ in 2013. In particular, the replacement of natural gas with pulverized coal (PCI) in blast furnaces is accompanied by a significant increase of CO₂ emissions. Such significant changes are associated with increased raw material’s price and uncertainty for natural gas imports from Russia. In general, the environmental impact of steel companies is largely determined by the level of energy efficiency and technologies used and the structure of energy consumption, which in turn is associated with the ensuring competitiveness, thus closing the circle on sustainable development.

![Chart showing direct GHG emissions from main sources of iron and steel industry in Ukraine (in %)](chart.png)

Fig. 4.25 Direct GHG emissions from main sources of iron and steel industry in Ukraine (%)

### Table 4.4

Atmospheric emissions of iron and steel industry in Ukraine

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014*</th>
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</thead>
<tbody>
<tr>
<td>Air pollution by iron &amp;</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>steelmaking, ktons</td>
<td>1397.2</td>
<td>1149.7</td>
<td>926.7</td>
<td>1076.8</td>
<td>1102.3</td>
<td>1015.8</td>
<td>1004.6</td>
<td>802.1</td>
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<tr>
<td>Share of iron &amp;</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>steelmaking in total air</td>
<td>29.0</td>
<td>25.4</td>
<td>23.6</td>
<td>26.1</td>
<td>25.2</td>
<td>23.4</td>
<td>23.4</td>
<td>26.4</td>
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<tr>
<td>pollution by all economic</td>
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<td></td>
<td></td>
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<tr>
<td>activities, %</td>
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<td></td>
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<td>Air pollution per 1 ton</td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>of steel, kg</td>
<td>32.6</td>
<td>31.0</td>
<td>31.1</td>
<td>32.2</td>
<td>31.2</td>
<td>30.4</td>
<td>30.6</td>
<td>29.4</td>
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<tr>
<td>CO₂ emission from iron &amp;</td>
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<td></td>
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<tr>
<td>steelmaking, ktons</td>
<td>n.a.</td>
<td>38207.2</td>
<td>34348.3</td>
<td>39234.8</td>
<td>64073.1</td>
<td>59188.1</td>
<td>60520.6</td>
<td>n.a.</td>
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<tr>
<td>Share of iron &amp;</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>steelmaking in total</td>
<td>21.9</td>
<td>22.5</td>
<td>23.8</td>
<td>31.7</td>
<td>29.9</td>
<td>30.6</td>
<td>n.a.</td>
<td></td>
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<tr>
<td>amount of CO₂ emissions</td>
<td>n.a.</td>
<td></td>
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<tr>
<td>from all economic activities, %</td>
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<td>CO₂ emissions per 1 ton</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of steel, tons**</td>
<td>n.a.</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

* data do not include enterprises on the occupied territories
** State Statistics Committee of Ukraine do not report methodology of inventory, hence boundaries covered are not clear. Generally, data look much underestimated.

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4.2 Petroleum industry

M. Karpash, O. Karpash

Hydrocarbons are well known for being a major component in the global energy needs. The technical review of previous studies indicates that this horizon will not change in the near future until alternate sources of energy become available and economically sustainable. While this time arrives, the oil industry plays a significant role in the management of its operation in a way they do not affect our environment reducing to the minimum the ecological effect of emissions, pollution and other negative factors associated to the oil industry operations. At the same time, it has to be characterised by the fulfilment of human energy needs at an affordable cost and maximisation of the profit to be sustainable.

On the other hand, the oil companies have a social responsibility with the communities surrounding their operations. Most of the time, people living in areas where hydrocarbon extraction is present neither have a decent standard of living nor a positive image of companies involved in the operations. Oil companies can make a transcendental change in their neighbours just by considering two factors: Sustainable development and social responsibility. These factors do not require great amounts of money or work; however, the impact in their operations and the legacy they will leave once they finish their operations will be present for a long period of time.

Most of the hydrocarbons reserves are found in developing countries where oil industry is considered as an engine of growth for their economy. These countries are usually characterised by energy resources in environmentally susceptible areas where oil industry operations can have negative effects. Due to the global energy needs and being oil and gas well known for being a major component of them, the exploration and production of these resources cannot be stopped or decreased in the near future. Moreover, there is a general tendency of looking for hydrocarbon resources in areas that are even more environmentally sensitive [1].

On the other hand, there is a tendency towards corporate social responsibility; to consider increasing concerns about the contribution of business and the need to respond with new competitive strategies [2]. Social responsibility is a concept that needs to be understood and implemented by the oil companies to achieve their objectives in a way that benefit the communities surrounding their operations. Due to development in communications and politics, people in host communities demand more from oil companies in today’s world. They do not consider help from oil industry as a gift, the demand for it and social performance is considered a business imperative to achieve steady and successful operations.

We review two principles that are considered key factors for positive impact of international petroleum agreements between any oil company and the other two major components affected by or affecting its operations:
Government and host communities. These two factors are sustainable development and social responsibility. We think it is Moreover, the oil companies must have a positive impact in the environment and host communities in order to achieve their objectives in the most efficient way. We also demonstrate that an oil company can be successful in their operations and the management of their relations with the host communities and the environment if they recognise that their business is more than producing oil and gas in the most technically efficient and cost effective way. Oil companies also need to include responsibilities to shareholders, customers, employees, business partners and the society in general. As a result, their investment decisions cannot longer be only based on economic criteria but also environmental and social considerations.

The results presented demonstrate not only that sustainable development and social responsibility are key factors for positive impact of companies involved in any international petroleum agreement on the community near their operations. We also show how this can be achieved with an effort smaller than they might think bringing social development to the people and the host country. Moreover, the impact may have a constructive effect on their own operations helping to reduce the possible stoppage of their activities by the host communities.

To understand the impact of Sustainable Development and Social Responsibility on International Petroleum Agreements we need to define these two important terms first. Sustainable development has been defined as balancing the fulfilment of human needs with the protection of the natural environment so that these needs can be met not only in the present, but in the indefinite future. The term was used by the Brundtland Commission which coined what has become the most often-quoted definition of sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[3] The field of sustainable development can be conceptually broken into three constituent parts: environmental sustainability, economic sustainability and social-political sustainability.

Sustainable development does not focus only on environmental issues. More broadly, sustainable development policies involve three general policy areas: economic sustainability, environmental sustainability and social sustainability. In support of this, several United Nations texts, most recently the 2005 World Summit Outcome Document, refer to the "interdependent and mutually reinforcing pillars" of sustainable development as economic development, social development, and environmental protection [3]. Figure 4.26 shows a scheme of sustainable development and the confluence of these three constituent parts for a better understanding of this concept.

From this definition of sustainable development and the principle of social sustainability we can also highlight the importance of social responsibility which is
defined as an ethical or ideological theory that an entity whether it is a government, corporation, organisation or individual has a responsibility to society. This responsibility can be "negative," in that it is a responsibility to refrain from acting (resistance stance) or it can be "positive," meaning there is a responsibility to act (proactive stance). While primarily associated with business and governmental practices, activist groups and local communities can also be associated with social responsibility, not only business or governmental entities [4]. This term can be also linked with social performance or corporate social responsibility which definition is an extension of social responsibility applied to a particular case. The main areas of social performance include: Philanthropy, social investment, strategic social investment and social impact management. While the first two are known as techniques the others two are seen as the real value creators for the business. All of them can contribute to good social performance if there is a clear grasp of business and stakeholder requirements. This not only requires great attention to stakeholder dialogue and integration with the business but also a great commitment in the short and long term where any company is developing its hydrocarbon activities [5].

Fig.4.26. Scheme of sustainable development: at the confluence of three constituent parts

A case study how transnational oil companies in Nigeria in the Niger Delta managed their operations in sustainable way with close cooperation with local communities can be referred from [6].

When talking about ‘sustainable development’ sometimes we focus too much on ‘sustainable’ word, but for petroleum industry ‘development’ is considered as a key – development of the industry is nearly 100% technology (innovation) driven.
Innovation is the key ingredient to the success of any technology-based company independent of its size, market position or global presence. There are numerous worldwide examples that document that a company’s success is directly linked to its ability to innovate and solve complex drilling and completion challenges in increasingly difficult environments. Generally, most technology providers strive to be innovative, but many struggle to accomplish the goal. Questions arise; why cannot all companies be innovative; why are certain companies more innovative than others; why are some companies innovative over a certain period of time and then lose their ability to sustain it?

We attempted to outline key factors that correlate to a company’s ability to create innovations from within. The conclusions are derived from extensive internal studies, but they are applicable to all technology-driven companies across a broad spectrum of industries. We will include a list of action items designed to change a company’s culture to encourage innovation. These recommendations will also help companies sustain and predict innovation cycles.

When the next upturn in drilling activity begins, the industry must be prepared to respond with new and updated technologies/services to meet the next generation of drilling and completion challenges. By first understanding, then fostering a culture of innovation, the service industry will be properly positioned to efficiently accomplish future operator driven goals and objectives.

So what are the main reasons that cause an innovation to occur?

**Commitment to the Idea.** Probably the most important factor influencing innovation is having a constancy of purpose, even when the future is uncertain. It requires patience from management to wait for results and a determination to drive a concept to reality. The idea needs to be nurtured and given time to mature. For this to occur, it is critical to have buy-in and support from upper management.

**Individual Passion.** The individual passion and belief of a manager having the vision to pursue a new idea or an employee who truly believes in his or her idea is often at the core of any innovation. Whether it is a manager that had the vision to set in motion the project and provide resources to achieve the goals or an employee being proactive and developing solutions for a customer's application, it is common to find someone truly motivated at the heart of any innovation.

**Teamwork.** We started this discussion by stating the importance of individual passion and while it is nearly impossible to find any innovations that didn’t have passionate and driven people behind it, it is equally hard to find an innovation that did not require a group of individuals coming together and working effectively to cause an innovation.

Joint development teams working together in a cooperative and collaborative environment were another key cause of innovation. The teams were typically cross-
functional and usually covered various departments and in some instances went across business units. A partnership between departments and a clear communication methodology were found to simulate a culture of innovation.

**Seeking Input.** Actively seeking the input, advice, and concerns from a breadth of people, be it customers, employees or even people not directly involved with the process or products drives innovation. Successful innovations were found to be driven by people who from the inception of the idea through to the development actually asked and listened to the people on the ground who would have to use it, listening to what the customers are relaying through the sales groups as to their needs and actively gathering input from general working level staff, instead of just managers. By seeking input from as many sources as possible, employees had a much clearer vision of solution requirements to provide which helped them create the framework to innovate.

A management mind-set that looks for input and ideas from any source without prejudice is a major promoter of innovation. Be it a shop hand or a manager, every employee can contribute and should be encouraged to do so.

**Customer Knowledge/Requirements.** As the proverb goes, “Customer is King” so does the connection to innovation. Without understanding the customer’s needs and defining the specific requirement it’s difficult to develop a solution. The analogy would be a doctor prescribing medicine without fully understanding, then correctly diagnosing a patient’s illness. A clear understanding of what the customer does and how the customer’s company works is critical so the service provider can efficiently solve future operator driven challenges and objectives. While this might sound obvious, but we have found that a thorough in-depth examination of customer needs often creates ideas that result in successful innovations. Whether its product management, face-time with a customer or placing engineers on rigs and field locations, knowledge about the application and customer requirements are absolutely vital.

**External Environment.** Throughout our study we have found some of the common innovation drivers are not internal to a company but actually a result of a customer demand or competitor activity. These reactive innovations are driven by customer requirements that exceed the capabilities of current products and services and require a new and unique solution. As a customer’s needs change over time, a threshold is reached where incremental development cannot deliver a satisfactory solution.

In some instances competitor activity will cause a sudden increase in the demand for a better solution. A reactionary innovation might occur in response to new competitor technology and thus becomes a necessity to stay in business. Being able to predict what a competitor might offer in the future helps jump-start the innovation process leading to a proactive approach.
**Company Structure and Autonomy.** Opening the decision making process to base-level employees has an empowering effect and gives them ownership in the company’s success. Generally, the best environment to foster innovation requires free and uncluttered thinking and providing employees a certain level of autonomy. It is hard to innovate when pressured to perform.

The willingness of management to recognize the need for change and to experiment with the organizational structure to adapt to the changing environment is vital. New organizations tend to come with new vision, goals and clarity that trigger innovations.

**Revisiting the Past.** Innovations can come from investigating old projects that were deemed impractical at the time to see if new technology and materials knowledge has advanced enough to ensure success. This concept applies to the development of the internet, mobile connectivity and hand-held technology that was potentially useful but was commercially infeasible to develop and exploit at the time of conception. Assignment of resources to assess areas for such innovations from the past on a periodical basis might simulate new innovations today.

Armed with an understanding of the factors that drive innovation, let’s investigate some of the biggest obstacles.

**Short Term Focus.** In large publically traded companies shareholders closely monitor quarterly performance. In this environment, management tends to focus on short-term financial results. This business philosophy can inadvertently direct focus on projects based on their ability to deliver quick results at the expense of long-term R&D that might reap significantly higher share value. Also with short-term focus, the project team can become reluctant to explore new ideas because too much emphasis is placed on delivering results. We recommend focusing on creating sustainable value instead of counting dollars spent as a useful counter-step [7].

**Lack of Time.** Very few innovations come from keeping your nose to the grindstone! Innovators need time to think and work through various scenarios. Tight business tolerances and busy work schedules are a hindrance to innovation. It’s important to leave time for “thinking” and not occupy all an employee’s time “doing.” Management must overcome the perception that "thinking time is not productive time.” Innovators need time to sit down, focus and process out-of-the-box ideas and concepts.

**Fear of Failure.** We have discussed that individual passion and commitment is one of the key factors driving innovation. Geometrically opposed to that idea is the fear of failure. It is typical in most organizations to reward success, but we must be careful to not penalize failure. If an environment exists where failure comes with retribution, individuals will avoid high-risk approaches and stay on the safe, proven path.
Bonuses based solely on revenue with no allowance for risks during introduction of innovative technology might be a symptom of this problem. We have found that innovation must be encouraged and the lack of incentives or appreciation for risk taking to achieve a higher goal will make people risk averse.

It is important that upper management sets the proper tone for balancing risks and rewards and encourages employees who question the status quo. This is a critical requirement for an innovative culture to grow and it is not easy to achieve. Significant resource commitments must be made, but if done correctly, they will deliver a self-sustaining innovative culture that delivers new technology, processes and services on a regular and predictable basis.

**Departmental Conflicts.** We mentioned before that teamwork and cross-functional collaboration were significant factors for innovation. On the contrary, inter-departmental conflict, bureaucracy and self-promotion can be counterproductive. An environment where employees are concerned about getting credit will create turf wars that can side-line good innovative ideas just because they were not originated in the “right” department. We recommend an open culture where innovation is expected and sought from every department at every level of hierarchy within the organisation.

**Organisational Instability.** It has become fashionable in some companies to periodically rotate employees from one department or geographic location. While there are clearly some benefits to such a tactic, we have found this might have an ill effect on innovation in some cases. It is difficult to maintain consistency of philosophy, vision or implementation when there is a high turnover of employees or management or even organisation structure. An ever changing environment will lead people to focus on the short term thus reducing the ability to innovate. While change is a given, we recommend completing what was started before forging ahead with a new project. When a change is necessary, a good transition and transfer plan must be in place.

We discussed key causes for innovation as well as the significant obstacles. Finally, we would like to make recommendations on how to improve the culture of innovation within a company.

**Risk Taking Culture.** By nourishing a risk-taking culture, employees have the freedom to express themselves and ask questions. They will be quicker to embrace new ideas and be open to exploring technologies and ideas beyond the status quo. An acceptance of failure and an appreciation for risk-taking will help create such a culture.

**Out-of-the-Box Thinking/Brainstorming.** While the title is cliché, we recommend that a concerted effort be put on out-of-the-box thinking. Provide more freedom to potential innovators by unburdening them from inefficient procedures and
systems. Too many times an employee’s creative process gets stifled by rules, processes and paperwork leaving little time to explore for new solutions.

We recommend a strong push from upper management to encourage employees to seek innovative solutions that deliver potential performance step-change instead of tweaking a product or process for incremental gain. Encourage employees to seek fresh ideas looking outside past or current practices to arrive at better, big picture solutions.

A good way to achieve out-of-the-box thinking is through brainstorming sessions. Try and involve people from different job functions and ask them to generate new ideas without critique or criticism. The objective is to build on each other’s ideas and to generate as many ideas as possible without regard to their feasibility or practicality. We recommend planning a periodic brainstorming exercise with cross-departmental expertise.

**Resources.** Ensure there is adequate funding and management support for several high-risk/high-reward projects within the company. This might be achieved by increasing the R&D budget or by allocating separate funds for high-risk projects or start-up ideas. Many companies have successfully deployed the latter, and budgeting for such activity is highly recommended.

Outside of monetary funding, the other critical resource is people. Have the right people, in the right place and position them to be innovative! An under-staffed organisation is unlikely to have employees that have the time to step back to think and innovate. If a company is struggling with day-to-day operations, it’s unlikely the organisation will be able to innovate. We suggest that highly educated, well-trained employees are a company’s most valuable asset and investing in them will deliver substantial returns.

When hiring new employees, we recommend selecting people with diverse backgrounds within the functional team. A group of employees with the exact same experience, skill sets and abilities are unlikely to disagree and question fundamentals. Adding resources with different core competencies will help identify new challenges and ultimately solutions. When creating a project team, look to form multi-disciplined teams that include creative personalities, practical/disciplined types, and individuals who are consistent life-long learners. A diverse mix will create the opportunity for innovative thinking.

**Encourage and Reward.** We have discussed the need to develop and encourage a risk taking culture to create innovation. We also suggest creating an incentive mechanism that rewards innovation. While the exact nature of the program can vary substantially, it is important to develop some type of recognition plan. It’s our experience that employees are driven more by recognition from upper management and their peer group than a cash reward. We do recommend that the incentive program be inclusive in nature and be open to all employees.
**Knowledge Enablement.** Knowledge enablement or knowledge management has become a self-sustaining industry and is quickly becoming a focus in many companies [8]. Broadly the objective of the initiative is to arm employees with useful and pertinent information so they can make quick, effective decisions. Of course it’s transparent to see the connection to innovation. We have found that a significant amount of resources (time and effort) are regularly spent to develop solutions that were already in existence, in other words, re-inventing the wheel. Having a system in place where prior ideas and solutions can be readily identified and then effectively utilised can provide the foundation for developing new ideas and solutions in a timelier and cost-efficient manner.

An environment that encourages interaction and knowledge sharing is a key enabler. Also, exposing innovators to varied informational gathering environments (e.g. customers, operations, conferences, industry forums etc.), we have found to be highly productive for ideation. Discussions in industry forums and conferences often trigger new thoughts that might eventually turn into a successful innovation. Giving your employees more visibility to innovations and breakthroughs outside of your specific industry is also helpful. Overall, the more access and exposure employees have to knowledge, the more likely they are to innovate.

**Dedicated Person/Group.** For companies that do not currently have dedicated resources allocated to foster the culture of innovation it’s likely that no clear channel exists for new ideas to be submitted and reviewed. To address this issue, we suggest identifying a contact person to support new initiatives is a good first step. This individual or group would seek-out new concepts, inventions and ideas. They would solicit ideas and suggestions from all employees and provide an objective review. Alternatively, cross-departmental committees could also be tasked with this role, and would oversee the collection, screening and approval of new innovation ideas.

As a good illustration of the sustainable development approach by the transnational energy company – Shell International Exploration and Production BV.

The Royal Dutch/Shell Group has committed in its key policy documents to contribute to sustainable development. Shell accepts the Brundtland Commission definition of SD "meeting the needs of the present without compromising the ability of future generations to meet their own needs" as adopted at the 1992 UNCED or 'Rio' Conference, and recognises that it comprises three components - economic, environmental and social aspects - which are interdependent. For the E&P (exploration and production) business, the key challenge is to satisfy the growth for energy demand, whilst safeguarding the environment and acting in a socially and economically responsible manner. Particular issues facing E&P companies include emissions contributing to global climate change; local environmental, social and health impacts; conservation of biodiversity in sensitive areas; social and economic
development in concession areas; transparency and openness in communication and assurance of performance.

Here we will provide a background to SD and the issues that it raises for the E&P Business. It demonstrates how the commitment may be integrated into day-to-day activities and describes two tools which have been developed to allow for assessment and monitoring of progress towards a defined SD goal for new projects and for E&P companies respectively [9].

In March 1997, the Royal Dutch/Shell Group revised its Statement of General Business Principles (SGBP) and Health, Safety and Environment (HSE) Policy, including for the first time, a commitment to Sustainable Development (SD). Different groups have interpreted SD in different ways. The most commonly used definition, and the one accepted by the Group, is the Brundtland Commission definition of "meeting the needs of present without compromising the ability of future generations to meet their own needs" [10] as adopted at the 1992 UN Conference on Environment and Development (UNCED or Rio Conference). Full details of Shell's position on SD may be found on its website (http://www.shell.com/hse/susdev.html). A fundamental premise is that SD comprises three components - economic, environmental and social aspects - which are interdependent.

Having adopted this commitment, the challenge is now to ensure that it is integrated throughout business activities and that progress is assessed and monitored. Guidance, summarised in this paper, has therefore been prepared with the purpose of:
· providing a background to SD and the issues that it raises for the E&P business [11];
· introducing a tool that allows E&P companies to assess whether their current policies and practices are consistent with SD and to monitor progress over time (Sustainable Development Company Evaluation Tool);
· introducing a checklist concept for new projects or activities, to allow for early identification of SD issues for which more information may be required (Sustainable Development Assessment Checklist);
· summarising other key tools and techniques that may be used to help contribute towards SD, for example, life cycle analysis and impact assessments, and
· indicating how E&P companies may 'get started' in contributing to the principles using examples of some recent initiatives undertaken.

This case study presents only a first attempt to consider what SD means to the E&P business. The tools presented will evolve as experience with their use develops and our understanding grows. The focus is on making the hydrocarbon exploration and production process more sustainable. Movement by companies into other energy sectors such as renewables is not considered.

SD is firmly on the public agenda in the form of government policies and action plans aimed at implementing the agreements reached at the Rio conference.
Various aspects of sustainability are also at the heart of the causes championed by many national and international interest groups. All elements of society have a contribution to make and the industry must play its part along with others.

Responding to SD issues is important for employees and shareholders and for acceptability with the public. Today's business environment is characterised by fierce competition and society's expectations of multi-nationals are changing: increasingly the success of projects is dependent on achieving endorsement from local communities and other stakeholders who are concerned about oil and gas exploration and development. To be recognised as the top performer of first choice and to maintain their 'licence to operate', Shell companies must respond effectively to these challenges.

A responsible approach will enable Shell companies to contribute credibly to the public debate and to work constructively with regulators to agree the most effective means to achieve common objectives. In the longer term, a responsible approach will allow companies to take advantage of business opportunities which SD may present and to avoid unnecessary financial risks associated with investments that might not meet sustainability criteria.

**Issues for the E&P Business.** The E&P Business is well equipped to demonstrate its economic contribution to SD through the benefits it brings to society through energy, chemicals and other products, and through wealth generation and employment creation. The key challenge is to satisfy the growth for energy demand, whilst safeguarding the environment and acting in a socially and economically responsible manner. This represents a key change in focus from simply improving HSE performance to now fully considering social, environmental and economic issues and impacts. This raises a number of issues and challenges for E&P companies including:

- the contribution of air emissions to potential global climate change. Although it is not known to what extent the climate will change as a result of increased carbon dioxide and methane concentrations in the atmosphere resulting from the use of fossil fuels, there may be an effect. There is sufficient concern for prudent actions to mitigate this, such as efficient use of hydrocarbons in all phases of extraction and lifecycle;
- local impacts from operations and from using products. This includes both environmental, social and health impacts;
- conservation of biodiversity. Particularly relevant when operating in areas of high biodiversity such as the tropical rainforests and coral reefs;
- acting in a socially responsible manner and contributing to development in concession areas. This includes education and training of employees, contributing to social capital through technology transfer and support of community initiatives. These are already important aspects of management of many companies, but there
needs to be greater consideration of the social impact of operations to ensure that they cause the least possible disruption to local communities, but also contribute as much as possible to the host society;

- transparency and openness in communication and decision making and assurance of performance. There is a new emphasis on public accountability and external verification of performance consistent with the transition from the "trust me" to the "show me" world. Companies must show themselves more willing to listen, learn and interact with external stakeholders by developing and strengthening relationships and partnerships and fully consulting with stakeholders;

- in the longer term, the finite nature of resources. Fossil fuels are a finite resource, which nevertheless have a role to play on the road towards SD, if only because there are currently no alternatives to provide energy in sufficient quantities needed to meet the growing demands, particularly in developing countries. This includes the need to alleviate poverty which is a major source of environmental degradation. Whilst unsustainable in the long-term, oil and gas will contribute more to social and environmental well-being if developed than if left in the ground, but resources should be extracted and used efficiently,

- internalisation of environmental costs. In many countries discharging emissions and wastes is free of charge which does not encourage the efficient use of common resources. Internalising these costs and subjecting them to market forces may do so. It is also important to ensure that environmental and social criteria and costs are considered and integrated in business decisions.

Whilst it may be relatively easy to identify the key challenges facing the E&P business at the generic level, it is more difficult to identify what these issues actually mean for day-to-day business. To date, much of the discussion about SD has been theoretical and there have been many, often conflicting, views on the way forward. No structured mechanism has existed to allow companies to systematically identify and assess SD issues of importance when undertaking new activities or modifications to existing assets, nor to asses and monitor the progress of the company as a whole in moving towards being more sustainable.

To help address these gaps, the key challenges identified have been translated into a number of potential areas where action may be undertaken by E&P companies in order to move towards being more sustainable. These potential contribution areas are illustrated in Table 4.5 and form the basis for the sustainability assessment tools outlined below.
<table>
<thead>
<tr>
<th>Components of Sustainable Development</th>
<th>Potential Contribution Areas</th>
<th>Indicators of Sustainable Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient use of energy and resources</td>
<td></td>
<td>· Gas flaring</td>
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<td>· Hydrocarbon venting</td>
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<td></td>
<td>· Energy</td>
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<td></td>
<td></td>
<td>· Fresh water use</td>
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<td>· Waste generation</td>
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<td>· Land take</td>
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<td>· Materials</td>
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<td></td>
<td>· Renewables</td>
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<td></td>
<td></td>
<td>· Green purchasing</td>
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<tr>
<td>Reduce discharges and emissions</td>
<td></td>
<td>· Produced water</td>
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<td></td>
<td></td>
<td>· Oil- based muds and cuttings</td>
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<tr>
<td></td>
<td></td>
<td>· Oil spills</td>
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<td></td>
<td></td>
<td>· Gaseous emissions: CO2, CH4, SOx, NOx, H2,S, VOCs (including BTEX)</td>
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<td></td>
<td>· Halons and CFCs</td>
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<tr>
<td>Preservation of natural environments</td>
<td></td>
<td>· Biodiversity (habitats, ecosystems and species)</td>
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<td></td>
<td></td>
<td>· Site rehabilitation</td>
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<td></td>
<td></td>
<td>· Secondary effects of development</td>
</tr>
<tr>
<td>Maximize social benefits and minimize adverse social effects</td>
<td>Employment</td>
<td>· Employment</td>
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<tr>
<td></td>
<td>Education and training</td>
<td>· Education and training</td>
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<tr>
<td></td>
<td>Health</td>
<td>· Health</td>
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<tr>
<td></td>
<td>Safety</td>
<td>· Safety</td>
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<tr>
<td>Stakeholder involvement</td>
<td>Partnerships</td>
<td>· Partnerships</td>
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<tr>
<td></td>
<td>Consultation/participation</td>
<td>· Consultation/participation</td>
</tr>
<tr>
<td>Transparency and assurance</td>
<td>Communication</td>
<td>· Communication</td>
</tr>
<tr>
<td></td>
<td>External verification and certification</td>
<td>· External verification and certification</td>
</tr>
<tr>
<td>Maximize economic benefits of business activity</td>
<td>Effect on local economy</td>
<td>· Effect on local economy</td>
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<tr>
<td></td>
<td>Capacity building</td>
<td>· Capacity building</td>
</tr>
<tr>
<td></td>
<td>Technology transfer</td>
<td>· Technology transfer</td>
</tr>
<tr>
<td>Include environmental and social criteria in business decisions</td>
<td>Product portfolio</td>
<td>· Product portfolio</td>
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<tr>
<td></td>
<td>Reservoir depletion strategy</td>
<td>· Reservoir depletion strategy</td>
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<td></td>
<td>New developments</td>
<td>· New developments</td>
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<td></td>
<td>Environmental projects (existing operations)</td>
<td>· Environmental projects (existing operations)</td>
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</tbody>
</table>

**Sustainability Assessment Tools**

Two assessment tools have been developed: a Sustainable Development Company Evaluation Tool (SDCET) and a Sustainable Development Assessment Checklist for projects. Each tool is built around a range of indicators which have been established for the areas where companies may potentially contribute to SD. These are also shown in Table 1. By considering these issues, a company is able to obtain an indication of its position as regards SD, and an indication of which key issues must be considered both for the company as a whole and for new projects. It is recognised that some of the indicators may form part of more than one category set.
and that they are limited to those identified as important for the EP business as a whole. There may be additional issues which are of local importance to a company.

Sustainable Development Company Evaluation Tool. The evaluation tool allows a company to assess whether its policies and practices are consistent with SD and to monitor its progress in becoming more sustainable over time. For each of the indicators identified, it requires consideration of the company’s current practices and comparison of these to the practices that would be expected from a fully sustainable company. This expectation reflects the practices which a company would be expected to undertake to be sustainable in the long term and are inferred from Agenda 21 [12] and environmental best practice. They are also in line with international agreements such as the Montreal Protocol, and the long term HSE objectives set for the Shell Group. The key steps required to use the evaluation tool are:

Select relevant indicator. All indicators of relevance to the company should be considered in turn, including those areas where there are currently no activities or policies. Views of stakeholders may be sought in selection.

Compare company policy and practices to the descriptions given and allocate appropriate scores. For each indicator, five descriptions of policy and practice are given. These represent stages on a scale moving towards best sustainable practice. Each level of description generally incorporates those of the previous descriptions. To allow for performance assessment and tracking over time, each description has a score weighted from zero to ten.

Benefits. By defining which description best fits its policies and practices, a company is able to systematically:

- assess whether its current policies and practices are compatible with the objectives of SD;
- assess what it could and should do to move in a more sustainable direction by identifying areas where it scores low marks;
- use this information to prioritise areas for action and to develop improvement objectives and targets;
- monitor progress towards sustainability over time,
- report to the public on its achievements.

Relation to the Management System Process. The tool allows a company to assess how its practice and performance compare to those expected of a sustainable company. As such it forms part of the feedback loop in the HSE Management System (HSE MS). The results of the assessment should be used by company management when reviewing policy and strategic objectives and when planning and prioritising activities and investment.

Limitations. The tool described represents a first attempt to develop an evaluation tool for SD and will be updated as experience increases. It is designed to be used by companies of different sizes, operating in many different environments.
As such, the descriptions can only be general statements which are simplifications of reality. The indicators are limited to those identified as important for the E&P business as a whole. They may not be applicable to every local situation. There may well be additional issues which are of specific local importance to a company which should also be included. In particular, the tool does not consider indicators relating to movement by companies into other energy or business sectors. Companies may expand the methodology to include and address specific issues of local concern and omit irrelevant indicators.

**Tools and Techniques to Contribute to the Sustainability Process**

The tools outlined above will provide a company with an indication of the practices and policies which are expected from a sustainable company, and the types of SD issues which must be considered in new projects. Having identified their current status and key issues, companies need to adapt their policies and practices and employ appropriate tools and techniques in order to progress towards the objectives of SD.

A number of useful tools are already available to help progress towards sustainability, many as part of the Hazard and Effect Management Process of the HSE MS. A summary of tools and techniques that may be used to improve performance on each of the categories of indicators (provided in Table 4.6).

**Table 4.6: Tools and techniques to contribute towards sustainability**

<table>
<thead>
<tr>
<th>Components of SD</th>
<th>Indicator Category</th>
<th>Tools and Techniques to Progress towards expectation for a sustainable company</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental</strong></td>
<td>Efficient use of energy and resources</td>
<td>A selection of HEMP&lt;sup&gt;6&lt;/sup&gt; tools, life cycle analysis, benchmarking.</td>
</tr>
<tr>
<td></td>
<td>Reduce discharges and emissions</td>
<td>HEMP tools (e.g. environmental assessment), life cycle analysis, benchmarking.</td>
</tr>
<tr>
<td></td>
<td>Preservation of natural environments</td>
<td>HEMP tools (e.g. environmental Assessment).</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td>Maximise social benefits and minimise adverse social effects</td>
<td>HEMP tools (e.g. social impact assessment [13] and health assessments [14], ergonomics [15]).</td>
</tr>
<tr>
<td></td>
<td>Stakeholder involvement</td>
<td>External HSE and social reporting, social impact assessment.</td>
</tr>
<tr>
<td></td>
<td>Transparency and assurance</td>
<td>Social impact assessment, external HSE and social reporting.</td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td>Maximise economic benefits of business activity</td>
<td>Social impact assessment, ranking tools (e.g. Shell UK Expro approach of ETSAR [16]).</td>
</tr>
<tr>
<td></td>
<td>Include environmental and social criteria in business decisions</td>
<td>Full cost accounting, ranking tools.</td>
</tr>
</tbody>
</table>

<sup>6</sup> HEMP - Hazard and Effect Management Process (also referred to as hazard and risk evaluation)
Shell International E&P has produced comprehensive guidance on many of these issues [17]. However, issues such as life cycle analysis and full cost accounting are still at very early stages of development across the E&P business and need to be more fully considered and addressed.

Many of the activities and initiatives required to meet the objectives of SD require action at the local level in consultation with stakeholders and thus each individual company will arrive at different, local and company-specific way of working.

It is also clear that SD requires new ways of thinking throughout all levels of the E&P business. Whilst we have much experience on the economic and environmental components, E&P companies have less experience to date in matters such as social impact assessment, social capital building, communication, consultation and participation, and it will take time to fully consider and address these issues.

SD is a path which society expects industry to follow. Real progress in turning theory into practice will only be made by working together and sharing experiences and understanding.

All elements of society have a role to play in meeting the objectives. Increasingly, communication and partnerships with governments, NGOs and local communities will play a key role and consideration needs to be given as to how such cooperation and partnerships can be developed and strengthened to provide mutually beneficial results.

Oil industry plays a significant role in the management of this important energy source and the way it is extracted from ground with the less possible impact on the environment and communities that surround the extraction areas. Therefore, oil companies need to understand and implement the principles of sustainable development and social responsibility for the required balance and progress in most of the areas of hydrocarbon exploration and production. Due to the nature of energy business, the operations linked to it can affect our environment through the ecological effect of emissions, pollution and other negative factors associated to the oil industry operations. However, these negative effects can be avoided if they consider and implement good neighbour policies in their exploration and exploitation plans. According to most of available studies, the oil industry will continue being the main source to fulfil the global energy needs. From the review of previous studies, we understand that this horizon will not change in the near future until alternate sources of energy become available and economically sustainable. While this moment arrives, the oil industry has to be conscious of the need for operations in an environmentally and socially oriented framework reducing to the minimum the negative factors associated affecting not only the environment but also the host communities and the way they live.
There are three major components affected or affecting in the oil industry: the oil companies, the governments and the host communities. All of them can have different points of view about how sustainable economic development can be applied. However, it is not until their ideas converge that we will observe the accomplishment of their needs and successful and environment-friendly operations. To achieve this objective, each of these components needs to understand that they need to develop a partnership characterised by the mutual benefit of each part.

In the past, oil companies used to have some considerations with host communities in order to obtain licenses to explore and produce hydrocarbon resources. In some cases, they were given as a compensation for obtaining what they needed. In today’s world of better communications, increased sophistication and less political restrictions, people living in host communities have increased their demands for social development and environment-friendly operations. The African country case of study presented demonstrates that it is possible to achieve the continuity of the oil industry operations under a good neighbour policy. At the same time, politics taken by any oil company cannot be implemented unilaterally; they need to be the result of previous agreements between the oil companies, the government and the host communities.

The oil companies have a social responsibility with host communities. In most of the cases, people living in areas where there is hydrocarbon extraction have neither a decent standard of living nor a positive image of companies involved in the operations. Oil companies can make a substantial change in their neighbours’ way of life just by considering sustainable development and social responsibility. Implementing these factors in oil operations as a best practice can reward them not only in their image but also in the continuity of their operations. The practice of this good neighbour policy does not require great amounts of money or work; however, the impact in their operations and the legacy they will leave once they finish their operations will be present for a long period of time.

Those oil companies which have had success in their operations and the management of their relations with the host communities and the environment has recognised that their business is more than producing oil and gas in the most technically efficient and cost effective way. They also need and must include responsibilities to shareholders, customers, employees, business partners and the society in general. Therefore, their investment decisions cannot longer be only based on economic criteria but also environmental and social considerations.

The results presented demonstrate not only that these are key factors for positive impact of companies involved in any international petroleum agreement on the community near their operations. They also demonstrate this can be achieved with an effort much smaller than they might think. Furthermore, the impact may have a constructive effect on their own operations helping to reduce the possible stoppage of their activities by the host communities.
References
4.3. Mining

S. Ruban, I. Muzyka, O. Kalinichenko, N. Morkun, L. Kruhlenko

Among the areas of extractive industry a leading position belongs to mining which companies carry out the extraction of minerals. In practice, different sectors of the mining industry include both mining industry (mines, quarries) and processing (dressing, briquetting, sinter plants, etc.). According to the nature of the products, mining is divided into the following groups: 1) fuel (mining of coal, natural gas, oil shale, oil, peat, uranium); 2) ore-mining (mining of ferrous, precious, nonferrous and rare metals); 3) mining and chemical (mining of phosphates, potassium and other salts, apatite, etc.) 4) non-metallic minerals (mining of granite, limestone, kaolin, marble, etc.).

Mining industry has specific characteristics that influence the technical and economic parameters of its operation and management. Among the features are the following [1]:

- determining influence of natural factors;
- dependence on mineral deposits;
- permanent changing mining and geological conditions of mineral deposits development;
- a continuing need for carrying out the extraction front that requires significant investments, most of which are not for the increase but maintaining of the existing production;
- the limited life of the mine which depends on the size of mineral deposits of mine (quarry) fields (20 to 60 years or more);
- high capital intensity;
- a variety of geological conditions, which necessitates the use of different development systems, technology, methods and types of mechanisation with the same method of mine development;
- difficult conditions of mining machinery exploitation;
- mobility of jobs and close relationship of production and work processes, increased risk of work related to the conduct of drilling and blasting operations, manifestations of rock pressure etc.;
- less comfortable working conditions in mines than in other industries;
- prevalence of human resources and financial resources in the form of capital investments.

According to the estimates given in paper [2], as of 2012 there were estimated 2500 major mines, extracting raw materials on an industrial scale, about 25,000 mines extracting mining and chemical raw materials, and about 100 000 quarries, extracting industrial minerals for the needs of construction. Among 2500 mines 52%
carry out open pit mining, 43% – underground, and about 5% – extraction of minerals in the placer deposits and using geotechnical method. The share of ore materials mined by open pit is 85% of the total production, about 15% is mined by underground methods. In the last decade of the 20th century and the first decade of the 21st century, there is a trend to a slow increase in the volumes of extraction of ore materials by open pit mining. This is due to two main reasons [2]:

- The first to the depletion of the rich ore deposits underground mining, having a large in comparison with the cost of open pit mining, become economically unsound;
- The second to the use of new, more efficient technologies and equipment (e.g., hydrometallurgical method SW-EX for the extraction of copper) allows companies to use ores with poorer grade compared to traditional methods.

In Ukraine, more than 70% of mining operations are carried out in quarries. Further development of the open pit mining is associated primarily with an increase in the depth and area of the quarries, the increasing complexity of mining geological and technical conditions of development increase in the area of alienated lands. All this is happening against the background of ever-increasing requirements for environmental protection and rational use of natural resources.

The demand for mining products are mainly provided by the countries with emerging economies, while demand in the countries belonging to the Organisation for Economic Cooperation and Development (OECD), is forecasted to continue to decline [3]. Over the past century, mining of ore materials, mining and chemical raw materials increased by 27 times, mining for the needs of the construction – by 34 times, while the volume of production of biomass increased by only 3.4 times.

Fig. 4.28 shows the dynamics of changes in production volumes of basic types of minerals for 30 years (from 1984 to 2013) [4]. Thus, the volume of steam coal production increased by almost 2.3 times (from 2.5 to 5.7 billion tons), coking coal – by 1.75 times (from 0.57 to 1 billion tons), and iron ore – by almost 3.4 times (from 465 million tons to 1.56 billion tons).
Fig. 4.28. Global production of minerals, by type of raw material

Analysis of global trends in the ore mining and changes in gross domestic product (GDP) [3] shows the close link between the use of resources and economic growth (Fig. 4.29). By the middle of 90s trend analysis shows a slight improvement in the efficiency of resource use, but in recent years the production and consumption of raw materials for construction materials (iron ore, bauxite, copper and nickel) are growing faster than world GDP [3].

The close relationship between mining and economic growth could be weakened by the three main ways [3]:

– Due to the structural effect which means to shift the focus from the primary and secondary sectors of the economy towards the services sector.

– Due to the technological effect which means a wider implementation of more efficient technology in terms of materials using.

– Due to the trade affect which means moving intensive production stages in the use of materials to other regions of the world.

At the global level, a technological effect reduces the use of primary material resources [3].
Increase in demand for natural resources means increase in development and exploitation of deposits, as well as increase of the speed of mineral depletion in different regions [3]. Thus, Fig. 4.30 reflects the trends of the global distribution of the volumes of ore extraction (in percentage terms) from 1850 until 2009 years [5].

The distribution of mineral deposits in the world varies considerably. Most deposits of raw materials are not in the areas of maximum demand for corresponding materials. At present, developing countries have more than half [3, 6] of the world's reserves of large deposits of ore (Fig. 4.31).
As we can see, Ukraine is among the ten countries with the largest deposits of iron ore and coal. As of 2013, Ukraine took the 7th place in the world by volume of iron ore mining (3% of world production), 10th place – by volume of manganese ore mining (3%), 11th place – by volume of titanium ore mining (3%), 2nd place – by volume of gallium mining (14%), 14th place – by volume of bentonite production (1.3%), 7th place – by volume of kaolin production (5.6%), 13th place – by volume of salt production (2%), 10th place – by volume of zirconium production (1.8%), 11th place – by volume of steam coal production (0.75%), 8th place – by volume of coking coal (2%).

Fig. 4.32 shows the dynamics of changes in production volumes of basic types of minerals for 5 years (from 2009 to 2013) in Ukraine [4]. Thus, the volume of steam coal production increased by 20% (from 35.7 to 43.1 million tons), coking coal – by 5% (from 19.2 to 20.2 million tons), iron ore – by 28% (from 35 to 45 million tons), kaolin – by 82% (from 1.12 to 20.4 million tons), manganese ore – by 26.5% (from 375 to 474 thousand tons), bentonite – by 13% (from 195 to 220 thousand tons), salts – by 7% (from 5.41 to 5.8 million tons), gypsum – by 11% (from 1.99 to 2.2 million tons), uranium ore – by 28% (from 0.99 to 1.27 thousand tons). At the same time, the volume of titanium ore production declined by 44%, zirconium – by 19%, sulphur – by 11%.

Mining of raw materials in the world in general and in Ukraine in particular has a significant effect on the environment. As a result of intensive mining activities have emerged and continue to grow serious violations of the environment: the withdrawal of large areas of land from agricultural use for the construction of dumps for the storage of rocks, slime storage of rock refuse, storage of highly mineralised mine and quarry water; deformation, failures and subsidence of the earth's surface over the dead pits; progressive development of the flooding process of land areas; pollution of surface water bodies and underground aquifers, pollution of atmosphere with dust and gas emissions, etc. [7].
The most common as a result of mining and metallurgical complex is waste of extraction and enrichment of iron ore and coal, steel, ferroalloy, coke, electroplating and pickling plants, chemical plants and power plants. Global human and technology intervention into the geological environment has led to the accumulation on the surface of the planet of billions cubic meters of industrial waste. When the currently existing technologies from 10% to 99% of the original weight of the raw material obtained from the deposit becomes a waste that is stored on land or discharged into the atmosphere and water. The accumulation of waste leads to environmental pollution violated and polluted land, air, surface and ground water that have a direct impact on human health.

All states faced the problem of reducing waste in production and business activities, its systematic utilisation. With the exhaustion of natural resources, the involvement into the exploitation of the deposits with a lower content of minerals and improvement of processing technologies, the opportunity appeared to re-use many waste products. A small part of a manmade waste today is drawn into use, but it does not solve the problem as a whole.

Wastes tends to remain on the territory of the created object and become a source of danger over a long term through the potential displacement of leachate and the possibility of a serious accident at the production facility. As a result, the emissions into the environment may occur. In the past there have been a number of large accidents which have occurred on the tailing dams and caused serious consequences for the environment and public health (for example, in 2000 cyanide spill at Baia Mare (Romania) and in 2010, an accident in the red mud storage at the alumina plant in Hungary). In addition, the tails and waste rock piles can also be a source of dust emissions, resulting in the contamination of land and soils in the surrounding areas and are potentially dangerous to the health of the local population.

Taking into account that the environmental management of mining and metallurgical region has the resources processing nature, a significant problem is the
completeness of mineral resources. In this regard, the problem of sustainable development for the mining region is reduced to the rational use of available natural resources. The efforts of industrialised countries are focused primarily on the prevention and minimisation of waste generation, and then their re-use and recycling, the development of effective processing methods, neutralisation and final disposal, and burial is only applicable to waste that does not pollute the environment. All these measures will definitely reduce the negative impact of industrial waste on nature, but does not solve the problem of their progressive accumulation in the environment, and, consequently, the growing danger of penetration into the biosphere of harmful substances. A variety of products which with modern science and technology can be obtained and consumed without waste is rather limited and available only in a number of technological chains and for only highly profitable industries and industrial associations.

The way to minimise the negative impact of industrial waste on the environment is carried out in two trunk areas: 1) technology – improving environmental production safety; 2) ecology protecting – stabilisation and isolation of hazardous waste from the environment.

In recent years around the world attention has been paid much more to the industrial clusters of industrial wastes, and particularly to the storages incurred in the operation of mining enterprises. The strategy of member countries of the Basel Convention on waste strategy at the beginning of the XXI century is to balance waste management and the use of them with sustainable development [8]. To ensure this, in a number of developed countries the whole economic sector was set up and called “waste management”. The term “waste management” includes the collection, transport, processing or disposal of waste, in order to reduce their impact on human health and the environment. A completely non-waste production is a distant prospect, but already now it is necessary to solve this problem, both at the macroeconomic level and in the individual sectors of the economy.

The first step in the formation of territorial systems of without waste resource use can be the establishment of industrial units operating under a diversified economic complex of the region through a combination of different industries, cooperation between enterprises in the use of raw materials, industrial and household waste. It is important to emphasise that in many member countries of the UN European Economic Commission large industrial complexes were created by cascading designs, according to which the waste from one industrial plant is used as raw materials for another.

Qualified specialists in the field of using biotechnology or other competent people on these issues should start developing solutions for waste management problems in the mining industry, including design problems of tailings dams and waste heaps of waste rock. Most often, preference is given to the development of
passive waste treatment systems, since the use of active systems of processing of these wastes can cause problems with the treatment of these wastes after mine closure.

Prospects for the mining industry are based on the profound changes taking place in connection with:

- concern for the environment;
- intense competition resulting from globalisation and the emergence of new countries-suppliers of mineral raw materials;
- the need to ensure sustainable development.

Undoubtedly, the mining industry is facing many challenges related to sustainable development. These include social issues arising in connection with the activities in remote areas, the need to ensure the production with highly qualified specialists, the impact on the socio-economic development of local communities, environmental protection, climate change, the closure of mines etc.

The objectives of the sustainable development of mining industries include [9]:

- introduction of low-waste resource-saving production technologies and complex deep processing of raw materials;
- improvement of licensing and payment mechanisms for the use of mineral resources;
- search for new mineral deposits on the principles of environmental and economic feasibility of their development;
- ensure the possibility of using technogenic deposits and waste during the formation of the balance of natural resources at all levels of nature use;
- provision of the state control over volume, fullness, efficiency and feasibility of the use of non-renewable natural resources.

Environmental trends in the mining industry are mixed. Many global mining companies direct significant investments to environmental protection activities and achieve significant improvement in the environmental performance of their operations, including reductions in air pollutant emissions (especially CO₂ at metallurgical and ore processing plants), improving the quality of dust collectors, more careful handling of hazardous materials, such as cyanides. The use of more active measures to mitigate the effects of the discharge of saline water and better waste management, the risk management of breakthroughs from tailing dams, as well as the protection of biodiversity are all part of the waste management control. However, smaller mining companies are moving slowly to the use of good practice standards, and problems with artisanal and small-scale mining, and are still a serious threat when considering environmental protection.

The international nature of many of the problems of the mining industry and lessons of the past, including the possibility that measures aimed at solving social and environmental problems and health care issues, may affect the competitiveness when
mining minerals and metals and will requires from the governments a more effective and flexible approach. The principle of responsible and appropriate use of mineral resources and the resources of metals is proclaimed, and it is called the principle of safe use [10]. According to this principle, the rational use of minerals and metals, carried out in accordance with established practice in an environmentally friendly manner, is viewed from the perspective of the life cycle of minerals, including the use of the results of risk assessment and management strategy.

An important factor influencing the government policies is the concern and interest of indigenous peoples, which they exhibit in connection with the development of mineral deposits. The governments must respect also existing territorial and municipal mechanisms that regulate the development of mineral deposits. The concerns of the indigenous peoples in connection with the consequences of the exploration and mining of mineral resources and the impact of those activities on their traditional way of life is taken into account, as well as the desire of the indigenous peoples to participate in decision-making.

