WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE
For sustainable energy.

World Energy Perspective

Energy Efficiency Technologies

Overview Report

WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE

Officers of the World Energy Council

Energy Efficiency Technologies: Overview Report

World Energy Council

Published 2013 by:
World Energy Council
Regency House
1–4 Warwick Street
London W1B 5LT
United Kingdom

Registered in England and Wales

No. 4184478
VAT Reg. No. GB 123 3802 48
Registered Office
Regency House
1–4 Warwick Street
London W1B 5LT

ISBN: 978 0 94612 125 0

Members of the WEC Knowledge Network on Energy Efficiency Technologies

Klaus Willnow
(LEADER) Germany

Elena Nekhaev
(WEC Director)

Alexandre Jeandel
France

Antonio López-Rodriguez
Spain

Arshad Mansoor
United States of America

Brian Statham
South Africa

David Henson
United States of America

David Jarrett
Namibia

Eduardo Coelho Corrêa
Brazil

Flavio Beretta
Italy

Greg Schmidt
Canada

Hendrik Jogschies
Germany

Jean-Eudes Moncomble
France

Jim Kelly
United States of America

Magdalena Urhan Rojas
Colombia

Mohamed Lakhdar Habib
Algeria

Riccardo Lama
Italy

Roberto Venafro
Italy

Wayne Chodzicki
Canada

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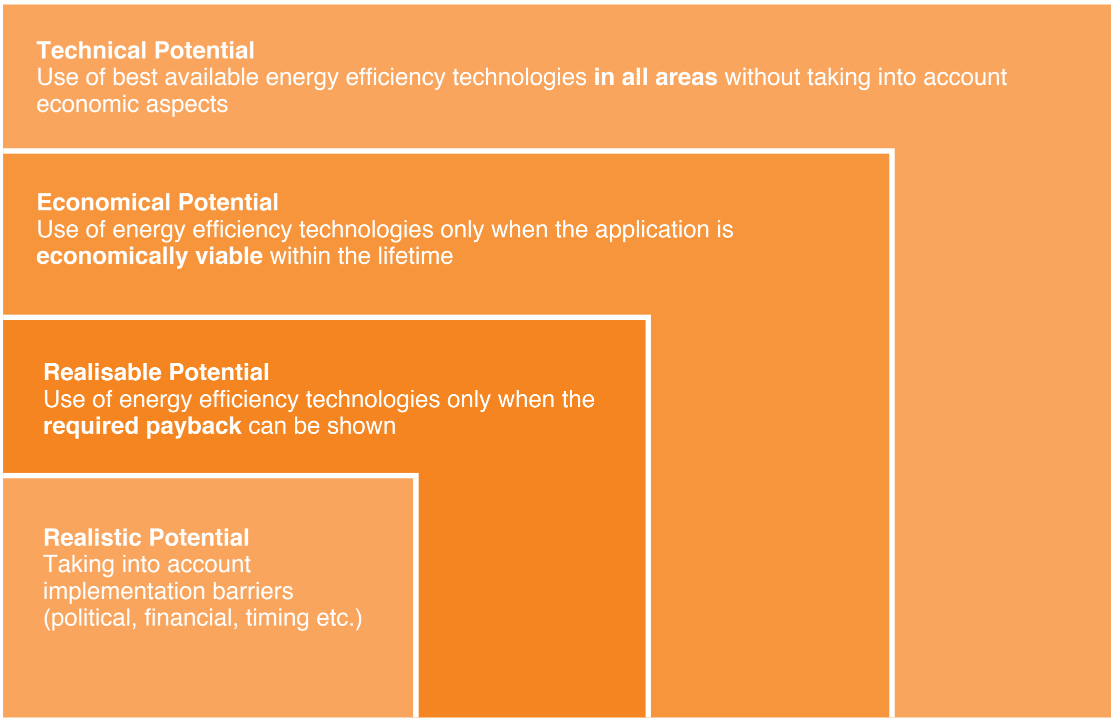
Summary

Ongoing development of technologies is an integral part of any business model, both for production and consumption. Technology is one of the main factors affecting competitiveness of the final product in the global market. Every new generation of products is by default more energy efficient than the previous generation, as energy efficiency is an important cost factor during the entire service life of the product. Energy efficient technologies can be found in all parts of the energy conversion chain: from exploration and production of primary energy resources, to power generation and oil refineries to electricity grids, to the final use in industry, buildings and transportation. But it is not only the technical potential which is crucial for successful introduction of energy efficient technologies. To assess the full potential of such technologies and identify the path towards their successful market introduction, it is necessary to consider their economic, realisable and also realistic potential. This report summarises the outcomes of a pilot project launched by the World Energy Council Knowledge Network on Energy Efficient Technologies in 2011. This work, focused on technologies, complements the well-established WEC work on Energy Efficiency Policies, and more recent study projects addressing Energy Trilemma and Scenarios.