During the last two decades, the governments and institutions of post-industrial countries, the authorities pay more attention to the closure of mines. Typically, mining companies are required to provide preliminary preparation of plans for decommissioning and closure of mining production mining facilities and performance of the full range of related long-term activities and funds reservation for it. In many countries with transitional economies, regulations for the closure of mining facilities are either absent or poorly enforced and monitored. With the expansion of mining activities in countries with transitional economies, such a legacy is becoming both a serious environmental and financial issue and at the stage that creates uncertainty and possible financial difficulties when the deposits have been exhausted.

Due to the large scale of its activities and the potential risk of serious adverse effect on many aspects of environmental sustainability mining companies are more aware of the need to follow good international practice in their work. This is a response that is put forward by external stakeholders, including investors and civil society organisations. This highlights the requirements for transparency, accountability and corporate responsibility in regard to the regulation of issues related to ensuring environmental sustainability. While in most countries representation of the company reports on various aspects of sustainable development is still largely voluntary, in large national and multinational companies such reports in scope and hardness of requirements for their preparation and publishing, are beginning to resemble the annual accounts of companies. Organisations such as the Global Reporting Initiative develop reporting mechanism and samples of reports in the field of sustainability, following which, for companies in most countries, remains essentially voluntary. Industry associations such as the International Council on Mining and Metallurgical Industries develop principles of sustainable development and appropriate standards of guarantees (which are consistent with internationally recognised standards ensuring the stability of the AA1000), mandatory for its members.
References to Chapter 1


4. Reichl C., Schatz M., Zsak G. World Mining Data. – Published by International Organizing Committee for the World Mining Congresses, Vienna, Austria. – 2015. – 253 p.


4.4. Environmental Impact of extractive industries

V. Kostenko, O. Zavyalova. T. Kostenko, Y. Zavalishyna

Ukraine has significant mineral reserves. These are energy sources, such as coal, onshore and the shelf zone gas, so-called shale gas; metallurgical raw materials, namely iron ore, manganese minerals, flux and fire retardant materials etc., while chalk, marl, sand, granite, clay and other materials belong to construction industry.

A brand new class of minerals is represented by the so-called techno-genic deposit, i.e. landfills, dumps and settling ponds of mining, processing, energy, metallurgical enterprises. Rocks, slag, sludge and solutions contained within these deposits acquire some characteristics of primary source materials because of physical, chemical and biological conversions which take place. In addition to this as a consequence of technological progress and softening requirements to raw materials further exploitation is possible.

As a consequence of field development by any means of known methods leads to disruption of the existing balance in the environment and, usually, deterioration of living conditions. If we think of the Earth's biosphere as simple as a combination of several components (Fig.4.34), analysis indicates that modern extraction processes lead to deformation of the said components.

![Fig.4.34. Structural components of the Earth's biosphere](image)

At this stage of evolution mankind is producing the majority its resources from subsoil deposits and will continue to produce them in the nearest future. Currently there is no alternative to the extraction of energy sources (i.e. gas, oil and coal) to satisfy energy demand of the modern civilization. This issue is specifically important to Ukraine, since the country’s vital energy sources are very limited. Therefore, exploration and development of coal, oil, gas, conventional gas, gas and oil deposits in sedimentary deposits is a matter of Ukraine’s national security. There is an obvious
need to evaluate the potential impact of extraction of energy or other resources on the environment in advance and strive to minimize the detrimental effect.

The most common production techniques in Ukraine are open-pit, mining and drilling. Exploration is mostly carried out via geophysical studies, while and additional exploration is carried out via drilling.

Once exploration and design works is complete field development begins. The "company-environment" ecosystem not only includes the mine works and surface service facilities. It should also include roads and railways, power lines, pipelines and canals to drain quarry and surface waters. Estimates indicate that construction of a simple 4 meters wide road will occupy the area of 1 ha per 2.5km of the road. Also, the ecosystem should include the sanitary protection zone (SPZ), established around stationary emission sources, waste dumps, water reservoirs, settling ponds and other facilities.

The landscape impact of mining operations can be seen in extreme restructuring of landscape, forming negative anthropogenic (denudation) and positive (accumulative) forms as well as leading to degradation of the primary biota. (Fig.4.35).

![Fig.4.35. Landscape view: open (a) and drilling (b) techniques](image)

The degree of destruction of natural landscapes may be divided into two categories:

- landscapes extremely transformed by economic/business activity;
- landscapes impacted by economic/business activities, i.e. land landscapes
where biological productivity is reduced due to contamination by mining wastes.

Often certain zoning is observed within natural and technical mining geosystems in terms of distribution of the degree of natural landscape transformation. It ranges between landscapes, completely transformed in the core of the system, where mining and processing facilities are concentrated, to almost intact ones outside of the functioning infrastructure.

There may also be intermediate zones and areas between these extreme levels of landscape disturbance, which are not as impacted as those in the core of the ecosystem, but significantly more impacted compared to those outside of it.

Often mining operations result of in creation of landscapes that combine different technogenic elements. Subject to the technology applied in the course of operations the following elements may be distinguished:

- Accumulative landscape forms, i.e. dump sites of dredge, bulldozer, excavator, automotive, gravity-flowing or pressure-hydraulic origin.

- Morphologically-specific dump sites which is tailing and silt-settling ponds.

- Denudation forms of landscape, including excavations, dredge facilities, quarries and pits.

Positive landforms remaining after mining operations are represented by dump sites that may be divided into internal (located inside quarry boundaries), and external (located outside of quarry boundaries), subject to quarry boundaries.

The following dump site forms are distinguished subject to their shape:

- flat if they are formed by hydro-transportation of rocks;

- plateau-like if transportation system is used during development and single-stage dumping of overburden rocks or terracing for multi-stage dumping;

- crest-like or crest system, formed by draglines or overburden spreaders or dredges in the course upper stage dumping.

All kinds of rock debris may be used for embankments and dams during construction of transportation lines or water facilities. Various quarries, trenches and ditches resulting from open-pit mining represent the negative landscape forms.

A quarry incorporates a set of mine openings resulting from open-pit mining. A quarry is commonly referred to as an opencast coal mine in the coal industry. The shape of quarry depends upon the mineral bedding conditions and the geometry of developed formation the reservoir or the developed ore body (Fig.4.36.).
Natural valley landscapes with many rivers are affected by open-pit development. One part of affected lowland landscapes is covered with secondary vegetation, another part is represented by technogenic badlands. In most cases, self-healing vegetation within the impacted valley landscapes does not reach its original biological productivity, typical for the zone and, therefore, has no environmental value and significance. Meanwhile, the valley landscape zones are of major value to natural ecosystems, as river valleys are the habitat of many rare species. River valleys are resting places for migration birds as well as food resource of ungulates during winter season, when animals are experiencing food shortage.

*Lands, impacted by mining operations*, are represented by slope surfaces of different shape and orientation, topped by crests or cones that are significantly different from natural ones in terms of natural properties.

Therefore, the most serious interventions into the environment occur due to open-pit operations, which generally require large area for quarries, dumps, railways and roads, processing plants and other industrial facilities. The average area of a quarry producing construction materials is equal to 30 - 250 hectares, manganese or coal quarry occupies 1000-2000 hectares, iron-ore quarry occupies 150-500 hectares.

Open-pit development technique is a branch of mining industry, which leads to increased number of territories, impacted in part or in full. Therefore, intense development of open-pit mining is accompanied by rising volume and number of overburden dumps.

Ore quarries reach 250m depth. Current overburden ratio (number of overburden rocks per unit of a mineral during produced during open-pit mining in t/t or m3/m3) is equal to 15 t/t for iron ore quarries and 20 t/t for copper ore quarries. Mining literature indicates that the depth of quarries will increase to 1000 m in 30 years. The current overburden ratio will change to 30-50 t/t as a result of this process. Since the height of dumps does not usually exceed 50m and is unlikely to be more...
than 100m, significantly larger territories will be necessary to accommodate increased amounts of overburden rocks. Estimates indicate that dump area will exceed quarry area by 4-7 times if mining depth reaches 500-1000m.

In accordance with modern site requirements for industrial constructions and facilities, used by mining enterprises (overburden excavation, workshops, warehouses, external dumps, settling ponds, service structures and amenities, pipelines, railways and roads, power lines, substations, etc.), it is better to use land areas of no agricultural and forestry value. However the area can constitute tens of hectares, therefore these requirements can only be met in part.

In any case, site preparation requires removal of topsoil and storing it for subsequent remediation. In the course of development of a quarry, its operational area should be prepared for the removal of overburden rocks via prior removal of topsoil. Unfortunately, modern techniques of soil relocation into piles does not ensure preservation of its fertile properties. Storage periods vary from several years to decades and result in deterioration of soil properties.

Mining activities include extraction of minerals within a prepared part of a deposit (Fig.4.37). Extraction includes the following main processes: breaking, loading, transportation and shipment of minerals. In opencast coal mining, coal breaking is aimed at separating it from the rock mass and simultaneous loosening. It is carried out using drilling and blasting operations, equipment and machines.

During coal extraction, transportation, loading and unloading a significant amount of rock and coal dust is generated, its total weight is equal to 1-2% of overburden and mining flows.

In case hard rocks are present in the top formation, drilling and blasting operations are carried out to crush the rocks. Usually, tens of blast wells, filled with tons of explosives, are set off simultaneously. This leads to significant changes in seismic shifts within a significant area of the rock mass. In addition, the explosions are accompanied by significant acoustic waves, disturbing the balance in the ecosystem.

Fig.4.37. Scheme of extraction, open-pit development: 1 - deposit; 2 – mining machinery; 3 – transportation gallery; 4 – settling pond; 5 – hydrographic facility; 6 – external dump; 7 – surface; 8 – formation top; 9 - removed fertile soil
Technological processes of mineral extraction (shaft mining) are similar to open-pit mining in terms of environmental impact (Fig. 4.38). The mine has the industrial site where background biota is deteriorated and the landscape is altered. Water aquifers are also impacted with mine shafts, leading to **deterioration of the hydrosphere**.

The borehole extraction technology also includes preparation of site, roads, pits for drilling mud and cuttings etc. Field production requires construction of transportation pipelines and scopes of drilling are considerably larger. These factors promote significant withdrawal of land for industrial sites and waste storage.

Along with production of solid, liquid and gaseous energy sources, emissions of **methane and other greenhouse gases and vapours from reservoirs occur and pollute the atmosphere**. The volume of such emissions is estimated based on the gas content within formations and rock layers.

![Fig. 4.38. Scheme of coal extraction, shaft technique](image)

**Fig. 4.38. Scheme of coal extraction, shaft technique:** 1 – air supply conduit; 2 – dump; 3 – downfold; 4 – rock fracture plain; 5 – ventilation shaft; 6, 8 – methane sandstones in formation top and bottom; 7 – coal-bed; 9 – extracted sections; 10 – main haulage road

**Mobile sources of pollution** also impact the atmosphere, i.e. mining trucks, autonomous mining machines (excavators, bulldozers, scrapers etc.), diesel locomotives, drilling rigs and trucks. The volume of such emissions can be specified as it is proportional to the amount of consumed fuel.

Usually work of mining, transportation, drilling, pumping and other machinery as well as blasting is accompanied by high noise levels. The noise deteriorates the environmental settings of the "mining company-environment" the ecosystem.
Normal operation of the key production elements of an enterprise requires ancillary elements: workshops, garages, administrative and residential complexes, dining room, boiler room, storage premises for wood products, fuel and lubricants, etc. Some of them also are emissions from stationary sources. These emissions are controllable as companies have relevant environmental certificates.

**Self-heating and spontaneous combustion** incidents occur in the course of open-pit development of lignite beds, leading to formation of significant volumes of toxic and greenhouse gases. The volume of emissions, resulting from fire, can be evaluated on the basis of the burnt coal amounts (Fig.4.39). Self-heating and spontaneous combustion most frequently occurs after rains and in windy environment, when coal and lignite is stored in warehouses and silos.

Sometimes freely burning fires occur when external sources of energy cause ignition of gas, oil, coal, equipment, machinery, electrical equipment, etc. In this case emissions should be calculated on the basis on the type and amount of burned substances.

Drw. 4.39. Combustion of coal seam in quarry, North Bohemia, Czech Republic. 2001p. (Photos: courtesy of Professor Alois Adamus, Ph.D. VSB - Technical University Ostrava)

During construction and the early period of a quarry, and shaft mine development, slate rocks are placed within specific areas in the form of dumps that are conical, vertical, flat and other shapes. The mass of these dumps amounts to tens of millions of tons. The weight of this material leads to a lowering of the surface it stored on and displacement of its bottom part outside of the dump boundaries. This leads to the formation of wetlands around the dump, deformation of infrastructure (premises, roads, pipelines and other facilities), located near the dump. We know from experience that the negative effects of soil deformation were registered at a distance of 100m from the dumps (Fig.4.40).
Fig. 4.40. Scheme of negative environmental impact of a dump (a) and thermal picture (b) of Northern part of Donetsk shaft dump “Zhovtnevyi Rudnyk” (2013), temperature range of 35...43°F:

1 – profile of the deformed surface; 2 – swamped part of the surface; 3 – rock dump; 4 – a source of self-heating or burning; 5 – deformed road; 6 – the initial level of surface

The dump mass consists of minerals that contain significant amounts of carbon, sulfur, phosphorus, iron and other elements, which react with oxygen in the presence of water. These reactions are exothermic, i.e. release heat. Bacteria also contribute to the process, feeding on highly active form of pyrite and forming highly active elemental sulfur. The sulfur burns up intensively and forms the vapor of concentrated sulfuric acid during interaction with moisture. All of the said factors leads to the appearance of **self-heating and ignition sources** at dump’s surface, the presence of these hot spots leads to disruption of gas and heat status of the ecosystem.

The temperature of rock mass at production depth is higher by several degrees than the annual average on surface. The temperature difference defines the change of **thermal environment and climatic shifts in the ecosystem.**

Mining activities and crossing aquitards during extraction contributes to **infringement of surface and underground water flows**, determining the change in movement and composition thereof. Specialized canals or trenches are constructed to withdraw surface water from mines leading to significant changes in the ecosystem.

Large mining areas provides a significant inflow of atmospheric precipitation, posing flood threat of work stations, transportation infrastructure, mines, etc. **Water, polluted with oil products and suspended solids,** flows through cracks and mine walls; **it dissolves chemicals, and favors increased amount of microorganisms.**

The presence of significant water inflows requires drainage and wastewater treatment facilities. Primary water treatment can be carried out in mines, for example, in properly designed and exploited sump or water collector. However, quality of the hydrosphere significantly deteriorates under the influence of wastewaters.

Borehole technique for extraction of energy sources allows for extensive use of directional drilling, thereby reducing distances between the adjacent wells and reducing landscape impact and waste creation on the ground.
Application of modern technologies of gas production from sedimentary rocks allows reducing the dimensions of storage facilities for drilling cuttings and mud as well as area of drilling sites (Fig.4.41.).

![Well site](image)

Fig.4.41. Well site.

**Environmental Risk Impact Assessment by Extractive Industries**

Assessment of environmental impact of extractive industries needs designation of the following parameters: the content (character), scale (volume, area, etc.), duration of the influence of operations or types of activity over the components of the biosphere.

Risks are characterised by probability of occurrence, scale of an event, possibility of risk localization, potential for complications:

\[ R = \beta \cdot Q \cdot k_r \cdot k_l \]

where: \( R \) – risk related to any process; \( \beta \) - probability of risk occurrence; \( Q \) - parameter defining the scale of risk; \( k_r \) – parameter, defining the potential for complications of the risk; \( k_l \) - parameter reflecting the possibility of risk localization.

Probability \( \beta \) is a parameter that reflects the proportion or percentage that the event will or will not happen in a specific place during the fixed timeframe. The variation limits of event probability change range from 0 if the considered event is impossible to 1 – if the event is certain to happen.

The risk scale can be assessed in actual size, i.e.:

Amount: \( Q_0 = V \cdot t = A \cdot B \cdot L \cdot t \);

or weight: \( Q_M = \rho \cdot A \cdot B \cdot L \cdot t \);

or concentration: \( Q_c = V \cdot c \cdot t \),

where: \( V = A \cdot B \cdot L \) - the estimated amount of product in the process is product of multiplication of linear dimensions (\( A \) - height, \( B \) - width, \( L \) – length); \( \rho \) - product density; \( c \) - concentration of harmful substances in the emissions.
stream; \( t \) - duration of the process or duration of the assessment period.

The scale may be rated in relative or dimensionless units. In this case the resulting risk magnitude is dimensionless. The relative scale presupposes its correlation with a specific constant value such as maximum allowable concentration, etc.

The \( k_r \) parameter takes into account the potential for complications. It indicates the possibility of product transformation into a more dangerous condition or substance. For example, accumulation of combustible gas up to explosion or ignition level within dumped rocks, sliding or collapse hazard. The parameter values range from one unit (safe conditions) to several units. The unit is calculated for each specific case and potential for complications is not considered.

The \( k_l \) parameter reflects the possibility of risk localization. It indicates the possibility to reduce the amount of risk through application of specialized technologies or equipment. For example, installation sulphur-filters at boiler houses allows the reduction of environmental risks in terms of sulphur dioxide emissions and acid rain formation. Use of mine rocks to lay underground voids or road construction can reduce surface contamination and prevent spontaneous combustion of the dumped wastes. The parameter values range from 1 (lack of localization) to 0 (full localization and no risk).

The presented estimate is an example of direct environmental risks, created by enterprises during extraction of energy resources in the eastern part of Ukraine (as of 2015). Detailed impact factors and the extent of impact of development and production on the biosphere are summarized in table 4.8. Results of an estimate of the analysed specific indicators, based on the above formulas, are illustrated in Fig.4.42-4.47.

The impact of energy source extraction on the lithosphere is mostly exhibited in the course of open-pit and borehole extraction as well as a result of work of large mining enterprises (PJSC MD “Pokrovske” for instance). A detailed analysis of impact parameters helps to define the most impacting component and take measures to reduce such it.

Table 4.8. Impact of mining activities on components of the biosphere

<table>
<thead>
<tr>
<th>Components of biosphere</th>
<th>Impact parameters</th>
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<td>Character</td>
<td>Scale</td>
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<tr>
<td><strong>Lithosphere</strong></td>
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<td>Large land lots are occupied for industrial needs</td>
<td>Area of an industrial site</td>
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<td>Landscape is disfigured</td>
<td>Areas of quarries, dumps, setting ponds, barns</td>
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<td>Waterlogging of surface near</td>
<td>Area of mechanical</td>
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<td><strong>Hydrosphere</strong></td>
<td><strong>Atmosphere</strong></td>
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<tr>
<td>Changes in the hydrological regime</td>
<td>Dust formation during excavation, transportation and storage of the rock mass</td>
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<td>Deterioration of stream water quality due to dumps</td>
<td>Emergency gas emissions during fires</td>
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<td>The emissions of mobile sources</td>
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<td>Emissions of stationary sources, ( K_{\text{asc}} )</td>
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<td>Reservoir-related greenhouse gas emissions</td>
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Enterprise #

Fig.4.42 – Assessment of specific indicators of environmental impact of mining companies on the lithosphere: 1,2- Konstantynivskiy, Morozivskyi sections; 3,4- wells: #1; #2; mine shafts: 5 - PJSC MD “Pokrovske”; 6,7,8,9, - SE "Krasnoarmiiskvuhillia": "named after A.H. Stakhanova", "named after H.Dymyrova", "Rodynska"; "Tsentralna"; 10,11,12,13 - SE "Selidivvuhillia": #1"Novohrodivska"; #3"Novohrodivska"; "Ukraine"; "Kurakhivska"; "Russia"; 14,15 - "SD Pavlivske": "Ternivska"; "Pavlohradska"; 16,17 - "SD Dniprovskе": "named after M.I. Stashkova"; "Dniprovskа"; 18,19 - "SD named after Heroiv Kosmosu": "Blahodatna"; "named after Heroiv Kosmosu"; 20,21,22 - "SD Pershotravenske": "Stepova"; "Stepova- block #2"; "Yuvelleyna"; 23,24 - SD "Ternivske": "Zakhidno-Donbaska"; "Samarska.

However, impact of the stated enterprise and that of "Zakhidno-Donbaska" mine shaft on atmosphere (Fig.4.44) is the largest due to significant production volumes from gas-rich formations.

Mine shafts and active quarry significantly impact the biota (Fig.4.45) as they occupy large industrial sites, which have been used for a long period of time. Well sites have significantly lower and shorter impact on the surrounding flora and fauna.

According to the analysis of physical fields (Fig.4.46), mine shafts have a major environmental impact due to huge amounts of produced warm gases and noise levels, followed by a significantly smaller impact of quarries and minor impact of well sites.
Fig. 4.43 – Assessment of specific indicators of environmental impact of mining companies on the hydrosphere (the legend is the same as that of Fig. 4.42).

Fig. 4.44 – Assessment of specific indicators of environmental impact of mining companies on the atmosphere (the legend is the same as that of Fig. 4.42).

Fig. 4.45 – Assessment of specific indicators of environmental impact of mining companies on the biota atmosphere (the legend is the same as that of Fig. 4.42).
Comparison of environmental risks, resulting from extraction of fossil fuels by means of open-pit, mine shaft and borehole techniques, brings up the issue of adequacy of such comparison due to the fact that the extracted minerals differ in chemical and phase composition. The only acceptable generalization is the energy-based assessment, i.e. bringing various fossil fuels and volumes thereof to a common indicator. This approach allows for comparison of impact of specific techniques on a specific element of the biosphere and enables an integral impact assessment of a specific company. It also offers capabilities for improvements to production cycle of the country of region via its further adaption to the environment.

All organic fossil fuels (oil and its derivatives, natural gas, coal, wood and peat) produce different amounts of energy during combustion. They have different chemical energy reserves. However, calculations need information on the amount of energy stored by each specific fuel. A concept of conditional fuel is used for this purpose.

Conditional fuel is a fuel with calorific value of 7,000kcal per 1kg. To convert a specific weight of fuel into conditional fuel, one needs to multiply the tonnage of the fuel by a specific ratio.

The mine shafts reviewed herein produce power generating coal. According to reference data, the conversion ratio into conditional units is equal to 0.876.

Quarries in the vicinity to Oleksandria city produce brown coal with referenced ration of 0.398.

When gaseous substances are considered, production is calculated in cubic meters (m³). Therefore conditional tons are converted into cubic meters (m³) of thousands cubic meters (Km³) of fuel (for gas). In order to calculate conditional tons, one needs to multiply the amount of thousands cubic meters of the fuel (for gas) by a specific ratio. The reference ration of natural gas is equal to 1.15 per Km³.
In other words, to acquire a unit of heat energy a unit of conditional fuel must be burnt or 1/0.876 = 1.141 units of coal, 1/0.398 = 2.512 units of brown coal, or 1/1.15 = 0.87 units of gas. Therefore, natural gas is the most efficient fuel due to the fact that significantly larger amounts of coal are needed to produce the same amount of energy.

Gas is the most environmentally friendly fuel to meet country’s or region’s energy demand, as it produces the minimum wastes. Most of the fields produce sweet/low nitrogen gas, therefore combustion gases contain no sulphur oxides and minimum amounts of nitrogen oxides.

Most of Ukrainian coal beds contain different forms of sulphur, minor amount of chemically-bound nitrogen, extracted rock masses contain significant amount of ash leading to creation refuse dumps in the course of coal beneficiation and accumulation of slag at TPPs.

However, not only these factors determine the impact of solid fuels. According to our calculations, to acquire the energy performance of gas, we would need 1.3 times more coal and 2.9 times more brown coal. This means that an increase of coal production results in significant increase of environmental impact. The authors revealed such an aspect for the first time.

Based on the environmental risks assessments and taking into account the use of advanced process techniques, borehole technology offers relatively low environmental risks in comparison to shaft mining and open-pit development processes. In case of sufficient investment, exploration and production of gas from compacted sedimentary masses may replenish Ukraine’s industrial reserves.

The future of open-pit extraction of brown coal remains uncertain. Quarries of the state enterprise "Aleksandriyavuhillya" are suspended; the major part of unique, however obsolete, equipment is abandoned. Most quarries have been converted into water reservoirs during reclamation process. Energy resources, used in Germany at the end of World War II and in South Africa - during the last four decades to produce liquid fuel, has unfortunately not been utilized in Ukraine. Rapid revival of this technology will not become reality without significant investment.

As of mid-2015, the majority of coal mines in Ukraine are unprofitable. The prime cost of domestic coal, rate of accidents and injuries are among the highest in the world. The situation may improve through integrated use of mine resources, in other words all of the rock mass components (rocks, moisture, gaseous components) should become a market product.

The amount of associated rocks, extracted from a mine shaft, ranges between 30% and 50% of the transport flow. It would be rational to keep these rocks in mine shafts and use them as support material or, alternatively, use them as additive to building mixes during road construction, etc.

Water resources of Donets Basin are five times less than the Ukraine’s average. It would be expedient to treat and process discharged water to comply with technical
and irrigation water requirements with the view to further sale thereof. Statistics indicate that more than three cubic meters of mining water are produced per one ton of fossil fuel.

Use of geothermal energy has high potential in terms of power supply of the mine itself and externally to the mine. The advantage of this energy source is that it is not subject to taxation, reserves are almost inexhaustible and determined by the lifetime of mine openings, carrying the heat medium.

The most substantial prospect is transition to development of coal-gas fields, i.e. simultaneous production of coal and gas. According to various estimates, reserves of the Donbas range from 12 to 25 Tm$^3$ of bound gas. The current best case scenario is use of 20-25% of methane, contained in a deposit and transferred into free state during production. Increased consumption of gas, which can be converted into electricity and heat, will reduce the prime cost of commercial coal, increase the safety of subsoil mining operations and improve the environment in the vicinity to sanitary protection zones.

Sustainable, safe and economically feasible functioning of coal mines can significantly improve the situation within the domestic energy market of Ukraine. This would improve energy independence from imports. In accordance with a well-known industry practitioner, researcher and political activist N.S. Surhay, coal can save Ukraine. However, intense upgrade of prospect mines is needed to accomplish this objective. It is very difficult in modern business environment, but completing this task is of essence in the future! The approaches to reaching this goal should be developed now.

Borehole production of oil and gas is the most reliable and near-term prospect of Ukraine’s domestic energy supply. It presents minimum and manageable risks. Increase of domestic reserves of tight and shale gas is quite real. Implementation of modern technologies i.e. clusters of deviated wells; hydraulic fracturing, vacuum treatment, etc. suggest significant increase of gas production with sufficient level of general and environmental safety.

Summarizing the referenced materials, it should be noted that mining industry is one of the major contaminators of the environment. However, nowadays Ukraine cannot exist without its products. Therefore, a promising way of upgrading the mining industry is to reduce direct environmental risks via stimulation of production. This approach can reduce the number of companies, and shorten their lifetime and, as a result, reduce environmental impact. The second way is comprehensive and efficient use of mineral resource itself as well as all material and energy components of production. This approach may minimize the footprint of the mining industry and bring both Ukraine and the whole biosphere to the sustainable state.
4.5 Minimising the Environmental Impact of Oil and Gas Pipelines

H.K. Winning, T. Coole

The chapter focuses on the environmental challenges facing the design and construction of major pipeline projects within the oil and gas industry. The methods discussed for mitigating the environmental impact of these projects cover improved processes, materials and the use of emerging technology.

The first section introduces the challenges facing today's pipeline engineer in the design, construction and operation of long distance hazardous fluid pipelines. One of the environmental challenges for pipelines is that of soil erosion, primarily due to storm events prior to the bio-restoration of the pipeline right of way.

The second section looks at mitigation of the soil erosion risk through the early assessment of the potential soil loss using remote sensed data and geographical information systems (GIS), thereby enabling the issue of soil erosion to be considered during the route selection process.

In the final section, the advantage of the selection of higher-grade steel for the pipeline is presented. This not only reduces the cost of the pipeline but also has the potential to reduce the use of natural resources during steel manufacture and reduce the carbon footprint of the project through reduced transportation requirements.

4.5.1 Introduction

A pre-requisite of industrial development is the requirement for reliable, cost effective sources of energy. The chapter discusses the issues of environmentally sustainable industrial development within the context of the oil and gas industry, specifically focusing on the impact of the construction and operation of long distance pipelines. Pipelines have been an integral part of our world for over 5000 years; during this time, the materials have changed from baked clay, copper and bamboo to steel, plastics and composites. As well as the changes in material technology, our knowledge of fluid mechanics has evolved; from implicit equations to model the effect of pipe friction on water flow such as Chézy's 1770s equation, to the development of computationally efficient explicit approximations for single phase flow (Winning and Coole, 2015). Other changes include the use of numerically intensive computer applications for the modelling and simulation of hydraulic flow of complex non-Newtonian fluids.

Pipelines represent the most cost efficient and best environmental solution for the transportation of oil and gas over long distances. There are now over 3.4 million kilometres of oil and gas pipelines worldwide (CIA, 2014), enough to circumnavigate the earth over 84 times. In order to meet an ever-increasing demand for energy there are over 145000 kilometres of new build oil and gas pipelines planned for
construction between 2014 and 2018 (Wood, 2014). Operational pipelines need to be maintained and inspected on a regular basis in order to ensure that the potential for environmental damage is minimised. As the world's reliance on oil and gas grows, so too does the legislative requirements governing the operation of these major pipelines. Since 2000, legislation has been introduced across the United States and Europe to improve pipeline integrity management (PIM) and reduce the potential for loss of containment failures for hazardous fluid pipelines.

The chapter looks at the potential environmental impact throughout the project lifecycle of the design, construction and operation of major oil and gas pipelines. Two methods are discussed for reducing the environmental impact. The first method looks at the potential for route optimisation to reduce the soil erosion of the operational pipeline using remote sensed data and Geographical Information Systems (GIS) during the design and selection of the pipeline route. The second method considers the impact of the use of higher strength steel to reduce the environmental and economic cost for pipeline systems.

4.5.2 Pipeline Engineering

Pipeline engineering is an established discipline, drawing on the fields of mechanical, civil and chemical engineering. The origins for pipeline engineering date back over 5000 years. Using the local materials of clay and bamboo, pipelines were constructed in Mesopotamia (present day Iraq), and China respectively. The Palace of Minos at Knossos in Crete, constructed between 2000 and 1500 BCE, is an early surviving example of the use of pipes for the management of water supply, water drainage and waste water (Fagan, 2011: 5). The next 1000 years saw the Greeks using an increasingly wide range of materials for the construction of pipelines as new materials and methods of material manufacture improved (Antaki, 2003: 2). The rise of the Roman Empire between 400 BCE and 150 CE saw significant innovation in the design and construction of pipelines; this innovation spanned system design, material technology, application of standards and quality control. The Romans were able to increase the length of the pipeline systems through the extensive use of aqueducts and with fountains being incorporated into the systems to mitigate pressure surges. This was complimented with improved delivery due to the use of standardised fittings made from a variety of materials including lead, copper and bronze. Evidence has also been found of the use of approved pipework being stamped with quality control marks. Unfortunately, much of the advancement in the field of pipeline engineering was lost during the middle ages (ibid: 2-3). By the seventeenth and eighteenth century, the use of cast iron pipelines in Europe was growing and mathematicians were working in the field of fluid mechanics to model fluid flow. These early formulae were devised to model the flow of water and
therefore excluded the properties of viscosity and density. An early flow equation devised by Chézy in the 1770s is given as

\[ V_{\text{mean}} = c(H_r C_s)^{0.5} \]  

(Eq.4.5.1)

**Equation 4.5.1 Chézy Flow Equation (Culvern, 1983: 1)**

In Equation 4.5.1, the mean velocity \((V_{\text{mean}})\) is a product of the Chézy roughness and conduit coefficient \((c)\), the hydraulic radius \((H_r)\) and the slope of the pipe \((C_s)\). The Chézy roughness and conduit coefficient is also affected by the fluid velocity, thereby making this an implicit function (Winning and Coole, 2013). The need for reliable energy sources to drive the Industrial Revolution of the nineteenth century saw an order of magnitude in the growth of pipelines for the distribution of natural gas, water and early oil pipelines, which continues to this day.

To compete in global markets, there is a requirement to manufacture in the most cost-effective locations and to be able to transport goods over increasing distances to market. Pipelines play a fundamental role in the energy infrastructure that is now essential to all aspects of modern life. By 2003, there were in excess of 3.7 million kilometres of oil and gas pipelines in the United States and (PHMSA, 2003)\(^7\) and almost 16000 kilometres of hazardous liquid pipelines in the UK (Department of Energy & Climate Change, 2013). Modern transmission pipelines, such as the Baku Tbilisi Ceyhan (BTC) pipeline and the South Caucasus Pipeline (SCP), present significant engineering and environmental challenges for today's pipeline engineer due to their diameter and length. The BTC pipeline has the capacity to deliver one million barrels of oil per day from the terminal at Sangachal on the shores of the Caspian Sea, through Azerbaijan and Georgia to Ceyhan on the Mediterranean coast in Turkey; a total length of 1768 kilometres. This 42/46-inch diameter pipeline is buried for its entire length. To support the operation of the pipeline there are 101 block valves, eight pump stations, two intermediate pigging stations and a pressure reduction station. The project, completed in 2007 had a total installed cost of $3.9 billion (Pitt, 2006); running adjacent to the BTC pipeline is SCP. This pipeline delivers gas from the Shah Deniz from the offshore gas fields in the Caspian Sea to the European gas network. This 42-inch diameter pipeline covers 691 kilometres through Azerbaijan and Georgia before crossing into Turkey and tying into the Turkish grid at Erzurum. The pipeline system comprises eleven block valves, two compressor stations and one intermediate pigging station (BP, 2012). The system was originally sized to transport seven billion cubic metres annually (bcma) of natural gas. The routes of the BTC and SCP projects are shown in Figure 4.5.1.

\(^7\) Pipeline and Hazardous Materials Safety Administration.
Increasingly, the environmental impact throughout the life cycle of the pipeline is being seen as a key issue, as is the need to be able to safely traverse difficult and challenging terrain.

4.5.3 The Environmental Challenge

Although pipelines minimize the environmental impact of transporting large volumes of oil and gas over long distances, they present significant environmental challenges to the pipeline engineer.

*Pipeline development inevitably results in economic, social and environmental change, both positive and negative. It is the responsibility of the pipeline promoters, construction contractors and government to manage such developments in a manner that ensures minimal negative impact and maximum sustainability.*

*(Swan, 2009: 34)*

One of the major environmental challenges for pipelines, particularly in areas of poor soils, is the issue of soil erosion for recently installed pipelines.

*On the basis of its temporal and spatial ubiquity, erosion qualifies as a major, quite possibly the major, environmental problem worldwide.*

*(Toy et al., 2002: 1)*

The impact of soil erosion is global; it affects food security and public health (Bandara et al., 2001, Pimentel, 2006). The estimated soil loss worldwide is in the order of 75 billion metric tons, with Asia, Africa and South America facing average annual losses of between 30 to 40 tons per hectare per annum (t ha⁻¹ year⁻¹) (Pimentel et al., 1995: 1117). The impact of soil erosion is not only societal it also has significant economic impact. It is estimated that the annual economic cost of soil erosion to the United States alone is in the region of US$30 billion (Uri and Lewis,
1998: 53) and US$44 billion (Pimentel et al., 1995: 1120-1121). Economic costs elsewhere, though smaller are still significant, with annual costs estimated for the UK at £106 million (Pretty et al., 2000: 113). These costs are a product of both the on-site and off-site impacts of soil erosion.

The impact at the point of soil loss is the reduction in soil function, resulting in reduced yields leading to issues of food security (Cohen et al., 2006: 250). In addition, there is the potential for damage to existing infrastructure including roads, railways and pipelines (Pimentel et al., 1995: 1120). Soil erosion also affects the wider environment through off-site impacts. This is largely due to the transportation of sediment in watercourses (turbidity) and its deposition. Turbidity can affect hydrological infrastructure by increasing the wear on bearings and abrasion to impellers and pumps.

In addition to the damage to infrastructure, increased turbidity can cause eutrophication. This occurs in aquatic systems when they are subjected to increased levels of phosphates or nitrates, which in turn leads to hypoxia – a reduction in the oxygen levels in the water - and the growth of algae (Ekholm and Lehtoranta, 2011, Vollenweider, 1970). Figure 4.5.2 shows eutrophication of the northern part of the Caspian Sea (green/blue area) due to the discharge of the Volga and Ural rivers which contain high levels of fertilizer rich soils from soil erosion (Leroy et al., 2007:3360).

![Figure 4.5.2 – Caspian Sea showing Eutrophication](https://example.com/caspian_eutrophication.jpg)

In order to mitigate the potential for soil loss on the reinstated pipeline right of way, soil erosion control measures are put in place. The current method involves the
field assessment of the proposed pipeline route by an environmental engineer to determine the permanent control measures. The route selection process therefore does not normally consider the potential for soil erosion.

4.5.4 Better by Design – Minimising the Soil Erosion Risk

The impact of soil loss on the newly reinstated pipeline right of way (RoW)\(^8\) is managed by permanent erosion control measures. In addition to the capital expenditure (CAPEX)\(^9\) costs of the construction of the permanent erosion control measures, regular monitoring and post installation remedial works to maintain them also add to the operational expenditure (OPEX)\(^10\) costs of the pipeline.

Currently, the soil erosion risk is assessed through a preliminary desktop study followed by a detailed field assessment, based on the design route. During this process, the route continues to mature and is subject to change due to the impact of other design criteria. The current method suffers from a number of significant limitations. It identifies the potential erosion risk for a specific route, which is not necessarily the final route and more importantly the field assessment does not form part of the route selection process. This approach prevents the optimisation of the route to minimise the soil erosion potential and relies on the design of the permanent erosion control measures to prevent soil erosion. The desktop review is generally focused on the slope gradient and length - key components in the modelling of soil erosion, with limited reference to the rainfall erosivity or soil erodibility factors, the other major components in soil erosion modelling. This method only serves to identify major watercourse crossings or significant changes in elevation. Therefore, it is the subsequent field assessment that is the primary method for the determination of the soil erosion risk to the pipeline; an activity that has impact to both cost and schedule. Finally, the current method provides limited data for interpolation of the soil erosion risk where the route subsequently changes from the route reviewed during the field assessment, potentially requiring further site assessment as the route matures. This requires the pipeline engineer to balance the cost and schedule impacts of future field investigation against the mitigation of the soil erosion risk during the design phase.

The proposed method is to use public domain remote sensed data within a GIS environment early on in the selection of the pipeline route process. As the project matures, targeted remote sensed data acquired for the project may be used to refine the soil erosion risk model. The value of this approach is in the identification of areas of concern, enabling the subsequent field assessment to be more targeted as well as providing some means of assurance that all the areas of highest soil erosion risk have

\(^8\) Right of Way. This is the construction corridor of the pipeline, where the top soil is stripped. For large diameter pipelines, this is typically in the region of between 35 and 40 metres.

\(^9\) These represent the costs for the design, procurement, construction and commissioning of the pipeline.

\(^10\) These include the fuel gas requirements for pumping/compression, transit tariffs, maintenance and inspection.
been identified. Additionally, changes to the route after the site verification can be re-assessed using interpolated data and a judgement made as to the requirement or value of any further site investigation.

Assuming that appropriate permanent soil erosion methods have been selected and correctly installed, the greatest risk to newly reinstated pipelines is the impact of storm events prior to the bio-restoration of the pipeline RoW. Given the length of these major pipelines it is frequently the case that there is a temporal gap between the pipeline reinstatement and the planting season, thereby increasing the potential impact of storm events. A storm event is defined by a number of factors, namely: its intensity, duration and return period. Typical values for a storm event is a duration of one hour with a ten minute peak intensity and a return period of ten years (Hann and Morgan, 2011: 11).

The potential for increased rates of soil erosion for construction sites is in part affected by the reinstatement of the site. As the topsoil is removed and the subsoil forms the working surface during construction, compaction of the subsoil occurs reducing the infiltration rate thereby reducing the porosity (Morgan, 2005: 2). Similarly, if over compaction of the reinstated topsoil occurs, the soils bulk density increases inhibiting plant growth and prolonging the time required for bio-restoration (Daddow and Warrington, 1983: 11).

The approach of using remote sensed data within a GIS environment (Winning and Hann, 2014) uses the Universal Soil Loss Equation (USLE) for modelling the soil loss. The selection of this model over others is the simplicity which, given the uncertainty of the inputs derived from remote sensed data is a practical approach. The USLE is defined as:

\[
A = R \times K \times S \times L \times C \times P
\]

(Eq. 4.5.2)

where

- \(A\) = Mean annual soil loss (t ha\(^{-1}\))
- \(R\) = Rainfall erosivity factor (MJ mm ha\(^{-1}\) h\(^{-1}\))
- \(K\) = Soil erodibility factor (t ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\))
- \(S\) = Slope steepness factor (dimensionless)
- \(L\) = Slope length factor (dimensionless)
- \(C\) = Crop management factor (dimensionless)
- \(P\) = Erosion control practice factor (dimensionless)

*Equation 4.5.2 Universal Soil Loss Equation (USLE)*

Of the six components of the USLE, the dimensionless parameters for the crop management factor (\(C\)) and the erosion control practice factor (\(P\)) are set to 1.2 and 1 respectively. The (\(C\)) factor is set to 1.2 to account for any potential over compaction of the subsoil as previously discussed, while the (\(P\)) factor is set to unity in order to determine the mitigation methods required. The slope steepness (\(S\)) and slope length
(L) factors can be accurately derived from a digital elevation model (DEM), a number of which are freely available, with a spatial resolution of between 30 to 100 metres. The remaining two factors of rainfall erosivity (R) and soil erodibility (K) can only be determined accurately through field trials conducted over time. Based on this approach, the R and K factors of the USLE are determined over a wider area of interest centred on the pipeline route, allowing for future analysis as the route matures. Using this data, a choropleth map (raster dataset) for these factors is created from which a contour model (vector dataset) is created.

Having identified the inputs for the USLE for a wider area of interest, it is possible to estimate the potential soil loss for any given route within the corridor. Based on the estimated soil loss, a soil erosion risk classification is identified using Table 4.5.1 for the newly installed pipeline RoW (tilled soil with no bio-restoration).

<table>
<thead>
<tr>
<th>Erosion Class</th>
<th>Verbal Assessment</th>
<th>Soil Loss (t/ha year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very slight</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>2</td>
<td>Slight</td>
<td>2 – 5</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>5 – 10</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>10 – 50</td>
</tr>
<tr>
<td>5</td>
<td>Severe</td>
<td>50 – 100</td>
</tr>
<tr>
<td>6</td>
<td>Very severe</td>
<td>100 – 500</td>
</tr>
<tr>
<td>7</td>
<td>Catastrophic</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>

Table 4.5.1 – Soil Erosion Risk Classification
(Morgan, 2005: 88)

Using the soil erosion risk classification, appropriate erosion control measures are selected to maximise the land use and minimise the environmental impact. This is referred to as the soil loss tolerance (Morgan, 2005: 152). Due to the slow rate of soil formation and the difficulty in determining the actual soil loss rate for a specific area without field observation over a significant period, a more pragmatic approach is to assume that the soil loss tolerance is equal to the current rate of soil loss. This method is frequently used for the determination of the soil erosion risk for construction projects (Ibid: 152).

Given the temporal aspect for the need to protect the pipeline RoW prior to the bio-restoration, an erosion class of 3 represents a practical risk based level of soil loss. However, where discharge (soil runoff) is likely to affect local watercourses this is generally reduced to erosion class 2.
The soil erosion classification obtained using this method compared to a field-based erosion risk assessment for a 450-kilometre pipeline compares well. Seventy-five percent of the route was correctly classified and ninety-five percent of the route was within ± one erosion class. This route traversed mixed terrain with varying soil types with a varying slope angles. The method of estimating the soil erosion risk using remote sensed data fails to identify the soil erosion risk associated with seismic fault and major river crossings. This is not an issue as these can be identified using other datasets and would always need to be evaluated through field observation.

The major area of uncertainty using this method is the determination of the soil type; this can tend to bias the results obtained. It has been found that with small slope angles, the uncertainty of the soil data can lead to an underestimation of the soil erosion risk. Conversely, on steep slopes the lack of soil data can result in an overestimation of the soil erosion risk in areas with good vegetation and cohesive soils. While this approach will not remove the need for site investigation, it will enable it to be more focused on the areas that pose the greatest risk. As part of the site investigation, information will be gathered that will enable the soil erosion risk model to be validated and improved.

4.5.5 The Lean Pipeline – Reducing the Pipeline Carbon Footprint

The previous section looked at the environmental benefits of using emerging technology and leveraging the growing availability of public domain remote sensed data during the design phase of the project. This section however, looks at the impact of material selection not only to the pipeline project but also to the carbon footprint and use of natural resources of the project as a whole. In order to meet the increasing global demand for energy, construction of high pressure large diameter pipelines are required. Barlow’s formula (Equation 4.33) determines the allowable operating pressure for a pipeline given the dimensions and material property (allowable stress) of the pipe.

\[
P = \frac{2St}{D}
\]

*(Eq. 4.5.3)*

where

- \( P \) = Pressure (bar)
- \( S \) = Allowable stress (bar)
- \( t \) = Wall thickness of the pipe (mm)
- \( D \) = Outside diameter of the pipe (mm)

*Equation 4.3.3 Barlow’s Formula*

It can be seen that in order to accommodate the flowrate and high pressures typically required, either the wall thickness or the allowable stress must increase. The allowable stress for a pipe is determined by the mechanical properties of the steel
and the manufacturing process. The pipe is manufactured to a standard such as API 5L\textsuperscript{11} or BS EN ISO 3183, which provide a classification (grade) of pipe by minimum yield strength – the allowable stress. In the API 5L standard, the grade of high strength pipe is designated with an ‘X’ prefix and a number that corresponds to the minimum yield strength in thousands of pounds per square inch (psi). Therefore, X70 and X80 grade pipe have a minimum yield strength of 70,000 psi (482 MPa) and 80,000 psi (552 MPa) respectively. In order to mitigate the impact of third party interference particularly for gas pipelines, there is a code requirement to assess the population density along the pipeline corridor and to change the design factor from 0.72 for class 1 areas to 0.5 for class 3 areas. Therefore, the wall thickness along a pipeline will vary in order to satisfy this code requirement.

Prior to the mid-1970s, large diameter pipe was manufactured using a process of hot rolling and normalising, producing grade X52 pipe. For a 42” pipeline, operating at a pressure of 95 bar, this would require a pipe wall thickness of between 22.2 mm and 31.8 mm, depending on the design factor of the pipe. In the mid-1970s, the thermomechanical rolling process was introduced. Using this process with steel that is micro-alloyed with niobium and vanadium produces X70 grade pipe with reduced carbon content and a higher yield strength (Hillenbrand et al., 2002). A 42” pipeline using X70 rather than X52 would need a wall thickness between 17.5 mm and 23.8 mm to operate at the same pressure as the previous example. In the 1980s, a further development of the thermomechanical process was developed, with the addition of accelerated cooling after the rolling process. Through using this improved process and the addition of molybdenum, copper and nickel it is possible to manufacture high-strength steel pipe up to grade X100; the historical development of the manufacture of high-grade steel for pipes is shown in Figure 4.5.4 and the application of X80 pipe for pipelines in Table 4.5.1.

![Figure 4.5.4 – Development of High Strength Steels (Hillenbrand et al., 2001: 544)](image)

\textsuperscript{11} American Petroleum Institute
<table>
<thead>
<tr>
<th>Year</th>
<th>Operator</th>
<th>Country</th>
<th>Diameter (Inches)</th>
<th>Length (km)</th>
<th>WT (mm)</th>
<th>MAOP (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>Megal II</td>
<td>Germany</td>
<td>44</td>
<td>3.2</td>
<td>14</td>
<td>93.7</td>
</tr>
<tr>
<td>1985</td>
<td>Transit Gas Pipeline</td>
<td>Czechoslovakia</td>
<td>56</td>
<td>1.5</td>
<td>16</td>
<td>98.9</td>
</tr>
<tr>
<td>1990</td>
<td>Empress Compressor Station NOVA (TCPL)</td>
<td>Canada</td>
<td>42</td>
<td>1.6</td>
<td>11</td>
<td>81</td>
</tr>
<tr>
<td>1992/3</td>
<td>Weme to Schluchtem Pipeline Rhur Gas</td>
<td>Germany</td>
<td>48</td>
<td>250</td>
<td>18.4/19.3</td>
<td>100</td>
</tr>
<tr>
<td>1994</td>
<td>Eastern Alberta Mahtzwin NOVA</td>
<td>Canada</td>
<td>48</td>
<td>54</td>
<td>12.1</td>
<td>86.5</td>
</tr>
<tr>
<td>1997</td>
<td>Central Main Line Loop TCPL</td>
<td>Canada</td>
<td>48</td>
<td>91</td>
<td>12.0/16.0</td>
<td>86.5</td>
</tr>
<tr>
<td>1997</td>
<td>Central Main Line Loop TCPL</td>
<td>Canada</td>
<td>48</td>
<td>27</td>
<td>12.0/16.0</td>
<td>86.5</td>
</tr>
<tr>
<td>1998</td>
<td>Peters Green to South Mimms Transco</td>
<td>UK</td>
<td>48</td>
<td>1</td>
<td>-</td>
<td>75</td>
</tr>
<tr>
<td>2000</td>
<td>Drointon to Sutton on the Hill Transco</td>
<td>UK</td>
<td>48</td>
<td>25</td>
<td>-</td>
<td>75</td>
</tr>
<tr>
<td>2001</td>
<td>Hatton to Silk Willoughby Transco</td>
<td>UK</td>
<td>48</td>
<td>112</td>
<td>15.1/21.8</td>
<td>75</td>
</tr>
<tr>
<td>2001</td>
<td>Canadian Resources Stream</td>
<td>Canadian</td>
<td>24</td>
<td>18</td>
<td>25.4</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>Roma to Birmingham</td>
<td>UK</td>
<td>48</td>
<td>102</td>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>2001</td>
<td>Canadian Resources Stream</td>
<td>Canadian</td>
<td>24</td>
<td>-</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>2002</td>
<td>Hatton to Silk Willoughby Transco</td>
<td>UK</td>
<td>48</td>
<td>112</td>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>2002</td>
<td>Estonian Main Line Loop TCPL</td>
<td>Estonia</td>
<td>48</td>
<td>16</td>
<td>16</td>
<td>99.7</td>
</tr>
<tr>
<td>2002</td>
<td>Estonian Main Line Loop TCPL</td>
<td>Estonia</td>
<td>48</td>
<td>22</td>
<td>16</td>
<td>99.7</td>
</tr>
<tr>
<td>2002</td>
<td>Estonian Abaladze-Madzavir TCPL</td>
<td>Estonia</td>
<td>48</td>
<td>22</td>
<td>4</td>
<td>99.7</td>
</tr>
<tr>
<td>2003</td>
<td>Venet to Schwartzhaupt Gas Pipeline</td>
<td>Germany</td>
<td>48</td>
<td>30</td>
<td>16</td>
<td>127.3</td>
</tr>
<tr>
<td>2004</td>
<td>Scheider Gas Pipeline NOVA(TCPL)</td>
<td>Canada</td>
<td>48</td>
<td>18</td>
<td>16</td>
<td>99.7</td>
</tr>
<tr>
<td>2004</td>
<td>Scheider Gas Pipeline NOVA(TCPL)</td>
<td>Canada</td>
<td>48</td>
<td>18</td>
<td>16</td>
<td>99.7</td>
</tr>
<tr>
<td>2006</td>
<td>Meckel I</td>
<td>Germany</td>
<td>48</td>
<td>44</td>
<td>24</td>
<td>168.5</td>
</tr>
<tr>
<td>2006</td>
<td>Meckel II</td>
<td>Germany</td>
<td>48</td>
<td>44</td>
<td>24</td>
<td>168.5</td>
</tr>
<tr>
<td>2006</td>
<td>Danemar (Lübeck) (Land)</td>
<td>Denmark</td>
<td>27</td>
<td>93.2</td>
<td>7.2</td>
<td>30</td>
</tr>
<tr>
<td>2009</td>
<td>Second West East CNPC</td>
<td>China</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Kinder Morgan USA</td>
<td>Kinder Morgan USA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.5.1 – X80 Projects (Gray and Siciliano, 2009: 33)
In order to demonstrate the potential reduction in the environmental impact of this approach, reference is made to a theoretical 42" diameter gas pipeline with a MAOP\textsuperscript{1} of 95.5 bar and a length of 500 km. Based on the requirements of the ASME B31.8\textsuperscript{m} standard, a design factor is applied to gas transmission pipelines based on population density along the pipeline route. Using the design factors for the different class locations the minimum wall thickness has been calculated for each ASME B31.8 location class. The ratio of location classes for an existing gas pipeline of over 400 km of 93.0\%, 4.6\% and 2.4\% for class 1, 2 and 3 respectively have been applied to this theoretical pipeline. Table 4.5.3 shows the wall thickness requirements for location classes 1, 2 and 3 for a solution using both X70 and X80 pipe for a 500 km gas pipeline with a MAOP of 95.5 barg. The wall thicknesses are based on the minimum required with a small rolling allowance added, rather than standard API 5L wall thicknesses.

<table>
<thead>
<tr>
<th>Location Class</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Factor</td>
<td>0.72</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Length (km)</td>
<td>465.053</td>
<td>22.899</td>
<td>12.048</td>
</tr>
<tr>
<td>x70 WT (mm)</td>
<td>14.7</td>
<td>17.7</td>
<td>21.2</td>
</tr>
<tr>
<td>x70 kg / m</td>
<td>381.388</td>
<td>457.913</td>
<td>546.631</td>
</tr>
<tr>
<td>x70 Pipe Weight (T)</td>
<td>177366</td>
<td>10486</td>
<td>6586</td>
</tr>
<tr>
<td>x80 WT (mm)</td>
<td>12.9</td>
<td>15.5</td>
<td>18.5</td>
</tr>
<tr>
<td>x80 T / m</td>
<td>335.260</td>
<td>401.838</td>
<td>478.245</td>
</tr>
<tr>
<td>x80 Pipe Weight (T)</td>
<td>155914</td>
<td>9202</td>
<td>5762</td>
</tr>
</tbody>
</table>

Table 4.5.2 – X70 and X80 Wall Thickness Comparison

As can be seen from Table 4.5.3, the total steel weight for the X70 pipe is 194.4 x 10\textsuperscript{3} tonnes and for the X80 pipe 170.9 x 10\textsuperscript{3} tonnes; a saving of 23.5 x 10\textsuperscript{3} tonnes. With this saving, come some additional challenges that need to be managed.

Depending on the geographical location of the project, consideration must be given to the availability and capability of suitable pipe mills to manufacture quality high-strength steel pipes. There are currently 19 pipe mills worldwide producing X80 pipe; 7 in Europe, 2 in Japan and a further 10 across the rest of the world.

Where there are problems in obtaining suitable induction bends\textsuperscript{n} or fittings in X80 this can be addressed using X70 bends or fittings with a suitably increased wall thickness, which are, then factory welded with X80 pups. This approach ensures that the welds between disparate materials are controlled and the subsequent field welding can follow the same pre-qualified procedure. However, this

\textsuperscript{1} Maximum Allowable Operating Pressure

\textsuperscript{m} American Society of Mechanical Engineers

\textsuperscript{n} Induction bends are factory formed short radius bends, typically manufactured with a 5D radius or less.
approach may have an impact within a tight piping arrangement such as pig trap piping due to the increase in length of bends and must therefore be considered during the design of the pipeline. Suppliers of linepipe, bends and fittings need to demonstrate quality assurance of the material properties, including control of running fracture in linepipe and its weldability.

In addition to the challenges during manufacture, the use of high-strength steel pipes in pipeline construction require consideration. The pipeline standards governing the installation of onshore pipelines (ASME B31.4, PD8010 and EN 1594) specify a maximum D/t ratio of 100. This is to prevent flattening, ovality, buckling, and denting during the handling and installation of the pipe. Although D/t ratios in excess of 100 are permitted, extra care is required to mitigate the potential issues.

Specialist sub-contractors perform the welding and NDT\textsuperscript{o} of the pipe, with the main welding being carried out automatically with manual welding being restricted to repairs and tie-ins. The contractor is required to pre-qualify each weld procedure and welder through mechanical tests ensuring good weld quality and overmatching weld consumables. With the thinner wall thickness of the high-strength steel, up to 25\% less weld metal is required to be put down, resulting in reduced welding times (Barbaro et al., 2002: 2). From a practical perspective, this reduction in welding time offsets the more onerous pre-qualification of the higher-strength steel. Field welding contractors need to take account of additional technical requirements and controls associated with an automated low hydrogen welding process. These include but are not limited to:

- Induction heating for increased preheat levels compared to X70 grade.
- Welding consumables with overmatching strength.
- Weld heat-affected-zone properties.
- Weld material cracking resistance.
- Automated ultrasonic inspection.
- Advanced welding equipment with demonstrated reliability and welding procedure development to suit project requirements.
- Possible pre and post heat treatments, and controlled cooling cycle.
- Welding in cold weather.

Given the larger internal diameter of the X80 pipe compared to the X70 pipe, the OPEX would potentially be reduced due to reduced fuel gas requirements at the compressor stations due to the hydraulic benefit of the increased internal diameter of the pipe.

A review of the technical issues associated with the design, installation, construction and operation of X80 grade pipelines indicates a potential saving in CAPEX due to linepipe material of 23.5 x 10\textsuperscript{3} tonnes. Based on a cost of US$1400

\textsuperscript{o} Non Destructive Testing.
per tonne for X70 pipe and a cost of US$1484 per tonne for X80 pipe, this potentially offers a saving in the region of US$ 18.6M. It would be reasonable to assume that the premium for X80 pipe will reduce as the use in new pipelines increases. Perhaps more important however, is the significant reduction in the use of water in the manufacturing process due to the reduced steel tonnage. Given the large distances between pipe mills and installation locations for these pipelines, there is also potential through the reduced tonnage to minimise the carbon footprint of the transportation of the pipe; from mill to coating shop, coating shop to pipe storage and pipe storage to right of way and installation.

4.5.6 CONCLUSION

Environmentally sustainable industrial development is dependent on secure, cost effective energy and the environmental challenges facing today’s pipeline engineer are diverse. These challenges are a product of legislation, the need to transport hazardous fluids over difficult terrain for greater distances and the requirement to deliver cost effective integrated solutions for major engineering projects.

The methods of improving the environmental sustainability of the construction of long distance hydrocarbon pipelines reviewed in this chapter have been selected to demonstrate the diverse approach needed to address these challenges. The use of emerging technology and cost effective access to remote sensed data enable the environmental impact of soil erosion to be considered as part of the design phase of the project. An improvement over the current method of addressing this as an issue to be managed during the construction and operational phases of the project. The use of higher strength steel, made possible through improved manufacturing processes and installation methods offers significant opportunities to reduce the environmental impact of the project. For long distance pipelines of large diameters, the saving in the quantity of steel required offers a number of benefits for the pipeline operator. These include a significant reduction in the CAPEX due the quantity of steel used, as well as a reduction in the transportation costs of transporting the pipe from mill to coating yard and finally onto site. However, this should be seen as an incentive, as the real benefit is the reduced environmental impact. Due to the quantity of water used in the steel manufacturing process of approximately a 100 tonnes of water for each tonne of steel produced, reducing the total steel content reduces the water required. The reduced wall thickness pipe also requires less energy for its transportation frequently over considerable distances, thereby reducing the carbon footprint of the project through reduced transportation emissions.

It is only through harnessing the emerging technologies and processes that we can strive to improve the environmental sustainability of industrial development. A 'cradle to grave' approach needs to be taken and consideration given to all phases of
the project. These solutions also offer the potential to reduce the CAPEX and OPEX of the project, encouraging pipeline operators to evaluate and use emerging and improved processes and materials to improve the environmental sustainability.

**Nomenclature**

- \( v_{\text{mean}} \): Mean velocity (m/s)
- \( c \): Chézy roughness and conduit coefficient
- \( H_r \): Hydraulic radius
- \( C_s \): Conduit slope
- \( P \): Pressure
- \( S \): Allowable stress
- \( t \): Wall thickness of the pipe
- \( D \): Outside diameter of the pipe

**Glossary**

- ASME: American Society of Mechanical Engineers.
- bcma: Billion cubic metres per annum. A measurement of the volumetric flow rate of gas through a pipeline.
- CAPEX: Capital expenditure. The capital cost of a project.
- MAOP: Maximum Allowable Operating Pressure.
- NDT: Non Destructive Testing.
- OPEX: Operational expenditure. The running costs throughout the operational phase of a project.
- PHMSA: Pipeline and Hazardous Materials Safety Administration. The department responsible for establishing national policy, setting and enforcing standards, and conducting research to prevent incidents, in the transportation of hazardous materials in the United States.
- Right of Way: This comprises both the permanent pipeline easement and the extended corridor required to construct the pipeline.
References


VOLLENWEIDER, R. A. 1970. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. *OECD REPORT, SEPTEMBER 1970. 159 P.*


5. Technologies for sustainable development: best available and breakthrough
5.1 Iron and steel industry

5.1.1. Best available technologies

V. Shatokha

The important part of sustainable development analysis is the overview of the available technologies, which can reduce the energy demand and/or greenhouse gases emissions. In the iron and steel industry a number of technologies are available to further enhance environmental performance. Some of them are largely deployed, while some others still await the implementation.

The detailed description of such technologies is beyond the scope of the current publication: if necessary, the readers can find the necessary information in the literature. However, it should be noted that information available is not always sufficiently systematized and often lacks science-based prioritization (e.g., considering such factors as the cost, the payback period, maturity of the technology, effectiveness, etc.) in the context of the gradual achievement of strategic objectives of the industry. Although some summaries of the Best Available Technologies (BAT) developed by reputed institutions at the national and international levels shall be also noted. The concept of BAT is the dynamic: new and improved technologies do not cease to be developed.

One example is the summary of the BAT for steel industry developed by the Institute for Prospective Technological Studies with the involvement of relevant experts under the auspices of the European Commission and approved by Directive in February 2012 [1]. This is one of the most fundamental documents of almost 600 pages based on 398 literature sources which cover following processes:

- loading, unloading and transportation of raw materials;
- mixing and dosing of raw materials;
- Sintering and pelletizing;
- Coke making;
- Production of pig iron in blast furnaces, including slag processing;
- The production and refining of steel in oxygen converters, including the desulfurization of pig iron and slag processing;
- Production of steel in electric arc furnaces and slag processing;
- Continuous casting.

The document contains a detailed description of technological processes, ways of formation and the nature of emissions and also the means of preventing the formation or capture of emissions. The updated version of the document is freely available in the internet [2].

Another important compilation is a guide of best technologies for iron and steel industry (SOACT) [3], developed under the auspices of the U.S. State Department
with representatives of the public sector and business structures of Australia, India, Canada, China, South Korea, USA and Japan in the framework of Asia Pacific Partnership for Clean Development and Climate. Reference combines the technologies for energy saving and reducing the environmental impact.

Quite interesting is the analysis performed by the Lawrence Berkeley National Laboratory (USA) and Fraunhofer Institute for Systems and Innovation Research (Germany) [4], focused on the technologies under development, industrial demonstration, or commercialisation, summarising information on 56 emerging technologies with significant potential to reduce energy consumption and carbon dioxide emissions.

Another valuable source is an analytic paper developed by the US Environmental Protection Agency, which combines the information on technologies with the greatest potential to reduce greenhouse gases emissions. This document mostly covers proven technologies and reflects peculiarities of USA industry. In particular, it lists the technology of natural gas injection into blast furnace tuyers, reflecting relatively low cost of this fuel in the US. Table 5.1 shows the results of the analysis for the case of an integrated enterprise. It should be noted, that according to American Iron and Steel Institute (AISI), activities with a payback period of more than three years are generally considered by enterprises as economically feasible. Of course, data the payback period data are also specific to the American market. In particular, an extremely long payback period for the top gas pressure recovery turbine that transforms the energy of compression of the top gas into electrical energy, obviously, owes to the low electricity prices (in the US they are about two times cheaper than the EU average).

The study [6] performed under the auspices of the European Commission, based on the state of the art analysis for enterprises in 27 EU countries offers the ranking BAT towards the energy saving potential and develops scenarios for the future of steel industry development in Europe in the context of reducing the greenhouse gases emissions. The ranking results are shown in Fig.5.1. In our opinion, the cited study has some errors (in particular concerning penetration of pulverised coal injection technology and continuous casting technology). The results of the study prove that, given the projected growth of production, using only the BAT will not enable significant reduction of CO₂ emissions until 2030 and only the application of radically innovative technologies (the details of these technologies are discussed below) can help to the strategic objectives of the EU.
Table 5.1
Parameters of Best Available Technologies by the US Environmental Protection Agency

<table>
<thead>
<tr>
<th>Option</th>
<th>Applicability and Feasibility Codes (see list below)</th>
<th>Payback Time (years)c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Ore Preparation (Sintering)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinter plant heat recovery</td>
<td>C</td>
<td>2,8</td>
</tr>
<tr>
<td>Reduction of air leakage</td>
<td>C</td>
<td>1,3</td>
</tr>
<tr>
<td>Increasing bed depth</td>
<td>C, S</td>
<td>0,0</td>
</tr>
<tr>
<td>Improved process control</td>
<td>C, EX</td>
<td>1,4</td>
</tr>
<tr>
<td>Use of waste fuels (e.g., lubricants) in sintering</td>
<td>C, S</td>
<td>0,5</td>
</tr>
<tr>
<td>Coal moisture control</td>
<td>C, EX</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Programmed heating</td>
<td>C, EX</td>
<td>0,7</td>
</tr>
<tr>
<td>Variable speed drive COG compressor</td>
<td>C</td>
<td>21,2</td>
</tr>
<tr>
<td>Coke dry quenching</td>
<td>C</td>
<td>35,7</td>
</tr>
<tr>
<td>Additional use of COG</td>
<td>C, EX</td>
<td></td>
</tr>
<tr>
<td>Single chamber system</td>
<td>C, N</td>
<td></td>
</tr>
<tr>
<td>Non-recovery coke ovens</td>
<td>C, EX</td>
<td></td>
</tr>
<tr>
<td>Ironmaking - Blast Furnace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulverized coal injection to 130 kg/ton iron</td>
<td>C, EX</td>
<td>2,0</td>
</tr>
<tr>
<td>Pulverized coal injection to 225 kg/ton iron</td>
<td>C, N</td>
<td>2,4</td>
</tr>
<tr>
<td>Injection of natural gas to 140 kg/ton iron</td>
<td>C, EX</td>
<td>1,3</td>
</tr>
<tr>
<td>Injection of oil</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Injection of COG and BOF gas</td>
<td>C</td>
<td>&lt;1,0</td>
</tr>
<tr>
<td>Charging carbon composite agglomerates</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Top pressure recovery turbines (wet type)</td>
<td>C, N</td>
<td>29,8</td>
</tr>
<tr>
<td>Recovery of BFG</td>
<td>C, EX</td>
<td>2,3</td>
</tr>
<tr>
<td>Hot-blast stove automation</td>
<td>EX</td>
<td>0,4</td>
</tr>
<tr>
<td>Recuperator hot-blast stove</td>
<td>C</td>
<td>8,7</td>
</tr>
<tr>
<td>Improved blast furnace control systems</td>
<td>C, EX</td>
<td></td>
</tr>
<tr>
<td>Improved blast furnace control systems</td>
<td>EX</td>
<td>0,4</td>
</tr>
<tr>
<td>Slag heat recovery</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Slag heat recovery</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Steelmaking - Basic Oxygen Furnace (BOF)</td>
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<td></td>
</tr>
<tr>
<td>BOF gas sensible heat recovery</td>
<td>C</td>
<td>11,9</td>
</tr>
<tr>
<td>Variable speed drive on ventilation fans</td>
<td>C, EX</td>
<td>9,9</td>
</tr>
<tr>
<td>Improvement of process monitoring/control</td>
<td>EX</td>
<td></td>
</tr>
<tr>
<td>Programmed and efficient ladle heating</td>
<td>C, EX</td>
<td></td>
</tr>
<tr>
<td>Casting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficient caster ladle/tundish heating</td>
<td>C, EX</td>
<td>1,3</td>
</tr>
<tr>
<td>Near net shape casting - thin slab</td>
<td>N, S</td>
<td>3,3</td>
</tr>
<tr>
<td>Near net shape casting - strip</td>
<td>N, S</td>
<td></td>
</tr>
</tbody>
</table>

C = Site-specific variables may affect costs and/or practicality of use of the option at all facilities.
EE = Options that could improve energy efficiency and potentially lower GHG emissions but may increase other pollutants.
EX = Process already widely implemented at many existing facilities.
N = Only feasible for new units.
P = Immature process that is still in research and/or pilot stage.
S = Specialized process technically appropriate only for some equipment configurations or types.

As noted in the recommendations of the high level round table on the future of European ferrous metallurgy, a potential for CO₂ emission reduction for steel industry of the European Union does not exceed 10%, while the most efficient enterprise of Europe already works at the limit of physical capabilities, using almost all of the BAT [7].

Given the uneven level of technological development, the potential for reducing carbon dioxide emissions in different countries is very different. Fig.5.2 shows the data for the potential CO₂ emissions reduction that can be achieved in different countries by the BAT deployment (estimation by IEA [8]). Fig.5.3 shows the possibilities of energy saving for steel industry of different countries and the world as a whole, estimated by IEA in 2011 [9], which demonstrate the potential of various measures for modernization. The data show that, for example, in Japan and South Korea the possibilities of CO₂ emissions reduction and energy saving through the BAT deployment are rather limited, because most of these technologies are already implemented. For example, in 2007 the level of use of top-pressure recovery...
reached 100%, and of coke dry quenching in 2010 was 93% - despite the fact that (see table 5.1), these technologies have a longest payback period.

At the same time, as can be seen from Fig. 5.2-5.3, in Ukraine it is possible to reduce CO₂ emissions and energy consumption significantly through the use of proven technologies, including those with a relatively short payback period.

Fig. 5.2. Potential of CO₂ emission reduction for the steel industry of different countries

Fig. 5.3. The energy saving potential in the steel industry of the world and individual countries (in EJ/year GJ/t steel)

5.1.2. Breakthrough technologies

Today there are quite a number of innovative technological solutions in various stages of development or testing with a great potential to reduce greenhouse gases emissions of ferrous industry. Given the limited format of current edition, this section discusses only those technologies that are part of some international initiatives or large national projects.
5.1.2.1 COURSE50 project

Funded by government and major steel companies of Japan the Cool Earth 2050 programme was launched in 2008 with a total budget of 10 billion yen (about US$ 860 million). Technologies that are on a development stage are illustrated in Fig.5.4 according to work [10]. A feature of this project is the retaining of the blast furnace and two-stage steel production.

The project includes several components, in particular:
1) reduction of CO₂ emissions in ironmaking through
   a. use of hydrogen as a reducing agent,
   b. reforming of cokemaking gas to increase content of hydrogen the sensible heat of wastes
   c. production of coke with high strength and high reactivity, suitable for a blast furnace that uses hydrogen as a reducing agent;
2) CO₂ capture from top gas for and use the remaining gas as a reducing agent;
3) Energy consumption reduction by utilizing the sensible heat of the wastes.

For the hydrogen-based ironmaking as well as for method of producing hydrogen the information is not disclosed in publications. One of the options that are
being developed is a preliminary reduction of iron ore materials in a shaft furnace with subsequent use of a partially metallized product in a blast furnace.

It is planned to reduce CO₂ emissions from the blast furnace through the reduction of iron ore using hydrogen-rich reducing agents such as coke oven gas (COG) or reformed coke oven gas (RCOG), which amplified hydrogen content is achieved through the use of a newly developed catalyst and waste heat available from the coke ovens.

Regarding improvements to existing technologies reported the following.

Firstly, by using of catalysts for reforming of tar and light oils from the coking gaseous products it is expected to increase hydrogen content in coke oven gas from the current 50-55% to 63-67%. The gas will be used for injection either to conventional blast furnace tuyeres or through the tuyeres employed in the lower part of the shaft.

Secondly, it is planned to use certain admixtures to coal mix for the coke quality improvement. Since the injection of reformed coke gas will reduce coke consumption, strength requirements to coke for ensuring the gas permeability in the blast furnace will grow. In addition, the endothermic effect associated with the reducing of iron oxides by hydrogen will reduce the temperature at a certain horizons of the blast furnace, which will require using of coke with higher reactivity. Designing of a special additive to coal mix (HPC, High performance coking additives) shall provide greater coke reactivity with increasing strength of coke.

Technology for capturing of CO₂ from the top gas for its further use as a hot reducing agent is known since the 1980s. In particular, the pilot plant was operated in NPO Tulachermet, Russia. Nowadays, there are three major methods for the removal of CO₂ from the gas based on use of chemical adsorbents, membranes and cryogenic technologies.

In the COURSE 50 it is intended to capture CO₂ using chemical sorbents - liquid solvents (fig.5.5)

![Fig.5.5. A top gas CO₂ capturing scheme](image)

The significant disadvantages of existing technologies are the gradual decomposition of the sorbent and large energy consumption for its regeneration. In
COURSE50 the energy consumption and cost of CO₂ capturing is ensured by the using innovative adsorbents and recovery of wastes’ heat. It is planned to reduce energy consumption to 2 GJ/t CO₂ - almost twice compared to conditional technology that the uses monoethanolamine as a sorbent and 1.25 times compared to earlier developed COCS (Cost Saving CO₂ Capture System) process [11].

To utilise the thermal energy from waste the project involves:
- recovery of sensible heat of slag;
- generation of electricity in an improved Kalina cycle (named after its developer, Alexander Kalina);
- use of materials with high specific heat of fusion (used to store energy);
- Use of heat pumps.

COURSE 50 will be combined with carbon dioxide capture and storage (CCS) technology, which is now intensively developed.

In 2012, Japanese researchers have conducted tests at the experimental blast furnace LKAB, Swerea MEFOS (Luleå, Sweden) with working volume of 8.4 m³ and a capacity of 35-40 tons of pig iron per day with the injection of coke oven gas through conditional tuyeres, injection of reformed coke oven gas through tuyeres employed in the lower part of the shaft as well as with injection of washed from CO₂ top gas through tuyeres in the upper part of the shaft. It was found that the CO₂ output can be reduced by 3% in case if 150 Nm³/thm of reformed coke oven gas is injected to the lower shaft.

At the same time, the fundamental studies of the reduction processes using hydrogen are being performed. COURSE 50 aims to commercialise the technologies developed until 2030. They have to reduce CO₂ emissions by 30% with the subsequent large scale deployment until 2050.

### 5.1.2.2. ULCOS project

The European project ULCOS (Ultra-low CO₂ steelmaking) has been involving as a partner all of the major steelmaking companies of the European Union as well as leading energy producers, research organizations and universities. It was performed with the support from the European Commission and the Research Fund for Coal and Steel, RFCS.

Project efforts focused primarily on the following technologies:
1) ULCOS-BF - recirculation of blast furnace top gas with the use of capture and storage of CO₂ (CCS);
2) smelting-reduction technology, HIsarna with CCS;
3) Production of DRI in ULCORED with CCS
4) Iron ores recovery by electrolysis ULCOWIN, ULCOLYSIS.

ULCOS also covers also technologies for producing steel using biomass and hydrogen.
5.1.2.2.1. ULCOS-BF

Technological aspects of blast furnace top gas recycling, similarly to COURSE 50, were tested in 2007-2009 at the experimental blast furnace in Luleå. The best results were achieved in the case when a part of washed from CO₂ top gas was injected after heating to 1000°C to the bottom of the shaft, and the other part after heating up to 1250 °C was injected to the conditional tuyeres. With the top gas recirculation degree of 90% coke consumption was reduced by 25%, enabling reduction of CO emissions by 24%.

However, at an integrated enterprise the top gas is an important energy mix constituent, hence for not challenging the energy needs, recirculation rate shall be much lower, which corresponds to limiting the CO₂ capture within 15% [12]. Further reduction of total CO₂ emissions by 50% is planned to be achieved through the application of CCS technologies to the flue gas emitted at power generation.

Demonstration of this technology was planned in 2015 at ArcelorMittal Florange (France) with the following technological aspects:

- industrial blast furnace with a hearth diameter of 9.4 m and a volume of 1532 m³ was planned to be retrofitted for the top gas recycling;
- for the carbon dioxide capture an industrial plant using a solid adsorbent had to be erected;
- the reduction of CO₂ emissions by 50% level was planned;
- captured CO₂ was planned to supply under pressure through specially built pipeline to below the sea rock bed with depths over 800 m. Conditions at such a depth - temperature above 31°C and pressure over 7.39 MPa – shall result in transforming the CO₂ to a supercritical fluid that behaves like a gas, filling cavities, but has the density of a solid substance, which prevents it from escaping to the surface; thus it was planned to store up to 1.2 Mt of CO₂ per year.

Unfortunately, due to financial and organisational problems, caused by withdrawal of ArcelorMittal from the project, ULCOS-BF was stopped in 2013. Currently it is being continued in the framework of the Low Impact Steelmaking project funded by ArcelorMittal and the French government, but the timeline of its implementation is unknown.

5.1.2.2.2. HIsarna

HIsarna™ technology combines components of two other technologies - Cyclone Converter Furnace (CCF) and HIsmelt™ Smelt Reduction Vessel (SRV). Its scheme is shown in Fig.5.6 [13].
In the early 1990's Hoogovens (The Netherlands) launched the CCF pilot plant with a capacity of 15-20 t of iron ore per hour. Studies included injection to CCF of ore and oxygen in the presence of artificial gas, which simulated the gas formed in the SRV unit, producing the partially reduced molten ore. The process’s scheme is shown in Fig. 5.7.

The heat of combustion is sufficient for melting and partial reduction of ore. The melt under the force of gravity flows down along the walls of the cyclone. Melt temperature is about 1450 °C with a reduction extent of 10-20%.

Technological concept of SRV HIsmelt™ (an acronym for High Intensity Iron Smelting) originates from a steel-making converter of the KOBM (Klockner Oxygen Blown Maxhutte) type modified for the production of pig iron. HIsmelt pilot plant with a capacity of 2 tons per hour was built in Maxhutte (Germany) in 1980s, with the subsequent construction of an up-scaled pilot plant with a capacity of 8 tons of pig iron per hour in Kwinana (Western Australia) in the 1990s. In 2005 a semi-industrial installation with a capacity exceeding 80 tons of pig iron per hour was launched and operated until December 2008, when it was stopped in the midst of financial crisis. As the whole process was well developed and a significant experience with this technology has been acquired on an industrial scale.
The HIsmelt scheme shown in Fig. 5.8. Fine ore was injected into the bottom of the vessel, where it was reduced by the carbon dissolved in metal. Coal was also injected to the same area to replenish the carbon consumed by the reduction process. The gaseous products of iron ore reduction and of coal gasification ascend to the bath surface, forming a fountain of molten products, mainly slag and a certain amount of metal. Injection of oxygen-enriched hot air with a temperature of 1200°C ensures post-combustion of the gaseous products with liberation of the a significant amount of thermal energy which is transferred to the bath by circulating slag and metal jets.

Liquid iron is constantly discharged separately from the slag through the siphon tap hole. The slag is discharged through a separate tap hole. To optimize slag properties, the fluxes (lime or limestone) are injected to the bath. Byproduct gas still has a significant energy value and after cleaning and cooling is used as fuel or for electricity production.

Compared with the production of pig iron in the blast furnace, HIsmelt has the following advantages [14]:

1. Smaller operating costs are ensured by possibility to use directly iron ore and coal without coking and agglomeration, as well as by the possibility to use cheaper low grade iron ore, non-coking coal, and even ferrous wastes (dust, sludge, scale, etc.).

2. Flexibility in the application of raw materials. HIsmelt can use a fine hematite ore (-6 mm) or magnetite concentrate. It is possible to use phosphoric ores, since, unlike the blast furnace, in HIsmelt a significant part of the phosphorus goes to slag. Preheating of iron ore may enhance the efficiency of the process, though it is possible to use cool materials. It is possible to use titanomagnetites and ferric quartzite.
3. Lowers capital costs are provided by phasing out coal coking and iron ore agglomeration processes.

4. HIsmelt has higher flexibility being not as inertial as blast furnace: ore, coal and flux are injected to the hearth releasing metal, slag, gas and heat energy almost instantly (in the blast furnace smelting charge materials reach the hearth within few hours after discharging. This makes possible to adjust consumption without challenging the product quality, and to easily maintain stable operation. The HIsmelt process can easily be stopped, idled and restarted.

5. Low environmental impact mainly also relates to phasing out coal coking and ore agglomeration processes. HIsmelt provides an overall reduction of CO₂, SO₂ and NOₓ emissions. In addition, it prevents the formation of dioxin, furan, phenol and enables the recycling of wastes.

The owner of HIsmelt™ is a British-Australian company Rio Tinto Group. After reviewing proposals from several companies for further development and commercial implementation of this technology, in 2013 the decision was made to move installations HIsmelt from Australia to China (Shandong province) for the further commercialization of the technology. Start of production was planned for 2014; however, no further information about this project was found in literature.

The ULCOS project in 2006-2007 has merged HIsmelt SRV and CCF technologies in a single process, named HIsarna. Initial plans suggested the launch of a pilot plant in 2010 at Völklingen Saarstahl (Germany). Due to the global financial crisis, these plans were revised. Today the project is being implemented at the Tata Steel Ijmuiden, Netherlands [15]. As Rio Tinto continues technical support HIsarna, this project brings together two continents – Europe and Australia. This confirms the fact that the final commercialization of this technology cannot be taken by any industrial company on its own.

Fig.5.9 shows how the technological concepts of the CCF and SRV are combined in a HIsarna apparatus. The fine ore and oxygen are injected to a cyclone located above the SRV, producing partially reduced molten iron ore that drips down to SRV. Pulverized coal is injected with high velocity into the bath to maintain the level of carbon dissolved in the metal at a level necessary for melting. The metal has a temperature of 1400-1450 °C and contains about 4.0 % carbon. The molten ore from the cyclone instantly dissolves in the slag. Pulverized coal forms a large area of interface and reacts with iron oxide producing iron. The final slag contains about 5-6% FeO. The carbon dissolves in the metal and reduces the iron from the slag producing CO which together with the volatile substances of the coal ascends upwards. In the upper part of SRV this gas is partially burned by oxygen, generating heat. Part of this heat is returned to the bath by circulating in the SRV flow of metal and slag. As a result, the gas has a temperature of 1450-1500 °C at the level of post-
combustion of about 50%. The balance of sensible heat and the chemical potential of the gas is used for partial reduction and smelting ore in CCF.

HIsarna pilot plant was built with a capacity of 8 tons of pig iron per hour. The first tests were launched in 2011. During the second campaign (in 2012) the production level with 65% of design capacity was achieved with the use of conventional raw materials for a long term period. During the third campaign (2013) a sub-bituminous coal and low-grade iron ore were used, and the pig iron produced was smelted in the BOF to produce steel. In 2014 the features of the use of different raw materials were explored and the upper limit of production performance was investigated. In 2015 a long term production period was completed over several months in a steady mode to determine the shortcomings of the design and to prepare the project for up-scaling. Demonstration is scheduled for 2018 and subsequent commercialization is planned after 2020.

The advantages and disadvantages of HIsarna technology were analysed by researchers from the Technical University of Delft (the Netherlands) [16]. With respect to environmental aspects, it is expected that the HIsarna will be able to reduce CO₂ emissions by 20% compared to the average European blast furnace. In combination with CCS, this value can reach 80%. Regarding efficiency, HIsarna will require significantly lower investments while retaining the existing quality of pig iron. The operating costs and energy consumption will also decrease. The possibility of using a wide range of charge materials, including low grade ones will be ensured. The quantitative findings of the analysis are given in table.5.2 (for the case of blast furnace the costs of construction of the coke plant and sinter plant are taken into account).
Table 5.2
Economic and environmental indicators of HIsarna compared to the production of pig iron in the average European blast furnace

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Blast furnace</th>
<th>HIsarna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production capacity (Mt of iron per year)</td>
<td>0.5–5.0</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>100% (≈ 17 GJ/t of pig iron)</td>
<td>80%</td>
</tr>
<tr>
<td>Emissions of CO₂, t/t pig iron</td>
<td>1.650</td>
<td>1.320 (-20%)</td>
</tr>
<tr>
<td>Capital cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>new project</td>
<td>100%</td>
<td>75%</td>
</tr>
<tr>
<td>Retrofitting</td>
<td>-</td>
<td>65%</td>
</tr>
<tr>
<td>Operating expenditures (excluding depreciation)</td>
<td>100%</td>
<td>90%</td>
</tr>
</tbody>
</table>

Obstacle to the introduction of HIsarna in Europe and in some other regions may be a low potential for production growth: the existing and future needs can be fully covered by existing blast furnaces. In addition, major reconstruction of the existing blast furnace costs about twice cheaper than building new one. The combination of these factors may prevent replacement of blast furnace to a HIsarna technology during the term of full depreciation of existing blast furnaces. Possibilities to deploy HIsarna in developing countries are more optimistic and partially analysed in Chapter 6.

5.2.2.3. ULCORED

The development of innovative technology for production of Direct Reduced Iron (DRI) is carried out by a company called LKAB and the research institute of MEFOS of Sweden and the Austrian company, Voestalpine in the framework of the project ULCOS. The initial requirements for the creation of new technology were established as follows:

1) the technology must substantially differ from existing, in particular, such as Midrex and HYL;
2) There should be a single source of CO₂ emissions from all the facilities of technological cycle;
3) Consumption of energy must not exceed 8.4 GJ/t of DRI;
4) Equipment and technology must be simple;
5) Use of other types of fuel than natural gas must be possible;
6) Capital investments should be comparable to other technologies.

Later, during the development of the technology with the name of ULCORED the following criteria were accepted:

- oxygen must be used instead of air in order to receive a maximal concentration of CO₂ in emissions;
- natural gas consumption shall be reduced by 15-20%;
- the possibility to use the processes of coal, biomass and bio-waste gasification, and to use of hydrogen like an alternative to a natural gas.
Midrex technology has already been using for 40 years to produce DRI with the use of natural gas, covering over the 60% production of this product in the world (the world production of DRI in 2013 was 75.2 million t) [17]. The owner of this technology is a company Kobe Steel Ltd (Japan). Substantial difference of ULCORED from Midrex and other analogue, HYL, is an application of oxygen conversion (partial oxidization) of natural gas (exothermic reaction of $\text{CH}_4+1/2\text{O}_2=\text{CO}+\text{H}_2$) instead of carbon dioxide or steam reforming (endothermic reactions of $\text{CH}_4+\text{CO}_2=2\text{CO}+2\text{H}_2$, and $\text{CH}_4+\text{H}_2\text{O}=\text{CO}+3\text{H}_2$). The reactor of partial oxidization (POX) was developed for this purpose with the pilot tests conducted by LKAB. Due to application of this reactor, ULCORED has such advantage, as absence of need to heat up the gas used for reforming that enables production of renewable gas consuming less energy. In addition, it was suggested to increase pressure in the vessel of direct reduction (a shaft furnace of ULCORED is similar to the one used in Midrex) to 6 atm. This will mitigate dust formation and will downsize the apparatus [18].

The options to develop the process with the use of natural gas and gasification of coal were considered. Primary plans envisaged the building of the pilot plant in 2013, but now the available literature reports only the results of laboratory research and mathematical modelling, testifying that CO$_2$ emissions in ULCORED must be decreased by 100 kg/t of DRI in comparison to Midrex or HYL [19].

5.1.2.2.4. ULCOLYSIS and ULCOWIN

The electrolysis of the iron ore is also considered within the framework of ULCOS. This process shall transform iron ore to iron and gaseous oxygen with the use of electrical energy only. Electrolysis is commonly used at the production of other metals - aluminium, zinc and nickel.

In the ULCOLYSIS process, iron ore is dissolved in a melt of silicon and calcium oxides, at the temperature of 1600°C which is higher than iron melting point. The anode made from a material that is inert in relation to oxide melt is used. The electric current passes through oxide melt between an anode and cell of liquid iron that serves as a cathode. In the process of electrolysis oxygen of oxides of iron on the anode transforms to gaseous oxygen, while a cell of liquid metal is filled up with iron that is discharged using a siphon. Currently ULCOLYSIS is on the laboratory researches phase. Similar technology is developed also under the sponsorship of the American Iron and Steel Institute (section 5.2.3.2).

In the ULCOWIN process the electro-deposition (electro-winning) of iron from hematite ore takes place in a water solution of sodium hydroxide at a temperature of 110 °C. ULCOWIN is on a final stage of laboratory research. Creation of the pilot plant with the productivity 5 kg/day is planned.
The processes based on the application of electrolysis can be considered as future technologies to production iron, providing all the electric power is received from renewable sources or from nuclear power plants. The energy consumption depends on configuration of process, chemical composition of electrolyte and temperature of process. The electrolysis in a molten electrolyte consumes about 2000 kW·h/t of iron at 1600°C that is much less compared to the energy spent in a blast furnace process (4980 kW·h / t pig iron (17.9 MJ)/t. If temperatures go down the energy consumption can be diminished [20].

Unfortunately, more detailed information about these technologies is absent in available literature. Their commercialization is planned not early than in 2030, or even in 2050 [21].

5.1.2.3. Projects of the American Iron and Steel Institute

The American Iron and Steel Institute (AISI) is an association combining most producers of steel in the USA as well as some steel companies of Canada and Mexico. The projects described below are considered to reduce the emissions of CO₂ and performed under the aegis AISI in partnership with the Energy Department of USA.

5.1.2.3.1. Ironmaking by Hydrogen Flash Smelting

A new method to produce iron - Suspension Hydrogen Reduction of Iron Oxide Concentrate - during 2005-2007 was developed by University of Utah in partnership with ArcelorMittal Dofasco, Gallatin Steel, Ipsco, Nucor, Praxair, Ternium, Timken and US Steel [22]. The target was to create an alternative method to produce iron by gas reduction of iron ore concentrate during its falling inside of the vertical vessel (e.g. a shaft or a cyclone). Hydrogen, natural gas, products of coal or plastic gasification or combination of these gases, shall be used in this method. The authors hope that their development will become competitive - both in relation to a steelmaking BF- BOF route and to some alternative methods of pig iron production. An option of further development by integration of technological principles of the instant smelting and direct steelmaking is also considered.

One possible process scheme is represented in Fig.5.10. Technically, the process is the analogue of technology of flash smelting used, in particular, for smelting of sulphurous copper ores and included to the EU Best Available Techniques in its industrial sector [23]. The substantial advantage of this process in relation to shaft furnaces and fluidized bed reactors is prevention of clinging and smelting of particles of feedstock at a high temperature.

Only theoretical and laboratory research have been done so far. Calculations testify that new technology will consume approximately by 38% less energy
compared to the blast furnace. In the case if hydrogen is used, CO₂ emissions will decrease compared to blast furnace by 96%; in the case if natural gas is used this figure goes down to 61%, and for coal – to 31%. A thermo-chemical modelling showed the possibility to produce metal with considerably less content of phosphorus without a reduction in the quality in terms of sulphur content. Experimental study of iron ore concentrate (sized 30 μm) gas reduction kinetics showed the possibility to achieve a degree of metallization of 90-99% within few seconds at a temperature over 1300°C. Proving the results for a large-scale laboratory reactor (diameter - 24 cm, height – 1.4 m, maximal temperature 1100°C) confirmed theoretical results. Future research, aimed at commercialization of the technology, envisage up-scaling to the industrial pilot plant.

From 2012 this project proceeds under the name of Ironmaking by Hydrogen Flash Smelting [24]. Plans for 2014-2015 envisaged the launch of a large laboratory reactor to operate at a temperature over 1400°C with the productivity over 1 kg of solid raw material per hour with duration over 6 hours. Among the important problems to solve is the high level of temperatures in the reactor (1300-1600°C). This is mentioned with the aim to accelerate the reaction velocity. However, the latest publications [25] available inform only about the study of processes of re-oxidation of iron powder after it’s unloading from the reactor.
5.1.2.3.2. Molten oxide electrolysis

An electrolytic production of metals from oxides is a proven technology - all aluminium in the world is produced by this method. In theory, an electrolytic method is applicable to the iron; however, taking into account very high efficiency of the blast furnace, this method did not get developed. Like the process of ULCOlysis, in the developed by the Massachusetts Institute of Technology process of Molten Oxide Electrolysis (MOE), molten iron and gaseous oxygen are obtained as the electric current passes between two electrodes, submerged to molten salt containing the liquid iron oxides [26]. The schematic of the method is illustrated in Fig.5.11.

![Fig. 5.11. Scheme MOE process](image)

In this process the difference between the electric potential in a molten electrolyte is used to split the oxide to oxygen and iron that might be summarised using the following reaction equation;

\[
4\text{Fe}^{3+} + 6\text{O}^2- \rightarrow 4\text{Fe} + 3\text{O}_2\text{(gas)}
\]

Although, physicochemical principle of the process is similar to the production of aluminium, a substantially higher temperature level shall be reached to exceed the iron melting point (1539°C), while for aluminium with the use of molten fluorite production takes place at a temperature of 950°C.

Using of the graphite electrodes is not reasonable taking into account formation of carbon dioxide, hence a major problem is the development of appropriate electrode, that shall be inert to a far more corrosive environment compared to that takes place at the production of aluminium, especially on the boundary of anode-electrolyte interaction, that is predetermined by a contact with aggressive melt that contains oxides of iron. Thus, an anode must withstand the high current density - over 1 A/m². Applicability of noble metals, in particular iridium was demonstrated [27];
however, the cost of this metal and its availability in the earth's crust does not allow the consideration of it for ironmaking on an industrial scale.

Other technological problem that needs solving is that, unlike at the production of aluminium, where on the metal surface there appears a chemically passive film preventing a re-oxidation of liquid metal, in case of iron, a dissolution of oxide layer in electrolyte takes place, that is followed by continuous oxidation of reduced metal [28].

Nowadays, the process of MOE is at the stage of the fundamental laboratory research that is focused on the development of effective carbonless electrodes and determination the most effective ways of work of electrolytic cell. The second phase of project envisages the development and verification of large-sized pre-pilot electrolytic cell with the productivity of about 70 kg of iron and 30 kg of oxygen per day.

As noted already, the potential of MOE in relation to reduction of CO₂ emissions depends on the source of electric power. Even, if traditional sources of electric power are used, depending on the structure of generation of electric power in that or other country, the process can provide reduction of CO₂ emissions.

The steelmaking route of "blast furnace - BOF" with the use of modern equipment and the technologies produces about 1750 kg CO₂/t steel. The production of iron by electrolytic method consumes from 2000 to 3500 kW·h of electric power per 1 t of steel. In case of Ukraine, the production of one kW/t of electric power on average corresponds to 563 g of CO₂ [29], so for MOE method, the emissions will be 1970 kg of CO₂/t steel. Approximately the same result can be calculated for the USA (547 g of CO₂ per 1 kW·h). But, in the case of France, where the majority of electric power is produced on nuclear power stations, at the production of one kW·h of electricity on the average is followed by emission of 71 g of CO₂, the emissions for method of MOE will be just 248 kg of CO₂/t steel.

5.1.2.3.3. Paired Straight Hearth Furnace

Paired Straight Hearth Furnace (PSH) is an alternative method to produce of DRI developed by McMaster University under the aegis of AISI. Raw material used is self-reducing pellets made of coal and iron ore concentrate. Fine wastes of the steel industry can be also used. During the heating process as a result of reduction product with the level of metallization of 95% is obtained for further smelting in electric arc furnaces. Gaseous CO is produced in the process of direct reduction, and its combustion provides the temperature level of process.

An ordinary rotary hearth furnace has limitations in relation to the height of pellets’ layer to 2-3 pellets. A temperature over the layer of pellets is artificially maintained not too high - about 1300°C – by keeping the ratio of CO/CO₂ ≈ 2. It
prevents clogging and re-oxidation of pellets, but it limits the productivity and energy efficiency.

In the PSH furnace a layer of 8 pellets (about 120 mm) is maintained. Gas is fully burned, providing a temperature over the layer about 1600°C. The speed of reduction in such conditions is limited by a heat transfer; hence higher temperature increases the productivity. The re-oxidation is prevented due to creation of gas rich in CO, which rises through a layer (a shrouding effect, effect of protection, actually, is the subject of patent by McMaster University). Complete oxidation of all combustibles materials in a furnace enables liberation of chemical potential in a form of sensible heat that decreases the energy consumption. Therefore PSH technology should substantially improve the productivity of the process and cuts down the energy consumption. The developers consider that PSH has the potential to replace blast furnaces and coke ovens at comparatively small capital and operational costs and to reduce energy consumption by 30%.

The PSH concept uses two parallel linear furnaces that have a common chain of moving pallets. Thanks to this in each of furnaces the movement of pallets with material takes place in the opposite directions. Pellets are loaded and discharged on the opposite ends of furnace, while the pallets in the process of movement go across from one furnace to another. Fig.5.12 demonstrates a scheme of PSH that represents a movement of materials and gas stream developed by McMaster University. In 2005 a Bricmont company has done the feasibility study for the PSH project with productivity levels of 46000 t DRI/year and suggested an optimised layout (Fig.5.13) with a different location of the hanging walls to provide more rational use of a thermal energy of gas flow [30].

![Fig.5.12. Scheme of PSH furnace developed by McMaster University](image)
PSH concept was experimentally tested on installation with a static furnace. Development of laboratory furnace with movable layer is ongoing. According to the AISI data, the new phase of the project began in 2012, aimed at delivery of the demonstration plant.

The perspective option for future applications combines PSH technology with an oxygen-coal converter earlier developed under the aegis of AISI. In this case, a hot DRI product with a temperature of about 1400°C will be loaded to the converter and the gas recovered from converter will be used in PSH furnace. Such a combination will decrease the consumption of coal threefold. Another option uses an electric arc furnace instead of converter. The schemes for both options according to the material balance calculated for 1000 kg of DRI are demonstrated in Fig.5.14 [31]. However, introduction of such technological chain is a remote perspective because PSH technology should be worked out at first.

**5.1.2.4. POSCO CO₂ Breakthrough Framework**

POSCO Company is the leader in development of innovations in a South Korean iron and steel industry. The level of BAT penetration is one of the world’s highest as it is seen from the table below (data for 2009) [32]:

![Fig.5.13. Optimized streams in the PSH furnace](image)

![Fig.5.14 Schemes combining PSH furnace with a converter and an electric arc furnace.](image)
Coke dry quenching with heat recovery | 93 %
Utilization of coke oven gas | 100 %
Heat recovery from sinter waste heat | 87 %
Utilization of blast furnace gas | 100 %
Use of top pressure recovery turbine | 96 %
PCI technology | 100 %
Hot stove waste heat recovery | 100 %
Heat recovery from BOF waste gas | 100 %

From these data it is obvious, that potential for the further cutting energy consumption and emission reduction of CO₂ for this company due to available technologies is very limited. Therefore POSCO is very active in research towards innovative technologies.

Carbon-lean FINEX project envisages the improvement of already proven FINEX technology. The FINEX’s prototype is a Corex technology for of production pig iron, commercialized in 1989 in South African Republic, and later also in India. Developed by Siemens VAI, Corex includes two parts - shaft furnace for preliminary reduction of ore and a melter-gasifier. Corex’s problem is relatively low efficiency of the recovery of gas energy. In sense of energy efficiency and reduction of CO₂ emissions, Corex can compete with a blast furnace technology only under conditions:

1) if top gas will be used to produce electric power in very efficient generators;
2) if the CO₂ emissions intensity during the generation of electric power in a network, where the electricity will be supplied, is over 0.9 kg CO₂/kW·h [33] (the case for countries, where the electricity generation is largely coal-based – e.g. SAR, India and China).

In 1992 POSCO in collaboration with Siemens VAI started development of the new process. In contrast to Corex a cascade of fluidized bed reactors for heating and pre-reduction of ore is used instead of shaft furnace, and compactor is used for briquetting pre-reduced ore and coal. These innovations enable the use of low-grade fine raw materials.