Technical Potential
Use of best available energy efficiency technologies **in all areas** without taking into account economic aspects

Economical Potential
Use of energy efficiency technologies only when the application is **economically viable** within the lifetime

Realisable Potential
Use of energy efficiency technologies only when the **required payback** can be shown

Realistic Potential
Taking into account implementation barriers (political, financial, timing etc.)

The following key messages emerging from the first phase of the pilot project describe the technical potential of Best Available Technology (BAT) today:

- Oil & Gas exploration: Energy efficiency of the electrical system in upstream is around 20%, which ranks the lowest in the entire energy value chain. By implementing an all-electric system approach, energy efficiency could be increased up to 50%.

- Power Generation: World average efficiency of power plants (LHV) is 34% compared to BAT for coal-fired power plants (46%) and BAT for gas-fired power plants (61%).

- Transmission & Distribution grids: Electricity transport losses reach up to 12% of global average; BAT for high-voltage transmission is less than 4% per 1000km.
- Effective energy management systems increase energy efficiency by at least 5% irrespective of size, technology or process.
- Buildings account for about 40% of the total global energy consumption. It is estimated that energy savings in buildings could be between 20 and 40% or roughly between 1 and 2 Mtoe per year which is equivalent to the annual energy demand of a country like Namibia, for example.

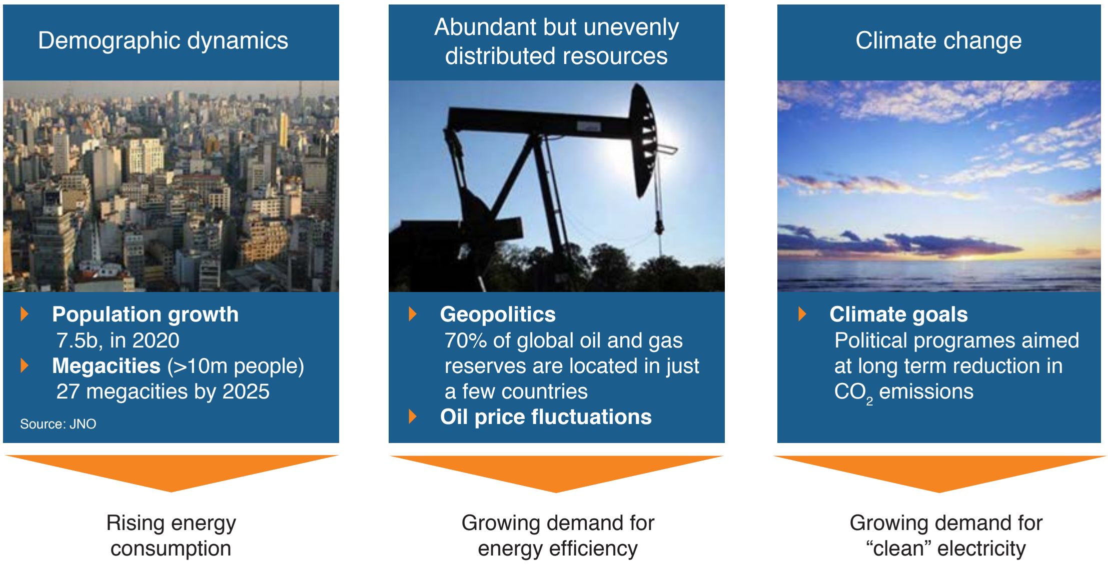
The key messages below describe the economical and realistic potential of Best Available Technology (BAT) today:

- A complete system analysis is required in many cases to leverage the full potential for energy savings, e.g. examine how energy efficiency of buildings can be best improved using insulation, automation, heating and cooling controls, or a combination of a few technologies, etc.
- Training and information for users are essential for reaching the full energy savings potential.
- The attitude of financial institutions should be changed to take into account the long-term nature of energy investments. Today, investors are looking for short-term gains, while energy projects have long lead times (3 year pay-back instead of 10 year pay-back for energy projects).
- Shift from CAPEX driven perspective to full life-cycle driven perspective is necessary to get a complete and real picture of the project costs vs benefits US & Canada.