In 1996 the experimental installation was developed with a productivity level at 15 ton per day. In 1999 it was up-scaled to 150 t per day, and in 2003 the demonstration plant was erected with productivity of 0.6 million t/year. The first commercial FINEX apparatus with the productivity of 1.5 million t/year was launched in April 2007 at Pohang Works, providing substantial material for further improvement of process. Finally, in January 2014, at the same enterprise the FINEX apparatus was launched with simplified design and productivity of 2 million t per year.

FINEX production layout, applied for an apparatus with the productivity of 1.5 million t/year is demonstrated in Fig.5.15 [34]. Fine ore together with a flux (limestone or dolomite) is loaded to the fluidized bed reactor. Passing through a
cascade of four reactors, ore is heated and partly reduced. Ore is briquetted using compactors and loaded to the melter-gasifier.

Fine coal can be loaded together with a pre-reduced ore to the dome part of melter-gasifier after briquetting, or supplied by the system of pulverized injection via the tuyeres to the hearth. Burned thanks to injection of clean oxygen it generates heat, which enables melting of metalized product, and a reducing gas that is used in the fluidised bed reactors. The part of top gas is recycled back to the melter-gasifier after capture of the CO₂.

It is not shown on a schematic, but some quantity of coke is also supplied to the melter-gasifier to ensure drainage of liquid products in the hearth. Table 5.3 shows data on the technological parameters of an apparatus with productivity of 1.5 million t / year. Coke consumption constitutes nearly 8%, whereas for Corex it is 15%. Substantial reduction of coke consumption in FINEX system is achieved by the application of a compactor. However, in the experiments it was found impossible to completely refrain from the use of coke, because of drainage problems in the hearth.

<table>
<thead>
<tr>
<th>Indexes</th>
<th>Operation parameters (May-October 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>million t/year 1.5</td>
</tr>
<tr>
<td></td>
<td>t/day 4300</td>
</tr>
<tr>
<td>Total solid fuel consumption</td>
<td>kg/t pig of iron 720</td>
</tr>
<tr>
<td>Including</td>
<td></td>
</tr>
<tr>
<td>coke</td>
<td>60</td>
</tr>
<tr>
<td>PCI</td>
<td>150</td>
</tr>
<tr>
<td>Composition of pig iron</td>
<td></td>
</tr>
<tr>
<td>[S] %</td>
<td>0.027</td>
</tr>
<tr>
<td>[Si] %</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Fig. 5.15. Chart of FINEX process

Table 5.3
The experience gained allowed the simplification of the design for an apparatus with the productivity level of 2.0 million t/year. In particular, in a previous version fluidised bed reactors provided the 85% degree of reduction; however it was found that the optimal level is 65%. Therefore, in a new design instead four reactors just three are used. In addition, a vertical conveyer for supplying of iron ore part was substituted by more efficient pneumatic system. These improvements allowed the decrease in the total height of construction from 121m to 77m, while the productivity grew by 25%.

The best attained operation result was consumption of 700 kg of solid fuel per ton of pig iron that corresponds to 97% of the world’s average for blast furnace technology. In the near future thanks to the optimization of process it is planned to achieve a level 680 kg/t with further reduction to 660 kg/t, that would correspond to 93% and 90% of CO₂ emissions compared to a blast furnace. Further plans envisage the development and application of the CCS system with the capture of 0.7 t of CO₂ per 1 t of pig iron that will bring down the CO₂ emissions by 53% compared to blast furnace. Application of CCS in the case of FINEX might be rather efficient, thanks to use of clean oxygen: CO₂ content in the gas is higher than in blast furnace top gas. The construction of a pipeline is planned for the CO₂ for its injection into the cavities of gas deposit of Donghae in Japanese Sea.

Among the other POSCO projects it is necessary to highlight the development of technology for iron ore reduction in the fluidised bed reactors with the use of hydrogen and smelting of steel from a metallised product in large electric arc furnaces. However, the method to obtain cheap hydrogen in present publications is not disclosed [35].

References

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30. The Final Report “Paired Straight Hearth Furnace Feasibility Study“ Submitted by Bricmont, Inc. to American Iron and Steel Institute, Nov. 8, 2005
5.1.3. Ways to Reduce Greenhouse Gas Emissions, Increase Energy Efficiency and Reduce Utilization of Depletable Resources in Mining and Metallurgy Industry of Ukraine

D. Stalinskiy, V. Botshtein, V. Mantula, I. Stalinska

5.1.3.1. Greenhouse gases emissions of mining and metallurgy industry of Ukraine

Signing, and later ratifying the framework convention of the United Nations on climate change (UN FCCC), Ukraine assumed the responsibility to convey to the UN’s secretariat the reports on the countries status of greenhouse gas emissions into the atmosphere, and also to inform about the results of measures taken to reduce them. The main reporting document according to addendum 1 to the UN FCCC is the “National Inventory Report of anthropogenic emissions from sources and adsorption sinks of greenhouse gas in Ukraine” (further – National Inventory Report), which must be sent to the secretariat every year [1].

The characteristics, given in the National Inventory Report, are for major greenhouse gases emission sources, fluctuation dynamics of emission volumes starting from the base year 1990, and also analysis of results of measures to reduce emissions in a reporting period.

Information, contained in the National Inventory Report, serves as the basis for the functioning of Kyoto protocol mechanisms, which were introduced in January, 2008.

Thus, during the period of action of the Kyoto protocol, the National Inventory Report combines two different informational functions:

- It characterizes Ukraine as a source of greenhouse gases emission and the emission status as compared to the base year;
- It provides data about statuses of greenhouse gases emissions’ volumes in specific industry sectors, which may be used while implementing Kyoto protocol mechanisms.

As for the first function, the distribution of production facilities or enterprises between sectors, characterized as autonomous entities in the National Inventory Report, has little importance to the Convention’s secretariat, most importantly; there should be a country’s general balanced value. That is why neither the management of sectors (ministries) nor the managers or owners of industries pay keen interest to the National Inventory Report.

When incorporating business entities into the process of implementing Kyoto protocol, the attitude towards information, which could significantly affect the results of its financial and economic operations, should principally change, and this must be considered while preparing the next National Inventory Report. Adequately verified
information about the volume of greenhouse gases emissions, provided in the National Inventory Report, will be needed both for the realization of surplus quotas, and for the realization of joint implementation projects.

The reliability of the distribution of industries and productions, provided in the National Inventory Report, could significantly affect the efficiency of actions of sectoral ministries, aimed to ensure the implementation of Kyoto protocol mechanisms at agency-controlled enterprises and the sector as a whole.

In October 1996, Ukraine had assumed the responsibility to develop, periodically update and submit to the secretariat of the UN FCCC the National Inventory Report, after the Ministry of environment and natural resource of Ukraine produced three National Inventory Reports, the last is for the 1990-2005 years. This National Inventory Report was developed in accordance with the latest demands of “Guiding recommendations of the UN FCCC dated 2004” and included inventory results of four direct impact greenhouse gases – carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and perfluorocarbons. As for hydro-fluorocarbons and sulphur hexafluoride, provided by the Kyoto protocol, they are not formed during operations of mining and metallurgy complexes of Ukraine; hence, data about these gases are not included in the National Inventory Report.

The most complete sections, from information perspective, in the National Inventory Report there are the ones, in which characteristics of greenhouse gases emissions sources were presented (parts 3-9). The information presented in these sections of the National Inventory Report was constructed in compliance with the recommendations of the Intergovernmental Panel on Climate Change (IPCC) with the categorization of greenhouse gases emissions sources according to the system, which was tested by the experiences of countries that developed earlier (much earlier than Ukraine) their own National Inventory Report.

As shown by the preliminary analysis of informational sections of the National Inventory Report that characterizes sources of greenhouse gases emissions, obtaining enough objectively reliable data for assessing the state of affairs on greenhouse gases emissions at mining and metallurgical enterprises of Ukraine remains a relatively difficult task. The distribution into the “sectors” of productions, as components of mining and metallurgy complexes, was done in such a way that emissions of greenhouse gases from pig iron and steel production, including the use of coke, and also ferroalloys and aluminium were assigned to the sector “Industrial processes”, while at the same time, emissions from the use of fuel in ferrous metallurgy and by-product-coking industry were assigned to the “Energy” sector. Greenhouse gases emissions from production and use of limestone and dolomite by mining and metallurgy complex were assigned to the sector “Industrial processes”.

It is clear that this baseless distribution of sources of greenhouse gases emissions into various sectors leads to the fact that the volume of greenhouse gases
emissions from such a production sector, like the mining and metallurgical complexes of Ukraine could be substantially modified, depending on the professional level of the developers of the National Inventory Report and the interests of various production entities like, for example, the fuel and energy. It was happened, for example, with the volumes of greenhouse gases emissions from pig iron and steel productions in the National Inventory Report for the years 1990-2004, where in the National Inventory Report for 2005, emissions of $CO_2$ for 1990 was estimated ~ 41 million tons, and in the National Inventory Report for 2006 this value has increased to about twice – 80.5 mln. tons. These types of amendments in documents submitted to international organs, and most especially concerning data, characterizing productions in the base year from where all other calculations for monitoring the implementation of Kyoto protocol take origin, are unacceptable.

In subsequent National Inventory Reports, the above mentioned inadequacies were mostly rectified, because of the calculation of values for volumes of greenhouse gases emissions from pig iron, steel, rolling-mill, lime, ferroalloys productions including use of limestone and dolomite was carried out, according contract agreements, by SE “UkrRTC “Energostal” – the main enterprise of the Ministry of industrial policy of Ukraine to solve priority packages of scientific and technical issues, including implementation of Kyoto protocol mechanisms to supplement the UN FCCC.

5.1.3.2. Comparative evaluation of greenhouse gases emissions' calculation for mining and metallurgy enterprises with data in the National Inventory Reports

Mining and metallurgical complexes is among the most important industry sector of Ukraine, just as per its share in the gross domestic product (GDP), so is as per its export share. The mining and metallurgical complexes of Ukraine comprises of over eighty large enterprises, producing all products required for a closed production cycle – from iron-ore raw material to rolled finished products. More so, among the mining and metallurgical enterprises of Ukraine, a quarter of them have the structure of integrated works. In fact, this indicates the presence of autonomous processes in their structure, which produces products that may be termed as marketable ones and may be sold to the market. Priority position of mining and metallurgical complexes of Ukraine in the country’s economy is confirmed by the fact that, products, which are produced by the mining and metallurgical complexes of Ukraine, in the last years, provided over 40% of foreign currency inflow of the country.

It is imperative to bear in mind that the operation of mining and metallurgical enterprises of Ukraine requires the consumption of tangible amount of fuel and energy resources (FER). By fuel consumption volume, the mining and metallurgical complexes occupy the second position after the energy sector of Ukraine. It is also
obvious that the mining and metallurgical complexes of Ukraine occupy its appropriate position in terms of greenhouse gases emissions volume.

Calculations [1], performed by the SE “UkrRTC “Energostal” in accordance with the recommendations of the intergovernmental panel on climate change (IPCC) and using the statistical data of industry reports on consumption of fuel resources for the year 1990, are given in Table 5.4.

Table 5.4: Volumes of greenhouse gases emissions when producing major products at mining and metallurgical complexes in the year 1990

<table>
<thead>
<tr>
<th>Production</th>
<th>Emissions of CO₂, million tons/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter</td>
<td>8.0</td>
</tr>
<tr>
<td>Coke</td>
<td>6.7</td>
</tr>
<tr>
<td>Pig iron</td>
<td>62.2</td>
</tr>
<tr>
<td>Steel</td>
<td>12.0</td>
</tr>
<tr>
<td>Rolled products</td>
<td>15.5</td>
</tr>
<tr>
<td>Lime, dolomite</td>
<td>2.9</td>
</tr>
<tr>
<td>Ferroalloys</td>
<td>5.3</td>
</tr>
<tr>
<td>Thermal energy</td>
<td>29.4</td>
</tr>
<tr>
<td>Repairs and other auxiliary sub-sections</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Total for mining and metallurgical complexes of Ukraine</strong></td>
<td><strong>145.2</strong></td>
</tr>
</tbody>
</table>

Data, presented in Table 5.4, confirms that emissions of greenhouse gases from the use of organic fuels in mining and metallurgical complexes of Ukraine amounts to almost a third of emissions from the whole commercial activities of the state and have the right to a separate representation in relevant government reporting documents, including the National Inventory Report. The appropriateness of this type of action follows on from the fact that individual processes of mining and metallurgical complexes are closely linked together, form parts of a production enterprises and are often combined into a single production plants. Just for example, production of sinter and pellets is the final process of the mining processing complexes; production of lime subsist the blast-furnace, open-hearth furnace and basic oxygen converter shops, and most of the products produced in plants serve as raw materials for the next phase of metal processing, and in general do not have a marketable products’ status.

Attempts of the developers of the National Inventory Report to adapt the industrial and economic scheme of the mining and metallurgical complexes, used in Ukraine, to scheme, used in other participant countries of UN FCCC, result in the discrepancies in report documents on status of greenhouse gases emissions in one of the major industrial sectors of the country. If we take data about greenhouse gases
emissions from processes, which are connected to the metallurgical industry, out of different sections of the National Inventory Report, we may achieve the picture shown in Table 5.5.

Table 5.5: Volumes of greenhouse gases emissions during production of metals in the year 1990 according to the National Inventory Report’s data

<table>
<thead>
<tr>
<th>Production</th>
<th>Emission category according to the National Inventory Report</th>
<th>Emission of CO₂, million tons/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous metallurgy:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fuel</td>
<td>Energy, 1.A.2.a</td>
<td>40.6</td>
</tr>
<tr>
<td>- Technology</td>
<td>Industrial processes, 2.C.1</td>
<td>80.5</td>
</tr>
<tr>
<td>Utilization of coke-oven gas for heating coke ovens</td>
<td>Production of solid fuels and other energy sectors using coke-oven gas</td>
<td>Data for the year 1990 is not available. In year 2004 the total is 8.9</td>
</tr>
<tr>
<td>Production of ferroalloys:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Energy</td>
<td>Together with aluminium production, 2.C.2</td>
<td>1.1</td>
</tr>
<tr>
<td>- Industrial processes</td>
<td></td>
<td>4.2</td>
</tr>
<tr>
<td>Production of lime</td>
<td>In the total national volume</td>
<td>5.7</td>
</tr>
</tbody>
</table>

In Table 5.5 we provided partial list of data from the National Inventory Report, which characterizes greenhouse gases emissions during the production of products at mining and metallurgical complexes of Ukraine, but it shows that the total volume of emissions correlates with calculations performed by SE “UkrRTC “Energostal”. Thus the thesis earlier offered in the assessment of the contribution of mining and metallurgical complexes of Ukraine to greenhouse gases emissions in the total national scale irrespective of the calculation method, which approximately equals 145 million tons of CO₂ in the base year 1990, is confirmed.

Considering the distribution of this volume among industries based on results of sectoral calculations and emission categories of the National Inventory Report, it shall be observed that significant inadequacies exist between them, which, at first, emerge in the form of presentation of assessment results, which does not allow, for example, according to the National Inventory Report, to define priorities of the sector’s technical policies on emissions reduction and monitor for the implementation of actions aimed at its realization. Thus, data in the National Inventory Report in this form does not provide the opportunity to the Ministries, industrial associations and industry managements, to use them as a supplementary lever to the UN’s FCCC for efficient implementation of Kyoto protocol mechanisms.
It would be more effective, if the mining and metallurgical complexes of Ukraine, with its volume of greenhouse gases emissions, could occupy a separate place in the content of the National Inventory Report of Ukraine, and the materials for this section are prepared by SE “UkrRTC “Energostal”. In this case, the data in the National Inventory Report would have simultaneously met the demands of the UN FCCC secretariat’s reporting format, and on the other hand - serve as an informational directory for managing the process of implementing the Kyoto protocol mechanisms.

To resolve this issue, it is pertinent that the Ministry of Economic Development and Trade of Ukraine makes an appropriate proposal to the Ministry of Ecology and Natural Resources of Ukraine.

Regardless of the outcome decision concerning raising the status of mining and metallurgical complexes of Ukraine in the National Inventory Report, it makes sense to include the carrying out works for determination of greenhouse gases emissions at each individual enterprise of the sector in the organization of actions aimed at implementation of Kyoto protocol by the Ministry of Economic Development and Trade of Ukraine. It would have been appropriate to present in this document the information about volumes of greenhouse gases emissions in the base year 1990, 2007 the preceding year before Kyoto protocol joined into force, and emission dynamics for each year thereafter.

5.1.3.3. Analysis of the investment programs of mining and metallurgy enterprises and available technologies for energy saving and reducing greenhouse gases emissions

Investment plans of enterprises growth were considered when developing “The state’s direct-purpose scientific and technical growth and reorganization of mining and metallurgical complexes program for the year period till 2012”, “Sectoral energy efficiency and energy saving program for the year period till 2017” and “Sectoral program for reduction of natural gas consumption by industrial enterprises of Ukraine and measures for its realization” (hereinafter - Programs) [2-10].

To increase the national production capacity and competitiveness of products of mining and metallurgical complexes of Ukraine, to create suitable conditions for investment attraction, to enhance the export potential and increase the presence of locally produced metallurgical products in domestic market, the Programs envisage the implementation of tasks and actions in the following direction:

- Construction of new and modernization of existing sinter plants (PJSC “Alchevsk Iron & Steel Works”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Yenakiieve Iron & Steel Works”, JSC “Zaporizhstal” steel works”, PJSC “Arcelormittal Kryvyi Rih”). It is assumed that at the new sinter plants, the content of fines in sinter will be reduced by 2 times, due to
this, in blast furnace production there will be reduction in the amount of coke consumed, and in sinter plants the flow rate of coke nuts and natural gas will be reduced;

- Construction of new, and modernization of existing blast furnaces with the introduction of pulverized-coal fuel injection technology (PCI). It was estimated that 11 blast furnaces (PJSC “Alchevsk Iron & Steel Works”, JSC “Zaporizhstal” steel works”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Yenakiieve Iron & Steel Works”, PJSC “Arcelormittal Kryviy Rih”, PJSC “Mariupol metallurgical plants named after Ilyich”) shall undergo total overhauling and complete technical re-equipment and modernization. The total production volume of these furnaces equals 17 million tons of pig iron. Major parts of blast furnaces re-equipment are:
  - optimization of the structure of blast furnaces with an increase in capacity and full automation of technological processes;
  - modernization of aspiration systems, including covering of troughs for pig iron and slag discharge;
  - PCI technology. It is worth noting that with the estimated investment volume of ~ 3.3 mln. UAH, the payback period of this technology is about 2 years;
  - new designs of energy-efficient air heaters;
  - utilization of excess pressure of top gases for production of electricity in compressor-less turbines.

It is expected that the planned reconstruction of blast furnaces will permit to reduce significantly coke consumption and exclude practically the use of natural gas:

- construction of new basic oxygen converter shops with decommissioning of open-hearth furnace shops, and increase in volume of liquid steel that is being casted on continuous casting machines (CCM) and processed in ladle-furnaces and vacuum degassers (PJSC “Alchevsk Iron & Steel Works”, JSC “Zaporizhstal” steel works”, PJSC “Mariupol metallurgical plants named after Ilyich”). It is assumed that the volume of steel, which will be produced in converter in the year 2012 will be 75%, and in electric steel-melting furnaces - 15%, which will help significantly reduce consumption of energy resources, especially to greatly reduce utilization of natural gas;

- Construction of new rolling shops (PJSC “Alchevsk Iron & Steel Works”, JSC “Zaporizhstal” steel works”, PJSC “Mariupol metallurgical plants named after Ilyich”, JSC “Azovstal” iron and steel works”). It is envisaged to use automated control systems for fuel consumption during preheating of ingots and billets, optimization of heating regime with the use of fibre heat insulation materials in pre-heating furnaces, introduction of new rolling technology, which provides for the reduction of utilized natural gas;
- technical re-equipment of the energy department with the replacement of energy consuming oxygen units by new generation design type (PJSC “Mariupol metallurgical plants named after Ilyich”, JSC “Azovstal” iron and steel works”, PJSC “Alchevsk Iron & Steel Works”, JSC “Zaporizhstal” steel works”, PJSC “Yenakiieve Iron & Steel Works”, PJSC “ArcelorMittal Kryvyi Rih”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, CJSC “Donetskstal metallurgical plant”, CJSC “MMW ISTIL (Ukraine)”). These installations allow to produce oxygen, inert gases and to save up to half of the consumed electric energy. Construction of new electricity generating units that utilize secondary energy resources (blast-furnace, converter and coke-oven gases);

- equipping process equipment by heat recovery units and evaporative cooling systems, this will allow to use secondary energy resources and to reduce consumption of primary fuels;

- modernisation and reconstruction of the units for manufacturing hot-deformed welded and cold-deformed pipes, energy conserving technologies and heat treatment equipment;

- technical re-equipment and commissioning of new aggregates for smelting and producing titanium-magnesium, for production spongy titanium, ingots of titanium and its alloys, including the use of electron-beam smelting method (PJSC “Zaporozhye Titanium & Magnesium works”, “Strategya MB” Enterprise, JSC “Pavlograd machine-building plant”), mastering the technology of obtaining flat and graded titanium rolled products (JSC “Zaporizhstal” steel works”, PJSC “Dneprospetsstal”), seamless elongated pipes (PJSC “Nikopol titanium pipe plant”) and wires for welding;

- construction of installations for dry quenching of coke, required for implementing energy saving technologies;

- reconstruction and modernization of enrichment, palletisation and agglomeration plants to increase the quality of commodity iron ore and iron content in ore concentrates and other products of its processing by 1.1-1.3 % up to 2012;

These outlined measures aim to indirectly reduce consumption of primary energy resources as a result of the implementation of the newest technologies and equipment, and likewise to directly utilize secondary energy resources.

Analysis of growth investment plans of enterprises of the mining and metallurgical complexes of Ukraine indicates that these outlined measures provide a reduction in the consumption of energy resources and allow reducing greenhouse gases emissions. As already known, the basic idea of the mechanism of joint implementation projects is to implement energy saving projects at major production units of leading mining and metallurgical enterprises of Ukraine through other countries investments. In exchange for this, the investors receive emissions reduction units (ERU) which are generated as a result of the realization of joint implementation
project (JIP). The mechanism of JIP envisages transfer and acquisition of ERU, obtainable in the year period 2008-2012.

Unlike conventional investment projects, JIP must meet the complementarity criteria and pass through a special approval procedure.

Joint implementation projects must be complementarity to domestic actions, which are implemented in the country to reduce greenhouse gases emissions and should ensure a further reduction of greenhouse gases emissions as opposed to those that would have occurred in the absence of the project.

The JIP mechanism must help Ukrainian enterprises:
- to provide additional financial resources for project implementation;
- to enhance the economic attractiveness of the project;
- to introduce modern technologies.

It has been established that these outlined measures may be included in the list of energy-saving projects, which can be defined as joint implementation projects. List of measures are listed in Table 5.6.

Table 5.6: Energy saving measures that can be defined as joint implementation projects

<table>
<thead>
<tr>
<th>Item №</th>
<th>Title of measure</th>
<th>Aim and major indicators</th>
<th>Enterprise</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7</td>
<td>Replacing open-hearth method of steel production by electric steelmaking method</td>
<td>Energy resource saving – natural gas.</td>
<td>CJSC “Donetskstal-MP”</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Energy Resource Saving</td>
<td>Companies/Works</td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9</td>
<td>Reconstruction of converter gas cooling equipment with the aim to utilize the heat energy</td>
<td>natural gas. Generation of steam and electricity. Utilization of SER.</td>
<td>PJSC “ArcelorMittal Kryvyi Rih”</td>
</tr>
<tr>
<td>11</td>
<td>Installation of automatic process control system (APCS) for annealing pits</td>
<td>natural gas.</td>
<td>CJSC “MMW ISTIL (Ukraine)”</td>
</tr>
<tr>
<td>12</td>
<td>Lining furnaces by refractory materials from the company “Plibriko”</td>
<td>natural gas.</td>
<td>PJSC “ArcelorMittal Kryvyi Rih”</td>
</tr>
<tr>
<td>13</td>
<td>Replacing electromechanical frequency inverters by static ones at small section mills and transformers of major mill drives with the reduction of design capacity</td>
<td>electricity.</td>
<td>PJSC “ArcelorMittal Kryvyi Rih”</td>
</tr>
</tbody>
</table>
5.1.3.4. Most efficient measures to reduce greenhouse gases emissions at mining and metallurgy enterprises of Ukraine

Emissions of greenhouse gases at enterprises of the mining and metallurgical complexes are determined by the products volume and fuel and energy resource (FER) consumption.

At the time before the enactment of Kyoto protocol to the UN FCCC (in the year 2007), at enterprises of the mining and metallurgical complexes of Ukraine it were produced:

- iron ore – 77.4 million tons;
- iron ore concentrate – 61.0 million tons;
- sinter – 49.7 million tons;
- pellets – 22.4 million tons;
- coke – 20.1 million tons;
- pig iron – 35.6 million tons;
- steel – 42.8 million tons;
- rolled products – 36.2 million tons;
- steel pipes – 2.6 million tons;
- ferroalloys – 1.7 million tons.

According to data of the State statistics committee of Ukraine, in this period the country’s GDP increased by 7.3% when compared with previous year’s indicators. According to data of the association “Metallurgprom” for this period, iron
ore production increased by 6%, sinter – by 4.8%, pellets – by 7.2%, coke – by 5.5%, pig iron – by 8.2%, steel - by 4.7%, finished rolled products – by 5.1%, ferroalloys – by 7.7%. Production of steel pipes fell by 0.9%.

Statistical reports show that approximately 45.4 mln. tons of equivalent fuel (million tons of e.f.) was used at enterprises of the mining and metallurgical complexes of Ukraine in the year 2007. The highest amount of fuel and energy resources consumption took place at metallurgical enterprises – about 78%. Significantly smaller proportion of the total fuel and energy resources consumption were from coke chemical plants (about 16%). The shares of enterprises in other productions (non-ferrous metallurgy, ferroalloy productions, production of pipes, ore-mining and refractory production) are 0.6 to 2.6%.

SE “UkrRTC “Energostal” found that coke is the main type of fuel whose share in the total consumption of FER amounts to about 50%. It should be noted that the share of coke increased by about 1.2% in 2007, in relation to the year 2006 figures. The shares of natural gas and blast-furnace gases amount to 21.5% and 19.6% respectively. Shares of other types of fuel are insignificant (from 4.8% for coke gas to 0.5% for black oil). As determined earlier, the total of greenhouse gases emissions at enterprises of the mining and metallurgical complex of Ukraine in the year 2007 amounts approximately to 95.7 mln. tons of CO₂. In the year 1990, emission of greenhouse gases at enterprises of the mining and metallurgical complex of Ukraine equals 145.2 mln. tons of CO₂.

Based on the above outlined, as soon as the Kyoto protocol joined into force, the contribution of enterprises of mining and metallurgical complex of Ukraine amounts to 49.5 mln. tons of CO₂ according to the assessment of SE “UkrRTC “Energostal”.

Emissions of greenhouse gases at mining and metallurgical complexes of Ukraine in the year 2007 decreased by almost one third compared with the 1990 value. It should be noted that the production of major product types for this period decreased by 10-20% (pig iron – by 20.8%, steel – by 10.9%, rolled products – by 13.6%). Thus, we can say that besides the decrease in production at enterprises there were significant changes in the rate of consumption of fuel and energy resources, which led to the reduction in greenhouse gas emissions.

To improve the growth of domestic productions and the competitiveness of products of mining and metallurgical complexes of Ukraine, to create favourable conditions for attracting investments, to increase export potentials and to broaden the availability of locally metal products in domestic markets, it is envisaged to implement a set of energy saving measures that will lead to decrease volume of greenhouse gases emissions, and which can be considered as joint implementation projects (JIP), viz:
1. Replacement of agglomeration machines of old designs by newer units with increased surface area for roasting and improved production technology.
2. Development and introduction of the equipment and technology of pulverized-coal fuel injection into the hearth of blast furnaces with corresponding works for the modernization of main and auxiliary equipment.
3. Upgrading the design of air heaters for blast furnaces.
4. Reconstruction of blast furnaces with the construction of TPRT.
5. Replacing open-hearth method of steel production by basic oxygen converter method.
8. Reconstruction of converter gas coolers with the aim of utilizing the heat.
9. Replacement of preheating furnaces of outdated designs by modern ones.
10. Adjustment of heat and technical modes of fuel combustion in preheating and thermal furnaces.
12. Modernization of the compressor facilities.

Reduction of the total volume of greenhouse gases emission (GG) depends on the volume of produced products, and also on the specific GG emission reduction.

According to the programs it was envisaged to increase production of major product types of mining and metallurgical complexes of Ukraine (compared with year 2007) up to year 2012 (the year of expiration of the Kyoto protocol to UN FCCC):
- sinter – by 28 %;
- pellets – by 26 %;
- coke – by 24 %;
- pig iron – by 26 %;
- steel – by 17 %;
- rolled products – by 18 %;
- pipes – by 10 %;
- ferroalloys – by 25 %.

When calculating the specific greenhouse gas emission reduction resulting from the implementation of energy saving actions, emissions of CO₂ are considered (the main greenhouse gas that is formed during processes of mining and metallurgical complexes of Ukraine), which are connected with:
- combustion of fuel energy resources (natural, blast-furnace, coke-oven and converter gases, black oil, coal and coke);
- transition of carbon from pig iron into steel;
- use of lime, limestone and dolomite;
- indirect emissions of CO₂ when using electricity at the point of it production;
- the residual carbon left in steel that does not result in emissions of CO₂.

This approach allows to consider all factors affecting emissions of greenhouse gases in whole, and to make grounded conclusion about quality indicators (specific GG emissions reduction per ton of produced products) of greenhouse gases emissions reduction when implementing one or more energy saving measures. Calculations of greenhouse gases emissions were carried out taking into account research results.

5.1.3.4.1. Replacement of sintering machines of old designs by newer units with increased roasting surface area and improved production technology

Replacement of agglomeration machines of old designs by newer units having increased surface area for roasting and improved production technology was scheduled at PJSC “Arcelormittal Kryviy Rih”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Alchevsk Iron & Steel Works”, JSC “Zaporizhstal” steel works.

Implementation of these actions results to reduction of specific consumption rate of coal by 10.1 kg of e.f./tons, natural gas – by 0.5 kg of e.f./ton, coke gas – by 0.12 kg of e.f./ton, coke fines – by 0.9 kg of e.f./ton, blast-furnace gas – by 0.003 kg of e.f./ton, and likewise decrease of electricity consumption by 5.6 kW h/ton.

Decreasing the specific consumption rate of fuel and energy resources (FER), needed to produce a ton of sinter, will lead to decrease in the specific greenhouse gases emissions by 30.69 kg of CO₂/ton.

5.1.3.4.2. Implementation of equipment and technology of pulverized coal injection into the hearth of blast furnaces

Implementation of this technology was scheduled at CJSC “Donetskstal-MP”, PJSC “Alchevsk Iron & Steel Works”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Yenakiieve Iron And Steel Works”, PJSC “Mariupol metallurgical plants named after Ilyich”, PJSC “Arcelormittal Kryviy Rih”, JSC “Azovstal” iron and steel works”, and JSC “Zaporizhstal” steel works”. A practical experience of pig iron production with the technology of pulverised-coal fuel injection into the hearth of blast furnaces, which was completely implemented at CJSC “Donetskstal-MP”, allows to determine the energy saving potential at other enterprises, and as well as to evaluate the volume of fuel and energy resources that can be saved.

Pulverized-coal fuel injection in the amount of 107.17 kg of e.f./ton into the hearth of blast furnaces lead to reduction of coke consumption by 97.58 kg of e.f./ton, natural gas by 76.13 kg of e.f./ton and blast-furnace gas 136.6 kg of e.f./ton. The total reduction in the specific fuel consumption for the “blast furnace – air heaters” complex equals 66.54 kg e.f./ton on average.
Reduction in the specific fuel consumption for the “blast furnace – air heaters” complex, due to the implementation of technology of pulverized-coal fuel injection into the hearth of blast furnaces, leads to reduction of specific greenhouse gas emissions by 120.98 kg of CO₂/ton of pig iron.

5.1.3.4.3. Upgrading design of blast furnaces hot stoves


To operate the blast furnaces’ air heaters, only blast-furnace gas can be used. Experience of the improvement of old air heaters design at PJSC “Yenakiieve Iron and Steel Works” confirms that this measure helps to increase the blowing temperature up to 1150-1200°C, which is higher that blowing temperature level of current air heaters by 180-230°C. An increase in the blowing temperature leads to a decreased coke consumption in the blast furnace by 5-8%, i.e. by 25-40 kg/tons.

However, it is worth noting that in improved air heaters, greater amount of blast-furnace gas (by 2 kg of e.f./ton) is utilized than in older ones. Besides, to stabilize the combustion process in the improved air heaters, natural gas in the volume of 2.9 kg of e.f./ton is used. In other words, evaluation of the energy saving potential of implementing air heaters should be done taking into account the whole “blast furnace – air heaters” complex. Efficiency of the air heaters’ improvement action at PJSC “Yenakiieve Iron and Steel Works” shows that the reduction in specific consumption of fuel for the “blast furnace – air heaters” complex amounts to 19.8 kg of e.f./ton.

Reduction of the specific consumption of FER for the “blast furnace – air heaters” complex through modernization of outdated air heaters will lead to decreasing specific emission value of greenhouse gases by 61 kg of CO₂/ton of pig iron.

5.1.3.4.4. Reconstruction of blast furnaces with the construction of TPRT

Reconstruction of blast furnaces with the construction of top-pressure recovery turbines (TPRT) was scheduled at PJSC “Arcelormittal Kryviy Rih”, PJSC “Alchevsk Iron & Steel Works”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, and JSC “Zaporizhstal” steel works.

Implementation of TPRT provides to use of blast-furnace gas’ pressure excess to produce electric energy. Thus, the implementation of TPRT behind the blast furnace with volume 1513 m³ and capacity of 1.05 mln. tons/year allows to generate 4.5 MW (35.5 GW/h/year) of electric energy utilizing the pressure excess of blast-furnace gas in the amount of 250 thous. Nm³/h (1.97 billion Nm³/year). Specific
electric energy production is 33.8 kWh/ton of pig iron, which is equivalent to a reduction of greenhouse gases emission by 30.2 kg of CO₂/ton.

5.1.3.4.5. Replacing open-hearth method of steel production by basic oxygen converter method

Replacing open-hearth method of steel production by basic oxygen converter method was scheduled at PJSC “Mariupol metallurgical plants named after Ilyich”, PJSC “ArcelorMittal Kryvyi Rih”, PJSC “Alchevsk Iron & Steel Works”, JSC “Zaporizhstal” steel works”.

Replacing open-hearth method of steel production by basic oxygen converter method leads to reduction in the consumption of natural gas by 76.2 kg of e.f./ton, electricity - by 4.3 kWh/ton, oxygen - by 10.9 m³/ton, and also an increase in lime consumption by 49.3 kg/ton and coal by 6.3 kg e.f./ton.

Considering the above mentioned the specific greenhouse gas emission reduction, when replacing open-hearth steelmaking method by basic oxygen converter method, constitutes 354.1 kg of CO₂/ton.

5.1.3.4.6. Replacing open-hearth method of steel production by electric steelmaking method

Replacement of open-hearth method of steel production by electric steelmaking method was scheduled at CJSC “Donetskstal-MP”. Six open-hearth furnaces with total steel production volume of 0.91 mln. tons/year are operating at enterprise.

When replacing open-hearth method of steel production by electric steelmaking method, the specific natural gas consumption reduction constitutes 115.4 kg of e.f./ton. Consumption of electricity increases by 137.4 kWh/ton, lime – by 23.7 kg/ton. The use of dolomite and limestone is almost completely excluded. It should be noted that the specific rate of electricity consumption in electric steel production depends significantly on the composition of charge mix, specifically the proportion of molten pig iron, steel scrap and other charge components. In other words, the FER saving may vary with expected average parameters.

Reduction of specific greenhouse gases emissions taking into account consumption of FER, electrodes, lime, dolomite and other carbon-containing components, when replacing open-hearth method of steel production by electric steelmaking method, constitutes 80.3 kg of CO₂/ton on average.

5.1.3.4.7. Implementation of continuous casting machines

Implementation of continuous casting machines was scheduled at JSC “Azovstal” iron and steel works”, PJSC “Mariupol metallurgical plants named after Ilyich”, PJSC “Dneprovskiy Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Yenakiieve Iron And Steel Works”, PJSC “Alchevsk Iron &
Implementation of continuous casting machines (CCM) to replace blooming mill shops will allow to reduce specific consumption of natural gas by 41.17 kg of e.f./ton, blast-furnace gas by 31.6 kg of e.f./ton and electricity by 20.4 kW·h/ton. The reduction in energy intensity of products, due to the implementation of CCM, constitutes about 80 kg of e.f./ton.

This energy saving measure helps to reduce specific emissions of greenhouse gases by 276 kg of CO₂/ton.

5.1.3.4.8. Reconstruction of converter gas coolers with the aim of heat recovery

Reconstruction of converter gas coolers with the aim of utilizing the heat was scheduled at PJSC “ArcelorMittal Kryviy Rih”.

Converter gas cooler is designed to evacuate and to cool gases, released from the converter during the process of steel smelting, purify and utilize them. Gas from the converter with a temperature of 1900°C enters into the cooler, where its heat is used to produce steam with a pressure of 0.8-2.9 MPa for plant’s own use or to produce electricity. Herewith, the specific equivalent fuel saving, which could have been spent for producing heat or electric energy, constitutes 43.9 kg of e.f./ton. When converted to CO₂ units, the amount of greenhouse gases emission reduction equals 39.2 kg of CO₂/ton of steel.

5.1.3.4.9. Replacement of preheating furnaces of outdated designs by modern ones

Replacement of preheating furnaces of outdated designs by modern ones was scheduled at PJSC “Mariupol metallurgical plants named after Ilyich”.

Natural gas is used as fuel in preheating furnaces. In old furnace designs, the specific fuel consumption is 131 kg of e.f./ton on average. Use of impulse burners, fibre insulation materials and the “hot charge” technology helps to reduce specific consumption of fuel up to 52 kg of e.f./ton.

Considering this indicator, the specific greenhouse gases emissions reduction rate during the replacement of old preheating furnaces with newer models constitutes 129.87 kg of CO₂/ton of steel.

5.1.3.4.10. Adjustment of heat and technical modes of fuel combustion in preheating and thermal furnaces

Adjustment of heat and technical modes of fuel combustion in preheating and thermal furnaces was scheduled at CJSC “Donetskstal-MP”, CJSC “MMW ISTIL (Ukraine)” and JSC “Azovstal” iron and steel works”.

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Many-years experience of SE “UkrRTC “Energostal” indicates that the adjustment of modes of fuel combustion of preheating and thermal furnaces will allow reducing consumption of FER by 7% on average. Specific fuel consumption rate for preheating or thermal processing of metal constitutes 131 kg of e.f./ton on average. The specific reduction in fuel consumption due to the adjustment of heat and technical modes of fuel combustion constitutes 9.2 kg of e.f./ton, and the specific reduction in greenhouse gases emissions – 14.8 kg of CO₂/ton.

5.1.3.4.11. Construction of combined-cycle steam-gas plants

For producing electricity, a combined-cycle steam–gas plants, which use secondary energy resources – blast-furnace, coke-oven and converter gases, were scheduled for construction at PJSC “Alchevsk Iron & Steel Works”, PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Stahanov ferroalloys plant”. To present time all blast-furnace and converter gases excesses were not utilized, they were burned and thrown into the air. It should be noted that the general designer of infrastructure objects of the combined-cycle gas-turbine electric power station at PJSC “Alchevsk Iron & Steel Works” is SE “UkrRTC “Energostal”.

Production of electricity due to utilization of blast-furnace, converter and coke gases leads to the reduction of CO₂ emissions at thermal power plant (TPP) and/or combined heat power plant (CHPP) by 89.3 kg of CO₂/kW.h.

5.1.3.4.12. Modernization of oxygen units and the compressor facilities

Oxygen and compressed air are used for production purposes at metallurgical enterprises of Ukraine, production of which requires corresponding oxygen units and compressor facilities. To produce oxygen and compressed air there must be expenditure of electric energy, its production is connected with emission of greenhouse gases at points of its production. In other words, energy saving measures aimed at reducing electricity consumption must be considered.

Implementation of modernized oxygen units will lead to the reduction of specific consumption of electric energy by 320 kW.h/thous. m³ of oxygen an average, which will result in specific reduction of greenhouse gases emissions by 285.76 kg of CO₂/thous. m³ of oxygen.

Implementation of modern compressors will help reduce specific consumption of electric energy by 35 kW.h/thous. m³ of compressed air, which is equivalent to specific reduction of greenhouse gases emissions by 31.26 kg of CO₂/thous. m³ of compressed air.

In Table 5.7 there is a summary of data about the efficiency of specific and average annual greenhouse gas emissions reduction at mining and metallurgical
complexes of Ukraine resulting from the implementation of energy saving measures, envisaged in investment plans of industrial enterprises.

Table 5.7: Summary of data about specific and average annual greenhouse gases emissions reduction at mining and metallurgical complexes of Ukraine

<table>
<thead>
<tr>
<th>№</th>
<th>Measure</th>
<th>Specific greenhouse gas emission reduction, Kg of CO₂/ton (kg of CO₂ /kW·h, kg of CO₂/thous. m³)</th>
<th>Name of enterprise</th>
<th>Production capacity, mln. ton/year (MW; thous. m³/year)</th>
<th>Greenhouse gases emissions reduction, thous. tons of CO₂/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Replacement of agglomeration machines of old designs by newer units with increased surface area for roasting and improved production technology</td>
<td>30.69</td>
<td>PJSC “Arcelormittal Kryviy Rih”, PJSC “Dneprovsky Integrated Iron &amp; Steel Works named after Dzerzhinsky”, PJSC “Alchevsk Iron &amp; Steel Works”, JSC “Zaporizhstal” steel works”</td>
<td>28.92</td>
<td>887.6</td>
</tr>
<tr>
<td>3</td>
<td>Modernizing the design of air heaters for blast furnaces</td>
<td>61</td>
<td>PJSC “Arcelormittal Kryviy Rih”, PJSC “Dneprovsky Integrated Iron &amp; Steel Works named after Dzerzhinsky”, PJSC “Alchevsk Iron &amp; Steel Works”, JSC “Zaporizhstal” steel works”</td>
<td>15.5</td>
<td>945.5</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4.</td>
<td>Reconstruction of blast furnaces with the construction of TPRT</td>
<td>30.2</td>
<td>15.5</td>
<td>468.1</td>
<td>354.1</td>
</tr>
<tr>
<td>5.</td>
<td>Replacing open-hearth method of steel production by basic oxygen converter method</td>
<td>80.3</td>
<td>0.91</td>
<td>73.1</td>
<td>276</td>
</tr>
<tr>
<td>6.</td>
<td>Replacing open-hearth method of steel production by electric steelmaking method</td>
<td>39.2</td>
<td>6.12</td>
<td>239.9</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Implementation of continuous casting machines</td>
<td>129.87</td>
<td>1.33</td>
<td>172.7</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Reconstruction of converter gas coolers with the aim of utilizing the heat</td>
<td>14.8</td>
<td>6.63</td>
<td>98.1</td>
<td></td>
</tr>
</tbody>
</table>
According to data analysis provided in Table 5.7, it can be concluded that the total reduction of greenhouse gases emissions, achieved by implementing energy saving actions at mining and metallurgical complexes, constitutes 16.4 mln. tons of CO₂/year. The most efficient reducing average annual volume of greenhouse gases emissions will be able to be achieved by implementation of the following measures:
- replacing open-hearth method of steel production by basic oxygen converter method – 4.68 mln. tons of CO₂/year (28.6% of total reduction);
- implementation of continuous casting machines – 3.90 mln. tons of CO₂/year (23.8%);
- implementation of technology for pulverized-coal fuel injection into the hearth of blast furnaces – 2.81 mln. tons of CO₂/year (17.2%).

The total reduction in greenhouse gases emissions, resulting from the implementation of these energy saving measures, constitutes about 70 % of the total reduction of CO₂ emissions.

According to analysis of the impacts of energy saving measures aimed at reducing emissions, the specific CO₂ emissions reduction indicators, which are assignable to a product unit, may be used. The most effective reduction of specific greenhouse gases emissions has place after executing the following measures:
- replacing open-hearth method of steel production by basic oxygen converter method – 354.1 kg of CO₂/ton;
- modernization of oxygen units – 285.8 kg of CO₂/ton;
- implementation of continuous casting machines - 276 kg of CO₂/ton;
- developing and implementing equipment and technology for pulverized-coal fuel injection into the hearth of blast furnaces - 121 kg of CO₂/ton.
5.1.3.5. Evaluation for reduction of greenhouse gases emissions and the rate of energy resources consumption during reorganization of mining and metallurgical complexes and implementation of energy saving technologies and equipment

Results of researches, carried out by SE “UkrRTC “Energostal”, established that there are significant potentials for reducing greenhouse gases emissions in most metallurgical enterprises (Table 5.8).

Table 5.8: Greenhouse gases emissions reduction potential of leading mining and metallurgical complexes of Ukraine

<table>
<thead>
<tr>
<th>Plant</th>
<th>Volume of greenhouse gas emissions reduction, mln. tons of CO₂/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Potential</td>
</tr>
<tr>
<td>PJSC “Alchevsk Iron &amp; Steel Works”</td>
<td>4.1</td>
</tr>
<tr>
<td>PJSC “Arcelormittal Kryvyi Rih”</td>
<td>2.4</td>
</tr>
<tr>
<td>JSC “Zaporizhstal” steel works”</td>
<td>3.8</td>
</tr>
<tr>
<td>PJSC “Dneprovsky Integrated Iron &amp; Steel Works named after Dzerzhinsky”</td>
<td>1.9</td>
</tr>
<tr>
<td>PJSC “Mariupol metallurgical plants named after Ilyich”</td>
<td>2.6</td>
</tr>
<tr>
<td>JSC “Azovstal” iron and steel works”</td>
<td>0.7</td>
</tr>
<tr>
<td>CJSC “Donetskstal-MP”</td>
<td>0.7</td>
</tr>
<tr>
<td>PJSC “Yenakiieve Iron And Steel Works”</td>
<td>0.2</td>
</tr>
<tr>
<td>CJSC “MMW ISTIL (Ukraine)”</td>
<td>0.07</td>
</tr>
<tr>
<td>JSC “Nizhnydniprovsk pipe plant”</td>
<td>0.2</td>
</tr>
<tr>
<td>JSC “Avdiyev coke and chemical plant”</td>
<td>0.12</td>
</tr>
<tr>
<td>JSC “Bagleikoks”</td>
<td>0.08</td>
</tr>
</tbody>
</table>

At most of the leading mining and metallurgical complexes of Ukraine there is a significant potential for energy saving, its implementation will allow to considerably reduce greenhouse gases emissions (0.7-4.1 mln. tons of CO₂/year). Unfortunately, only an insignificant part of this potential is currently being implemented as JIP.

The most active implementation of energy-saving measures as JIP, according to earlier mentioned, is at PJSC “Alchevsk Iron & Steel Works”. However, even at this enterprise, there are considerable numbers of energy-saving measures that were not arranged as JIP. Primarily, this is the use of pulverized-coal fuel injection in blast
furnaces and utilization of pressure excesses of the blast-furnace gases with the aid of TPRT.

At PJSC “Arcelormittal Kryviy Rih” and JSC “Zaporizhstal” steel works”, implementation of energy-saving measures is insignificant too. About 16 to 45 % of energy-saving measures are actualized as JIP. Analogical to other enterprises, technology for pulverized-coal fuel injection into blast furnaces and pressure excesses of blast-furnaces gases in TPRT is not utilized. Replacement of open-hearth method of steel production by basic oxygen converter method and steel casting in CCM is also not implemented.

At other enterprises, firstly, at the leading producers of pig iron, steel and rolled products - PJSC “Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky”, PJSC “Mariupol metallurgical plants named after Ilyich” and JSC “Azovstal” iron and steel works”, neither of energy-saving measures has been arranged as JIP.

Therefore, about 75% of the potential reduction of greenhouse gases emissions at leading mining and metallurgical complexes of Ukraine is not arranged as JIP, as a result the possible significant losses from the sale of greenhouse gases emission reduction units by enterprises.

Conclusions:

1. Analysis of the investment programs of mining and metallurgical enterprises showed that total reduction of greenhouse gases emissions, achieved as a result of implementing energy-saving measures at mining and metallurgical complexes of Ukraine, constitutes 16.4 mln. tons of CO₂/year.

2. The most efficient reducing average annual volume of greenhouse gases emissions (about 70% of the total reduction of CO₂ emissions) will be able to be achieved by implementation of the following measures:
   – replacing open-hearth method of steel production by basic oxygen converter method – 4.68 mln. tons of CO₂/year (28.6% of total reduction);
   – implementation of continuous casting machines – 3.90 mln. tons of CO₂/year (23.8%);
   – implementation of technology for pulverized-coal fuel injection into the hearth of blast furnaces – 2.81 mln. tons of CO₂/year (17.2%).

3. According to analysis of the impacts of energy saving measures aimed at reducing emissions, the specific CO₂ emissions reduction indicators, which are assignable to a product unit, may be used. The most effective reduction of specific greenhouse gases emissions has place after executing the following measures:
   – replacing open-hearth method of steel production by basic oxygen converter method – 354.1 kg of CO₂/ton;
   – modernization of oxygen units – 285.8 kg of CO₂/ton;
– implementation of continuous casting machines - 276 kg of CO₂/ton;
– developing and implementing equipment and technology for pulverized-coal fuel injection into the hearth of blast furnaces - 121 kg of CO₂/ton.

4. About 75% of the potential reduction of greenhouse gases emissions at leading mining and metallurgical complexes of Ukraine is not arranged as JIP, as a result the possible significant losses from the sale of greenhouse gases emission reduction units by enterprises.

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5.2 Petroleum industry

M. Karpash, A. Yavorskyy, I. Rybitsky, I. Darvai

Companies consider corporate social responsibility as a voluntary act, not mandates by law, to work for the welfare of the community and share with them benefits extracted from their indigenous resources. Oil companies have to determine the welfare of its stakeholders on the priority basis in order to ensure healthy environment within the premises. Oil Industry is considered as the backbone of any economy as it extracts revenue from earth and can contribute huge revenue to Gross National Production (GNP). While working in any economy, oil companies either from domestic environment or international are required to fulfil their Corporate Social Responsibilities and prove themselves as good corporate citizens. From time to time, oil companies are blamed for not paying proper attention to the community in which they operate their business and generate revenues. Earlier, when people had no awareness of the Corporate Social Responsibilities, they didn’t raise objections, but with the passage of time, when awareness developed among the masses, objections raised from every corner against lack of concern on the part of oil companies for the welfare of community.

Petroleum industry is at a time of dramatic, perhaps unprecedented, change and challenge in the global oil and gas business. A number of factors, such as changing geopolitical relationships, the emergence of new competitors, changes in supply and demand dynamics, social and environmental pressures, and demographic shifts, are transforming and reshaping our industry. But there is one indisputable fact that affects not only our industry but the world as a whole: global demand for energy will continue to increase dramatically, driven in large part by population growth and the strong desire of developing countries to achieve economic prosperity. Experts may disagree about the rate of growth, but there is no dispute that growth in the demand for energy is inevitable.

The world’s population grows by a quarter of a million people every 24 hours. By 2030, it is expected that 8 billion people will occupy this planet, up from 6.5 billion today, with 95% of the growth occurring in the developing world. Secure, affordable, accessible, and ample supplies of energy are absolutely essential to both economic growth and a reasonable standard of living, so it is only natural to expect that developing countries, with their growing economies and populations, will drive increased energy demand.

Using ExxonMobil’s latest energy outlook, the world today consumes about 230 million BOE/D with oil and gas supplying about 60% of the total demand, coal another 20%, and the remaining 20% coming from such sources as nuclear, hydro, wind, and solar. By 2020, worldwide energy demand is expected to increase by about 55 million BOE/D, or 24%, from 230 to 285 million BOE/D, with about 80% of this
growth in developing countries. Oil and gas will continue to supply about 60% of world energy demand by 2020, which means an incremental 30+ million BOE/D of oil and gas production is required. And that does not include the new production that will be needed to offset the natural base decline. This is indeed a daunting task, and 15 years is a relatively short period given the long lead times for large projects in our business.

To achieve such growth will require the full commitment of resources (people, capital, and technology) and collaboration between all global energy players, including international oil companies (IOCs) and national oil companies (NOCs) and governments. From my perspective, I see four major challenges that the industry needs to address to meet future demand for oil and gas.

First, and perhaps most critical, is access to significant quantities of economically recoverable oil and gas resources. Other oil company CEOs have stated their belief that there are more than ample supplies of oil and gas globally to meet future demand. But more than 80% of the world’s oil and gas resources are in the hands of NOCs and host governments and are not currently available to IOCs. Some of these NOCs are moving forward to fully develop these resources and increase production. Saudi Aramco is the best example of this, but many other NOCs either are not doing so or are not doing so at sufficient levels. It is therefore critical that the IOCs be allowed to gain access to these resources as soon as possible and under reasonable fiscal terms so that they can apply their people, capital, and technology to the potential for increasing oil and gas production.

Recent high commodity prices have not helped; indeed, they have prompted increased resource and economic nationalism and fostered the emergence of aggressive new competitors. But IOCs and NOCs are simply going to have to find new, innovative, creative ways to work in partnerships that both increase value and meet the respective needs of both parties. Such partnerships would likely involve things such as

- Integration across the value chain (upstream, midstream, and downstream)
- Joint investments outside the host country
- Different commercial terms and risk sharing
- Greater shared control
- More intense technology transfer and development of the local workforce.

The second major challenge is the availability of and increased costs for services across the board, including seismic, drilling, facilities, engineering, procurement, and construction. This too is a function of higher commodity prices, which have driven industry activity to a point that exceeds the service industry’s capacity to respond.

Capacity is being increased in some areas, particularly drilling rigs, where new builds will be available for onshore areas over the next decades and for deep-water
areas starting about 5-7 years out. But building rigs and new equipment solves only part of the problem: trained, experienced people will be required to operate them, and this could be a limiting factor—all of which means that as we take on larger, more complex, longer-lead-time projects around the world, we are certain that our actual cost structure will be high, while we have no assurance of what oil and gas prices, our revenue stream, will be when these projects come on stream 5-10 years from now.

The third challenge is a continuing need for new, breakthrough technologies that can help find, develop, and/or produce more oil and gas. More than anything else, technology has been the driving force behind our industry’s continued ability to deliver increased oil and gas production safely, efficiently, and in an environmentally sound manner.

It really was not all that long ago that 600 ft. water depth was considered the operational and economic limit; that we did not believe we could ever record and image reliable seismic data below salt; or that shales, which we all learned in geology could only serve as source or seal rocks, could actually be prolific reservoirs if stimulated and completed properly. What concerns us is that we do not believe that our industry is devoting sufficient people and capital to developing innovative and breakthrough technologies. Comparative statistics bear this out. In 2004, the global oil and gas industry’s R&D was 0.3% of net sales vs. 16% for pharmaceuticals/biotech, 11.5% for software, and 7% for health. Informal analysis of the industry R&D, and from what we have been able to determine, a significant part (60 to 80%) of oil and gas R&D is focused on incremental advances (doing better what we do today) rather than new breakthrough or game-changing technologies.

Contrary to what the general public believes, our industry is fiercely competitive, and we all want to establish a technological competitive advantage, so there is not as much sharing or collaboration as there could be. We need collaborative partnerships, alliances, or joint ventures involving oil companies, service companies, governments, and academia, all pooling their knowledge to achieve breakthroughs in these targeted areas in far less time and at lower cost than if everyone goes about it alone.

The fourth and final challenge is that of having sufficient well-trained and capable technical people. Much has been said about this issue, and we all know how we got here, but the real question is: What do we do about it? Solving the people issue will require us to do things considerably differently from how they were done in the past.

Finally, we will need to continue to improve our business and technical processes to allow greater collaboration, teamwork, and knowledge transfer from a variety of remote locations. Higher productivity and greater time allotted to value-added work will need to be achieved.
These four challenges are critical to our industry, but they are also critical to our world. Economic growth and a reasonable standard of living are in large part dependent on access to ample supplies of affordable and reliable energy, of which oil and gas will continue to be major contributors.

Petroleum companies approach to improving the sustainability of its overall business portfolio considers:

• Improving the sustainability of existing operations
• Expanding beyond traditional hydrocarbon businesses
• Integrating sustainable development into core business strategy and continuously improving through stakeholder engagement
• Fostering innovation and technology to achieve sustainable growth

Another way of looking at this is that we are improving upon the things we already know how to do and exploring new ways to provide safe, environmentally sound and economical energy to a growing marketplace. The following are examples of the types of actions being taken that reflect the commitment toward a more sustainable business strategy. Some of these examples have already served to demonstrate the economic contribution of such a business strategy. Others have not matured such that profitability can be verified, but many companies like ConocoPhillips, ExxonMobil, BP are confident that they too will add to the value of the companies.

Good examples could be derived from Conoco cases below [1].

*Improving the sustainability of existing operations*

By looking at its existing operations in different ways, IOCs find sustainable growth opportunities that deliver economic, societal and environmental improvements.

**Norske Conoco Multi-Energy Joint Venture** – Conoco is participating in a joint industry project in Norway where methane produced in the giant offshore Heidrun oil and gas field feeds an onshore methanol plant located above the Arctic Circle. This methanol plant generates CO2 which is used in combination with solar energy to operate a greenhouse complex. “Waste” heat is used to accelerate the growth of commercially valuable fish in an aquaculture facility. The project provides local jobs, revenues, more efficient businesses and additional products for export and domestic consumption.

**Sulphur Recovery Project – Ponca City, Oklahoma** – Conoco and its joint venture partner, Jupiter Tessender/Kerley have initiated a sulphur recovery project that will increase the sulphur recovery capacity of the Ponca City refinery by 50% while reducing sulphur dioxide emissions. The project will significantly improve the refinery’s economics and create higher valued Jupiter sulphur products, furthering the by-product synergy advantage already present in the joint venture.
Double-hull Tankers – One hundred percent of Conoco’s fleet of tanker ships and barges are double hulled. This represents the completion of the company’s commitment made in 1990, and occurred 16 years before U.S. law will require double-hulled vessels in U.S. waters. The double-hulled vessels have already proved their worth in two separate incidents.

Expanding beyond traditional hydrocarbon businesses

The development of more sustainable energy sources will require new technology and innovation. Conoco is expanding beyond its traditional “oil and gas” business into other ventures which will contribute to increased sustainability.

Conoco Carbon Fibres – Conoco is a recognised leader in coke- and pitch-based carbon technologies. Conoco is constructing its first carbon fibre manufacturing facility in Ponca City, Oklahoma. Production is scheduled to begin by year-end 2001. Using a proprietary process, this carbon fibre will be made from “bottom of the barrel” pitch-based materials. This fibre will provide the raw material for stronger, lighter and more durable products. The sustainable aspects of such a product are numerous. Automobile brakes and car body panels that are stronger, lighter and longer lasting will reduce consumption of competitive resources such as steel and increase gas mileage efficiency. Concrete that is one third the thickness of conventional panels and longer lasting will reduce natural resource consumption. Applications for advanced electronics technology are expected. There are many other exciting possibilities for such a product to reduce the consumption rate of other natural resources. Conoco Carbon Fibres has conducted a product stewardship review and will continue to quantify the sustainable aspects of this lighter, stronger material.

Natural Gas Refining – Conoco is developing technology to enable natural gas to be economically converted into liquid fuels. There are literally trillions of cubic feet of natural gas that is “stranded” around the world because it cannot be economically transported to a market. Technology capable of converting this resource into such products as methanol and ultra-clean diesel will provide cleaner fuels that can displace less efficient, “dirtier” fuels in the transportation market.

The U.S. Department of Energy has selected Conoco’s work in converting stranded gas to ultra-clean fuels using its proprietary syngas technology to be part of an R&D funding effort to promote cleaner fuels. Part of this work involves performing a comprehensive life cycle analysis (LCA) to determine how the production and use of these cleaner fuels compares environmentally, socially and economically to conventional coal and heavy oil feedstocks. The LCA will inventory all emissions and wastes, assess potential impacts resulting from production through to consumption of this fuel and compare it with competitive products.

Conoco is hopeful that the production of the sulphur-free diesel will provide a cleaner alternative at an economical price. While not the “breakthrough” technology that certain factions seek in renewable energy sources, this product will provide a
practical, cleaner alternative in the near term. The concept of sustainability cannot ignore the fact that the global economy and energy base will depend upon fossil fuels into the foreseeable future. Conversion to renewable energy sources must inevitably occur over time. Meanwhile improvements in fossil fuel technology that are affordable and less polluting will help maintain the strong global economy necessary to provide the financial resources to fund research and development of renewable energy sources.

**Integrating sustainable development into core business strategy and continuously improving through stakeholder engagement**

By having sustainable growth as a mind-set and a way of doing business, opportunities to improve the sustainability of existing businesses and develop new sustainable businesses will emerge. Engagement of stakeholders in all phases of business development is a critical success factor in ensuring the long term success of business ventures.

Examples of how Conoco is achieving this integration are varied. Conoco is developing a “Sustainable Development Risk Assessment Tool” to assess the sustainability of new projects and challenge conventional thinking in favour of those designed for no environmental impact or positive net impacts.

We are improving upon our ability to collect, analyse and report accurate, objective environmental data, recognising this ability as a critical step in assuring continuous performance improvement. Ernst & Young, a global accounting and auditing firm, is conducting an independent evaluation of Conoco's worldwide data and data collection processes for future reporting of safety, health and environmental performance. Another leading environmental consulting firm has helped the company define the parameters of an “Environmental Footprint” that is being integrated into the annual long range planning process so that executive decision makers may more completely understand the environmental impacts of various business strategies.

A Search Conference on Sustainability was recently held with a broad and diverse cross-section of energised Conoco employees participating to explore what sustainability means for Conoco.

Learning from stakeholders helps Conoco understand and adapt to society’s changing needs. Citizen’s Advisory Councils (CACs) in communities where the company has significant operations provide a structured forum for regular interaction. Employee opinion surveys are another valuable tool for stakeholder input. Expanding stakeholder engagement is one of the ways Conoco intends to enhance transparency and accountability.

Conoco Indonesia has worked with the people of Matak Island to create a community development program that has evolved from a “charity approach” through a phase of social/public programs to build interpersonal relationships between the community and company personnel, to a strategic relationship of “social
empowerment”. This empowerment focuses on creating sustainable improvements in skills, resource utilisation and the quality of life in general.

A Conoco European Sustainable Development Team has existed since 1998 to search for business opportunities which demonstrate Conoco's leadership in reducing the impact of business on the environment and at the same time engage in business growth opportunities.

*Fostering innovation and technology to achieve sustainable growth.* The value of partnerships as a means to learn and discover new and innovative technologies and business approaches that will lead to further sustainable growth opportunities cannot be overemphasised.

By-product synergy is a concept whereby, “One company’s waste is another company’s raw material.” The aforementioned Conoco/Jupiter joint venture is a perfect example of realising this concept. The concept is a logical result of the practice of waste minimisation and the reduce – reuse - recycle efforts industry has been practicing for years.

Conoco is an equity owner of Applied Sustainability, a company with a mission to implement sustainable development projects among a variety of industries. Applied Sustainability helps companies discover ways, through by-product synergy, to send new savings and new revenue dollars to the bottom line while simultaneously eliminating waste, cutting pollution and reducing resource use. Conoco is also a sponsor of the Greater Houston By-Product Synergy Project, where companies from diverse industries explore the potential for profitable synergy projects in the Houston region.

Conoco works with St. Andrews University in Scotland to sponsor an annual St. Andrews Prize that recognises practical solutions to environmental problems from hundreds of essays submitted globally. We are also evaluating technologies to improve economics of offshore wind power and to convert waste lubes to diesel and biomass to fuels.

Conoco recognises the importance of maintaining a highly motivated workforce to achieve sustainable growth. Shortly after becoming Chairman and CEO of Conoco in 1995, Archie Dunham created Conoco University with the purpose of “creating a sustainable learning environment that is premier in the oil industry and beyond.” This “virtual” learning institution provides a means to help the company develop the leadership necessary to meet our business objectives and gives each and every employee the opportunity to grow within the organisation. The curriculum is organised under three themes: World Class Executive Development, concentrating on building a cadre of leaders who can envision and build a future that inspires everyone to excel; Shared Purpose and Direction, developing broad ownership for Conoco's overall vision, strategies, and business operations; and Fundamentals for the Future, providing developmental experiences to broad cross sections of employees in key
strategic areas where expertise is critical to our future. In addition to the strong reinforcement for Conoco’s core values already provided by Conoco University, there are abundant opportunities to utilise sustainable development concepts within the programs to focus current and future leaders on creating a future based upon sustainable growth.

**Longer Term Approaches**

The aforementioned questions posed to Conoco managers included a projection on how different they believed the energy industry would be in ten years. The answers trended toward “dramatically different”. This answer was based on a number of key trends seen as shaping the future. The focus on global climate change will continue to have a profound impact on how oil and gas companies do business in the future. Clean fuel technology and renewable energy sources will provide growing opportunity for competitive advantage for those companies prepared to create and capture the value for shareholders. Stakeholder expectations for sustainable performance and demand for increased transparency continues to rise as issues such as human rights, corporate social responsibility, changing roles of government and strengthening civil society become increasingly important to governments, locally affected parties and the investment community.

Conoco recognises there will be dramatic changes as the energy industry evolves. However, the company will in all probability remain primarily an oil and gas company for many years as our sustainable growth strategy evolves in the context of our business priorities. Our strategic planning process must stay in tune with the key trends and we must be prepared to take advantage of them. We must continue to ask, “are we doing the right things?” and not be content just with doing things “right”.

Stakeholder engagement is critical in understanding the key trends that will evolve over time, in understanding society’s response to the trends and in understanding society’s expectations for businesses that are viewed as socially responsible. We will build on work already in progress, as well as incorporating new stretch targets to identify sustainable growth opportunities that meet the “triple bottom line” test. We will then invite key stakeholder groups to help us assess any issues relative to these opportunities. This will chart the path for a series of specific strategic goals against which we will measure performance and report our progress.

Work in progress to lead Conoco further down the path of sustainable growth includes development of a corporate position statement on sustainable growth. To date, Conoco has purposely not adopted a formal policy statement. This may appear inconsistent with more traditional approaches taken by corporations when addressing important issues. For Conoco it made more sense to internally communicate the business case for the sustainable development concepts and understand its value throughout the organisation prior to publishing a policy statement that may not focus on the right business drivers. Once this understanding is internalised, a policy can be
developed that supports the integration of sustainable growth concepts into our management systems and decision-making processes and communicates them effectively to all stakeholders. This policy is a priority of the manager of sustainable development and is expected to be adopted in 2001.

**Conclusion**

Supported by a strong set of internal principles known as Conoco’s core values, the company has begun its journey toward sustainable growth in a world that has recognised the criticality of attaining the concepts of sustainable development. As part of an industry that derives value from primarily non-renewable resources, perhaps it is not surprising that our work is better described as a “purposeful journey” rather than a “non-stop jet flight” toward the destination. This is not to say that success in reaching the goal is not critical. Conoco and other leading energy companies well understand that their survival depends on it.

Conoco assumed leadership roles in regional and global sustainable development councils to accelerate the learning process on the concepts. Action steps were taken to build awareness about the business value of sustainable development among management and all employees. A manager-level position responsible for focusing the company on the opportunities for sustainable growth was created. As learning and enrolment continued, indicators that awareness of the value of our work began to rise at the business and project levels. By-product synergies, clean fuels projects, community action plans, “lighter/stronger” product technologies and efforts to better understand Conoco’s “environmental footprint”, are just a few examples of work that is aligned with sustainable development concepts.

This work has contributed to Conoco’s being recognised by external entities such as the Dow Jones Sustainability Group Index and Oekom Research AG as among the leaders in sustainability in our industry.

Conoco realises we are far from where we need to be and that we will be continuously learning and improving if we are to stay ahead in this rapidly evolving new era. In summary, we will continue to evolve our vision for sustainable growth as well as finalise corporate positions on sustainable development and social responsibility. Processes for increased stakeholder consultation and involvement will be developed and implemented. We will integrate sustainability into our management and business decision processes, measure and monitor performance and report openly to our stakeholders. We are committed to continuous improvement. This is Conoco’s roadmap to sustainable growth.
5.2.1. Monitoring non-technical accumulation of fluid in the cavity of the existing pipelines

Factors and causes of non-technical accumulation of fluid in the cavity of the existing gas pipelines. The impact of non-technical accumulation of fluid in the cavity of the existing gas pipelines in operational reliability of the gas transportation system.

One of the factors that reduces the efficiency of the GTS, despite the existing gas drainage systems, is the presence of moisture in transported product. Past studies [2, 3] indicate the following reasons of high gas humidity:

1) lack of quality of gas treatment in the fields;
2) incomplete removal of fluid after hydro test and back-log of work on dehydration on majority of facilities, reconstruction and full repair of pipelines;
3) operation of separation equipment in such modes that cannot cope with the separation of the liquid phase. This contributes to the fact that the separation equipment is operated with a capacity that significantly exceeds the nominal data on passport or parameters are incorrectly selected according pressure and temperature in the separator;
4) fluid ingress into the pipes cavities during accidents and construction;
5) conducting works on inner-pipe diagnosis and attributable to them change modes and gas flow rates;
6) presence of fluid that accumulates in the cavities of gas pipelines that do not have pigs for starting and receiving of cleaning devices, and its removal during the re-distribution of gas flows and related to these changes in modes of gas pipelines;
7) design features of structures with the presence of dead areas, closed volumes, "dead" cavities (cavity between the body and the gate valves, narrowing construction bridges between pipelines, etc.), which complicate the fluid removal from pipelines cavities;
8) failure of temperature control in pipeline route. In the system of production of gas and gas condensate into one pipeline multiple units of complex gas treatment (gas processing facility) can operate. Gas treatment at each of them is different, and therefore the hydrocarbon dew point and moisture in the gas that comes out of each gas processing facility, is different, the gas temperature may differ among them in a rather wide range. Mixing gas flows from each gas processing facility will lead to the fact that gas from one gas processing facility will degrade the gas dew point from another gas processing facility, accompanied by heavy hydrocarbons and fluids precipitation from the gas-liquid flow. On the other hand, the existing regulations set gas dew point at inlet pipeline below the temperature of the gas, but does not regulate its value. Reducing the gas temperature during transport below the dew point will promote condensation of liquid from the gas stream;
9) gas pipelines operation with low flow rate. The decrease of gas flow rate at the pipeline site is a result of it. According to the gas pipelines operation experience, by maintaining the pumping speed more than 12-15 m/s there is no substantial liquid sludge and the process of gas pipeline self-purification occurs, and while decreasing of speed to 5.11 m/s there is aperiodic wave fluid flow, accompanied by its dumping from the bend, and when the flow deceleration is below 5 m/s there is a process of gradual accumulation of fluid contamination.

Availability of fluid accumulation sites in the pipeline cavity to a certain extent is identified by revealed ascending differences of input and output pressures. Location of liquid accumulations is determined by means of pipeline route diagram in areas of pipeline route profile degradation. In areas with the greatest risk of fluid accumulation valves are tie-ins at the bottom point of the pipe for pipeline drainage (Fig. 5.16).

In the 80-90s of the last century a lot of attention was paid to the two-phase flow study, gas and fluid flow model in pipes were developed, new ways to determine the amount of fluid in the pipeline cavity and how to extract it from the pipeline by creating a pulsed mode of working gas stream (so called "method of high-speed gas flow") were developed, the device for fluid drainage was upgraded. At this time abroad, much attention was paid to the pipeline inner cavity purification using the method of transmission the cleaning devices of different designs, and to the adjusts calculation techniques of pipelines hydraulic condition.

![Fig. 5.16. Valve tie-in into the pipeline for fluid drainage](image)

However, the ability of fluid migration in the pipeline cavity (so called moving "slugs"), makes it impossible to determine accurately the location and accumulation of fluid level. Given the terrain complexity of pipelines laying, especially in mountainous areas, the need for large amounts of excavation and containers transport for collecting fluid from the pipeline, such errors in determining the fluid locations in the pipeline lead to considerable expenses, reduce GTS productivity as a whole, increase the risk of failures or accidents. In this case the emergency is cut off by line valves, followed by a release of gas and liquid into the atmosphere through gas vents, gas equipment or at least by pipes cutting (Fig. 5.17). This method is used as a...
desperate measure, since it leads to a significant loss of gas and harm the environment.

Analysis of fluid accumulation locations and fluid level in the pipeline cavity showed that currently there are no devices or systems that have made it possible to solve the problem according to the requirements.

![Image](image1.jpg)

Fig. 5.17. Emergency popping of gas and fluid from the pipeline cavity in case of gas supply intermittence, caused by large fluid accumulation

Analysis of fluid accumulation locations and fluid level in the pipeline cavity showed that currently there are no devices or systems that have made it possible to solve the problem according to the requirements.

**Development of the system for non-technical fluid accumulation monitoring in the existing pipeline cavity**

One of the solutions for the foregoing problem may be widespread adoption of pipeline state monitoring, which is implemented by periodically measuring the level of non-technical fluid and determining the volume of fluid in its cavity using a specialised system.

Taking into consideration the operating conditions of the gas transportation system and safety requirements, such system of non-technical fluid measuring in the pipeline cavity must meet the following requirements:

- provide the opportunity of liquid level measurement without interference into the pipeline operation and pumping regimes abuse;
- any action when installing, debugging and operation should not lead to discontinuity walls of the pipeline or of any kind of defects;
- high precision measurement, all-season system, ease of operation;
- low cost of installation, configuration and operation.

To solve the above listed problems and taking into account the general requirements, the professionals of non-destructive testing and technical diagnostics of oil and gas industry facilities laboratory at Ivano-Frankivsk National Technical University of Oil and Gas developed a system for measuring the non-technical fluid level in the pipeline cavities. Fluid level determination is held in the field without interference in the pipeline [4]. The system consists of a network of test points (TP) installed in places where there is a risk of fluid accumulation in the pipeline and a portable control device. Fluid level determination is based on acoustic echo-pulse method of products thickness determining. Control process is in successively
measuring the fluid level in the pipeline by connecting the control device to each test point. Fig. 5.18 shows the implementation of a system for non-technical fluid measuring in gas pipeline cavity based on test point.

According to this functional chart (Fig. 5.18a) of the system for non-technical fluid measuring in gas pipeline cavity, it consists of the acoustic unit 1, which is attached to the bottom of the pipeline 2 and measuring unit 3 (a portable control unit). Cable of acoustic block 4, which connects acoustic block 1 with the ground part is installed in the column of test point 5 and is connected to the measuring unit 3 with a measuring block cable 6 by means of the connector 7, which is mounted in the wall column of test point 5. It is suggested to select modern electrochemical protection columns (Fig. 5.19) of domestic production as a basis for test points.

![Functional chart of the system](image1)

![Piezo electric ultrasonic transducer structure](image2)

![Acoustic block structure](image3)

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**Fig.5.18.** Implementation of a system for non-technical fluid measuring in gas pipeline cavity based on test point: a) measuring system functional chart; b) piezo electric ultrasonic transducer structure; c) acoustic block structure;

**Fig.5.19.** Construction of test points for non-technical fluid measuring in gas pipeline cavity based on modern electrochemical protection columns
This column is made of durable plastic resistant to the environment impact and is equipped with "vandal-proof" device to prevent unauthorised removal test point from the ground. Test point column can be simultaneously used as an information and warning sign (to indicate safety zone and an underground gas pipeline route) and as test point electrochemical protection.

The basis for the proposed measurement system is an acoustic unit. Schematic structure of the acoustic unit is shown in Fig. 5.18, b. The piezoelectric ultrasonic transducer 8 is concentrically placed in a cylindrical body neck 9 and spring-pressed with the spring 10. Equipped with sealing rubber cuff collar 11. With collar 12 it is implemented a secure mounting of the body 9 to the wall 13 of the pipeline 2 (Fig. 5.18, a) protected with insulation 14. Temperature sensor 15, such as a thermocouple, is located in the body 9 near ultrasonic piezoelectric transducer 8 and contacts the outer surface of the pipe wall 13 of the pipeline. Two connecting wires 16 of ultrasonic piezoelectric transducer 8 and conductors 17 of temperature sensor 15 converge in the acoustic block cable 4. Sealing of the hole in the bogey 9 for acoustic block cable take-off 4 is maintained by using the rubber gasket 18 and choke valve 19. The rubber gasket 20 is located between the choke valve 18 and body 9, provides a reliable seal of the acoustic block.

At the same time measuring block conducts fluid temperature measuring in the pipeline by means of a temperature sensor placed in the acoustic unit.

The fluid level in the pipeline will be equal to half of the multiplied dependency ratio of ultrasonic waves velocity propagation in the fluid on its temperature, fluid temperature, ultrasonic waves velocity propagation in the fluid under normal conditions and time T, that is equal the time of ultrasonic waves transmitting from the piezoelectric transducer to the fluid-gas interface and reverse, and is measured by measuring block after creating a ultrasonic waves reflection dynamics envelope curve from the media interfaces (Fig. 5.18, c).

Dependence ratio of ultrasonic wave’s velocity propagation in the fluid on fluid temperature and ultrasonic wave’s velocity propagation values in the fluid at normal conditions are elected from data of reference [5].

For the purpose of testing the proposed methodology for determining the volume of non-process fluid in the cavity of the pipeline, there have been conducted experimental researches at the pipeline site "Pasichna-Tysmenysia" (525 mm diameter) of Bogorodchany LDGTPA at the most critical site concerning the non-process fluids accumulation in the pipeline cavity (Fig. 5.20).
The study found that the fluid level in the pipeline cavity is 206 mm, which covers almost the half-section of the pipe, and for pipeline process parameters according to Fig.5.20 ($\alpha=5^\circ$, $\beta=30^\circ$, $d_{\text{wit}}=525$ мм) the calculated fluid volume was according to the given dependence (3.25) was 87 l. The next release of fluid through the drainage device, mounted at the research site showed, that the non-process fluid volume was estimated with a precision of 10 %. Such accuracy in non-process fluid volume determination is sufficient for operational decision-making concerning fluid timely release from the pipeline cavity in prescribed order for preventing emergency situations.

5.2.2 The organisation of training of gas transmission companies to find the origins and definitions of natural gas on the basis of best international practices

The curriculum of training the gas transportation company determine the direction of gas leaks from pipelines and gas equipment

Financial, social, political and legal consequences of accidents in the gas industry necessitate their prediction and prevention. According to existing rules and regulations on pipelines service, a range of periodic work is assumed: gas pressure control and odourisation, check of moisture and condensation availability and their further disposal, the annual valves and joints maintenance, pipelines monitoring by pipeline routes skipping, inspection by means of test equipment, current and capital repairs. According to the same existing rules and regulations underground pipelines routes skipping must be carried out by linear inspectors of linear operational service. Regulations define in detail a procedure for routes order dividing, tasks execution as rout chart, types of works in progress, inspector team lists, but the existing methods of leakages tracing and control of underground engineering facilities for gas presence have are serious gaps. As well, modern specialised publications - books, manuals, textbooks gas facilities [6] do not provide methodological aspects for the procedures of gas leakages tracing. The vast amount of such literature merely reflects existing regulations and user specifications for some of gas leakages tracing means.
Consequently, all actions of operational services mostly are reduced to visual inspection of the equipment and pipeline states for external characteristics and detection of gas leakages tracing.

Methods of gas leakages tracing from underground pipelines and gas equipment should clearly define the required operation sequence and carrying conditions, requirements for test equipment.

At the same time the world and domestic practice had a significant amount of hardware tools and technologies for leakages tracing and losses assessment at different technological cycle stages of extraction and transportation of natural gas to consumers [7].

All of the above mentioned require organisation and conducting of the permanent specialised both theoretical and practical training of personal that according to their regular duties would be involved in gas pipelines and equipment inspection for gas leakages tracing.

Due to the specific problems such gas transmission company personal training gas transmission company would be most effective on the base of independent special training centre. In Ukraine, according to the authors, the most appropriate way is the creation of the training centre for gas leakages tracing in pipelines and gas equipment in Ivano-Frankivsk National Technical University of Oil and Gas. Various positive statements support this proposal:

- the only one in Ukraine higher education institution that prepares specialists for all areas of the oil and gas industry;
- from 2001 the university established and operates Personnel certification authorities (PCA) of oil and gas industry, which was examined and registered with the Derzhstandart of Ukraine;
- the university has experienced practicing teachers, recognised leading experts in the field of pipelines transportation;
- from 2004 the university has successfully operating International simulation drilling centre (This precedent shows that the university is able to carry out postgraduate training of personnel in the oil and gas industry according to international standards).

According to the set problem, university experts developed personal training education program for gas transportation companies specific for gas leakages tracing in gas pipelines and equipment, which is designed for 50 academic hours, the content of the program is shown in Table 5.10 [8]. The program is in accordance with requests and requirements of the gas industry of Ukraine and international experience, including methodology "Leak detection and repair at the stages of natural gas production, processing, transportation, storage and distribution and at the refining facilities", approved by the United Nations Committee on Climate Change.
Table 5.10: Scope of education program for gas transportation company personal training for gas leakages tracing in gas pipelines and equipment

<table>
<thead>
<tr>
<th>#</th>
<th>Study topic</th>
<th>Materials, subject of the study</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gas parameters measuring</td>
<td>Metrology. Gas measurement. The main parameters of gas: pressure, temperature, volume, density, concentration, calorific value.</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Fuel gases and their characteristics</td>
<td>Natural gas composition. Standards for gas fuel. Natural gas characteristics.</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Gas losses structure during gas pipeline transportation</td>
<td>Basic definitions related to gas losses (failure, leakages, impermeability, degradation, defect, overflow). Balance losses and gas discharge (imbalance). Technical gas losses. Loss of (technological) gas in the event of failures and damage of the equipment (facilities), accidents. Causes of gas leakage (breaking at weld, pipe corrosion, mechanical damage, flanges leakiness). Calculation of technical losses due to gas equipment leakage.</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Methods classification for gas leakages detection in gas pipelines and equipment</td>
<td>Qualitative and quantitative methods of gas leakage detection. Main stages of gas leakage detection (establishing the fact of gas leakages, determination of gas leakage causes, verification operations processing for gas leakage detection). Gas pipelines tracing and visual inspection of gas leakage symptoms. The use of sniffer dogs for gas leakage detection. Drilling in the approximate locations of gas leakages.</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Classification and use of test equipment and accessories for gas leakages qualitative measurement</td>
<td>Principal physics, operating principle, characteristics and application of: flame ionization, absorption, infrared gas analysers and detectors; laser and radio wave gas detectors; ultrasound detectors of gas leakages; special thermal imaging cameras for gas leakages monitoring. Gas leakages detection technology using test equipment. Normative regulation.</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Classification and use of test equipment for gas leakages qualitative measurement</td>
<td>Gas leakages type classification and their volume ranges (micro leakages, mini leakages, small leakages, medium leakages, large leakages, vast leakages, near miss incident leakages). Basic equipment for gas leakages detection (rubber and plastic measuring chambers, anemometers, rotameters, pressure-gauge tubes, gas meters, samplers, gas analysers). Technology for gas leakages volume measuring and calculation. Normative regulation.</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Gas pipeline technical screening</td>
<td>Main indicators that determine pipeline technical condition. Complex of works on pipeline technical condition inspection (pipeline tracing, insulation coating check-up, protective current density value determination, pipe meta status control defined-ment value of protective current density, control of the state of the pipe metal). Normative regulation.</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Gas leakages detection in ground gas pipelines and equipment</td>
<td>Leaks detection at welded and flanged joints of ground gas pipeline. Leaks detection at ground gas equipment and gas valves, located in gas sumps. To solve this task the following technical equipment is used: laser gas detectors and specialised infra-red cameras (long-range aids), gas detectors</td>
<td>6</td>
</tr>
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</table>
and gas analysers, ultra-sound gas leakages detectors (short-range aids).

<table>
<thead>
<tr>
<th></th>
<th>Ground gas pipeline surface control</th>
<th>Steel and polyethylene underground gas pipeline tracing from the ground; underground steel gas pipeline occurrence depth determination from the ground; failures determination of steel gas pipeline insulation coating; measuring complex running for corrosion state and underground steel gas pipeline insulation coating assessment. For solving this task the following technical equipment is used: pipeline finders, metal detectors, georadar, insulation coating failures detectors, specialised monitoring voltmeter</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>Gas leakages volume measuring and calculation</td>
<td>Preparation and management of measurements at the elements of ground and certain areas of underground gas pipeline and at gas fittings. Leakages volume classification. Selection of appropriate method for gas leakage volume assessment.</td>
</tr>
<tr>
<td>11</td>
<td>Total:</td>
<td>50</td>
</tr>
</tbody>
</table>

**Example of the design and construction of the test site for practical training and qualification of gas transportation company personal, specific in gas leakages detection in gas pipelines and equipment**

The training base for practical training in natural gas leakage and losses detection in gas pipelines and equipment was organised on the base of IFNTUNG within the framework of the Training and scientific centre «Energy-effective technologies in oil and gas transportation and storage systems» activities and implementation of energy-effective technologies at existing energy-intensive oil and gas facilities.

The given training base consists of two training-test sites – for underground pipelines technical diagnostics (phase 1) and natural gas leakage and losses detection in gas pipelines and equipment (phase 2). For training and scientific test sites construction the adjacent area to the Department of technical diagnostics and monitoring, in the courtyard between academic buildings #5 and #9, was selected, hereby the only complex of specialised practical training on the base of the university was created. The geographical lock-on to the locality is given in Fig. 5.21.

**Phase 1 training test site** is designed for situation modelling concerning underground gas pipelines state inspection from the ground (identification of route, occurrence depth, insulation coating state, protection level and cathodic protection system functional efficiency, prohibited tie-in presence) and gas leakages detection in underground polyethylene gas pipelines.

The courtyard territory around the test site is also congested with undergrounds utilities – three high voltage cable lines with applied voltage of 10 kV, heating line with thermal camera, sewage collector. Hereby, the organised test site fully simulates the congested arrangement of different underground utilities in urbane conditions.
Phase 1 test site area is 63 m², the following facilities are located on this territory: research areas simulating underground steel (diameter 56 mm) and polyethylene (diameter 40 mm) pipeline and cable line (4 × 6 mm²) with appropriate damages the protective insulation, and 6 test post and ground grids.

![Image](image1)

**Fig. 5.21.** IFNTUOG training base geographical lock-on to the locality: a) training and scientific test site for underground pipelines technical diagnostics (phase 1); b) training and scientific test site for leakages and losses detection in gas pipelines and equipment (phase 2)

Phase 1 test site chart is given in Fig. 5.22. The test site construction process and its view from the eland surface are given in Fig. 5.23 and 5.24. Test post #1 is of standard CP post PVEK.305431.005.

![Image](image2)

**Fig. 5.22.** Phase 1 test site chart: 1-metal pipeline; 2-test post (TP); 3-plastic pipeline; 4-connecting plastic coupling; 5-plastic T-branch; 6-plastic plug (plastic pipeline onshore landfall (POL); 7-plastic tie-in simulation; 8-cable line; 9-adjacent metal pipeline simulation; 10-control ground conductor; 11-anodic ground connection.
Connections of metal pipeline, control ground conductor, cable line and signalling conductor of plastic pipeline are brought to the special-purpose connection box on the body of TP1 (Fig. 5.25).

Test posts #2 and #6 are made according to in-house design in the form of plastic post with fixed hermetically sealed connection box on the top of the post. TP2 and TP6 connections are given in Fig.5.26.
Between TP2 and TP6 at metal pipeline insulation coating the artificial damages of two types are applied: «end-to-end» in case of direct interaction of pipe wall with ground electrolyte and «delaminating» in case of no direct interaction, but significant corrosion defects can occur under insulation coating. Insulation coating damages of «blue» and «white» strand are performed between TP4 and TP5. Non-insulated pipe segments are installed for simulation of crossing and associated occurrence of underground utilities with metal pipeline. Plastic tie-in connection to the metal pipeline is simulated near TP4. The simulating situation is given in Fig. 5.27.

![Simulating situations at training test site (phase 1) for underground pipelines technical diagnostics: a) «end-to-end» insulation coating damage of metal pipeline; b) insulation coating damage of metal pipeline in case if «delaminating»; c) insulation coating damage of cable line; d) crossing and associated occurrence of metal pipeline with utilities; d) «tie-in» at plastic pipeline.](image)

For approval of phase 1 training test site after its construction, the studies were performed using the equipment that would be used for personal training. Correspondingly the operations were conducted for processing the technology of underground gas pipelines simulators detection and inspection from the surface. For
such purpose the line finder measuring complex RIDGID was facilitated. The operations were conducted on detecting the route with special labelling, occurrence depth and insulation coating depth of underground gas pipeline simulator (Fig. 5.28).

Underground metal gas pipeline insulation coating state control on the territory of phase 1 training test site was conducted by means of magneto-electric amplitude-difference method. At each test point (at a peach of 0,5 m) the amplitude difference of the current signal applied to the pipeline was measured. Processing the technology of underground gas pipeline insulation coating state control at different current signal frequencies. Research results are given in Fig.5.29. According to the correlations obtained, taking into consideration the control procedure [8], the insulation coating damages at the sites “13 m” and “14,5 m” are much in evidence.

Defects location clearly fits the occasion of artificially created metal pipeline insulation coating defects (underground gas pipeline simulator) Fig.5.26. According to the research results, the underground pipeline route is clearly detected (Fig. 5.27c) with an accuracy of ±0,05 m

In order for practical gas pipeline technical state control training from the ground surface, practical trainings with students within the contests of the disciplines “Oil and gas support system technical diagnostics” and “Technical diagnostics methods and techniques” are given at the phase 1 training test site (Fig. 5.29).

To solve the problems of underground gas leakages simulation the underground plastic pipeline (made of polyethylene gas pipe) simulating the gas pipeline, is used at the training test site. Surface connection with the plastic pipeline cavity is realised by means of outlets, closed with leak-proof plugs (Fig. 5.30).

For gas pipeline damages simulation and correspondingly for underground gas leakages simulation in the underground location of plastic pipeline, the well-distributes end-to-end orifices are made.
Fig. 5.29. Attenuation curves of input current signal at the research site of underground pipeline:
a) a) – 1 kHz; b) – 33 kHz; c) – 512 Hz; d) – 982 Hz

Fig. 5.30. Practical training processing according to the gas pipeline technical state inspection from the ground surface at the territory of phase 1 training test site during practicums with IFNTUOG students

Fig. 5.31. Plastic pipeline outlets, closed with leak-proof plugs

Underground leakage simulation system realises a gas injector input into plastic gas pipeline cavity through its surface outlets. There are such 4 outlets for the test site pipeline, correspondingly 2 direct outlets and 2 pipe bends (Fig. 5.32).
Gas injector peculiarity is in its both sides sealing with rubber seals that allows simulation of gas leakage at clearly marked site on the plastic pipeline route, not permitting gas overflow within the total pipeline cavity, significantly decreasing the gas losses. Gas feeding from the gas losses and pressure disposition terminal towards the gas injector and its further pushing through the plastic gas pipeline cavity is realised by using flexible pipe, made of stainless steel. Gas vessels, equipped with reduction valve for pressure and losses setting, are used as a natural gas source.

Phase 2 training test site allows in-situ approval conducting of measuring equipment and techniques for gas leakages location and volume detection [9]. Besides, the test site will be used for practical training and further certification of gas transportation companies personal specific in gas leakages detection in gas pipelines and equipment and for IFNTUOG students training according to special areas of practice. The given test site allows leakages simulation in the range from 0.004 m³/h (micro leakages) to 10 m³/h (large leakages).

Underground gas pipeline network is simulated by means of two metal pipe strings and one plastic pipe string.

By means of shutoff valves (ball valves) the pipelines are brought together into one operating medium feed point. The operating medium (natural gas, artificial gas mixture, air) are injected with pressure up to 0.05 MPa through the diaphragm gas meter for losses detection (low-pressure gas network is simulated). Under a pressure from 0.05 to 0.5 MPa (medium-pressure gas network is simulated) the operating medium is injected round about the fixed gas meter through the shutoff valves and flow choke. Appropriately, for pressure capturing in gas network while various operating modes simulation the manometers with pressure measuring range 0.06 and 0.6 MPa are used. For controlled underground leakages simulation the magneto-electrical valves with appropriate devices for leakage simulation (diffusers with orifices of different diameter) were used. The relevant supervision is remotely controlled by means of ground surface control cabinet. By turning on various electro valves the gas leakage simulation can be managed, providing various flow rate and various sites of leakage on the test site. Electro valve power supply is provided by using portable storage battery.

The basic structural elements and construction stages of training test site for natural gas leakages and losses detection in gas pipelines and equipment are
presented in Fig. 5.33. Taking into consideration the peculiarities of constructed test site and its location on the territory of IFNTUNG (asphalt-concrete surface and the possibility of gas flow to the academic body of the University), the decision was taken regarding the placement of test site equipment in a specialised building envelope with overall dimensions of $6 \, \text{m} \times 12 \, \text{m}$, which is made of sheet metal.

The constructed building envelope (Fig. 5.34) provides for the installation of the necessary gas equipment in its cavity, then the cavity is filled with sand and grassed soil bedding, for simulation of gas equipment underground environment. For the safety giving of practical trainings, this building envelope is fitted with safety rails and steps.

![Fig. 5.33. The basic structural elements and construction stages of training test site: a) test site metal and polyethylene pipelines for gas networks simulation; b) manometer for low pressure gas networks simulation modes; c) gas magneto-electrical valves with simulation tools of underground leakage; d) gas electric valves control cabinet; e) assembly of test site structural elements and pneumatic leak testing](image)

![Fig. 5.33.](image)
5.2.3 Analysis of methods and technical control means of natural gas quality

A topical question under the conditions of constant rise of prices for gas and its consumption volumes is the issue of natural gas amount and quality. And if the issues of gas amount determination were being given a proper place, then issues of natural gas quality determination and its determination procedure are of current concern and [10].

According to the ISO 15112:2001 natural gas calorific value (NGCV) can be determined by means of facilities containing sample system and measuring device that belongs to one of the groups:
- direct measurements (e.i. using calorimeter);
- indirect measurements (e.i. using gas chromatograph);
- correlation methods

Analysis of methods will be focused on these groups of NGCV determination.

Theoretical research of new method for natural gas quality control

Determination of NGCV by means of calculation method requires taking measurements for determination of many components of the gas mixture: hydrocarbons (methane, ethane, propane, butane, etc.), oxygen, carbon dioxide,
nitrogen and other inert gases, mercaptans, etc. Therefore, it is necessary to find the optimum amount of natural gas indicators, by having determined which, it will be possible to evaluate natural gas quality. The research idea, described in this chapter is shown in fig. 5.36.

According to Fig. 5.36, natural gas calorific value is determined by positive influence of hydrocarbon components (those, releasing heat during flaring) and by negative influence of components, releasing no heat during flaring or prohibit flaring of hydrocarbons. In order to determine characteristics, that are strongly related to the content determination of gas hydrocarbon components, it is necessary to carry out the correlation analysis of normative physical and chemical characteristics of natural gas. The basic non-hydrocarbon components contain carbon dioxide and nitrogen, and content of other components can be neglected. It is known, that nitrogen in gas state is no noble chemical component, therefore does not react with other components. Though, there are problems with facilities selection for monitoring of this factor in operating conditions, it is necessary to conduct research on reducing the number of control informative parameters.

The first phase of research provided analysis of basic physical and chemical parameters of natural gas, regulated by existing normative documents in Ukraine, concerning identification of relationships between them by means of correlation and statistical methods. In particular, the existence and character of relationships between the following parameters were determined: hydrocarbon components content (methane, ethane, propane, butane and higher hydrocarbons), density, molar mass, sound velocity, nitrogen content, carbon dioxide content) as well as gas calorific value, as it was pointed before, that is one of the basic parameters of natural gas quality.
For clarification of optimal number of natural gas informative parameters, the base was used, containing more than 95 samples of natural gas mixtures. The base was arranged by South-West Research Institute, USA, and is the collection of natural gas mixtures, which value of physical and chemical parameters were obtained using chromatographic method [11].

However, taking into account the nonlinearity of NGCV relationships with selected parameters, it is ensure their integrated use in the NGCV calculation. For solving of this task it is necessary to solve the problem of nonlinear approximation of NDCV as a function of several parameters, in particular the most appropriate way is to apply artificial neural network (ANN). To validate the proposed approach of determining the natural gas qualitative parameters, the simulation of determining the NGCV, using artificial neuron network (ANN), which was trained by means of input parameters. ANN was selected because of its’ ability to nonlinear multi-parameter approximation of calorific value as a function of sound velocity in gas, contents of nitrogen and carbon dioxide. The input parameters for network were obtained from modifies base (with data of 95 natural gas samples), the parameter values of which were received by using chromatographic method.

Simulation using ANN involves in general the carrying out the sequence of the following steps:

Determination of input and output parameters. The output parameter for ANN was natural gas calorific value, and the input parameters were the above pointed characteristics: sound velocity in gas, contents of nitrogen and carbon dioxide.

Data collection. This phase, the base of natural gas mixtures, used for setting up of correlation coefficients, was divided into two parts – training (practice) and test. For artificial neuron network training 87 samples of natural gas qualitative parameters were selected, and for ANN testing – 8 (10% of a training collection). Model training involves the selection of architecture, training algorithm and network parameters. ANN architecture – is a number of layers and neurons in them, as weak as the type of conversion function in neurons. It has to be noted, that, architecture selection for each specific case is individual, depending on the degree of task complexity, present calculation possibilities and researcher’s experience. As the base the neuro network architecture was selected, the chart of which is described in Fig. 5.27. As training the algorithm of back propagation of Levenberg-Markwardt error, that is recommended for such cases, when the network and the number of training pairs in the collection are small (below thousand).

Analysis and data pre-processing. Before artificial neuron network training all input data were normalised by dividing them into the difference between maximum and minimal values.

Neuron network training. Neuron network training was organised by means of input data, which did not contain 8 test samples.
Testing of trained network. It should be noted that according to general practice, testing of neural networks is performed by using data, not used during training (unknown for neural network) – hereby the objective evidence on network ability to the approximation of necessary function is provided. While testing phase 8 test parameters’ combinations were given to the input. Three input parameters (sound velocity in gas, contents of nitrogen and carbon dioxide) were given for testing from one output parameter was received – natural gas calorific value. The results of ANN testing are given in Table 5.11.

According to Table 4.6, the actual calorific values correspond to the values, received by means of ANN with high accuracy. The given error normalised to the range in this case is equal to 11 % that allows to make a conclusion of positive testing results and to move to the next research phase.

\[ IW\{1,1\} \text{ – weight coefficients of neurons’ first layer – matrix } 10 \times 3; \ b\{1\} \text{ – first layer’s delay – matrix } 10 \times 1; \ LW\{2,1\} \text{ – weight coefficients of neurons’ second layer – matrix } 1 \times 10; \ b\{2\} \text{ – second layer’s delay – matrix } 1 \times 1. \]

Fig.5.37. Neuron network structure

Table 5.11: Testing results of artificial neuron network

<table>
<thead>
<tr>
<th>№</th>
<th>Actual calorific value, MJ/m³</th>
<th>Calorific value with ANN, MJ/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42,399</td>
<td>42,403</td>
</tr>
<tr>
<td>2</td>
<td>42,395</td>
<td>42,395</td>
</tr>
<tr>
<td>3</td>
<td>38,229</td>
<td>38,233</td>
</tr>
<tr>
<td>4</td>
<td>38,233</td>
<td>38,214</td>
</tr>
<tr>
<td>5</td>
<td>38,266</td>
<td>38,262</td>
</tr>
<tr>
<td>6</td>
<td>41,854</td>
<td>41,862</td>
</tr>
<tr>
<td>7</td>
<td>41,851</td>
<td>41,858</td>
</tr>
</tbody>
</table>

Thus, the results obtained by using artificial neuron network confirms the results of correlation analysis – the natural gas calorific value can be obtained by determining the sound velocity in natural gas and taking into consideration of harmful components (nitrogen and carbon dioxide).