1. Global Trends

The 21st century has so far been characterised by considerable changes in the way we understand and use energy, especially compared to the beginning of the industrialisation which started in the countries today referred to as “developed”. Today, the population of these countries accounts for 20% of global population and is hardly growing any longer, while in developing countries the population growth rates are considerably higher. Migration of people to large urban centres is leading to the emergence of megacities. The challenges of building infrastructure to match the global needs for energy, mobility, housing and food are enormous, and none of these challenges can be met without energy. While global energy resources are abundant and can meet the growing demand for energy for decades to come, their distribution around the world and implications for energy markets call for a more efficient use of both resources and energy systems. The current imbalances are amplified by a number of other associated issues, including for example an increased exploration of shale gas in North America. Climate change remains the most serious issue and it is driving the trends towards cleaner electricity and higher energy efficiency.

Figure 1
Global trends towards higher electrification



Demographic dynamics

- **Population growth** 7.5b, in 2020
- **Megacities** (>10m people) 27 megacities by 2025

Source: JNO

Rising energy consumption

Abundant but unevenly distributed resources

- **Geopolitics** 70% of global oil and gas reserves are located in just a few countries
- **Oil price fluctuations**

Growing demand for energy efficiency

Climate change

- **Climate goals** Political programes aimed at long term reduction in CO_2 emissions

Growing demand for “clean” electricity

The sustainable energy system is by definition a system where the three main drivers: security of supply, economics and environment are in balance with each other, the so called Energy Trilemma which is comprehensively covered in the WEC report World Energy Trilemma 2011 – Policies for the Future: Assessment of Country Energy and Climate Policy.

According to the International Energy Agency (IEA), the actual increase in global demand for electricity has been significantly higher than the projections of primary energy consumption (Fig. 2). This is a clear indication of the increasing importance of electricity for energy supply and end-use applications. For example, the annual increase of energy demand of 1.3% per year in the IEA's New Policies Scenario is considerably lower than the increase in electricity demand of 2.3% per year in the period until 2035. Moreover, the amount of electricity generated with low CO_2 emissions will rise substantially.

Figure 2a
Development of Global Energy Demand [3]

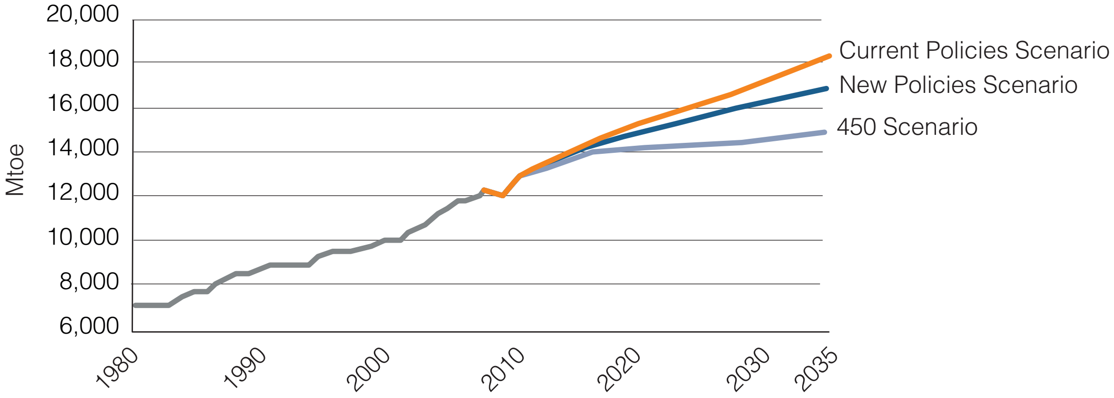
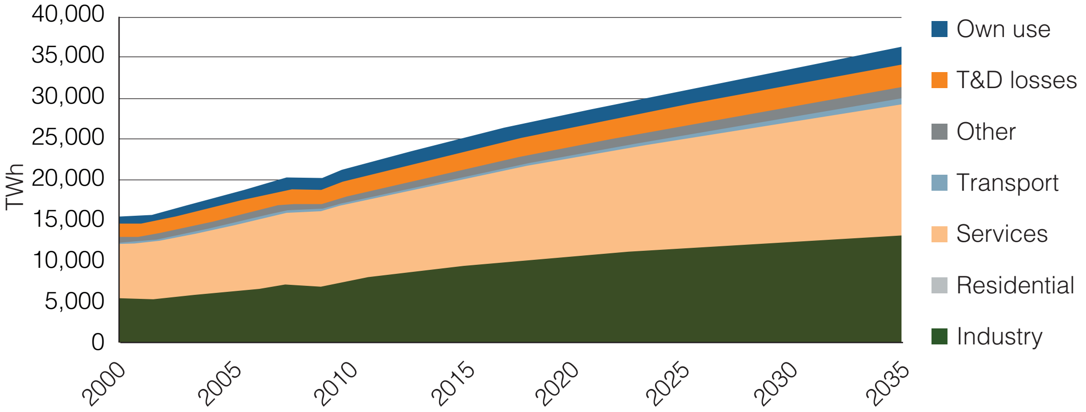