As a result, the possibility of applying of particular physical and chemical parameters of natural gas (sound velocity in gas, contents of nitrogen and carbon
dioxide), regulated by current normative documents as informative for NGCV determination.

Thus, the new method of NDCV control was developed, that is about simultaneous measurement of sound velocity in natural gas and determination of nitrogen and carbon dioxide contents, further measurements results ‘processing in special artificial neuron network, allowing to determine NGCV with satisfactory fidelity.

**Industrial testing of experimental unit and technique development for natural gas calorific value determination in the industrial environment**

To ensure the practical application of the research results the draw of SUC «Natural combustion gas. calorific value express-control. Methodology» was developed. This normative document is harmonised with international standard ISO 15112 that specified the application of techniques that fall into the correlation category, along with application of traditional techniques (direct measurements – by using calorimetric instrumentation, indirect measurements – by using gas chromatographic instrumentation).

The noted draw contains the recommended practice and description of the algorithm for performing of measurements and calculations by developed experimental unit for NGCV determination. The SUC draw also contains practical guidelines concerning the implementing the proposed method in the Ukrainian industry. The results of natural gas calorific value express-control in combination with the flaw measurements can be used to determine natural gas energy according to the requirements of ISO 15112:2001. In case of NDCV over range above (31,8-38,5) MJ/m³, it is reasonably to conduct chromatographic analysis of gas samples in the laboratory.

Thus, the experimental unit advantage is in the following: natural gas energy can be calculated in real-time conditions without samples pre-carriage to the laboratory. The results of proposed SCU draw application can be used by companies, specialised in distribution and sales of natural gas, for the purpose of financial settlements with consumers.

**Industrial testing of express-control method**

The next phase of testing the industrial application possibility for the proposed method was in its testing in OJSC «Ivano-Frankivskgaz» (Fig. 5.38). While testing 20 samples were collected from the gas distribution stations and units of Ivano-Frankivsk and Ivano-Frankivsk region (Horodenka GDS, Kolomya GDS, Broshniv GDS, Uhryniv GDS – 16 objects at all). From there, collection of samples was performance almost at all Ivano-Frankivsk regions from various natural gas pipelines.

Technology for industrial testing of experimental unit for NDCV determination was the same as for the experimental validation of the method. Two gas samples were collected simultaneously. One natural gas sample was analysed by chromatograph
Crystall-2000M (ind. num. 721753). The gas compositional analysis and NDCV were determined. The determination of gas calorific value by using second gas sample was performed at experimental unit (Fig. 5.39). The research results were compared, and documented in a special industrial testing report industrial testing.

Fig.5.38. Collection of natural gas samples in OJSC «Ivano-Frankivskgaz» environment

Fig.5.39. Experimental unit for determination of natural gas calorific value: 1 – gas treating block; 2 – block for determination of sound velocity in gas; 3 – sensor of CO2 concentration in natural gas; 4 – gas analyser; 5 – manometer; 6 – thermometer-hydrometer; 7 – ultrasound flaw detector; 8 - sampler

To provide the accuracy of measurement performance the gas samples temperature must be constant – within (18±1) °C. The natural gas pressure was also stabilised during measurement of parameters of sound velocity and carbon dioxide content in gas, the values of which were about (2,2±0,2) kPa. In order to determine the humidity influence on the sound velocity values, the change of the last parameter from the value of relative humidity in the range of 5 %. Significant influence of humidity on the value of sound velocity in gas was not observed.
According to the developed technique of experimental research using the experimental unit, the measurements of carbon dioxide content in natural gas and ultrasound velocity in it were performed. The results on determining basic parameters of natural gas, necessary for further research, are given in Table 4.14. During research the lower gas calorific value was determined, as far as inter-state standard GOST 5542 specified the requirements to this value, not to the higher calorific value.

Fig. 5.40 shows the connection of measured values of carbon dioxide by experimental unit with the actual values of carbon dioxide (measured by chromatograph «Crystall-2000M») it is in ear connection and correlation coefficient of carbon dioxide measured and actual value is 0.998.

Table 5.12 and Fig. 5.40 show that it is necessary to improve the method for CO2 determining as there are difficulties in determining this parameter within the range from 0% to 0.25%.

The accuracy of determining the sound velocity in gas by means of experimental unit is checked by the program FLOWSOLV™- AGA10 Gas Speed of Sound Calculation Input, that allows calculating the sound velocity in gas based on natural gas chromatographic data and implements the method, approved by the American gas association [13]. The test results of the accuracy in determining sound velocity in gas are shown in Fig. 4.41. According to the Fig. 4.41 the values of the measures sound velocity in natural gas are equal to the value, calculated by means of the program FLOWSOLV™- AGA10 Gas Speed of Sound Calculation Input. The correlation coefficient between these two values is 0.98.

The research results allowed setting the presence and the relationships between natural gas calorific value and sound velocity in gas (Fig. 5.40)

<table>
<thead>
<tr>
<th>Lower gas calorific value, according to chromatograph, MJ/m³</th>
<th>Carbon dioxide content, determined by chromatograph, %</th>
<th>Carbon dioxide content, determined by experiment, %</th>
<th>Sound velocity in gas, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.95</td>
<td>0.748</td>
<td>0.85</td>
<td>420.8269</td>
</tr>
<tr>
<td>33.70</td>
<td>0.072</td>
<td>0</td>
<td>437.2918</td>
</tr>
<tr>
<td>34.29</td>
<td>0.732</td>
<td>0.79</td>
<td>425.7564</td>
</tr>
<tr>
<td>33.91</td>
<td>0.532</td>
<td>0.6</td>
<td>427.3900</td>
</tr>
<tr>
<td>34.76</td>
<td>0.616</td>
<td>0.69</td>
<td>423.7630</td>
</tr>
<tr>
<td>33.98</td>
<td>1.345</td>
<td>1.59</td>
<td>424.6738</td>
</tr>
<tr>
<td>33.92</td>
<td>0.53</td>
<td>0.56</td>
<td>430.7159</td>
</tr>
<tr>
<td>33.92</td>
<td>0.538</td>
<td>0.59</td>
<td>430.2920</td>
</tr>
<tr>
<td>33.99</td>
<td>1.565</td>
<td>1.86</td>
<td>424.7973</td>
</tr>
<tr>
<td>10</td>
<td>0.071</td>
<td>0</td>
<td>437.1080</td>
</tr>
<tr>
<td>11</td>
<td>1.332</td>
<td>1.57</td>
<td>425.5931</td>
</tr>
<tr>
<td>12</td>
<td>0.173</td>
<td>0</td>
<td>424.9928</td>
</tr>
<tr>
<td>13</td>
<td>0.409</td>
<td>0.44</td>
<td>419.6791</td>
</tr>
<tr>
<td>14</td>
<td>0.985</td>
<td>1.13</td>
<td>428.0924</td>
</tr>
<tr>
<td>15</td>
<td>0.404</td>
<td>0.43</td>
<td>431.3390</td>
</tr>
<tr>
<td>16</td>
<td>0.089</td>
<td>0</td>
<td>436.9938</td>
</tr>
<tr>
<td>17</td>
<td>0.07</td>
<td>0</td>
<td>437.3565</td>
</tr>
<tr>
<td>18</td>
<td>0.526</td>
<td>0.56</td>
<td>424.2429</td>
</tr>
<tr>
<td>19</td>
<td>0.489</td>
<td>0.53</td>
<td>424.8192</td>
</tr>
<tr>
<td>20</td>
<td>0.976</td>
<td>1.05</td>
<td>427.5515</td>
</tr>
</tbody>
</table>
Fig. 5.40. The dependence of the measured values of carbon dioxide from the actual values

![Graph of carbon dioxide content comparison](image)

Fig. 5.41. The dependence of the measured sound velocity in gas from the calculated ones by AGA 10

![Graph of sound velocity comparison](image)

The dependence in Fig. 5.42 is nonlinear inversely proportional, the correlation coefficient is -0.82. Theoretically calculated value of the coefficient is -0.63, which indicates compliance of theoretical experimental results. In order to determine NGCV, gas samples are divided into two parts (17 samples and 3 samples. The software was set up by means of the results of 17 gas samples study that provide the determination of gas calorific value. Testing of the developed technique for determination of calorific value was done, using the results of the other 3 gas samples. The calorific value calculation results according to the proposed method in comparison with the results obtained by chromatographic analysis are shown in Table. 5.13.
The error normalised to the range, in determining lower natural gas calorific value is equal 1.6% (absolute error is equal to 0.033 MJ/m³). Unresolved question at this stage is still a matter of getting the NGCV dependence from the complex of parameters set in the analytical, tabular or graphical form.

Table 5.13: Industrial testing results

<table>
<thead>
<tr>
<th>Sample number (according to the protocol)</th>
<th>Lower calorific value (according to the protocol), MJ/m³</th>
<th>Carbon dioxide content (according to the protocol), %</th>
<th>Lower calorific value (experimental unit results), MJ/m³</th>
<th>Carbon dioxide content (experimental unit results), %</th>
<th>Ultrasound velocity (experimental unit results), m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (T1)</td>
<td>34.29</td>
<td>0.732</td>
<td>34.31</td>
<td>0.79</td>
<td>425.76</td>
</tr>
<tr>
<td>2 (T1)</td>
<td>33.98</td>
<td>0.985</td>
<td>33.92</td>
<td>1.13</td>
<td>428.09</td>
</tr>
<tr>
<td>3 (T6)</td>
<td>34.54</td>
<td>0.489</td>
<td>34.52</td>
<td>0.53</td>
<td>424.82</td>
</tr>
</tbody>
</table>

However, it is known that the trained neural network in a hidden form contains the desired relationship. Record of this dependence is analytically possible, but it will be cumbersome and matrix entry form, which significantly complicate its analysis. Therefore, it was built a graphical representation of the so-called "surface solution" that was generated by the network during its training and shows the desired relationship. The analysis of such images is easy. The essence of this presentation is the modelling of neural networks by artificially generated input parameters. Parameters are generated with a certain constant step within the range of valid values of the relevant parameter. Fig. 5.43 shows such surface for the neural network, which was used to verify the proposed method.

Thus, we obtained a graphical representation of NGCV from the sound velocity and the content of carbon dioxide in natural gas. By analysing the image (Fig. 5.43), we can assert that the trends observed in the analysis are repeated - NGCV depends on the sound velocity non-linearly and inversely, and the content of carbon dioxide – the dependence is essentially nonlinear and has a different nature, in particular:
- in the range from 0% to 0.5% - the dependence to a greater extent is directly proportional;
- in the range from 0.5% to 5% - the dependence is inversely proportional (confirmed by theoretical studies).

The complex nature of the decision surface indicates the nonlinearity of the relationship between inputs and NGCV, which confirms the results of the correlation analysis. Also, it should be noted that the complexity of the received decision surface confirms the usefulness of neural networks application for solving nonlinear multi parameter approximation problem.

The advantage of this method is the speed of NGCV determining. The time for analysing one natural gas sample by modern chromatograph is about 20 minutes and by using experimental unit - up to five minutes, which is a significant advantage, especially since the experimental unit can be used in the field conditions.

The disadvantage of the experimental unit is the absence of an automated process for NGCV calculating. The specialised software was developed in accordance with the calculation algorithm to solve this problem.

Consequently, the proposed method and experimental unit, which realise it, can determine NGCV in express mode and with good accuracy (5%) by measuring the sound velocity and carbon dioxide content in natural gas. These provisions are entirely consistent with theoretical results obtained by the authors earlier [14].

**Device for natural gas calorific value determination**

Continuing the started work on the technical implementation of the proposed device a portable device for natural gas calorific value determination was developed.

The device was designed to determine the natural gas calorific value, both for enterprises and in the field conditions. As informative parameters for determining the natural gas calorific value the information on the ultrasound velocity propagation, and the carbon dioxide concentration, temperature, pressure and humidity in the selected gas sample, which is processed using artificial neural networks, are used. For these parameters, the device is used.
The device was designed for operating in the conditions UKP 3.1 to +35 °C, relative humidity less than 95%, and IR 40 according to GOST 14254-96. Conventional product designation - GAZ-01.

The basic specifications and characteristics of the device are shown in Table 5.14.

Table 5.14: Specification of the device GAZ-01

<table>
<thead>
<tr>
<th>Parameter title</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Natural gas calorific value limits, kcal:</td>
<td></td>
</tr>
<tr>
<td>Low limit, not less</td>
<td>7 950,0</td>
</tr>
<tr>
<td>High limit, not less</td>
<td>8 550,0</td>
</tr>
<tr>
<td>2 Relative permissible error in determining natural gas calorific value, %, not more</td>
<td>5</td>
</tr>
<tr>
<td>3 Operation mode setup time, min, not more</td>
<td>10</td>
</tr>
<tr>
<td>4 Continuous operation time, h, not less</td>
<td>8</td>
</tr>
<tr>
<td>5 Device power supply:</td>
<td></td>
</tr>
<tr>
<td>Built battery</td>
<td></td>
</tr>
<tr>
<td>- voltage, V,</td>
<td>12</td>
</tr>
<tr>
<td>- capacity, A/h, not more</td>
<td>7</td>
</tr>
<tr>
<td>6 Power consumption, Wt, not more</td>
<td>10</td>
</tr>
<tr>
<td>7 Overall dimensions, mm, not more</td>
<td>300x260x130</td>
</tr>
<tr>
<td>8 Weight, kg, not more</td>
<td>15</td>
</tr>
</tbody>
</table>

The manufactured device, implementing the proposed technology, passed many comparative field studies, which confirmed its main advantages:
- No need in gas burning or in chemical analysis
- Operation speed - up to 1 minute to perform measurements
- Accuracy - relative error of 5% compared with the chromatography results
- Easy to use.

The general view of the device shown in Fig.5.44.
The draws of Guidelines for maintenance as well as programs and techniques of device certification are developed.

References to Chapter 5
8. http://cdm.unfccc.int/filestorage/L/V/8/LV8NU1GYWT0K6COJPD1XQ35FR2MA47/EB63_repan14_AM0023_ver04.0.0.pdf?t=NDF8bjNrcXR1fDD5u0kG1yhCJCD0PjS17ToNC
5.3. Home charging of electric vehicles: how your car differs from your smartphone
B. Rotthier, J. Cappelle

5.3.1. Introduction
This chapter provides information on some important aspects of the home charging of electric vehicles. It will guide you through the various possibilities and limitations of home charging. Most of this information is valid in all countries involved in the HETES-project (Belgium, Spain, Sweden, United Kingdom and Ukraine), some described aspects are specific for Belgium.

This chapter is the result of the research project THEO (Home charging of electric vehicles), whereby the Flemish government, in collaboration with various universities and companies, informed the professional Flemish electrician about the home charging of electric vehicles. The project took place in collaboration with the Flemish Living Lab Electric Vehicles, focusing on public charging.

Should you still have questions after carefully reading through the document, please feel free to contact the project staff by mailing at info@evladen.be.

5.3.2. Electric cars?

Electric vehicles are slowly gaining ground in Europe. They offer an interesting alternative for conventional cars. Serious advantages are the absence of local emissions and a quiet engine (Do not vroom, just hum!). For security reasons, some electric cars even have a built-in alarm system, triggering a warning sound to alert other road users at slow speeds. At higher speeds, the noise produced by the tires, takes over this task. Electric vehicles possess an innate potential for saving energy. The car can be refueled at home or at work, with green energy using your own CHP or PV system.

Frequently mentioned disadvantages of electric cars are the limited driving range and the higher purchase price. The driving range (the distance that can be driven without recharging the battery) of the average electric car currently varies between 100 and 500 kilometers. The driving range highly depends on a variety of factors such as driving style, average speed, air conditioning, lights, etc. Therefore, the standardized operating range as specified by the manufacturer, is rarely achieved in practice.

Electric vehicles do indeed have a higher purchase price compared to conventional vehicles, but compensate (at least partially) for this drawback by the lower cost of maintenance and the cheaper "refueling".

Finally, it should be mentioned that driving an electric vehicle is really nice and comfortable owing to its instantly available high torque and the absence of serious engine vibrations!
Full electric cars only have an electric motor and a battery pack. Besides pure electric vehicles, hybrid electric vehicles exist. In addition to the electric motor, they are equipped with a classic combustion engine, which takes over when the battery pack is exhausted or when the power demand surpasses that of the electric motor. Examples of these hybrid vehicles are the Toyota Prius, Opel Ampera, Chevrolet Volt, Fisker Karma, Mitsubishi Outlander, BMW i8,…

5.3.3. Charging of electric cars

In recent years, various actors have been working to the set-up of a network of public charging points. A comprehensible overview of the Belgian network is available on the website of ASBE: www.asbe.be/nl/laadpunten.

Despite their growing number, public charging points and the "the rather limited public charging facilities" remain a frequently heard negative factor for purchasing an electric car. However, for everyday trips, electric vehicles can be charged simply and inexpensively at home or at work. For longer distances, there may be a need for additional charging on the road, in which case public charging points can be accessed.

Unlike conventional vehicles, where refueling only takes place when the petrol or diesel tank is empty, electric vehicles should be recharged at every stop. It requires a small change in behavior to efficiently use the time the electric car stands still at home or at work. During these periods batteries can be easily charged, either by plugging into the electrical grid (using the cheap night tariff) or by one’s own green electricity, generated at home.

In essence, a properly secured sufficient household outlet near the parking location (e.g. in the garage or on the driveway) suffices to recharge at reduced speed. Several manufacturers also offer home charging infrastructure, whereby safe charging can take place, at a faster charging speed and in a more intelligent way.

This chapter, presents the typical terminology, technology and various points to be taken into account when charging electric cars:

- Different charging modes
- Common connectors and adapters
- Mode 3 charging protocol
- Charging and degradation of Li-ion batteries
- Installation of a mode 3 charging point
- A charging problem of some electric cars at 3x230V grids

*The major difference between the charging of a mobile phone battery and that of an electric car is the amount of energy that needs to be transported. To transfer these large and prolonged electric currents, special connectors and various charging modes have been elaborated.*
5.3.4. Charging modes

The simplest charging method is the one whereby the car is plugged in with the household plug we know from electrical appliances. Unlike a mobile phone or a laptop, the rectifier is on board the vehicle. This method of charging is called Mode 1 charging. It is of utmost importance for the electric vehicle that the used circuit is well secured. In Mode 1 charging, this is not necessarily the case. Mode 1 charging is, consequently, no longer used for electric cars. In some countries (e.g. US, Israel and Canada) Mode 1 charging is even prohibited by law.

![Fig.5.45 Mode 2 charging](image1)

If charging takes place by using a household socket outlet, Mode 2 charging offers the solution. In Mode 2 charging, also a standard household outlet is used, but there is an In Cable Control Box (ICCB) incorporated in the charging cable. The ICCB accommodates a Residual Current Device (RCD) and a current limitation. Provided a good grounding is available, this always ensures a good protection of the downstream system (charging cable and electric car) when charging. Since in Mode 2 charging household sockets are used, it is important to limit the charging current. Household electrical outlets are not designed to be loaded regularly for a long time with a high current. Through a regular long-term load with a high current, the jacks can degrade in the socket, leading to a dangerous heating of the socket.

Research of KUL and VUB, in collaboration with NIKO, on a significant part of the available products in the market, has shown that the charging current for Mode 2 charging is best limited to 10A. With such a charging rate, per hour enough energy will be transferred to the electric car to drive approximately 10 km.

![Fig.5.46 Mode 3 charging](image2)
To safely charge at higher charging speeds, i.e. in order to charge the vehicle more quickly, a Mode 3 charging protocol has been developed. It uses sockets and plugs that are specially designed for the charging of electric vehicles. The socket is built into a charging point that is an integral part of the electric installation. In Mode 3 charging, there is a continuous communication between the charging point and the electric car, leading to a safe charging process. By using mode 3 charging, an average electric car can be easily charged 60% faster because of the possible higher currents, and because more than one phase can be used. For the 2013 Nissan Leaf model, for example, Nissan says that charging a battery, Mode 2, takes 10 hours, compared with an average of 4 hours for Mode 3. Another advantage of Mode 3 charging is that some Mode 3 charging points can be configured in such a way, that the charging only starts at night. In this way, the car can always be charged with cheaper electricity.

When purchasing an electric car, it is recommended to install a Mode 3 charging point at home, when possible. For some types of electric cars, the home charger comes as a standard feature, for others it may mean an additional investment. Mode 3 charging points are available in all colors and sizes.

![Mode 3 home charging systems](image)

Some electric vehicles can use Mode 4 charging, so-called quick charging. For AC charging (mode 1, 2 and 3), the rectifier is placed in the car while converting the AC voltage from the grid to DC voltage for the car battery. For Mode 4 charging, the rectifier is placed in the charging station (hence outside the car), making this an expensive system, prone to vandalism. The high cost and high charging power make this system unsuitable for home charging.

![Mode 4 charging](image)
Fast charging does not damage the battery pack up to a charging rate at which the charging capacity is 1.5 to 2 times the energy content of the battery pack. Thus a car with a battery pack of 24 kWh, can be charged with a power up to 36 to 48 kW. Charging at higher power can affect battery lifetime. The above values are typical values for the large group of Li-ion batteries. For information about a particular car always consult the information from the car manufacturer.

**In Summary**: the home charging of electric vehicles can be done through mode 2 or mode 3 charging. Mode 2 charging is done via a charging cable with an In Cable Control Box. For mode 3 charging a home charging station has to be installed. Mode 3 charging is preferred because of the higher charging speed and the higher flexibility.

### 5.3.5. Charging cable

When charging an electric vehicle, a charging cable is used. The cable has a plug and a connector; the plug is placed in the socket, the connector, in the vehicle.

![Charging cable terminology](image)

In Mode 2 charging, a connector is used, which has been specifically designed for the charging of electric vehicles. A type 1 or type 2 connector (see below) connects the car with the charging cable. The charging cable is connected to the electrical grid with a conventional household plug. The In Cable Control Box is encased in the charging cable.

In Mode 3 charging, also a type 1 or type 2 connector is used. Unlike for Mode 2 charging, in Mode 3 specially designed plugs are used for the connection to the electrical grid. These plugs are suitable to regularly conduct sustained high currents. Therefore, electric cars can be charged faster by using mode 3 charging.

There exists two types of connectors; these are dependent on the type of car:
5.3.5.1. Type 1: SAE J1722

This is the original Japanese and North American standard for the charging of electric vehicles. With this type of connector it is only possible to charge vehicles single phase.

While compiling this brochure (autumn 2014), vehicles of the following brands possessed a type 1 connector: Chevrolet, Citroen, Fisker, Ford, Mia, Mitsubishi, Nissan, Opel, Peugeot, Renault (Renault Fluence and Kangoo, NOT Renault Zoé), Toyota,...

5.3.5.2. Type 2: VDE-AR-E 2623-2-2

This is the original European standard for the charging of electric vehicles. With this type of connector, it is possible to charge vehicles in both single-phase and three-phase mode.

While compiling this chapter, vehicles of the following brands possessed a type 2 connector: Audi, BMW, Porsche, Renault Zoé, Smart, Tesla Model S, Volkswagen, Volvo V60 PHEV,...

Previously, there were also two different types of plugs to connect the charging cable to the charging point: the type 2 and type 3 plug connector of the EV Plug Alliance. The latter was especially used in France and Italy. In early 2013, European policy makers decided that the type 2 plug would become the standard in Europe.
In Summary: In Belgium, a mode 3 charging cable must have a type 2 plug (at the charging station’s side) and a type 1 or type 2 connector (side car). The type of connector is dependent on the purchased vehicle. A mode 2 charging cable has a standard household plug at the grid side and a type 1 or 2 connector on the car.

5.3.6. Charging process

In a type 2 plug, two additional pilot contacts have been foreseen: the PP contact (Proximity Pilot) and the CP contact (Control Pilot). Through this pilots, information is exchanged between the charging point, and the charging cable and the electric car respectively.
Between the PP contact and the protective earth conductor (PE), a resistor is placed in the plug of the charger cable. The value of this resistance encodes the maximum current that may flow through the cable. Via the CP the charging station communicates with the car itself. In the charging station, a certain voltage is placed between the CP and the PE. In the car are two resistors that communicate whether the vehicle is ready or not ready to be charged. If the car is ready to be charged, these two resistors will be placed in parallel. As a result, the total resistance value will decrease and the current through the CP-conductor will increase.

On the basis of the signals from the PP and the CP, the charging point determines whether the electric car is ready to be charged and what the maximum current is that may flow through the charging cable. On the charging point itself, the maximum permissible current of the present grid and the charging point itself is set. The charging station selects the lowest (restrictive) current value and passes it through a PWM signal to the electric car. When the charging point signals the car that the charging may start and communicates the maximum charging current, the outlet of the charging point comes under tension. As long as the charging point has not given the signal for charging, the outlet will remain without tension.

The current communicated through the charging point, is called: the maximum charging current. The battery charger in the vehicle can autonomously determine with which current the battery pack will effectively be recharged, taking into account the imposed maximum value.

When charging via charging mode 2, i.e. using the In the Cable Control Box, the ICCB provides communication with the car. In other words, the car itself, so to speak, does not distinguish between mode 2 and mode 3, apart from the lower maximum charging current.

5.3.7. Charging processes and Li-ion battery degradation

Most modern electric cars have a type of lithium-ion battery.

The charging process of these batteries can be explained simply by saying that to fully charge them, the battery passes through two phases. First of all, the battery is charged with a constant current. In this phase, the charging current is at its highest and therefore charges the battery at its fastest. From the moment the battery reaches a certain voltage, it is transferred to the next stage in the charging process. Here, a constant voltage is applied to the battery and the charging current will systematically decrease.

Generally speaking, the transition between these two phases of the charging process takes place when the battery is charged 80% of its total capacity. Up to 80%, the battery will be recharged at the maximum available speed. When this threshold is reached, the charging speed is being reduced. Thus, fast charging only takes place during the first part of the charging process.
Fast charging, does not damage the battery pack to a charging rate at which the charging power comprises (in kW) 1.5 to 2 times the energy content of the battery pack (in kWh) (rule of thumb). However, it is bad for the battery pack to fast-charge only. It is important to regularly go through the constant voltage phase of the charging process. It is in this part of the charging process that the battery cells are mutually balanced.

During storage, Li-ion batteries are best not fully charged. With an unused fully charged battery, the degradation (the irreversible reduction of the maximum capacity) will be at its highest level. Ideally the battery is kept in a cool environment charged between 25% and 50%.

Fig.5.54 Charging process of Li-ion batteries

5.3.8. Installation of mode 3 charging points in Belgium

Electric charging points in Belgium have to be single phase connected to a separate electrical circuit, protected by a suitable residual current device and circuit breaker.

Some electric cars (such as the Renault Zoé and the Tesla Model S) could charge faster if fed by three phases. For three-phase charging points the manufacturer usually requires a type B residual current device, which can also detect DC faults. However, the General Rules and Regulations for Electrical Installations (AREI) in Belgium, stipulates that for domestic installations only, residual current devices of type A may be used.

For this reason, it is recommended, and often also required, to connect home charging points single phase. If one has a three-phase mains, it is advised to already install a three-phase 6 mm² cable to be able to switch easily when regulations change.

In most other European countries (France, Spain, Portugal, Britain, Germany,…) it is legally allowed to install an RCD type B or B+.
Since the installation of this additional circuit implies an expansion and/or extension of the electrical installation, this should happen after a new inspection by an authorized body. The expansion of the electrical installation must take place in compliance with AREI stipulations. When introducing the installation mentioned it is important for safety’s sake to take into account the following issues:

- The earth resistance of the grounding must be less than 30 ohms.
- Protective conductor and equipotential connections must be carried out conformity.
- Your electric switchboard should have a main residual current device of at least 40A, with a sensitivity of up to 300mA. This residual current device is of type A and sealed.
- The internal cables and busbars in your switchboard must be appropriately sized.
- The electrical installation has to be finger safe. There should be no approachable parts.
- An electric single line diagram and situation schedule of this extension (from the counter to the device) is to be submitted.
- The cable to the mode 3 charging point is secured with appropriate fasteners.

5.3.9. Charging problem of some electric cars at 3x230V grids

Currently only 3x400V+N networks are installed by the distribution network operators in Belgium. But in some places, especially in big cities, also the 3x230V grid is still in use. Approximately 20-30% of the Flemish and Brussels domestic installations are connected to a 3x230V grid. For systems connected to a 3x230V network, problems can occur when charging some types of electric cars. To determine what type of network you are connected to, you can contact your distribution network operator (Eandis or Infrax).

For a 3x400V+N grid, consumers are always connected between the neutral and a line conductor. Consequently, there is always a jack of which the tension between the jack and the earth is approximately equal to 0V. For a 3x230V grid,
consumers are connected between two line wires, so there is not always such a jack present. Because such 3x230V networks are not standard in the rest of Europe and America, the situation in which no jack on earth potential is present, is experienced “faulty” by some electric cars, so they will not charge.

This charging problem can be solved by installing an isolation transformer. After an isolation transformer, a new grid is started, wherein a jack is at earth potential. On some cars, this solution (purchase and installation of isolation transformer) is already included in the purchase price.

To determine whether this situation will occur when home charging your desired car, you should contact your distribution network operator and your car dealer.
Literature to Chapter 1


5.4 PROFIenergy: a PROFINET energy saving profile for the manufacturing industries
Philippe Saey, Stijn Noppe, Frederic Depuydt, Mathieu Troch, Thomas De Landtsheer, Hendrik Derre, Ward Hauspie

5.4.1 Introduction

Europe 2020\(^1\) is a strategy proposed by the European Commission in March 2010. One of its main targets is energy related: to reduce greenhouse gas emissions by at least 20% compared to 1990, to increase the share of renewable energy in final energy consumption to 20%, and to achieve a 20% increase in energy efficiency Figure 5.58. The energy-related targets most probably will be achieved, except for the efficiency increase and energy consumption decrease, as indicated in Figure 5.59.

![Energy-related targets of the EU 2020 strategy](image)

**Figure 5.58:** Energy-related targets of the EU 2020 strategy [1].

![Status of the energy saving targets in 2012](image)

**Figure 5.59:** Status of the energy saving targets in 2012 [1]. So far, the EU is not on track to meet its 20% energy saving target by 2020.

In order to comply with the “EU 2020” strategy, energy consumption needs to decrease even more, also in the manufacturing industries. PROFIenergy [2] has been

developed upon request of the German car manufacturing industries, to reduce energy consumption during production standstill (pauses, weekends, etc.). Indeed, during production – e.g. while waiting for a component to arrive –some devices could go into standby mode in order to save energy Figure 5.60.

A more comprehensive study on advanced standby strategies in automobile production can be found in [3].

The remaining part of this chapter describes the basic operating principle and typical scenarios, further specifies detailed operation and example measurements, and concludes with potential energy savings in an industrial case study.

5.4.2 How it works

5.4.2.1 Operating principle of PROFIenergy
The PROFIenergy profile enables sending PROFIenergy commands to multiple IO-devices in the PROFINET industrial ethernet. PROFIenergy can be entirely integrated in existing PROFINET configurations. By using acyclic communication, PROFIenergy commands do not interfere with the cyclic (fast, more deterministic) PROFINET IRT and RT communication (Figure 5.62); PROFIenergy commands are sent in the “standard” communication time frame. Commands can be programmed in the same IO-controllers that are already used to control the plant. Switching on and off is achieved within the IO-devices themselves, no additional switching hardware is required (Fig. 4).

The operating principle is quite simple. The IO-controller sends a command to the energy consuming device containing the duration of the offline state. The device then autonomously executes the corresponding commands in its energy profile (Fig. 6, 7 and 8).
In order to switch back to the normal operating mode, another message is sent over PROFINET. In fact, the user requires just two commands in its program. This way, control logic commands can stay separated from energy management commands. Integrating PROFIenergy commands does not enlarge the volume of user settings, no additional addresses are required in the process image. New commands can be used in existing program libraries and factory standards, without influencing them. Firmware updates can be used to add new functionality.

Since switching on and off is achieved in the IO-device itself, manufacturers can decide themselves on how to switch off certain devices. For example, the motor in a conveyor belt could ramp down instead of braking.
PROFIenergy consists of two control commands, ‘start_pause’ and ‘end_pause’. With the ‘start_pause’ command, the controller forces the device to a state of lower energy consumption. This command contains a $t_{Pause\_Time}$, the duration of the pause, which is a criterion to decide if the device switches to the PROFIenergy mode. If the pause duration is less than the minimal pause time, the device will not change its operating mode. If the pause duration is exceeded, the device will not automatically switch back to its ‘PE_ready_to_operate’ mode. If multiple PROFIenergy modes exist within the device, it will automatically select the optimal mode in which most energy can be saved in the available timespan.

5.4.2.2 Typical use cases

PROFIenergy is used for both planned as unplanned pauses or for the collection of energy consumption measurements\(^2\).

Short pauses usually last less than an hour and happen during the manufacturing process. This enables devices to transition to a standby mode or to be turned off, if the time in pause exceeds the time required to save energy. Some devices can’t be turned off for a set period of time and then be turned on again, as this would waste energy (e.g. thermal processes).

Longer pauses (hours to days) usually mean that most devices can be turned off, with the exception safety related equipment and continuous processes (e.g. blast furnaces, petroleum cracker, etc.). Unplanned pauses usually have a random duration, thus predicting the end of the pause can be quite tricky.

PROFIenergy can also be used for the collection of data\(^2\). In this way, it is possible to manage and visualize the energy consumption in real-time, and to analyze and track inefficient consumers.

5.4.2.3 Some advantages

PROFIenergy is an open standard that holds many advantages in different areas.

A lot of time can be saved during installation, because it’s a PROFINET profile, whereas older energy saving systems are usually client made and hardware based, complex and often patented.

With PROFIenergy, switching on and off is achieved within the IO-device itself. Due to intelligent switching methods, the devices’ life expectancy will rise and fewer breakdowns will occur (compared to external switching).

The return on investment is relatively high due to the large saving potential and low investment cost.

\(^2\) Either with dedicated energy logging tools (e.g. Sentron), or with built-in tools (e.g. drives).
Energy measurements can be communicated to the PLC, which in some cases allows reducing power peaks.

In general, most energy can be saved with the largest consumers. However, this doesn’t mean that focus should be solely on these. Smaller devices can also contribute to save energy, since many manufacturing plants typically apply a large number of “small” devices.

### 5.4.3 Measurements and analysis

#### 5.4.3.1 Measurements

An experimental test setup was made in the Laboratory of Automatic Control (KU Leuven Technology Campus Gent) during the HETES project, in order to measure and demonstrate the basic behavior of PROFlenergy. The setup can be seen in Figure 5.66, Figure 5.67 and Figure 5.68. In this application only the total current to the ET200SP remote IO Device (Siemens) was measured. The 24 V\textsubscript{dc} load consisted of relays switching LEDs and load resistors, as “visual demonstration”. Actual loads differ of course from application to application.
For the current measurements, a DPO 4054B oscilloscope and a TCP312A current probe from Tektronix\(^3\) were used.

The oscilloscope was set-up to trigger on a current falling edge to detect the start of the PROFIenergy command, showing the original current to the ET200SP in the pretrigger part, and the lower current when PROFIenergy is enabled. The original current was 544 mA, the current during standby mode 400 mA; only one input and one output module was disabled by the PROFIenergy command.

Paragraph 1.1.4 describes measurements on similar IO-Devices, but with actual industrial loads.

5.4.3.2 Analysis of the PROFIenergy UDP telegrams

In this paragraph, the communication between IO-Controller and distributed IO-Device for the start and end command of the PROFIenergy state is explained. An
overview of the typical messages exchanged between the IO-Controller and a distributed IO module is shown in Fig. 14.

To start and stop the PROFIenergy state, 8 UDP messages are sent, 4 sent by the controller and 4 by the distributed IO.

The IO-Controller initiates the sequence by sending the start command which is displayed below. This is a write command: PROFIenergy has to be started and the time it has to stay in this state of lower energy consumption is communicated.

Next, the IO-Controller will send a read request on which the slave answers with its actual values.

To end the PROFIenergy state, another write command is sent containing PROFIenergy information and the command to end the energy saving state.

Finally, the controller sends another read command in order to know if the device really left its energy saving state.
5.4.4 How PROFIenergy performs in industrial applications

5.4.4.1 Case study at Daimler and Volkswagen car manufacturing plants

Figure 5.73: Typical setup of power analysers during the measurement campaign in a car manufacturing plant [4].

Figure 5.74: Typical layout of measurement points during the measurement campaign [4].
PROFIBUS International in combination with the University of Cologne has conducted research to the energy saving potential of PROFIenergy. The goal of the measurement campaign was to actually measure cost benefits of the PROFIenergy protocol through energy savings and possible increase of life expectancy of the IO devices in the production line. The goals set were to:

- save and analyze load profiles in a typical manufacturing process
- analyze energy consumption of individual components
- locate large energy consumers
- check the effect on energy consumption during different action profiles
- search the minimal useful pause length for relevant energy savings.

These measurements, taken in Germany at the Daimler and Volkswagen factories [4], enabled analyzing the load, spread of load and typical types of pauses. With measurement equipment spread in the factory, different types of loads could be checked in different steps of the manufacturing process. Nominal, maximum and mean energy usage was measured for entire production cells, in different sections and for all devices within the production cell.

From these measurements, an overview of the large production pause times in the factory (weekend, lunch break, etc.), the duration of unplanned pauses (due to malfunctioning equipment, faults, etc.) and actual duration of maintenance pauses was acquired. Using this information, conclusions can be made about the energy saving potential of different kinds of pauses.

![Figure 5.75: Instantaneous power fluctuations during a 24 hour logging in a production cell [9].](image)

Over the course of 24 hours, a lot of peaks in the power consumption are observed (Fig. 18). Maximum load is about 80 kW while during standstill the power consumption is still about 17 kW. Figures 19 and 20 show Sankey diagrams of the (average) power used by the different production cell components during production resp. standstill. The robot is the largest consumer in the production cell; the robot requires 18.51 kW during production, and still uses 35% of that power (6.16 kW)
during standstill. The entire production cell uses 17.74 kW during standstill, and 32.62 kW during production.

5.4.4.2 Analysis of pauses

Pauses have different causes, such as lunch breaks, holidays, maintenance, breakdowns, shortage of material, etc. Since most breakdowns happen at startup of machinery, engineers are more prone to keeping their production lines fully operational, which clearly has a negative effect on energy consumption. An analysis of duration and energy saving potential is needed; Fig. 21 shows the distribution of pauses in the investigated production cells.

For the car manufacturing plants under investigation, pauses from 3-5 minutes and longer are found to be economically interesting for using PROFIenergy standby modes. Shorter pauses are not interesting, since starting and stopping the production line takes time and energy. The cumulative pause times are found in the graph of Fig. 22, showing that 64% of the total standstill time is economically interesting for PROFIenergy standby modes.
5.4.4.3 Potential energy and cost savings, and resulting CO₂ reduction

Based on the Klasen study [4] in a typical car manufacturing plant with a 2-shift operation, almost half of the energy is used during pauses. In these production lines, energy consumption during pauses is equal to about € 162 per week.

Figure 5.80: Energy consumption and costs in 1 week [4].
If we assume PROFIenergy to be able to take advantage of 70% of the pause time then savings up to 33% could be achieved. This means implementing PROFIenergy could save up to € 114 per week.

On a yearly basis, nearly € 6000 could be saved. An overview on yearly basis can be found in [10]. Finally, the resulting decrease in CO₂ emission is presented in Figure 5.82; CO₂ emission is estimated at 0.59 kg/kWh.

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<td>17 250</td>
<td>5 700</td>
<td>100 450</td>
<td>33 250</td>
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Table 5.15: Extrapolation of the measurement campaign to a yearly basis [10].
5.4.5 Bibliography


6. Sustainable development scenarios

6.1. Climate change mitigation scenarios

V. Shatokha

In this chapter the possible futures of the global steel industry are discussed in the context of the climate change mitigation scenarios. These scenarios aim to simulate the possible futures where the global warming might be limited by implementing certain technological, economic and social measures. Such methodological approach doesn’t aim to predict the future with a certain probability. Instead, these scenarios allow understanding of what humanity can do to ensure its own sustainable future. Typically, development of climate change mitigation scenarios is approached methodologically as follows:

1) based on the modelling of the effect of greenhouse gas concentrations in the atmosphere on the global warming some global target to limit the concentration of CO₂ in the atmosphere within a certain period of time is established;

2) based on the estimated needs of humanity in materials, food, energy, transport services possible share of a particular field of human activity in a future greenhouse gas emissions is determined and the sectoral targets are defined in order to achieve the global target;

3) feasibility of achieving the target, established for certain industry e.g. by deployment of various best available and/or radically innovative technologies as well as new materials is studied.

The development of scenarios, especially on a global scale is extremely difficult task due to the large number of factors and the interdisciplinary nature of information. In this chapter we examine several scenarios - primarily in order to demonstrate possible methodological approaches to this issue.

The first group of scenarios developed under the aegis of the International Energy Agency (IEA) [1] belongs series of publications World Energy Outlook [2], published periodically which is widely recognised as a source of information for global forecasting and analysis, and contains a large amount of data and advisory materials for the governments and businesses. From time to time new scenarios emerge, therefore, here we provide brief information about scenarios that are available at the time when this book is developed:

- **New Policies Scenario** - a scenario that takes into account the large number of political commitments announced by various countries, including national commitments to reduce greenhouse gases emissions and plans to stop subsidising fossil fuels in the field - even if the measures for implementation of these commitments yet to be determined. It is used as a baseline scenario by the IEA;
- **450 Scenario** - a scenario that models the energy consumption according to the task of limiting global temperature increase to 2 °C which corresponds to limiting the concentration of greenhouse gases in the atmosphere at 450 ppm equivalent of CO₂.

- **Efficient World Scenario** - scenario based on the assumption that existing proven technologies are implemented worldwide;

- **Deferred Investment Case** – scenario of the future investments that analyses how global markets will develop in the case if investments in energy production in the Middle East and North Africa over the next few years will be lower than envisaged in the New Policies Scenario;

- **Energy for All Case** - scenario that evaluates a required additional investment to provide access to modern forms of energy (e.g. electricity) worldwide by 2030;

- **Low Nuclear Case**: the scenario, studying the consequences for the global energy balance if, for whatever reasons, the part of nuclear energy will be much lower than predicted earlier in the World Energy Outlook 2011.

- **Current Policies Scenario** predicts events in the absence of changes in policy and legislation.

Another set of scenarios refers to Energy Technology Perspectives [3] (ETP) series published periodically by IEA and widely recognised as a source of information, especially about the opportunities of the modern and future technologies for achieving the objectives of reduction the consumption of energy and climate change mitigation.

Relevant to current publication are the following:

- **-6°C Scenario (6DS)** - foresees an extension of the current development trends. According to it, by 2050 the energy use will double (relatively to 2009), and the total GHG emissions will rise even higher. In the absence of efforts to stabilise the GHG content in the atmosphere the global temperature is expected increase at least by 6°C. This scenario is consistent with the Current Policy Scenario to 2035;

- **-4°C Scenario (4DS)** is a scenario that takes into account the recently adopted commitments by countries to reduce emissions and implement measures to improve energy efficiency. This scenario implies an increase of the temperature by 4 °C and is generally consistent with New Policies Scenario to 2035. To some extent it is an ambitious scenario and requires significant changes - both in international law on climate change, and the technologies used. Moreover, long-term limiting of temperature increase even by 4°C requires substantial emissions reductions after 2050;

- **-2°C Scenario (2DS)** is a subject of the focus of the Energy Technology Perspectives. It describes a sequence of changes in emissions that with the
reliability of the 80% will limit the temperature increase at the level of 2°C. The scenario sets the target to reduce CO₂ emissions, associated with energy production more than twice by 2050 (relative to 2009) and its further reduction after 2050. Importantly, the 2DS recognises that transformation of the energy sector is vital, but not sufficient: the goal can only be achieved if greenhouse gases emissions will be reduced in other areas. 2DS generally follows the 450 Scenario by 2035. Target of this scenario has been widely discussed and accepted as the global target of the Paris Agreement.

Some scenarios refer to figures that correspond to increasing of the temperature or concentration of the greenhouse gases. As shown in the Table 6.1 there is certain match between these variables. The data in table 6.1 by [4] does not fully correspond to the results of simulation within RCP scenarios, used in the assessment reports of IPCC (see Table 1.2, Chapter 1).

Table 6.1

<table>
<thead>
<tr>
<th>The temperature increase, (°C)</th>
<th>Change the concentration</th>
<th>Change of CO₂ emissions by 2050 (% relative to 2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All greenhouse gases (ppm CO₂ equivalent)</td>
<td>CO₂ (ppm)</td>
</tr>
<tr>
<td>2,0-2,4</td>
<td>445-490</td>
<td>350-400</td>
</tr>
<tr>
<td>2,4-2,8</td>
<td>490-535</td>
<td>400-440</td>
</tr>
<tr>
<td>2,8-3,2</td>
<td>535-590</td>
<td>440-485</td>
</tr>
<tr>
<td>3,2-4,0</td>
<td>590-710</td>
<td>485-570</td>
</tr>
<tr>
<td>4,0-4,9</td>
<td>710-885</td>
<td>570-660</td>
</tr>
<tr>
<td>4,9-6,1</td>
<td>885-1130</td>
<td>660-790</td>
</tr>
</tbody>
</table>

Despite the efforts of the UN and other international organisations and the successes of individual countries, the above and many other scenarios are rather ambitious wishes than real pathway. Moreover, as stated in the ETP 2010 [5], the world is moving in the opposite direction than required for sustainable development and in an accelerated pace. However, in our view, knowledge of the results of simulation under these scenarios is a necessary attribute of the modern engineer who should understand the role of new technologies in specific industrial sector and to support their development and implementation in the overall context of sustainable development. Below we reviewed the results of the simulation, with focus on the modernisation of iron and steel sector, based on to the IEA materials as well as some other publications.

6.2. Scenarios of futures for selected industries

6.2.1. Iron and steelmaking

V. Shatokha

Energy Technology Perspectives 2014 (ETP 2014) [6] uses a combination of forecast and backcasting analysis. Backcasting deals with developing possible ways for achieving a certain goal. This approach allows identifying of the major milestones
to be achieved and to determine the trends that should be corrected to achieve the intended result. The advantage of forecasting, in which the final state has to be estimated (not pre-determined), is a possibility to better understand the short-term restrictions that prevent movement in the right direction.

Typically, the modelling aims at the most cost-effective achievement of desirable results, although the result not always reflects the perfect cheapest option. Some factors are not subject to cost determination including political decisions, speed of technologies implementation and availability of funds for capital construction and acceptance of certain technologies by society. The cheapest solution is not always acceptable for customers. In general, long-term forecasting contains many uncertainties and cannot be very precise. Another problem is a difficulty to accurately take into account the costs of adaptation to climate change. ETP combines different models and involves a number of experts, so the analysis is sufficiently scientifically justified.

The 2°C Scenario (2DS) is not based on the deployment of radically innovative technologies. All technologies taken into consideration in ETP are either already commercialised or are at the final development stage, suggesting the possibility of their commercialisation by 2050. It is assumed that the cost of introduction of such technologies may reduce. The analysis takes into account only the ETP policy approaches in the field of climate that are either already implemented or announced.

In order to provide more reliable results, ETP analysis is based on a "portfolio", which includes a range of technologies. If some technology fails there is a chance to achieve the goal through the introduction of other technologies or the use of alternative fuels.

The future need in materials (including steel) is calculated based on the GDP of some countries and regions, income levels, volume production capacity, current consumption levels, historical trends on the intensity of demand, availability of resources and so on. Total production is modelled based on technologies, "age" of the structure of industrial enterprises and materials flow. Total production is the same in various scenarios of ETP, but the means of production are significantly different. For example, in the case of the steel industry, the level of steel production in scenarios 6DS and 2DS is the same, but 2DS is based on much extensive use of scrap. Models take into account differences in consumption patterns and levels of energy saving in various countries and regions. Forecast also involves change of this pattern due to the assumption of penetration of best available technologies (BAT) and restrictions caused by the availability of raw materials.

Owing to the not very reliable long-term forecasts of production volumes, ETP 2014 includes two options - high and low demand for steel. The world steel production forecasts are shown on Fig.6.1. Target values of CO₂ are taken the same for both options, given that the implementation of high demand option implies a
substantial reduction of specific emissions. Achieving the goals of 2DS for the industry will require a coordinated efforts of the international community to overcome many challenges, including the impact of the deteriorating quality of raw materials (ore and coal) on technology and energy efficiency, public perception and environmental implications of using recycled materials as fuel and deficit of scrap. In particular, the simulation results show that, to achieve the 2DS objectives, the global CO₂ emissions in the steel industry by 2050 shall be reduced by 28% (to 1.633 billion tons of CO₂ per year) while the production will increase by 51%. The result will mostly be achieved by reducing energy consumption, which should give reduction of the CO₂ by 42%. The greatest potential for global outcome would be the elimination of open-hearth furnaces in Ukraine and Russia, as well as improving of blast furnace in India, China and Ukraine. It is expected that in 2050, 40% of direct CO₂ emissions (or 812 million tonnes per year) will be captured using the CCS.

As it is seen from Fig.6.1, real production of steel in the world has been consistent with projection of high demand scenario, but in 2015 and 2016 it dropped even below low demand projection which may demonstrate deviation of global development from the model applied unforeseen in 2DS.

The structure of factors impacting achievement of the CO₂ emissions reduction in the iron and steel industry is shown in Fig. 6.2.
The relevance of 2DS short-term results is rather ambiguous: the current trends of the steel industry are completely opposite to results of forecast. From 2000 to 2011 the energy consumption in steel production increased by 6.2% - mainly due to the increase in output by 7.1%. However, the 2DS implies energy consumption growth from 2011 to 2025 by 1.2%, with projected production growth by 27%. Hence, 2DS implies a radical change of the existing trends in relationship between the growth of production and of energy consumption. Moreover, this change shall take place during the next ten years.