Figure 2b
Development of Global Electricity Demand [3]



In the energy sector, the measures to combat climate change result in three strategic priorities:

- decarbonisation of electricity supply,
- increase of energy savings along the entire energy value chain, and
- electrification of fossil fuelled based applications e.g. heat pumps, e-cars

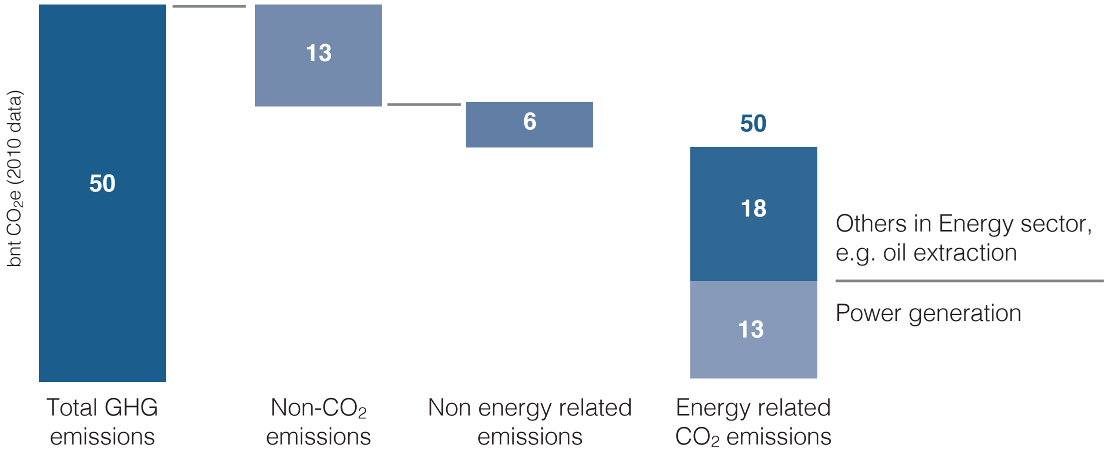
where there is a significant potential for net energy savings and emissions reductions. Energy efficiency is critical to all three aspects of this strategy.

According to the International Energy Agency (IEA) Energy Technology Perspectives (ETP) 2010 Blue Map Scenario, and the World Energy Outlook 2011, energy savings in the electricity sector alone could reduce carbon dioxide (CO_2) emissions by 7.3 Gigatonnes (Gt) in 2050 relative to business as usual (BAU), representing 17% of total anthropogenic emissions reduction.