Analysis of current and longer-term trends observed in the past, shows that in the period from 1950 to 2000 the average indicator of specific energy consumption in steel production declined approximately by 60%, and its further reduction by using existing technologies has largely been exhausted [7]. Thus, in XXI century the world average energy efficiency stabilised - according to IEA, the energy consumption in 2011 was 20.7 GJ/t of steel (in 2013 according WorldSteel Association - about 20 GJ/t) versus 21.7 GJ/t steel in 2000. In fact the increased energy efficiency has been offset by decline of the share of steel produced from scrap worldwide from 47% in 2000 to 29% in 2011, which negatively affected the overall energy consumption. This happened mostly due to the fact that the steel production in China mainly developed by the BF-BOF route. In the short-term 2DS implies the increase in the share of electric arc furnaces in steel production to 37% in 2025. This part of the forecast also contradicts to what was actually observed over the last decade.

The 2DS is based on the assumption that all new and modernized enterprises will introduce BAT, open-hearth furnaces will be fully phased out and coal use in the DRI production will be limited. The technological part of ETP is based on the assumption of successful accomplishing of ULCOS and COURSE50 projects and the progress in the further development of technologies HIs melt and Finex. In particular, owing to the introduction of these technologies in the 2025 the average level of specific energy consumption should be reduced to 18.9 GJ / t steel, i.e. by 10% compared to 2011.

The IEA scenarios largely exploit a back casting approach. They describe what can be done to achieve certain quantitative indicators such as total CO₂ emissions over a period of time. However, it is not always clear how both global and local needs of humanity will be met, given the fact that today there are no mechanisms that would encourage humanity in general, and the governments of individual countries to coordinate the industrial development with the goal of preventing climate change, instead of overcoming the problems of poverty, unemployment, resource dependency etc. Hence, the likelihood of these scenarios is rather questionable. The analysis of the current situation above shows that the world as a whole continues to move in the direction opposite to the IEA scenarios.
Of certain interest is another group of scenarios being developed based on the analysis of certain current trends and historical factors, and projection of them to the future (forecast). Given the large number of publications and limited nature of the current edition, below – just as an example – we analyse the results of research carried out by a group of authors working with the University of Cambridge (UK), Norwegian University of Science and Technology (Trondheim) and Delft University of Technology (Netherlands).

To forecast the future emissions it is important to define the ratio between the production of steel from ore and from scrap which, in turn, requires solving of a complex problem of forecasting the availability of scrap in future. Moreover, production of steel from scrap derived from the products that have served their age is not a completely adequate alternative to the production of primary steel considering the required quality indicators.

One of the more popular approaches is the use of Material Flow Analysis, which includes:

- determining the amount of materials that are in operation in the form of the goods manufactured from them (e.g. amount of iron in steel made products);
- estimation of the life cycle for these goods;
- estimation of the ratio of recycling of used products and so on.

This approach might be applied to forecast future demand for steel. Today steel is the most recycled material in the world. However, technically, it is possible to further increase the level of steel recycling. Table 6.2 demonstrates the data by WorldSteel Association [8] on the current and projected levels of recycling and lifetime of steel in the form of products of downstream industrial sectors (figures do not include the so-called internal recycling of steel - in cut-off pieces, substandard products, etc.).

The amount of steel in the form of various consumer products or different constructions per capita in developed countries has the trends to saturation over time; hence future demand depends on the lifetime of these products or materials. In theory, future demand for certain materials in the emerging countries might be estimated, based on assumption that this saturation behaviour will be similar to those earlier observed in the developed ones.

Table 6.2

<table>
<thead>
<tr>
<th>Industry</th>
<th>Recycling rate, %</th>
<th>Life cycle, years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2050</td>
</tr>
<tr>
<td>Construction</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>Automotive</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td>Electrotechnics</td>
<td>50%</td>
<td>65%</td>
</tr>
<tr>
<td>The weighted average of the world</td>
<td>83%</td>
<td>90%</td>
</tr>
</tbody>
</table>
Data collection on the current quantity of steel in the form of goods or constructions for each country of the world is an impossible task. Instead, indirect methods based on application use of macroeconomic indicators are used. For example, Muller et al [9] investigated the statistical relationship between the level of gross domestic product (GDP) per capita and the quantity of steel in use for the six developed countries during the last hundred years (Fig. 6.3). Based on this statistical relationship the current material flows were estimated and, using also GDP forecasting methods, forecasting future material flows for the other countries were estimated.

![Fig.6.3. Steel consumption (tons per capita) versus GDP per capita (in international US Dollars of 1990 - hypothetical monetary unit with the same purchasing power as in 1990 the US Dollar had) for developed countries. Gray line shows the general trend.](image)

The work by Pauliuk [10], with a symbolic title "The steel scrap age" proposed the dynamic model for estimating the amount of steel that will be in use in future, which is also based on the assumption of saturation of this amount per capita in developing countries in the future. In addition, the authors performed forecast supply of scrap from various industries. The simulation results show the following trends and challenges.

**The trends of demand for steel and scrap availability.** The simulation results indicate the possibility of extreme changes of demand for steel in China, the Middle East, Latin America and India during the XXI century. In particular, as shown in Fig.6.4, China's demand for steel will reach a maximum between 2020 and 2030, with a further decrease. At the end of the XXI century in China demand for steel will increase again, which is a direct result of the model’s assumptions concerning the life
cycle: the current construction boom in China, with an average lifetime of 75 years will lead to a wave of replacement of steel structures after 2070.

According to the simulation, scrap supply does not change as rapidly as the demand for steel. Today, most of scrap comes from developed countries but it will be changed after 2025, when China will become the largest supplier of scrap. At the end of the century both in steel consumption and the supply of scrap will dominate the countries which today are considered as the developing ones.

As regards of global indicators, simulation results show the following. The total final demand for steel in the form of materials and consumer products will increase from 1,100 billion tons per year in 2008 to 1,600 billion tons in 2050 and about 2000 billion tons in 2100 (Fig.6.5). Although the steel consumption in some regions will hit a maximum over the century, the global consumption will increase after 2100 - mainly due to growth of consumption in developing countries in Asia and Africa. After 2020 there will be a peak in demand for the construction steel caused by the development of construction in China. Today the scrap is usually recycled in the production of structural steel, but after 2025 the number of the available scrap will exceed the need for structural steel that will motivate the use of scrap to produce steel also for machinery manufacturing. After 2050 the amount of available scrap will exceed final demand not only in China but also in Western Europe and the former Soviet Union.
Owing to numerous reasons (production of steel from scrap is cheaper, environmentally safer and less energy intensive) the need for global steel obtained from pig iron may reach peak approximately in 2025 with a subsequent reduction that will result in the emergence of excess blast furnaces in the next years. It is expected that the production of steel from scrap will more than double by 2050 and will exceed the primary steel production between 2050 and 2060.

**Challenges for the integrated steelwork.** A large volume of steelmaking capacity may become unnecessary to meet the domestic needs in Western Europe, developed countries of Asia and China. However, if by that time India, Latin America and the Middle East, where the demand will increase, were not be able to satisfy their own needs, then the possibility of steel export to these regions can extend the existence of steel companies in the developed countries. Based on the above, two scenarios are proposed by Pauliuk et al [10].

The first scenario assumes that the needs of individual countries are satisfied in the global market - "trade follows the capacity". In this case, the production will take place on existing sites, no matter where the demand appears, and the final steel product is delivered to where it is needed. In this case, there is the possibility that, despite the reduction of demand for primary steel, after 2025 a significant part of the existing production facilities integrated companies may reach 60-year-old "age limit" and be decommissioned in the natural way. However, even in this scenario between 2040 and 2060 blast furnaces with a total production of about 200 million tons per year will have to be decommissioned before reaching the final depreciation level. Moreover, between 2020 and 2070 there will be no need to invest in new blast furnaces. However, in this scenario open markets can contribute to more or less efficient use of existing capacities in a global scale.

Another scenario is when production capacity follows the demand. In this scenario, different regions of the world for the sake of resource security and independence, will build their own steel infrastructure, despite the existence of excess
capacity in other countries. In this case, construction of the new facilities in India, Middle East, Latin America and Africa will continue. The result will be premature decommissioning - mainly in China and Western Europe – of the existing capacity with total volume of 500 million tons per year in addition to another 100 million tons of capacity, which will reach full depreciation. Thus, location of facility towards the regional needs, with a large degree of probability, will lead to overcapacity, falling prices and crises. Unfortunately, this scenario is very realistic and actually is being implemented today.

**Challenges for secondary steel producers.** Given the trends in population, as well as assumptions regarding the amount of steel consumption, scrap supply in the future in China, Western Europe and CIS will exceed demand for final products of steel industry after 2050. In theory, this will allow these regions to implement closed cycle and to stop production of the primary steel. However, the production of quality steel from scrap might be problematic as impurities (primarily - copper and zinc) can accumulate in recycled metal that decrease a quality of steel, notably in production of automotive sheet. To prevent it, the system of collection and sorting of scrap should be substantially reorganised. The solution can also be by adding of a certain amount of primary metal during the smelting in electric arc furnaces or the production of structural steel grades for which the copper content up to 0.4% is acceptable. Therefore implementation of the scenario with increased production of recycled steel will require not only reorganising waste management, but also optimising the flow of materials towards the regional needs in different steel grades.

**Challenges and potential environmental impacts associated with the future location of primary steel producers.** The premature shut down of existing enterprises could undermine an economic strength of steel companies and the result will be an increased unemployment. Both industry and governments are naturally interested in an increase of the investment and improving energy efficiency in order to maintain the competitiveness of enterprises and the compliance to environmental standards. For example, blast furnace campaign lasts over 20 years and during this period it might be revamped to the new technological standards. In contrast, the relocation of capacities to other regions creates the potential for radical technological and structural changes, including deployment of alternative ironmaking technologies.

**Scenario of sustainable future based on the assumption of increasing the efficiency of steel materials.**

As can be seen from the IEA scenarios, the growth of demand for steel, and the production outweighs the benefits of increased efficiency and without large scale deployment of CCS sustainable environmental development will not be possible. However, large scale CCS has not yet been proven and its implementation will require overcoming many barriers of technological, social and economic nature.
Allwood et al [11] have demonstrated the growth of demand for steel can be satisfied with a reduction in the production of crude steel by improving the efficiency of steel materials. In another paper [12] Allwood et al gave a detailed analysis of the problems to be solved to ensure more efficient use of materials and proposed the following four groups of strategic measures that can ensure reduction in material need:

- manufacture of products with characteristics that provide the ability to use them for a longer period;
- reuse of components - some parts can be reused without re-melting;
- producing with less materials - e.g. the introduction of innovative type I-beams with optimised variable section can provide a reduction in weight of construction by 30%.

Although the results of the study may look obvious, there are many technological, social and legislative obstacles for implementing these strategies. Allwood et al [12] modelled several scenarios for the future development of the steel industry with varying degrees of energy and material efficiency.

Following technologies are considered to reduce the CO₂ emissions, (detailed description of these technologies is provided in Chapter 5).

1. The top gas recycling and use of alternative fuels and plastics can reduce coke consumption by 50%.

2. Smelting-reduction technologies. Energy consumption and CO₂ emissions in HIsmelt are higher than the blast furnace (ca 1.6 t CO₂/t of pig iron). But by considering the phasing out of sinter and coke production, it is assumed that the total CO₂ emissions are 80% from blast furnace.

3. Advanced DRI production technology (1.0 t CO₂/t DRI). The main advantage is a possibility to eliminate the production of coke. Production of DRI followed by the smelting of steel in electric arc furnaces will reduce CO₂ emissions by about half in the case of natural gas is used. However, the availability of cheap natural gas, of "low carbon" electric power and of high quality ore may limit the introduction of this steel production route.

4. Production of iron by electrolysis. The use of electrolysis can eliminate coke, sinter and blast furnace production, and in the case of "low carbon" electricity (eg nuclear power) can reduce emissions to 0.24 t of CO₂/t of metal. However, this technology is still at a very early stage of development.

5. Decarbonisation of electricity generation through the introduction of CCS, nuclear power and renewable sources. The investigated scenarios envisage "decarbonisation" in the range of 25 to 75% by 2050.

These five technological approaches have significant limitations in terms of investment, hence seven scenarios (Table 6.3) provide different levels of implementation of these technologies:
- business-as-usual (BAU) suggests that the level of recycling of steel will be increased to 90% with increasing consumption of scrap during the steel production in converters from 10% to 20% by 2050, and all BAT will be introduced by 2020;

- three energy efficiency scenarios in which - in addition to improvements in BAU scenario - low, high and medium levels of innovative technologies deployment and decarbonisation of electricity are assumed;

- three scenarios for material and energy efficiency, which in addition to the average energy efficiency, apply a maximised material efficiency with a three levels of implementation - slow, moderate and fast.

Table 6.3 shows values of CO₂ specific emissions at the different phases of steel production used in modelling (cited work averaged data from 15 references).

<table>
<thead>
<tr>
<th>Year when maximum financial efficiency is reached</th>
<th>2050</th>
<th>2100</th>
<th>2150</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGR by 2050</td>
<td>0</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>DRI share by 2100</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Share of reduction-smelting by 2100</td>
<td>0</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Share of electrolysis to 2010</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>The level of decarbonisation of electricity by 2050</td>
<td>0</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workflow</th>
<th>t CO₂ / t product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agglomeration</td>
<td>0,22</td>
</tr>
<tr>
<td>Coking</td>
<td>0,43</td>
</tr>
<tr>
<td>Production of pig iron in blast furnaces</td>
<td>1,48</td>
</tr>
<tr>
<td>Production of DRI</td>
<td>1,28</td>
</tr>
<tr>
<td>Steel production in oxygen converter from pig iron</td>
<td>0,12</td>
</tr>
<tr>
<td>Production of steel in electric arc furnaces with DRI</td>
<td>0,36</td>
</tr>
<tr>
<td>Production of steel in electric arc furnaces from 100% scrap</td>
<td>0,33</td>
</tr>
<tr>
<td>Continuous casting</td>
<td>0,007</td>
</tr>
</tbody>
</table>

The results of simulation of CO₂ emissions by the seven scenarios mentioned in Table 6.3 are shown in Fig.6.5. In scenario 1 (BAU) the emissions will reach the maximum in 2025 at a level that is almost 25% higher than the emissions in 2008.
Then, despite the growing demand for steel, the overall global emissions are reduced below 3 Gt CO₂/year, which is associated with increasing of the share of production of steel in electric arc furnaces, where specific CO₂ emissions are much lower. After 2045 the emissions will increase again as the demand for steel will increase offsetting the positive effect of reducing specific emissions. Implementation of energy efficiency scenarios (2-4) can reduce emissions by 20% compared to a BAU, however, even in case of the most active implementation of energy efficient technologies (Scenario 4) the emissions to exceed the 2050 target by more than 120 %. In contrast, even the moderate scenario 6, combining the energy and material efficiency, almost exactly matches the set goals. In the most radical scenario 5 (moderate energy efficiency and fast implementation of material efficiency) the minimum emissions is observed around 2037, but after 2040, the emissions are rising again as the rapid introduction of lightweight steel structures and steel with longer lifetime will adversely affect the scrap availability. However, in this scenario, by 2050 the emissions will remain in the target range.

![Fig. 6.5. CO₂ emissions in the production of steel under different scenarios (numbers - in tabl.6.3)](image)

[12]

Fig. 6.7 illustrates the emissions allocation for various technological units for steel production scenarios BAU (1) moderate efficiency (3) and moderate energy and material efficiency (6). Under scenario 1 the distribution of emission does not change over time, and the largest contributor remains blast furnace. For the other two scenarios share the blast furnace significantly reduces. Energy efficient scenario increases the share of emissions from the alternative technologies of iron production, while scenario of material and energy efficiency decrease of steel production involves a reduction in emissions at all technological levels.

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Of course, each of the proposed scenarios requires different production volumes. Fig. 6.7 demonstrates the changes over time for steel production in oxygen converters and electric arc furnaces in scenario 6 (dashed line) according to the scenario BAU. Both scenarios predict an increase of the production of steel in electric arc furnaces, however in scenario with material and energy efficiency the increasing is less pronounced due to smaller resource of available scrap. More noticeable is the difference between the forecast of steel production in converters: in the BAU scenario, production will reach a maximum around 2025, followed by a decrease to 2045, after which there will be an increase. In the scenario of material and energy efficiency converter steel production will reach a maximum in 2018 after which it will steadily decline, reaching about 35% of the current level. This analysis shows that without introduction of additional restrictions of emissions, the total production of pig iron in blast furnaces will increase by around 50% to 2025. Allwood et al believe that halving of emissions by 2050 requires that the last blast furnace in the world is to be built not later than in the next ten years (study completed in 2013).

Regardless of whether we agree to the above scenarios, the results are very interesting. The most important conclusions in our opinion are the following.

Firstly, there is an urgent need to coordinate efforts of the international community to prevent climate change - including through the introduction of mechanisms to ensure the economic security of developing countries, while maintaining the steel capacity in developed countries, at least for the period of their complete depreciation.

Second, the pace of commercialisation of technologies that can provide a radical reduction of energy consumption and CO₂ emissions must be accelerated significantly.

Thirdly, even the successful introduction of innovative technologies will not secure the achievement of the environmental objectives established without significantly increased material efficiency.

Fig. 6.6. Distribution of CO₂ emission reductions for various technological phases of steel production for different scenarios (numbers correspond to Table. 6.2) [12]
Fig. 6.7. Global steel production in oxygen converters (BOF) and electric arc furnace (EAF) for scenarios 1 and 5 [12]

References to Chapter 6.2.1.
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2. www.worldenergyoutlook.org
3. www.iea.org/etp
5. Energy Technology Perspectives 2010: Scenarios & Strategies to 2050: IEA, 2010, p.49
6.2.2 Petroleum industry  
*M. Karpash, A. Yavorskyy*

Petroleum industry over the last decades considered three recognised institutions drawing reliable and promising scenarios for the future landscape of the industry and respective trends: International Energy Agency (IEA), BP and Shell. All prognoses provide not only long-term forecasts and sustainable development vision. All of them represent different timescales (2030, 2035 and 2100), but general trends are more or less similar – serious fraction of fossil fuels in energy mix, climate change challenges to be faced, technologies with right policies are the key solution pathways.

**IEA scenario**

This chapter focuses on the different scenarios for world energy demand and supply, along with their implications on energy-related CO2 emissions from IEA. If energy policies do not change significantly (the reference scenario), energy demand will increase significantly over the next two decades, and, because of the fossil fuels in the supply energy mix, greenhouse-gas emissions are projected to increase at alarming levels.

IEA has developed alternative scenarios to lower the emissions, while providing supply security. The growth in energy use depends on many variables, and principally on growth in population and gross domestic product (GDP). Fig. 6.8 show the evolution and forecast of the energy mix between 1980 and 2030. With a larger share of the world population having access to energy (electricity, transport, etc.), world energy demand expands by 45% between 2010 and 2030, corresponding to an average rate of increase of 1.6% per year. Coal accounts for more than a third of the overall rise in the next 2 decades.

Use of coal had already increased by an average 4.8% annual rate over the last 30 years, compared with 2.6 and 1.6% for gas and oil, respectively. China, India, and the Middle East will account for nearly 80% of oil-demand growth from 2007 to 2030. The investments required in the same time period to sustain such a level of increase in energy use amount to USD 26 trillion, split between the power sector (generation, transmission, and distribution) - 52%, the oil sector - 24%, and the gas sector - 21%.

**Sustainability of Scenario.** The energy-related CO2 emissions (76% of total CO2 emissions and 61% of global greenhouse emissions in 2006) will increase from 17 G tonnes in 1980 to more than 40 G tonnes by 2030 in the reference scenario. A major part of the emissions increase is from countries not part of the Organisation for Economic Cooperation and Development (OECD) and is associated with coal. Emissions from fossil-fuel power plants amounted to 11.4 G tonnes of CO2 in 2006 (41% of the world total). They are projected to increase to 18 G tonnes in 2030, 45%
of the total! Transport is a distant second for emission generation. Coal-fired power plants are the main emission sources, representing nearly three-quarters of total power-sector emissions, and these sources are mainly in China and India.

Fig. 6.8. Energy supply in a “business as usual” scenario

Power plants built today are likely to be in operation for the next 40 to 60 years. The 2050 outlook given in the IEA publication Energy Technology Perspectives shows an increase of energy-related CO2 emissions that rise to 62 G tonnes per year. The 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report gives ranges of probable temperature increases related to greenhouse-gas emissions. While a stabilisation of emissions in 2050 at current levels would lead to an average 3–4°C increase, the forecast emissions of 62 G tonnes would lead to an average 4–7°C increase! A 50% reduction in emissions in 2050 (compared with current levels) still leads to a 2–3°C increase.

How Could We Reverse the Trends? An energy revolution is required, combining a more efficient use of energy in the residential, transportation, and industrial sectors with lower emission (decarbonised) energy sources. Options in the power generation sector include renewables, increased efficiency, switching from coal to gas, CO2 capture and storage (CCS), and nuclear energy. Fig. 6.9 shows the potential impact of a major change in the energy portfolio under the IEA’s “BLUE” scenario, which aims at a 50% reduction in CO2 emissions by 2050. The top curve represents the emissions in the “business as usual” scenario. Getting to the lower curve requires a combination of energy efficiency (the largest component, with 36% of the emission reduction), renewables (21%), CCS (19%), and other measures. In addition to changes in energy-consumptions patterns, achieving this improvement requires increased support of R&D technologies and deployment of energy technologies whose costs can be reduced through learning by doing. New policies with CO2-reduction incentives to encourage the adoption of low-carbon technologies
should be adopted and implemented. Raising public awareness and engaging all stakeholders will be critical for the success of this energy revolution. The challenge is global; it requires the involvement of OECD economies as well as emerging economies.

Fig. 6.9. Contribution of emission-reduction options during 2005-2050

How Much Will This Cost? The costs can be given in terms of marginal abatement of CO2 (or greenhouse-gas emissions). The energy portfolio requires a combination of measures with negative marginal cost (end-use efficiency) and positive marginal cost. A significant portion of the curve corresponds to the power sector. CCS in power generation would be triggered by emission-reduction incentives equivalent to USD 50–75 per tonne of CO2. The latter cost translates into an increased cost of electricity production of USD 0.03 to 0.045 per kW-hr for a coal-fired power plant.

Engaging the Industry in the Energy Revolution Worldwide, only four large-scale CCS projects (i.e., above 1 million tonnes CO2 injected per year) are currently in operation. A massive effort is needed to increase this activity by three orders of magnitude by 2050. Requirements for large-scale deployment of CCS include:

- Increased public awareness about the technology
- Financial mechanisms to offset additional cost for capture and storage
- International cooperation
- Technological developments to reduce costs, especially with capture
- International and national legal and regulatory frameworks
- Creation of a CO2 transport infrastructure (pipelines, shipping)

The oil and gas industry, with the community knowledge of subsurface sciences, can effectively support the ongoing efforts to demonstrate that with the appropriate level of site assessment, wellbore isolation, and monitoring and verification, CO2 injected will remain contained for long periods of time within the formation layers that had been targeted. That would provide increased levels of
assurance for the public that any hazards associated with CO2 transport and storage can be mitigated effectively.

\textit{Opportunities for Young Professionals (YPs)} If the projected level of activity in CCS materialises, requirements for geoscientists, who will conduct the subsurface assessment and monitoring, will increase significantly. This will create opportunities for today’s and tomorrow’s YPs to engage effectively in the development of a sustainable energy future. In addition to the financial mechanisms for carbon abatement, one of the other main requirements for CCS deployment is increased public awareness and acceptance. YPs can play a major role in the dialogue between stakeholders (including nongovernmental organisations and the educational sector) to highlight the potential of CCS and provide an informed technical contribution to the discussion about long-term storage concerns.

**BP Energy Outlook to 2035**

BP Energy outlook till 2035 states that primary energy consumption growth slows and the growth is almost all in the non-OECD (Fig. 6.10).

![Consumption forecast by region](image)

![Ten year increments by region](image)

Fig. 6.10. Consumption forecast by region (BP Energy Outlook 2035)

Primary energy demand increases by 41% between 2012 and 2035, with growth averaging 1.5% per annum (p.a.). Growth slows, from 2.2% p.a. for 2005-15, to 1.7% p.a. 2015-25 and just 1.1% p.a. in the final decade. We are leaving a phase of very high energy consumption growth, driven by the industrialisation and electrification of non-OECD economies, notably China. The 2002-2012 decade recorded the largest ever growth of energy consumption in volume terms over any ten-year period, and this is unlikely to be surpassed in our timeframe.

There is a clear long-run shift in energy growth from the OECD to the non-OECD. Virtually all (95%) of the projected growth is in the non-OECD, with energy consumption growing at 2.3% p.a. 2012-35. OECD energy consumption, by contrast, grows at just 0.2% p.a. over the whole period and is actually falling from 2030.
onwards. China has emerged as the key growth contributor, but by the end of the forecast China’s contribution is starting to fade. India’s contribution grows, almost matching that of China in the final decade of the forecast.

By sector (Fig. 6.11), industry remains the dominant source of growth for primary energy consumption, both directly and indirectly (in the form of electricity). Industry accounts for more than half of the growth of energy consumption 2012-35. This reflects the unprecedented pace and scale of industrialisation in Asia. Energy for industry grows at 2.6% p.a. over the decade 2005-15, but this slows to just 1.0% p.a. in the final decade of the forecast as China’s rapid industrialisation comes to an end.

The next major component of growth is energy used in the ‘other’ sector (residential, services and agriculture), predominantly in the form of electricity. By the final decade, growth in other sector energy use almost matches industry in volume terms.

The transport sector continues to play a relatively small role in primary energy growth throughout the forecast, growing steadily but accounting for just 13% of total growth during 2012-35.

All fuels show growth over the forecast period (Fig. 6.12), with the fastest growth seen in renewables (6.4% p.a.). Nuclear (1.9% p.a.) and hydro-electric power (1.8% p.a.) both grow more rapidly than total energy. Among fossil fuels, gas is the fastest growing (1.9% p.a.) and the only one to grow more rapidly than total energy. Oil (0.8% p.a.) shows the slowest growth, with coal (1.1% p.a.) only slightly ahead. Coal’s contribution to growth diminishes rapidly. It is currently the largest source of volume growth, but by the final decade coal adds less volume than oil and is only just ahead of hydro. Again, this reflects the shift away from coal-intensive industrialisation in China. In that final decade, gas is the largest single contributor to growth; but non-fossil fuels in aggregate contribute even more than gas, accounting for 39% of the growth in energy in that period.
New sources help to supply sufficient energy to meet demand growth (Fig.6.13). World primary energy production grows at 1.5% p.a. from 2012 to 2035, matching consumption growth. Growth is concentrated in the non-OECD, which accounts for almost 80% of the volume increment. There is growth in all regions except Europe. Asia Pacific shows both the fastest rate of growth (2.1% p.a.) and the largest increment, providing 47% of the increase in global energy production. The Middle East and North America are the next largest sources of growth, and North America remains the second largest regional energy producer.

There is expansion across all types of energy, with new energy forms playing an increasingly significant role. Renewables, shale gas, tight oil and other new fuel sources in aggregate grow at 6.2% p.a. and contribute 43% of the increment in energy production to 2035. The growth of new energy forms is enabled by the development of technology and underpinned by large-scale investments. BP’s Outlook assumes that the right competitive and policy conditions are in place to support that investment and technical progress.
Energy is gradually decoupling from economic growth and the fuel mix is slowly shifting away from fossil fuels (Fig.6.14). Energy consumption grows less rapidly than the global economy, with GDP growth averaging 3.5% p.a. 2012-35. As a result, energy intensity, the amount of energy required per unit of GDP, declines by 36% (1.9% p.a.) between 2012 and 2035. The decline in energy intensity accelerates; the expected rate of decline post 2020 is more than double the decline rate achieved 2000-2010.

Fuel shares evolve slowly. Oil’s share continues to decline, its position as the leading fuel briefly challenged by coal. Gas gains share steadily. By 2035 all the fossil fuel shares are clustering around 27%, and for the first time since the Industrial Revolution there is no single dominant fuel. Taken together, fossil fuels lose share but they are still the dominant form of energy in 2035 with a share of 81%, compared to 86% in 2012. Among non-fossil fuels, renewables (including biofuels) gain share rapidly, from around 2% today to 7% by 2035, while hydro and nuclear remain fairly flat. Renewables overtake nuclear in 2025, and by 2035 they match hydro.
The power sector takes an increasing share of energy and plays a key role in shaping the fuel mix (Fig.6.15). One of the longest established trends in energy is the increasing role of the power sector. The share of primary energy devoted to power generation rises in industrialising as well as in mature economies, where growth is dominated by the service sector. In 2012, 42% of primary energy was converted into electricity in the power sector, up from 30% in 1965. By 2035 that share will rise to 46%. Fuels for power generation account for 57% of the growth in primary energy consumption 2012-35. And the power sector is the one place where all the fuels compete.

At the global level coal remains the largest source of power through 2035, although in the OECD coal is overtaken by gas. Carbon-free sources (renewables, hydro and nuclear) increase their combined share of power generation from 32% in 2012 to 37% by 2035. Renewables overtake nuclear as a source of power generation in 2028, increasing their share of power generation from 5% today to 13% in 2035, and showing little sign of approaching any limit to their market share.
The security and sustainability of energy supply continue to pose significant challenges (Fig 6.16). Regional energy imbalances – production minus consumption for each region – suggest that trading relationships will change significantly by 2035. North America switches from being a net importer of energy to a net exporter around 2018. Meanwhile, Asia’s need for imported energy continues to expand; by 2035 Asia accounts for 70% of inter-regional net imports – and nearly all of the growth in trade.

Among exporting regions, the Middle East remains the largest net regional energy exporter, but its share falls from 46% in 2012 to 38% in 2035. Russia remains the world’s largest energy exporting country. Energy security is a theme that will run through the fuel-by-fuel projections described later in BP Outlook 2035. The biggest challenge in terms of sustainability remains the level of carbon emissions, which continue to grow (1.1% p.a.) – slightly slower than energy consumption, but faster than recommended by the scientific community.
Shell: Scenarios for Future (Mountains and Oceans)

Shell in 2013 published the “New Lens Scenarios. A shift in perspective for a world in transition” which contains two different scenarios called “Mountains” and “Oceans”.

Shell states that the world in the future will be defined by how people and governments meet the challenges posed by institutions, inequality, and insecurity in relation to the paradoxes of prosperity, leadership, and connectivity.

Those scenarios are designed to provide new lenses through which to explore these issues – or, as we explore these contrasting worlds, two panoramas: high Mountains where the benefits of an elevated position are exercised and protected, and those who are currently influential hold on to power; and wide Oceans with rising tides, strong currents, and a volatile churn of actors and events with an irregular accommodation of competing interests.

These panoramas have distinctive social, economic, and political features that can be discerned over the next 20 years or so, with consequences for energy developments over half a century. Together these shape ecological outlooks beyond 2100. They form the New Lens Scenarios for the 21st century.

Fig. 6.17 and 6.18 reflect the energy demand and consumption for Mountains and Oceans scenarios from Shell.
### MOUNTAINS TOTAL PRIMARY ENERGY - BY SOURCE

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### MOUNTAINS TOTAL FINAL CONSUMPTION - BY SECTOR

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Fig.6.17. Mountains scenario – energy demand and energy consumption
The Shell’s New Lens Scenarios describe plausible developments in the socio-political-economic spheres and then push to explore longer-term energy and related boundaries. These boundaries reflect possible consequences of each scenario but are not mechanistically linked to them. For example, if the relevant choices are made, it is possible for the robust global economic picture in Oceans to be accompanied by some of the energy developments currently ascribed to Mountains.

This would provide some relief to the more extreme energy and environmental stresses to be found at the outer boundary of the Oceans story. It is also possible for the more optimistic assumptions about global tight/shale gas and CBM resources found in Mountains to be true in either scenario.

Over the century, cumulative CO2 emissions (Fig. 6.19) are nearly 25% higher in Oceans than in Mountains, raising severe concerns about ongoing climate turbulence and highlighting the need for directing attention and resources to adaptation. It is, of course, very sobering to consider this ‘tight’ Oceans boundary – but it is also important to recognise that even the ‘loose’ Mountains boundary represents a significant challenge to long-term environmental sustainability. The
build-up of greenhouse gases in the atmosphere still exceeds current targets for limiting atmospheric temperature increases to 2°C.

This is the case even with lower economic trajectories, rapid displacement of coal by gas, advances in energy efficient compact urban development, and accelerated deployment of CCS and other technologies. These challenging conclusions highlight the significance not only of the scenarios themselves, but also of the wider dialogue they must contribute to and the choices made as a result.

![Fig.6.19. Global energy-related CO₂ emissions (Shell)](image)

Economic growth is generally positive in itself, even though it naturally increases pressure on resources. If only sluggish or reactive policy responses are offered in the energy arena, then the trajectory towards the boundary described in Oceans will result. It will place severe stress on resource economics and the environment, not just in CO₂ terms but also for fresh water and food resources.

If unsustainable outcomes are to be avoided, the key lesson is the need to accelerate proactive and integrated policy implementation – and emphatically not to argue that poor economic outcomes for the developing world would constrain greenhouse gas emissions. In fact, vibrant economies may well be a necessary catalyst for smart resource policies because environmental concerns tend to fall down the agenda when economies are sluggish.

An impression of the impact of accelerated and coordinated policy can be gleaned from the Fig.6.19. This illustrates a sensitivity analysis in which the Oceans global economic trajectory is combined with the resource and supply-side developments explored in Mountains and earlier implementation of the utilisation efficiency responses highlighted in Oceans (Oceans – clean and green).
While still not ideal from an emissions perspective, the positive impact is substantial – an encouraging outcome. In this sensitivity, growing demand is initially met by rising fossil fuel supply and the deployment of CCS. By the 2030s, more and more renewable energy sources enter the economic mix at scale, at first to meet incremental demand, but increasingly to substitute for coal and oil. The energy intensity of economic development trends downward as a result of improved urban planning and efficiency gains in energy utilisation.

Together, these developments lead to an energy system built on efficient structures and applications, gas, coal with CCS, and renewable resources. Made up of abundant resources, this system caters to demand, keeps prices affordable, and ultimately reduces its impact on the environment.

One conclusion that can be drawn from the New Lens Scenarios is that substantive change will not come about by itself – as a result of pricing signals or policy responses delayed until crises become apparent. A positive outcome requires a series of proactive, far-sighted, and coordinated national and international policy developments that, to date, seem beyond the bounds of plausibility.

Once the worst of the current financial crisis has passed, the stark prospect of such negative outcomes for all players should stimulate renewed attention. If these issues are not addressed, the tight boundary described in Oceans will begin to become a reality. If, however, the climate consequences accepted by the majority of the scientific community are correct, the boundary described here becomes increasingly unlikely. In other words, the high emissions associated with Oceans could eventually lead to a level of climate turbulence that severely damages the economy, dramatically lowers energy demand, and reduces emissions albeit by a negative route.

This work illustrates a hypothetical trajectory for greenhouse gas emissions, with potential disruptions resulting from climatic turbulence that will have an increasingly severe impact on global economic, social, and political conditions. Given uncertainties around potential developments in the longer term, it is not fruitful to build such dramatic feedback loops directly into the core scenarios. Instead we want to be clear about where the trajectories are heading and to support a better informed dialogue about the potential consequences.

**Ukrainian energy forecast**

By signing the European Union Association Agreement, Ukraine made a historic decision on its development priorities [1]. This decision not only entails a number of obligations having an impact on Ukraine’s social and economic development priorities and, in particular, on its energy sector. This fundamental choice made by Ukraine with respect to the country’s full integration into the community of European nations determines the need to change Ukraine’s approach to formulating the country’s energy policy, which has to be consistent with the EU principles and practices.
In this context, the Energy Strategy of Ukraine defines the purpose and the methods of implementing Ukraine’s energy policy in the long term, as well as outlines the mechanisms for this implementation. In this way, unlike the current edition of the Energy Strategy of Ukraine through 2030, this Strategy is not a program of action or an organisational and administrative document regulating the development of the fuel and energy complex of Ukraine. This Strategy is a political document formalising the country’s policy, defining the objectives of the public administration system, and setting the mechanism for focusing all public efforts on the achievement of the development goals set for the entire energy sector of Ukraine.

This Strategy is the main instrument of state energy policy defining the general goals of the country’s energy sector development in the long-term, setting the objectives and outlining the implementation mechanisms of the state energy policy. The aim of the Strategy is to provide for the society and the economy demand in fuel and energy resources in a technically safe, secure, cost-effective and environmentally sound manner to ensure improved living conditions of the population.

The target status of Ukraine’s energy sector, at which the Strategy is aimed, is determined based on the need to:
- meet the population’s demand in both normal and emergency conditions;
- ensure the technically reliable and safe operation of the power supply system;
- provide for the economic efficiency of Ukrainian power supply systems and the energy sector in general;
- ensure the efficient energy use by the population and the national economy;
- find an environmentally sound solution to the environmental and climate impact of the energy sector;
- enable the state to form and implement policies aimed at protecting national interests regardless of the existing and potential internal and external threats to the energy sector.

The quantitative and qualitative targets of the Strategy are defined with due account of the need to ensure the sustainable development of the Ukrainian society in the long term, national economy priorities, and international obligations of Ukraine.

The major targets for the period through 2035 are:
- to reduce GDP energy intensity by 2035 to the level of 0.17 koe per 1 USD Ukrainian GDP (PPP) and to bring this indicator nearer to that of the countries with similar climatic, geographic, and economic conditions;
- to optimise the structure of the country’s energy balance basing on energy security requirements and to bring the share of renewable energy to 20%;
- to achieve by 2020 the level of dependence on energy supplies from a single country (company) not exceeding 30% of total imports (for nuclear fuel, targets are set separately);
- to achieve by 2035 the level of dependence on supplies from a single country not exceeding 30% of the total consumption of all types of energy;
- to ensure a guaranteed compliance of generating capacities to the volumes and modes of energy consumption in the United Power System of Ukraine, particularly with regard to regulatory capacities availability;
- to ensure by 2025 the technical integration of Ukrainian and European electricity and gas markets (cross-border transmission networks) amounting to at least 15% of Ukraine’s domestic market volume;
- to form by 2035 a system of guaranteed power supplies to meet the demand of the national economy and the population during an emergency period equivalent to 90 days of consumption.

**Long-range plan scenarios of the economy and fuel and energy complex development**

The further development of Ukraine's economy and the corresponding amendments to the consumption and production of energy resources are considered from the perspective of economic growth and the GDP structure, calculated on the basis of forecasts of the Government of Ukraine. Scenarios range from pessimistic, in which a lot of risks are implemented, associated with a slowing economic recovery, decline in the pace of recovery in global demand for metallurgical products and other industries (the projected average annual real GDP growth to 2030 - around 3.8%) to the optimistic (for the same period - around 6.4%) (Fig. 6.20). The base is the scenario where the average GDP growth is 5% per annum until 2030. All scenarios take into account the effect of economy de-shadowing.

In all scenarios the economic development of Ukraine will be held in two stages:

- high post crisis economic growth and pre-crisis GDP level achievement;
- slowing down of the economy along with gradual changes of GDP breakdown upwards service sector of the economy.
As base scenario for markets forecast calculation it is used the scenario with average annual real GDP growth in 2010-2030 – 5 %. At the same time, the regular updating of Energy Strategy requires to monitor the real markets and GDP development, and under the conditions of faster development as it is covered in base scenario it is necessary to provide the correction of forecast.

In base scenario, the proportion of service sector GDP in industry GDP up to 2030 will draw near the level of developed economy (the service sector will be 70% of GDP, industry 21%, other 9% is for agriculture). Under the base scenario, GDP in Ukraine in 2030 will reach 2,9 trln. UAH. The optimistic scenario assumes a more intensive industrial development in which the real GDP of Ukraine is growing annually by an average of 6.4% of GDP, furthermore, the GDP structure is also shifting towards the services sector. The main factors of growth will be GDP growth in the industrial sector (5.2% annually), the GDP of the service sector (6.9% annually) and the GDP in the agricultural sector (7.1%). In this scenario, in 2030 GDP will reach 3,8 trln. UAH. In the pessimistic scenario, GDP growth is significantly lower than in the scenario range, through low rates of GDP growth in the sectors: 1.4% - in industry, 4.2% - in the service sector and 6.1% - in agriculture sector. In the case of the pessimistic scenario of Ukraine's GDP development in 2030 it will amount to 2,3 trln. UAH.

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4 Hereafter, all the amounts are in real terms in 2010, and the data are taken from official sources, unless otherwise is noted.
**Forecasting of energy resources balance**

The base year for the calculation of the fuel and energy needs is taken 2010, in which prices indicators for 2015-2030 are forecasted.

Indicators in this section are given accurate to tenths, so they may differ slightly from the figures referred to in other sections due to rounding.

Table 6.4: Pro forma energy resources balance of Ukraine for the years 2015-2030 (base scenario)

<table>
<thead>
<tr>
<th>Balance item</th>
<th>Grade</th>
<th>2010 (real)</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Resources, total</td>
<td>mln. t.o.e.</td>
<td>231,8</td>
<td>226,8</td>
<td>251,8</td>
<td>264,7</td>
<td>286,6</td>
</tr>
<tr>
<td>1 Energy production, total, including.</td>
<td>mln. t.o.e.</td>
<td>131,9</td>
<td>142,6</td>
<td>165,6</td>
<td>186,3</td>
<td>223,7</td>
</tr>
<tr>
<td>1.1 Fossil fuels extraction</td>
<td>mln. t.o.e.</td>
<td>71,9</td>
<td>78,5</td>
<td>91,8</td>
<td>104,4</td>
<td>131,5</td>
</tr>
<tr>
<td>1.1.1 Coal production</td>
<td>mln. t.</td>
<td>54,8</td>
<td>63,9</td>
<td>76,9</td>
<td>83,8</td>
<td>92,8</td>
</tr>
<tr>
<td>1.1.2 Oil</td>
<td>mln. t.</td>
<td>3,6</td>
<td>2,8</td>
<td>2,4</td>
<td>2,4</td>
<td>3,6</td>
</tr>
<tr>
<td>1.1.3 Natural gas</td>
<td>billion cub. m</td>
<td>20,5</td>
<td>20,9</td>
<td>23,7</td>
<td>29,8</td>
<td>44,4</td>
</tr>
<tr>
<td>1.2 Production of electricity without fossil fuel costs, incl.:</td>
<td>mln. t.o.e.</td>
<td>39,0</td>
<td>40,8</td>
<td>46,5</td>
<td>52,8</td>
<td>58,1</td>
</tr>
<tr>
<td>1.2.1 NPP</td>
<td>bln. kWh</td>
<td>102</td>
<td>109,5</td>
<td>128,5</td>
<td>149,0</td>
<td>168,0</td>
</tr>
<tr>
<td>1.2.2 HPP and PSPP</td>
<td>bln. kWh</td>
<td>13</td>
<td>15</td>
<td>20</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>1.2.3 WPS, SPS, small HPP</td>
<td>bln. kWh</td>
<td>0</td>
<td>3,5</td>
<td>12,5</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>1.3 Thermal energy generated by NPP</td>
<td>mln. Gcal</td>
<td>1,5</td>
<td>1,7</td>
<td>1,9</td>
<td>2,1</td>
<td>2,2</td>
</tr>
<tr>
<td>1.4 Thermal environmental energy</td>
<td>mln. Gcal</td>
<td>0,6</td>
<td>3,4</td>
<td>10,4</td>
<td>27,6</td>
<td>47,2</td>
</tr>
<tr>
<td>1.5 Other sources of fuel and energy</td>
<td>mln. t.o.e.</td>
<td>20,7</td>
<td>22,3</td>
<td>25,2</td>
<td>24,1</td>
<td>25,8</td>
</tr>
<tr>
<td>2 Energy resources imports</td>
<td>mln. t.o.e.</td>
<td>70,9</td>
<td>61,5</td>
<td>57,7</td>
<td>51,7</td>
<td>34,1</td>
</tr>
<tr>
<td>Balance item</td>
<td>Grade</td>
<td>2010 (real)</td>
<td>Pro forma</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2015</td>
<td>2020</td>
<td>2025</td>
<td>2030</td>
</tr>
<tr>
<td><strong>2.1 Coal</strong></td>
<td>mln. t.</td>
<td>12,1</td>
<td>7,6</td>
<td>7,6</td>
<td>7,0</td>
<td>6,5</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>9,5</td>
<td>6,0</td>
<td>6,0</td>
<td>5,5</td>
<td>5,2</td>
</tr>
<tr>
<td><strong>2.2 Oil</strong></td>
<td>mln. t.</td>
<td>7,5</td>
<td>9,0</td>
<td>9,4</td>
<td>10,2</td>
<td>9,8</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>10,7</td>
<td>12,9</td>
<td>13,4</td>
<td>14,6</td>
<td>14,0</td>
</tr>
<tr>
<td><strong>2.3 Petroleum products</strong></td>
<td>mln. t.o.e.</td>
<td>7,5</td>
<td>3,5</td>
<td>6,9</td>
<td>8,4</td>
<td>9,1</td>
</tr>
<tr>
<td><strong>2.4 Natural gas</strong></td>
<td>billion cub. m</td>
<td>36,6</td>
<td>33,7</td>
<td>27,1</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>42,5</td>
<td>39,1</td>
<td>31,4</td>
<td>23,2</td>
<td>5,8</td>
</tr>
<tr>
<td><strong>2.5 Electricity</strong></td>
<td>bln. kWh</td>
<td>1,9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>0,7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>3 Fuel residues in the storages and warehouses at the beginning of the year</strong></td>
<td>mln. t.o.e.</td>
<td>29,0</td>
<td>22,8</td>
<td>28,5</td>
<td>26,7</td>
<td>28,8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Items of expenditure</th>
<th></th>
<th></th>
<th>231,8</th>
<th>226,8</th>
<th>251,8</th>
<th>264,7</th>
<th>286,6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>II. Resources allocation, total</strong></td>
<td>mln. t.o.e.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Energy resources consumption, total, incl.:</td>
<td>mln. t.o.e.</td>
<td>190,7</td>
<td>200,9</td>
<td>212,8</td>
<td>223,1</td>
<td>238,1</td>
<td></td>
</tr>
<tr>
<td>1.1 Fossil fuels extraction, total, incl.:</td>
<td>mln. t.o.e.</td>
<td>132,3</td>
<td>139,2</td>
<td>141,0</td>
<td>143,5</td>
<td>148,1</td>
<td></td>
</tr>
<tr>
<td>1.1.1 Coal</td>
<td>mln. t.o.e.</td>
<td>48,3</td>
<td>55,5</td>
<td>58,5</td>
<td>59,3</td>
<td>61,2</td>
<td></td>
</tr>
<tr>
<td>1.1.2 Petroleum products</td>
<td>mln. t.o.e.</td>
<td>17,9</td>
<td>20,4</td>
<td>23,6</td>
<td>26,4</td>
<td>29,6</td>
<td></td>
</tr>
<tr>
<td>1.1.3 Natural gas</td>
<td>mln. t.o.e.</td>
<td>66,1</td>
<td>63,3</td>
<td>58,9</td>
<td>57,8</td>
<td>57,3</td>
<td></td>
</tr>
<tr>
<td>1.2 Electric power generated without fossil fuel costs, incl.:</td>
<td>mln. t.o.e.</td>
<td>39,0</td>
<td>40,8</td>
<td>46,5</td>
<td>52,8</td>
<td>58,1</td>
<td></td>
</tr>
<tr>
<td>1.2.1 NPP</td>
<td>mln. t.o.e.</td>
<td>34,0</td>
<td>33,9</td>
<td>34,9</td>
<td>40,8</td>
<td>46,0</td>
<td></td>
</tr>
<tr>
<td>1.2.2 HPP and PSPP</td>
<td>mln. t.o.e.</td>
<td>5,0</td>
<td>5,6</td>
<td>7,3</td>
<td>7,4</td>
<td>7,3</td>
<td></td>
</tr>
<tr>
<td>1.2.3 WPS, SPS, small HPP</td>
<td>mln. t.o.e.</td>
<td>0</td>
<td>1,2</td>
<td>4,3</td>
<td>4,6</td>
<td>4,8</td>
<td></td>
</tr>
<tr>
<td>1.3 Thermal energy generated by NPP</td>
<td>mln. t.o.e.</td>
<td>0,2</td>
<td>0,3</td>
<td>0,3</td>
<td>0,3</td>
<td>0,3</td>
<td></td>
</tr>
<tr>
<td>1.4 Thermal environmental energy</td>
<td>mln. t.o.e.</td>
<td>0,1</td>
<td>0,6</td>
<td>1,8</td>
<td>4,7</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.4: Pro forma energy resources balance of Ukraine for the years 2015-2030 (base scenario)

<table>
<thead>
<tr>
<th>Balance item</th>
<th>Grade</th>
<th>2010 (real)</th>
<th>Pro forma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>1.5 Other sources energy</td>
<td>mln. t.o.e.</td>
<td>20,7</td>
<td>22,4</td>
</tr>
<tr>
<td>1.6 Energy balance (exports-imports)</td>
<td>mln. t.o.e.</td>
<td>1,6</td>
<td>2,4</td>
</tr>
<tr>
<td>2 Energy resources exports, incl.:</td>
<td>mln. t.o.e.</td>
<td>13,1</td>
<td>3,6</td>
</tr>
<tr>
<td>2.1 Fossil fuels</td>
<td>mln. t.o.e.</td>
<td>10,8</td>
<td>1,2</td>
</tr>
<tr>
<td>2.1.1 Coal</td>
<td>mln. t.</td>
<td>6,2</td>
<td>1,5</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>4,9</td>
<td>1,2</td>
</tr>
<tr>
<td>2.1.2 Oil</td>
<td>mln. t.o.e.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.1.3 Petroleum products</td>
<td>mln. t.o.e.</td>
<td>5,8</td>
<td>0</td>
</tr>
<tr>
<td>2.1.4 Natural gas</td>
<td>billion cub. m</td>
<td>0,1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>0,1</td>
<td>0,0</td>
</tr>
<tr>
<td>2.2 Electricity</td>
<td>bln. kWh</td>
<td>6</td>
<td>5,5</td>
</tr>
<tr>
<td></td>
<td>mln. t.o.e.</td>
<td>2,3</td>
<td>2,4</td>
</tr>
<tr>
<td>3 Fuel residues in the storages at the end of the years</td>
<td>mln. t.o.e.</td>
<td>28,0</td>
<td>22,3</td>
</tr>
</tbody>
</table>

Problems of energy policy

Reduction in the natural gas production on the territory of the country. Oil and gas production in Ukraine is in a state of stagnation, if not a decrease, despite the presence of undiscovered reserves of conventional and unconventional gas deposits. The country has the capacity to meet their needs in gas consumption by production of domestic resources by 2030 already. Nevertheless, without comprehensive reform and foreign investment, it may not be able to increase domestic gas production and significantly increase safety of energy supply.

Subsidies for energy consumption. The high level of public consumption of subsidised gas, heat and electricity remains unstable. The question is to mobilise political and public support for the plan of market prices advancing at a socially acceptable level and ensuring that energy companies will become economically competitive.

5 The resulting values may differ from the arithmetic sum of the parts due to rounding
Market and regulatory framework. Government structures are dominated among Ukrainian suppliers of oil, gas and energy resources. Current energy markets are created for the maintenance of its prevalence and subsidising energy consumption in municipal and public sectors. The problem is in designing and implementing effective regulatory framework that would have increased competition, strengthen market efficiency and was attractive to investors.

Terms of investment. Current considerations on transparency in the energy sector, inefficient energy flow determination, limited accounting and control, poor implementation rules for the establishment and management of prices make it difficult for foreign and domestic investment. Appropriate governance improving is a prerequisite for attracting investments.

Natural gas and oil transportation. Development of alternative oil and gas supply routes from Russia to Ukraine, and profits from these transports that make up a significant share of the financial standing of Ukraine. Keeping the importance of active transportation is a concern for energy policy.

Reducing the environmental impact of fuel burning. Ukraine has a great potential to reduce greenhouse gases through expanded access to international hydrocarbon funding. Moreover, Ukraine undertook to implement EU directives on large combustion plants by 2018.

Political aspects

Ukrainian government is involved in the process of the energy sector reforming and solve the problematic issues identified in the Program of Economic Reforms for 2010-2014. The program recognised that the energy sector of Ukraine was in poor condition due to obsolete assets, inefficient energy production and transfer, inefficient public organisations, market secrecy and incompatibility regulation, price distortions, subsidies and lack of motivation to invest in energy efficiency. Promoting energy efficiency through price performance and improving the competitiveness and reliability of the energy sector are the main objectives of the program of energy sector reforms. The main approaches to achieve those goals need to update the national energy strategy, to ensure regulatory independence, to raise tariffs for more costs reflecting, to start subsidies elimination and to provide incentives for improving energy efficiency.

The main energy policy priorities

Ambitious and effective programs are necessary for centralised power supply, especially for the establishment of gas flow measurement substation in each building and for the transition to the tariffs that provide a refund, including the renovation and improvement of the system. It is important that houses and other structures are allowed measure the flow and, correspondingly, has a possibility to change their consumption. These sites require a strong institutional capacity at central and local government levels for the development of policies and programs. Enhanced
cooperation of city authorities and local stakeholders should identify problems, quantify the potential to collect best data, develop policy and monitor progress.

*Expansion of the development and production from the pristine sources of energy.*

Ukraine has considerable potential for further development of hydrocarbon energy sources, including conventional and unconventional natural gas deposits such as shale gas and coal bed methane. To promote domestic production, Ukraine has to attract companies with relevant technology, expertise and financial resources.

The government should ensure proper and transparent legal and regulatory frameworks, including non-discriminating third party access to networks. Gas production by state-owned companies from the existing deposits shall be encouraged, allowing gas at more market price than the set normalised price that would improve the ability of investment and access to technology. The benefit for the country might be even higher if this approach would be combined with measures to limit the demand for gas. Ukraine also should focus on realising its biomass potential, such as biogas and power conversion of waste into energy.

*Supply chain modernisation*

Ukraine's energy sector requires significant and sustained investment for modernisation, security and competitiveness. The level of investment required should be at least of 1 700 billion UAH (EUR 170 billion) for the period up to 2030. Initially, the investments are required for oil and gas potential implementing. The infrastructure of natural gas transportation, distribution as well as central heating gas burning installation storage require major investment.

By having the largest transport infrastructure in the world and transporting huge volumes of Russian gas to European markets, Ukraine plays an important role in European energy security and, in turn, benefits from great transport revenues. To maintain its role in the transportation of gas and related income, Ukraine needs to attract investment for modernisation and optimisation of the transmission system, and the transparency and predictability of operations. In turn, the restructuring of NSC "Naftogaz of Ukraine" and the separation gas distribution and transportation systems at EU requirements will be very important indicators of change.

*Subsidies elimination*

Another strategic priority is a predictable and progressive elimination of subsidies for consumers of gas, coal and electricity and redirect budget funds to maintain energy efficiency measures. Although it will affect society hard, it will increase profits. These include: improving public funding and to redirect funds to support energy efficiency; ensuring price indices for industrial and domestic customers to upgrade equipment and technology, and investment effective improvements; improve the financial situation of NGOs, which have the burden of the high cost of subsidies.
Implementation of reforms in the sector

Structural reform of Ukraine’s energy sector takes time to develop and reach spheres of influence. This project provides a broad time frame in accordance with the following directions:

Within 3-4 years:
- subsidy burden can be lightened considerably and eliminated, as prices rise to market levels;
- improving energy efficiency can have an impact when there will be the improving of conditions enabling environment for investments, in response to some market price indicators (the most vulnerable subject to protection).

Within 5-8 years:
- domestic production of unconventional gas deposits and biomass could increase significantly, thus reducing dependence on imports and enhance energy security;
- natural gas consumption maybe reduced in central heating systems;
- improving consumer and industrial energy efficiency can bring significant results and lead to job creation and the development of new small and medium businesses.

Over 15 years:
- Ukraine itself will provide natural gas;
- the reform of the energy market may form the basis for active and more diversified energy sector, which has a complete and sustainable economic growth.

References to Chapter 6.2.2
ANNEXES

Oil balance, mm. t.

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### Optimistic scenario

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### 2.5. Natural gas balance, billion cub. M

#### Basic scenario

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#### Items of expenditure

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7. Carbon dioxide emissions accounting methodology

7.1. Accounting Methodology for Greenhouse Gases Emissions in Ironmaking, Steelmaking and Ferroalloys Production

D. Stalinskiy, V. Botshtein, V. Mantula, I. Stalinska, S. Spirina

7.1.1. Overview of mining and metallurgical works in Ukraine

Ferrous metallurgy is one of the leading economic sectors of Ukraine, which in the last decade provided about a quarter of the country’s GDP and approximately 40% of foreign currency inflow from products exports. Ukraine occupies the eighth position in the world in pig iron and steel production, and the fourth position in their exportation [1]. According to statistical accounting data on fuel-energy resources (FER) consumption indexes, mining and metallurgical works occupy the second position in industrial FER consumption in Ukraine [2]. Production of pig iron and steel is concentrated in 13 metallurgical complexes. In most cases, they are integrated enterprises where pig iron, steel and rolls are produced; also produced are sinter, lime, heat and electric energy, oxygen, blasts, compressed air and other alternative energy carriers. Metallurgical enterprises consume more than ¾ of all FER consumed by mining and metallurgical complexes of Ukraine.

7.1.2. Production of Sinter, Pellets, Ferroalloys, Pig Iron and Steel

7.1.2.1. Production of Sinter

Agglomeration – a thermal process of pelletizing fine dispersible materials (ferrous or manganese ore, concentrate, sinter turnover, metallurgical production waste and others), which are constituent parts of metallurgical charge, by baking with adequate quantity of flux (conventional or dolomitic limestone) using solid fuel (coke fines, anthracite culms) to achieve high quality raw material for the blast furnace process.

The most widespread method of agglomeration is baking of ore fines on grates with suction of air through the charge mix layer. During this, solid fuel, part of the charge, undergoes combustion. The charge mix must be maximally homogeneous. For an even oxidation of fuel in sinter process and to achieve a firm and porous sinter of desired chemical composition, it is necessary that the sinter possess required gas permeability, which depends on the grain size and the initial moisture content. To prepare charge mix, ore and raw materials are mixed in appropriate proportions. Compositionally homogenised charge mix, used in mining and metallurgical enterprises of Ukraine is as follow: sinter ore- from 90.8 to 320 kg / ton of sinter, concentrate- from 441 to 868 kg / ton of sinter, ferrous materials- from 30 to 487 kg / ton of sinter, lime- from 30 to 70 kg / ton of sinter, limestone- from 60 to 250 kg / ton of sinter, solid fuel- from 40 to 100 kg / ton of sinter.

The following are used as solid fuel in the sinter process. These are coke fines, anthracite culms, coal and turf. For filling sinter charge mix gas fuel is used (natural gas, blast furnace gas, coke gas and their mixtures in various proportions); likewise, ferroalloy gas in ferroalloy production.
Today in Ukraine, there are 67 functioning agglomeration plants in 10 enterprises:

- PJSC «ArcelorMittal Kryvyi Rih»;
- JSC «Zaporozhstal» steel works;
- PJSC «Azovstal iron & steel works »;
- PJSC «Mariupol metallurgical plants named after Ilyich»;
- PJSC «Dneprovsky Integrated Iron & Steel Works named after Dzerzhinsky»;
- PJSC «Yenakiieve Iron and Steel Works»;
- PJSC «Southern mining and processing complex»;
- PJSC «Nikopol Ferroalloys Plant»;
- PJSC «Alchevsk Iron & Steel Works»;
- PJSC «Ordzhonikidze mining and processing complex».

The highest volume of sinter produced in the year period 2001-2014 occurs on the year 2005, during which the volume of produced sinter totalled 47,520,000 tons.

During the sinter process, harmful impurities are evacuated, such as sulphur, and intangible amount of arsenic, carbonates are decomposed and the yield obtained is a lumpy porous fluxed material (agglomerate).

Fuel combustion during agglomeration is accompanied by emission of monoxide and dioxide of carbon, methane, oxides of nitrogen and sulphur.

Burning of carbon fuel during agglomeration leads to the formation of monoxide and dioxide of carbon according to the following reactions:

\[
2C + O_2 = 2CO,
\]
\[
C + O_2 = CO_2,
\]
\[
CO_2 + C = 2CO.
\]

Sources of carbon dioxide emissions into the atmosphere are fuel combustion processes and thermo chemical processes of decomposition of carbonates, contained in sinter charge.

Peculiar to agglomeration process is the complete heat absorption by the narrowing in height, lower layer zone of charge mix, which with a relatively high rate of gas suction practically exclude the possibility of complete combustion of CO (this reaction occurs at temperatures above 700° C). In other words, significant emission of carbon monoxide during agglomeration is technologically conditioned by the peculiarities of the sinter roasting process.

Therefore, origins of combustion products in gases are always removed first in agglomeration process.

Content ratio of \( \text{CO}_2 / \text{CO} \) in agglomeration practice is ¾, the ratio decreases with increase in fuel consumption.

Optimal carbon content in a charge mix must be in the range 2.5-5.5%.

Just as increasing the carbon content away from the optimal, so as decreasing it in charge mix will lead to agglomerate’s quality deterioration in terms of mechanical strength, and reduction in the productivity of sinter machines.

The major pollutants of atmospheric air in sinter production are the agglomerate roasting conveyor machines (the volume of pollutants emitted by the
sinter machine equals about 95% of total emissions from stationary sources in sinter production).

Analysis of emissions into the atmosphere from agglomerate roasting machines shows that the main culprits in polluting the atmosphere are carbon monoxide, sulphur dioxide, nitrogen compounds and substances in the form of suspended solid particles.

78% of emissions, released in agglomeration process are represented by carbon monoxide, other 8% - suspended solid particles, 11% - $SO_2$ and 2.5% - $NO_x$. The yield of CO in sinter production is proportional to the amount of fuel consumed for the baking process.

In agglomeration process about 2.5-4.0 thousand $m^3$ of sinter gas is produced from 1 ton of produced agglomerate.

Waste gases of sinter production at 110-120°C contain 73-77% of nitrogen, 15-19% of oxygen, 4-6% of carbon dioxide, about 1.0-1.3% of carbon monoxide, less than 0.01% of sulphur dioxide and up to 0.01% of nitrogen oxides, which are released into the atmosphere.

**7.1.2.2. Production of Pellets**

The main production of high grade iron ore pellets from the mixture of concentrate, limestone, bentonite and turnovers in Ukraine were organised at PJSC «Northern mining and processing complex», PJSC «Central mining and processing complex» and PJSC «Poltava ore-mining and processing complex».

The highest volume of pellets produced in the year period 2001-2014 occurs in the year 2007 – 22,380,000 tons.

The process of pellet production is comprised of two stages: achievement of crude (wet) pellets and strengthening of pellets (drying at temperature 300-600°C and roasting at temperature 1200-1350°C).

Wet pellets are obtained in rotary drums or dish-like and corpuscular granulators.

Concentrates which are sent for pelletization contain 8-10% of moisture. With the aim of imparting strength to crude pellets, small amounts of fine-grained clay (bentonite), limestone and others are added to the charge mix.

To improve the strength of pellets they are dried and roasted, typically, on the same set of installations; for example, roasting in “LURGI” and “OK-306” kilns at PJSC “Northern mining and processing complex”; “OK-324” at PJSC “Central mining and processing complex”.

Crude pellets of specific technological size are fed onto the screen, with the aid of which fines are separated, graded pellets are loaded onto the mobile lattice grates evenly, where drying and preheating takes place.

During preheating process, high temperature gas passes through pellets from top downwards, which allows achieve pellets of required strength, before roasting in the oven. The average temperature in the oven is 980°C. Thermal treatment of pellets on the lattice grate is done using hot gas, which is released from the rotary kiln.

The technological scheme provides for the release of residual gases from the rotary kiln into the preheating zone.
The kiln is equipped with a fan to supply air during the gas combustion. Burning of pellets is done by the combustion products of gas, which is fired with the aid of gas burners installed in chambers of the roasting zone.

After the kiln, pellets are transferred to the stationary cooling screen. After screening, pellets are fed for cooling to the ring cooler. At the loading section of the cooler there is a leveller, a wall for forming even layer of pellets. The cooler rotates in a horizontal plane; structurally it is divided into three sections: the working section, where pellet cooling takes place; loading section; discharge section.

Cooling of pellets is done by blowing cool air from top downwards. The working section is divided into two zones: recuperation cooling zone, where 70-80% of heat is absorbed from pellets, and the final cooling zone, where pellets are cooled down to 120°C. Gases are expelled into the atmosphere from the final cooling zone.

Roasting of pellets is an oxidation process, during which magnetite is converted to hematite:

$$4\text{Fe}_3\text{O}_4 + \text{O}_2 \rightarrow 6\text{Fe}_2\text{O}_3.$$ 

The formed hematite at temperatures above 1000-1250°C re-crystallises; its small grains combine to form larger ones due to diffusion in solid state, which results in strengthening of pellets. During fluxed-pellets production, in strengthening them, transformation through the liquid phase based on calcium ferrite $\text{CaO} \cdot \text{Fe}_2\text{O}_3$ and $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$ with melting point temperature of 1216-1230°C also plays a role.

The content ratio of FeO and Fe$_2$O$_3$ in pellets amounts to 5% and 95% respectively.

### 7.1.2.3. Production of ferroalloys

Ferroalloys are semi-finished products of metallurgical production – alloys of iron with silicon, manganese, chromium, and other elements, which are used during steel smelting (for deoxidising and alloying of steel, to bind harmful impurities, to provide metals with required structure and properties), and also to achieve other ferroalloys (processing ferroalloys). Ferroalloys differ in their constituent amount of major elements, carbon and impurities.

Ferroalloys are obtained by pyrometallurgical methods of reducing oxides of basic metals and iron. The most common is electrothermal (electrical-furnace) method of producing ferroalloys (so-called electroferroalloys). Reducing agents, by type, are differentiated into carbon-reductant, through which carbon containing ferroalloys (5-8% of C) and all silicon containing ferroalloys are obtained, and metallothermal (to which conditionally, silicothermal belongs), through which alloys with low carbon content (0.01-2.5%) are obtained.

Smelting of ferroalloys is carried out in open-type and closed-type three-phase ore-reducing and refining furnaces.

Alloy production technology envisages a continuous process with periodical discharge of molten products. According to the direct reduction technology, clean carbon coke and coal are used as reductants. As a result, the products of reduction are carbon monoxide and carbon dioxide (CO and CO$_2$).

In the operative furnace, electrodes are immersed into solid charge mix, which is replenished when it melts. An electrode is comprised of a cylindrical housing that
is filled with special electrode mass. The electrode mass is prepared from thermal anthracite and peck.

In refining electric furnaces that are operated in intermittent mode, the reducing agent is silicon of silicomanganese.

Presently in Ukraine, the strongest producers of ferroalloys, accounting for 88 to 96% of total production in different years are:

- PJSC «Zaporozhe Ferroalloys Plant» (ZFP);
- PJSC «Nikopol Ferroalloys Plant» (NFP);
- OJSC «Stakhanov Ferroalloys Plant » (SFP).

The major types of ferroalloys which are produced in these enterprises are silicon- and manganese-containing ferroalloys (ferrosilicon, ferrosilicomanganese, ferromanganese, metallic manganese). These alloys are smelted in ore-reducing electric furnaces of various capacities (from 5 to 75 MVA).

7.1.2.3.1. Types of ferroalloys

**Ferrosilicon** – an alloy of silicon and iron, which is used as a deoxidiser and an alloying addition in steelmaking.

Ferrosilicon production method includes reduction of silicon from quartzite by a carbonic reducing agent. To produce various grades of ferrosilicon (FeSi20, FeSi25, FeSi45, FeSi65, FeSi70 and FeSi75), the following charge materials are employed: quartzite, coke nut, coal coke of various size grades, metal chips. Smelting of ferrosilicon is carried out by continuous process in closed electric furnaces.

**Ferromanganese** is the name of alloys obtained by silicothermal and carbothermal reduction of oxidising materials, whose basic element is iron, and manganese with fractional mass from 65 - 95 % and limited by the upper fractional mass value of carbon, silicon, phosphorus, sulphur.

Depending on the fractional mass of carbon, ferromanganese obtained via electric furnace route is divided into low carbon-containing (fractional mass of carbon not exceeding 0.5%), medium carbon-containing (2.0%) and high carbon-containing (7.0%).

At PJSC «NFP» the production of carbon-containing ferromanganese is carried out by the flux-less and fluxed methods in closed furnaces of type “RKZ-22.5, RPZ-48 (63)” and sealed furnaces of type “RKG-75”. PJSC «ZFP» specialises in the production of high carbon-containing and medium carbon-containing ferromanganese.

**High carbon-containing ferromanganese** of FeMn78PB grade is alloy used for de-oxidation and alloying of steel.

To smelt high-carbon ferromanganese at PJSC «ZFP» to be used: imported manganese ore and manganese concentrates from Nikopol’s basin; 10x25mm coke nuts, allowed as substitutes for some parts of coke nut is coking coal of other size grades, likewise, coal of DGM and AM grades that meet specified technical parameters; steel chip of 14A grade or oxide scale.

Smelting of ferromanganese is carried out in open-type ore reducing furnaces on electrodes, which self-bake, by continuous process.

**Metallic manganese Mn95** is used for alloying and deoxidising special steels and alloys, as well as in chemical industry.
In Ukraine, metallic manganese is produced at PJSC «ZFP» in open refining electric furnaces of type “RKV” with capacity of 5 MV·A and 7 MV·A.

To smelt metallic manganese to be used the following charge materials: processing manganese slag ShMP78, processing ferromanganese 82% of SMnP grade in molten and solid form; lime of IF-2 grade.

Lime and solid components of charge mix are measured and fed into the electric furnace in self-discharging tubs. Pre-weighed processing manganese slag and ferrosilicomanganese are poured into electric furnaces in molten form. Smelting of alloy is done in open electric furnaces on graphite electrodes by periodic process.

Silicomanganese, and by the new terminology – ferrosilicomanganese is the alloy of silicon with manganese. It is used in steel production as deoxidiser and alloying addition. This is a ferroalloy based on manganese with fractional mass not less than 60%, silicon with fractional mass from 10% to 35% and phosphorus, sulphur and carbon with limited upper fractional mass values.

Smelting of ferrosilicomanganese at PJSC «NFP» is conducted in three-phased thermal ore-furnaces of RPZ-48 (63) type in a closed and sealed design and sealed furnaces of RKG-75 type. These furnaces, when required, are periodically rescheduled from ferrosilicomanganese production into producing high-carbon ferromanganese. Smelting of ferromanganese is done by continuous process with constant loading of charge materials.

7.1.2.3.2. Dust and Gas emissions

Production of ferroalloys in ore-reducing electric furnaces is accompanied by formation of the process gases (ferroalloy gas), of which the principal component is carbon monoxide (70-85%), smelting dust (suspended solid particles), sulphur dioxide, as well as nitrogen oxide in small amounts.

Carbon monoxide is formed in ore-reducing furnaces as a result of the reduction of oxides of basic alloy elements by carbon, contained in the charge mix. The formed carbon monoxide partly burns out in the working sector of furnace. CO content in ferroalloy gas that is collected under the arches of sealed and closed furnaces, depending on the produced alloy, is within the range 70-90%. Typically, the content of CO and CO₂ in ferroalloy gas are:

- When producing various grades of ferrosilicon CO is 80-88%; CO₂ is 3-7%;
- When producing ferromanganese CO is 71-82%; CO₂ is 9.5-10%;
- When producing ferrosilicomanganese CO is 80-85%; CO₂ is 7-10%.

During this period, waste gases of the ferroalloy furnaces undergo purification only from dust (suspended solid particles). Chemical cleaning of waste gases from its gaseous pollutants is not conducted.

Waste gases of hoods of ferroalloy furnaces

Part of ferroalloy gas (about 15%) from under the arches of closed ore-reducing electric furnaces via the annular gap (feeding funnel with charge mix) passes through the charge mix and burns on electrodes to form dust-gas-air mixture.

For this reason, all closed and sealed electric furnaces are covered by hoods equipped with aspiration equipment systems.
In open ore-reducing and refining electric furnaces, during alloy smelting, process gases with significant amount of dust are emitted from furnace baths. While escaping from the furnace top, these gases partially combust. Withdrawal of furnace top waste gases from open ferroalloy furnaces is done with the aid of hoods installed above furnaces.

Dry-type gas cleaning systems are installed for cleaning waste gases escaping from umbrellas of closed and open electric furnaces from dust.

### 7.1.2.4. Production of Pig Iron and Steel

In previous studies [3] it was found that iron and steel in the mining and metallurgical industry of Ukraine has the most significant contribution of greenhouse gas emissions (over 85%). This defining contribution of iron and steel to the total greenhouse gases emissions in mining and metallurgical industry of Ukraine is primarily conditioned by the significant consumption rate of FER in this domain. Greenhouse gases emission are defined by the volume and type of fuel used in production and also by the derivatives of carbon formed in the production.

It is also significant that the technological and energy purpose use of coke (the last being the blast furnace gas) accounts for 68% of fuel consumption in ferrous metallurgy (Fig. 7.1). It should be noted that the emission of coke and blast-furnace gas are the largest among all fuel types.

![Fig. 7.1. Consumption of different types of fuel at metallurgical enterprises](image-url)

Since 2000 till 2004, as observed in [4], at the metallurgical enterprises gradual growth of production capacity and introduction of low-cost energy efficient measures took place simultaneously. In 2004, and especially since 2005, technical upgrade of main production and energy equipment with introduction of new process technology and equipment were commenced. In 2007, production of rolled products equals 73% of the 1990 level, and utilisation of production capacity of major installations increased to an optimal level - 80-90%.
The increase in production capacity led to an adequate fall in energy intensity of products. In 2007, industrial and sectoral energy intensity of finished products practically reached the 1990 levels. The industry average, based on our calculations, of specific through consumption per ton of rolled products amount to 1.2 tons of equivalent fuel/ton, which is approximately 30% higher than the energy intensity of rolled products in developed countries.

At enterprises of Ukraine when producing pig iron, the major types of used fuel are coke, natural gas, coal, blast furnace and coke gases, as well as black fuel. Coke, coal and natural gas are supplied directly to the blast furnace. Natural gas, as a reducing agent and fuel in the blast furnace process, is used only in Russia and Ukraine; in countries of the European Union it is not used. Among all fuel types that are supplied directly in the blast furnace at enterprises of Ukraine, coke represents more than 82%. It is worth noting that in the last years, due to a fall in the direct use of natural gas in blast furnaces from 84 to 76 m³/ton, the use of coke has increased by 11.2 kg / ton.

Domestic and foreign experiences show that, as a result of using pulverised-coal fuel (PCF) in the amount of 200-260 kg/ton, it is possible to reduce coke consumption by 30-50% up to 270-310 kg/ton. Worldwide, this technology has been successfully implemented at over 130 modern blast furnaces. But presently, implementation of the PCF injection technology has been done only at 3 enterprises of Ukraine, as a result the coal use as fuel in blast furnaces is on average less than 22 kg/ton.

Steel smelting in Ukraine is mainly concentrated in the open hearth and the basic oxygen converter production routes. Worldwide, on average, 63.3% of steel production is done in basic oxygen converters. On average, 33.1% of steel is produced via the electric steelmaking route. Open-hearth steel production is preserved only in Russia and Ukraine. Average world production of steel in open-hearth furnaces amounts to 3.6%; in Russia it exceeds 22%.

Currently 67.3% of steel produced in Ukraine is from basic oxygen converter, which is higher than the world’s average. At the same time, a considerable lag exists in electric steel production (5%), while open-hearth production, irrespective of the 1.5 times downsizing as compared to year 2004, still produces about 28% of steel.

In the open-hearth production, in present day conditions, average use of equivalent fuel is 87.8 kg/ton of steel, including over 65 m³/ton of natural gas and 9 kg/ton of black fuel. Coke gas is used in insignificant amount. Single or double-bath open-hearth furnaces are utilised. It has been established that they differ significantly in consumption of fuel and pig iron. Single-bath furnaces consume larger amount of fuel, but however, consume less pig iron. In basic oxygen converter production, fuel consumption is 15 times lower than that of open-hearth production – 5.9 kg of equivalent fuel / ton of steel. Here the major fuel is natural gas - 3.8 m³/ton, as well as insignificant amount of coke, coal and coke gas.

In electric steel production, fuel consumption equals 31.6 kg of equivalent fuel / ton of steel, including natural gas – 15.4 m³/ton, coke – 7.8 kg/ton and coal – 7.1 kg/ton. Likewise, small amount of blast-furnace gas may be used in electric steel production. The rate of electrode consumption in electric arc furnace (EAF), on average, equals 4.0 kg/ton of steel.
It has been defined that in modern conditions, use of pig iron in steel production equals on average:
- in open-hearth production 698 kg/ton,
- in basic oxygen converter production 890 kg/ton,
- in electric steelmaking 32 kg/ton.

**7.1.3. Accounting Methods for Carbon Dioxide Emissions in Pig Iron, Steel and Ferroalloys Production**

**7.1.3.1. Carbon balance in pig iron production**
Carbon dioxide emissions in pig iron production are connected with the influx of carbon with fuel into the blast furnace, and with charge mix materials. Fig 7.2 shows the technological scheme of production of pig iron at metallurgical enterprises of Ukraine.

Sinter and pellets provide the main input in consumption of iron-ore part of charge mix, 69.4% and 29.4% respectively.

In pig iron production carbon is fed into the blast furnace mainly with fuel (coke, coal and natural gas). Coke carbon in the blast furnace process performs two functions: firstly, it is a reductant in the iron oxides reduction reaction, secondly, it also serves as a source of energy, since the reaction of carbon with oxygen is accompanied by heat production.

Likewise, carbon is supplied into the technological process of pig iron production with charge materials. Sinter, pellets and iron ore are used as iron-ore charge materials, and limestone and dolomite – as flux material. Flux carbon during dissociation is also supplied into the blast furnace. Part of the carbon remains in the pig iron while its large part leaves the blast furnace with blast-furnace gases.

Fig. 7.2. Technological production scheme of blast furnace pig iron at enterprises of Ukraine
It is worth noting that part of the blast-furnace gas carbon as CO is further utilised as fuel at different phases of metallurgical production, and also transported out of the plant’s boundary. According to [5] this portion of blast-furnace gas carbon should be considered as coke used by the energy sector. In accordance with the recommendations of the UN’s group of experts on climate change [6], emissions of CO₂ in connection with the energy use of coke should be accounted in the “Energy” sector, category 1.A.2.a – “Ferrous metallurgy”.

Residual carbon of blast-furnace gas in the form of CO₂ determines emissions during pig iron production. Pig iron is later used in steel production, and its small amount realised as a commercial product.

Based on these considerations, carbon balance when producing pig iron is as follows:

\[
CO_{PI} \cdot C_{CO} + CL_{PI} \cdot C_{CL} + NG_{PI} \cdot C_{NG} + L_{PI} \cdot C_L + D_{PI} \cdot C_D + A_{PI} \cdot C_A + \\
+ P_{PI} \cdot C_P + O_{PI} \cdot C_O = PI \cdot C_P + DG \cdot C_{DG} + EF_{PI}^S \cdot 12/44
\]

Where

- \(CO_{PI}\) – coke consumption for pig iron production, which is directly fed into the blast furnace, ton;
- \(CL_{PI}\) – coal consumption for pig iron production, which is directly fed into the blast furnace, ton;
- \(NG_{PI}\) – natural gas consumption for pig iron production, which is fed directly into the blast furnace, m³;
- \(L_{PI}, D_{PI}\) – limestone and dolomite consumption for pig iron production, which are directly fed into the blast furnace, ton;
- \(A_{PI}, P_{PI}, O_{PI}\) – amount of sinter, pellets and iron ore for producing pig iron, ton;
- \(PI\) – quantity of produced pig iron, ton;
- \(DG\) – quantity of blast-furnace gas that is evacuated from the blast furnace, m³;
- \(EF_{PI}^S\) – total carbon dioxide emissions from pig iron production;
- \(C_X\) – amount of carbon in charge mix and other materials, ton of C/ton;
- \(X\) – CO, CL, NG, L, PI, D, A, O, DG;
- \(EF_{PI}\) – carbon dioxide emissions during pig iron production, which are considered in the category “Production of pig iron and steel” 2.C.1 “GRF”, ton of CO₂;
- \(EF_L\) – carbon dioxide emissions during pig iron production, which are considered in the category “Utilisation of limestone and dolomite” 2.C.1 “GRF”, ton of CO₂.

According to [7, 8], iron-ore part of charge mix includes Fe₂O₃, FeO, SiO₂, Al₂O₃, CaO, MnO, P, S and does not contain carbon. Hence, it is suggested not to consider emissions associated with use of sinter, pellets and iron ore for future calculations of emissions of CO₂ in pig iron productions.

\[
C_{CO} = (Q_{CO} - m_{SCO} \cdot Q_s) \cdot 100\%: Q_{CA}
\]

\[
C_{CL} = (Q_{CL} - m_{SCL} \cdot Q_s) \cdot 100\%: Q_{CA}
\]

Where \(Q_{CO}, Q_{CL}, Q_s, Q_{CA}\) – the calorific value, kcal/kg of coke, coal, sulphur, and carbon respectively;

\(m_{SCO}, m_{SCL}\) – sulphur content of coke and coal.
The magnitude of the calorific value of carbon and sulphur was determined according to [9]. It amounts to 8100 and 2250 kcal/ton respectively. Sulphur content of coke and coal was determined according to [10]. The magnitude of the calorific value of coke and coal was determined as follows:

\[
Q_{CO} = 7000 \cdot KE_{CO} \\
Q_{CL} = 7000 \cdot KE_{CL}
\]

Where, \(KE_{CO}, KE_{CL}\) – caloric equivalent of coke and coal, adopted from the state statistical data of Ukraine, the reporting form “11-ICC”.

### 7.1.3.2 Carbon balance in ferroalloys production

During ferroalloy production, carbon is supplied into the furnace with manganese raw-material (ore, concentrate, sinter), limestone, reductants (coke, coal, electrodes etc). Fig. 7.3 shows technological scheme of ferroalloy production.

Table 7.1, gives, as an example, data about charge mix and fuel consumption in ferroalloys production at various enterprises.

<table>
<thead>
<tr>
<th>Description</th>
<th>Consumption, ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore</td>
<td>2,035,223</td>
</tr>
<tr>
<td>Limestone</td>
<td>34,745</td>
</tr>
<tr>
<td>Coke</td>
<td>467,269</td>
</tr>
<tr>
<td>Coke fines</td>
<td>37,349</td>
</tr>
<tr>
<td>Anthracite</td>
<td>49,797</td>
</tr>
<tr>
<td>Electrodes</td>
<td>19,709</td>
</tr>
</tbody>
</table>

The major component part of charge mix is ore (77%).

The data about production volume of ferroalloys by type at various enterprises of Ukraine is shown in Table 7.2.

<table>
<thead>
<tr>
<th>Description</th>
<th>Consumption, ton</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is worth mentioning that when producing ferroalloys in closed or sealed furnaces, ferroalloy gas is produced that consists of monoxides and dioxides of carbon within the range: 70-90% and 3-10% respectively. Ferroalloy gas after cleaning from dust enters into the collector and is transported for technological use as fuel. Excess ferroalloy gas is flared in flames.

Part of ferroalloy gas escapes from closed and sealed furnaces through loading funnels, passes through charge mix and burns out at the electrodes forming dust-gas-air mixture, which is captured and exhausted into the atmosphere after purification.
In open furnaces during smelting, technological gases escape from the furnace bath and are partially combusted while moving out of the furnace top. Evacuation of top gases is done with the aid of hood, installed above furnaces.

According to [11], to calculate carbon dioxide emissions during ferroalloys production to be adopted the mass balance approach, in which all carbon monoxide emissions, contained in ferroalloy gas, are taken as equivalent to carbon dioxide emissions.

Carbon balance in ferroalloy productions is composed as follows:

\[
\sum_j Q_{vS_j} C_{vS_j} + Q_b k_i + Q_p C_p = \sum_k Q_{vA_k} C_{vA_k} + W_i \cdot C_{W_i} + FG \cdot C_{FG} + \frac{12}{44} E_f, \quad (7.2)
\]

Where, \(Q_{vS_j}\) – consumed amount of reductant to produce ferroalloys, ton;
\(C_{vS_j}\) – carbon content of reducing agent, %;
\(Q_b\) – limestone consumption for producing ferroalloys, ton;
\(k_i\) – coefficient, characterising the carbon content in limestone, calculated by formula (7.3);
\(Q_p\) – flow rate of raw materials for ferroalloys production, ton;
\(C_p\) – carbon content of raw material, %;
\(Q_f\) – volume of ferroalloy production, ton;
\[ C_F \] – carbon content of ferroalloys, %;
\[ FG \] – amount of produced ferroalloy gas, ton;
\[ C_{FG} \] – carbon content of ferroalloy gas, %;
\[ W_i \] – amount of generated wastes, ton;
\[ C_{i} \] – carbon content of i-amount of wastes, %;
\[ E_f \] – carbon dioxide emissions, ton.

The coefficient \( k_i \) characterising carbon content in limestone or dolomite, is calculated by the formula:

\[
k_i = (P_{12} \times \frac{100}{84} + P_d \times \frac{12}{84}).
\]

### 7.1.3.3 Method of carbon dioxide emissions' calculation in the sinter production

According to [12, 13] a separate method of calculating carbon dioxide emissions in sinter productions was not provided, but in 2006 it was separated by the IPCC administration [11].

Production of sinter is an integral part of pig iron and steel production. As raw material for producing sinter in plants to be used iron ore, concentrate, iron-containing additions (blast-furnace dust from blast-furnace productions) and fluxes (lime, limestone and others). As solid fuel in sinter plants of Ukraine to be used coke fines and coal. For igniting charge mix materials to be used natural gas or mixture of gases (natural, coke-oven and blast-furnace).

Carbon dioxide emissions are formed when burning gaseous fuel, coke fines and coal, decomposition of limestone and reduction of iron oxides from ore.

Based on data given by Kryvyi Rih National Mining Institute (KNMI), carbon content in ore depends on the type of ore and varies on average in the range: magnetite - from 0.89% to 1.17% and silicate-carbonate-magnetite - from 1.33% to 5.07%.

Carbon content in coke ranges on average from 85.0% to 88.0% (according to plants’ data).

Carbon content in sinter is about 0.1% (according to plants’ data). Waste gases of sinter machines contain carbon in the form of carbon dioxide and carbon monoxide. Waste gases of sinter machines, containing methane, suspended solid particles, oxides of nitrogen, sulphur dioxide and others are exhausted via the chimney into the atmosphere.

According to [11], to calculate carbon dioxide emissions in sinter production to be adopted the mass balance approach, in which all carbon monoxide emissions, contained in waste gases of sinter machines, are taken as equivalent to carbon dioxide emissions.

Carbon dioxide emissions in sinter production are calculated by the formula:

\[
E_a = \frac{4A}{12} \cdot \left( \sum_i V_i C_{V_i} + \sum_j G_j C_{G_j} + \sum_h Q_{p_h} C_p + \sum_l Q_{a_l} k_{l} + Q_o C_o - Q_o C_a \right),
\]

(7.4)
Where, $V_i$ – flow rate of $i$-amount of solid fuel for sinter production, ton;
$C_{Vi}$ – carbon content in $i$-amount of solid fuel, %;
$G_j$ – flow rate of $j$-amount of gaseous fuel for sinter production, ton;
$C_{Gj}$ – carbon content in $j$-amount of gaseous fuel, %;
$Q_p$ – flow rate of sinter ore for sinter production, ton;
$C_p$ – carbon content of sinter ore, %;
$Q_{ls}$ – flow rate of limestone for sinter production, ton;
$k$ – coefficient, characterising carbon content in limestone or dolomite, calculated according to the formula (7.5);
$Q_o$ – flow rate of additions (blast-furnace dust etc.) for sinter production, ton;
$C_o$ – carbon content in additions, %;
$Q_a$ – amount of produced sinter, ton;
$C_a$ – carbon content in sinter, %.

It was suggested that emissions of carbon dioxide from sinter production, related to the use of limestone, should be assigned to the sector “Industrial processes”, category 2.A.3 “GRF” “Production of lime and dolomite”, and when using gaseous fuel – to the sector “Energy”, category 1.A.2.a “Ferrous metallurgy”, other – to the sector “Industrial processes”, category 2.C.1.a “Production of pig iron and steel”. In the future, after the enactment of [11], all these emissions are suggested to be assigned to the sector, in which they belong, viz to the category 2.C.1 “GRF” “Production of pig iron and steel” of the “Industrial processes” sector.

7.1.3.4. Method of carbon dioxide emissions calculation in the pellets production

According to [12,14] a separate method for calculating carbon dioxide emissions in pellets production was also not provided, but in 2006 it was separated by the IPCC administration [11].

Pellets production is also an integral part of iron and steel production. The raw materials used for pellets production are concentrate, bentonite, and fluxes (limestone etc). Natural gas is used when drying pellets.

Carbon dioxide emissions at pellet producing enterprises are formed during the combustion of gaseous fuel, decomposition of limestone and reduction of iron oxides from ore.

Waste gases of roasting machines, containing carbon monoxide and carbon dioxide, suspended solid particles, nitrogen oxides, sulphur dioxide and others, are exhausted into the atmosphere through the chimney.

According to [11] it is suggested to calculate tons of carbon dioxide emissions in pellets production thus:

$$E_o = \frac{44}{12} \cdot \left( G C_G + Q_p C_p + Q_o k_e - Q_o C_o \right),$$

(7.5)

Where, $G$ – flow rate of natural gas for pellets production, ton;
$C_G$ – carbon content in natural gas, %;
$Q_{ls}$ – flow rate of limestone for pellets production, ton;
$k_i$ – coefficient, characterising the carbon content in limestone, calculated according to the formula (7.5);
$Q_{p}$ – flow rate of raw materials for pellets production, ton;
$C_p$ – carbon content in raw materials, %;
$Q_o$ – volume of produced pellets, ton;
$C_o$ – carbon content in pellets, %.

It was suggested that carbon dioxide emissions from pellets production, related to the use of limestone, should be assigned to the sector “Industrial processes”, category 2.A.3 “GRF” “Production of lime and dolomite”, and when using natural gas – to the sector “Energy”, category 1.A.2.a “Ferrous metallurgy”. In the future, after the enactment of [11], all these emissions are suggested to be assigned to the sector, in which they belong, viz to the category 2.C.1 “GRF” “Production of pig iron and steel” of the “Industrial processes” sector.

7.1.3.5. Method of carbon dioxide emissions calculation in ferroalloys production

Method of calculating carbon dioxide emissions differs greatly in the IPCC administration of 1996 [14] and 2006 [13]. According to [14], the amount of carbon dioxide emissions was calculated only based on the level 1 approach, using only production data and corresponding emission coefficients. According to [13], the amount of carbon dioxide emissions is calculated using carbon material balance.

Depending on the type of ferroalloys, the content of carbon monoxide in ferroalloy gas is within the range 70-90%, and carbon dioxide - 3-10%.

Carbon content in manganese ore depends on the ore type and equals on average: for oxide manganese ores - about 1.0%, for carbonate manganese ores - about 8.0% (according to ferroalloy plants’ data).

Carbon content in ferroalloys fluctuates in the range from 1.5% to 6.5% depending on the type of alloy (according to ferroalloy plants’ data).

According to [11] it is suggested to calculate tons of carbon dioxide emissions from ferroalloys production thus:

$$E_f = \frac{44}{12} \cdot \left( \sum_i Q_{iS_i} C_{iS_i} + \sum_h Q_{jP_h} C_{jP_h} + \sum_j Q_{oF_j} C_{oF_j} - \sum_l W_{i, W_l} C_{i, W_l} \right), \quad (7.6)$$

Where, $Q_{iS_i}$ – flow rate of $i$-amount of reductant for ferroalloys production, ton;
$C_{iS_i}$ – carbon content in $i$-amount of reducing agent, %;
$Q_{jP_h}$ – flow rate of $h$-amount of raw materials for ferroalloys production, ton;
$C_{jP_h}$ – carbon content in $h$-amount of raw materials, %;
$Q_{oF_j}$ – flow rate of $j$-amount of limestone for ferroalloys production, ton;
It was suggested that carbon dioxide emissions from ferroalloys production, related to the use of limestone, should be assigned to the sector “Industrial processes”, category 2.A.3 “GRF” “Production of lime and dolomite”, other – to the sector “Industrial processes”, category 2.C.2 “Production of ferroalloys”. In the future, after the enactment of [11], all these emissions are suggested to be assigned to the sector, in which they belong, viz to the category 2.C.2 “GRF” “Production of ferroalloys” of the “Industrial processes” sector.

7.1.3.6. Method of carbon dioxide emissions calculation in pig iron and steel production

There are several methodological approaches to the calculation of greenhouse gas emissions. They differ in selection and formation of the output data, but in real, they are based on the guiding principles of the Intergovernmental panel on climate change (IPCC).

According to the sighted guiding principles of the IPCC dated 1996 [12] it was suggested that to calculate emissions of CO₂ in pig iron production it should be as follows:

\[ V_c = k_c \cdot A_c - \left( \frac{m_c}{100} \right) \cdot A_i \cdot \frac{44}{12} \]  

(7.7)

Where, \( k_c \) – coefficient of CO₂ emissions when burning and /or using reductants, ton of CO₂ / ton;
\( A_c \) – mass of reducing agents, ton;
\( m_c \) – carbon content in processed pig iron, %;
\( A_i \) – quantity of produced pig iron, ton.

The coefficient of CO₂ emissions when burning and /or using reductants according to [12] is calculated as follows:

\[ k_c = \left( \frac{d_c}{100} \right) \cdot \frac{44}{12}, \]  

(7.8)

Where, \( d_c \) – amount of carbon in coke, %.

According to IPCC, reducing agents in pig iron production can be coke, coal and petroleum coke.

Emissions of CO₂ in steel production according to [12] should be calculated thus:

\[ V_s = \left( \frac{(m_c - m_s)}{100} \right) \cdot A_s \cdot \frac{44}{12} + k_e \cdot A_e, \]  

(7.9)

Where, \( m_s \) – carbon content in steel, %;
ke_s – coefficient of CO_2 emissions in electric arc furnace (EAF), ton of CO_2 /
ton;
A_e – quantity of steel, produced in oxygen converter or open-hearth furnaces, ton;
A_es – quantity of steel, produced in EAF, ton.

The stated methodology was used in the National Inventory Report of anthropogenic emissions from sources and adsorption sinks of greenhouse gas in Ukraine, which was presented to the UN supervisory committee on implementation of the Kyoto protocol, but in the National Cadastre only coke was considered as a reducing agent.

According to [12] carbon content in pig iron should be taken at the 3-5 % level. Greenhouse gas emissions, relating to decomposition of limestone and lime, as proposed by IPCC, should not be considered in pig iron and steel production, but assign to lime production. CO_2 emissions, which are connected with the use of coal and natural gas in pig iron production was not considered when compiling the National Inventory Report.

The given methodology did not take into account the peculiarities of metallurgical enterprises in Ukraine, specifically the use of coal and natural gas as reducing agents and fuel in the production of pig iron.

Based on above considerations, it is proposed in the context of this work to calculate CO_2 emissions as follows (ton of CO_2):

- emissions in pig iron production (EF_{PI}):

\[ EF_{PI} = \left[ CO_{PIT} \cdot C_{CO} + CL_{PI} \cdot C_{CL} + NG_{PI} \cdot C_{NG} - PI \cdot C_{PI} \right] \cdot 44/12 \quad (7.10) \]

Where, \( CO_{PIT} \) – is the technological flow rate of coke in pig iron and steel production, ton.

Considering the energy consumption of coke (\( CO_{PIE} \)), according to [7], we determine the technological flow rate of coke \( CO_{PIT} \) as follows:

\[ CO_{PIT} = CO_{PI} - CO_{PIE} \]

Therefore, the formula for calculating emissions in pig iron production could be:

\[ EF_{PI} = \left[ CO_{PI} \cdot C_{CO} + CL_{PI} \cdot C_{CL} + NG_{PI} \cdot C_{NG} - PI \cdot C_{PI} - CO_{PIE} \cdot C_{CO} \right] \cdot 44/12 \quad (7.10a) \]

- in steel production (EF_{S}):

\[ EF_{S} = \left[ PI_{S} \cdot C_{PI} + BK_{S} \cdot C_{BK} + CE \cdot C_{CE} - S \cdot C_{S} \right] \cdot 44/12 \quad (7.11) \]

Where, \( CE \) – flow rate of carbon electrodes to produce steel, ton;
\( PI_{S} \) – quantity of pig iron that was used in producing steel, ton;
\( BKS \) – quantity of iron and metal scrap that was used in producing steel, ton;

\( S \) – quantity of produced steel, ton.

The coefficient of \( \text{CO}_2 \) emissions when burning and/or using reductants for coke \((k_{CO})\), coal \((k_{CL})\) and natural gas \((k_{NG})\) is proposed to be calculated as follows:

\[
\begin{align*}
k_{CO} &= C_{CO} \cdot \frac{44}{12} \\
k_{CL} &= C_{CL} \cdot \frac{44}{12} \\
k_{NG} &= C_{NG} \cdot \frac{44}{12}
\end{align*}
\] (7.12)

Emissions, relating to the use of limestone and dolomite, to be proposed to assigned to the sector “Industrial processes”, category 2.A.3 “GRF” “Production of lime and dolomite”, and when using coke and natural gas in steel production – to the sector “Energy”, category 1.A.2.a “Ferrous metallurgy”. In the future, after the enactment of [11], all these emissions are suggested to be assigned to the sector, in which they belong. For example, if limestone is used as a fluxing agent in pig iron and steel production, then emissions resulting from its use should be assigned to the category “Production of pig iron and steel” of the sector “Industrial processes” 2.C.1 “GRF”. Henceforth, emissions of \( \text{CO}_2 \) should be calculated as follows (ton of \( \text{CO}_2 \)):

- emissions from pig iron production \((EF_{PI})\):

\[
EF_{PI} = [CO_{PI} \cdot C_{CO} + CL_{PI} \cdot C_{CL} + NG_{PI} \cdot C_{NG} + L_{PI} \cdot C_{L} + \]
\[
D_{PI} \cdot C_{D} - PI \cdot C_{PI} - D \cdot C_{DG}] \cdot \frac{44}{12}
\] (7.15)

Or:

\[
EF_{PI} = [CO_{PI} \cdot C_{CO} + CL_{PI} \cdot C_{CL} + NG_{PI} \cdot C_{NG} + L_{PI} \cdot C_{L} + \]
\[
D_{PI} \cdot C_{D} - PI \cdot C_{PI} - CO_{PIE} \cdot C_{CO}] \cdot \frac{44}{12}
\] (7.15a)

- in steel production \((EF_{S})\):

\[
EF_{S} = [CO_{S} \cdot C_{CO} + NG_{S} \cdot C_{NG} + L_{S} \cdot C_{L} + CE \cdot C_{CE} + \]
\[
PI_{S} \cdot C_{PI} + BKS \cdot C_{BK} - S \cdot C_{S}] \cdot \frac{44}{12}
\] (7.16)

Where, \( L_{PI}, L_{S} \) – flow rate of limestone in pig iron and steel production respectively, ton;

\( D_{PI} \) – flow rate of dolomite in pig iron production, ton.

It is worth noting that the proposals for calculating greenhouse gas emissions in pig iron and steel production, given above (formulas 7.15-7.16), highly meet the recommendations of the IPCC, dated 2006 [11], with supplementary additions considering the national peculiarities of iron and steel production.

Conclusions:
1. This chapter provides a brief overview of the mining and metallurgical complex of Ukraine, its structure, particular properties of energy consumption and the formation of greenhouse gases emission in the production of sinter, pellets, pig iron, steel and ferroalloys.

2. The issues of formation of the carbon balance of the technologically most complex processes - production of pig iron, steel and ferroalloys were considered.


4. The developed method can be used in the formation of the National Inventory Report of anthropogenic emissions from sources and adsorption sinks of greenhouse gas in Ukraine.

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