Figure 3

Global anthropogenic CO_2 emissions by sector in 2010

Source: IEA, BP Statistics 2010

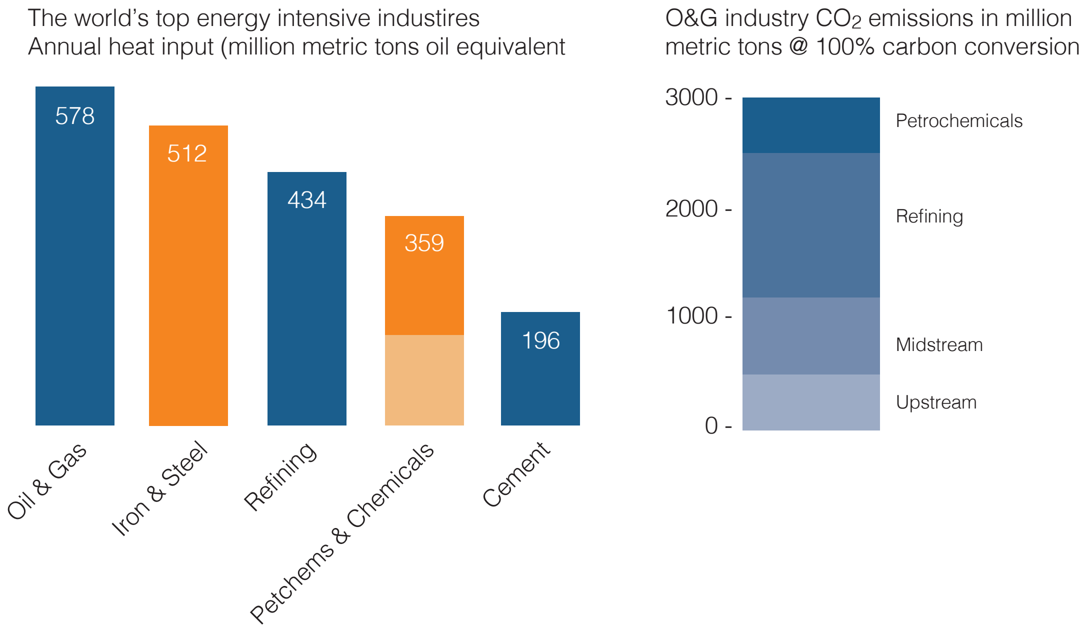


When it comes to emissions by sector of human activity, energy-related CO_2 emissions constitute the dominant part accounting for 62% of the total, and within this share, 13 $GtCO_{2e}$ come from power generation alone. The remaining 18 $GtCO_{2e}$ of the energy-related man-made emissions are divided between several industrial sectors. Fig. 4 shows that based on the heat input, the Oil & Gas sector with its up-/mid- and down-/stream business is the most energy intensive industrial sector.

Figure 4

Heat input of various industry sectors

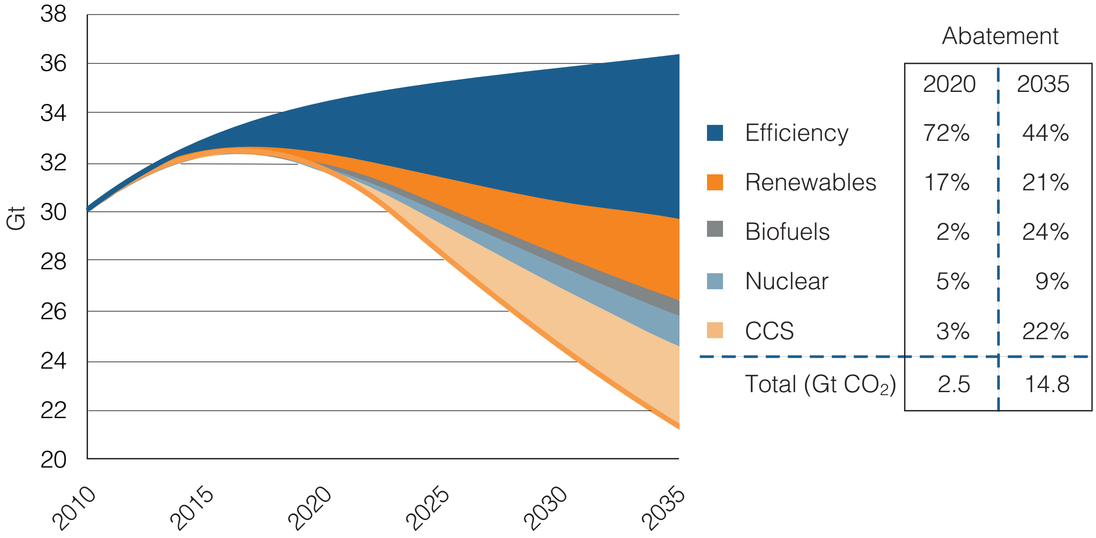
Source: IEA, DOE, Siemens (2008)



The IEA has shown in their 450 Scenario that improving energy efficiency is the least costly abatement option. Efficiency accounts for half of the cumulative global abatement share relative to the New Policies Scenario, or 73 Gt, between 2011 and 2035 (Fig. 5). The role of energy efficiency varies from one country to another, in terms of the remaining potential, energy pricing and other metrics. In OECD countries, despite significant efficiency improvements already in place, efficiency improvements in the 450 Scenario still account for almost 42% of abatement potential relative to the New Policies Scenario. Their share rises to 54% in non-OECD countries, where efficient energy production and use technologies are generally not widely deployed, due to both higher costs of efficient technologies and energy subsidies which do not encourage energy efficiency.

Figure 5

Scenarios for CO_2 emissions [3]



	2020	2035
■ Efficiency	72%	44%
■ Renewables	17%	21%
■ Biofuels	2%	24%
■ Nuclear	5%	9%
■ CCS	3%	22%
Total (Gt CO_2)	2.5	14.8

Many potential solutions for saving energy are readily available today and with already proven technologies. In power generation for example, ultra-supercritical coal combustion technologies (650°C, 265 bars) and combined cycle gas turbine power plants are excellent examples of highly efficient processes, so is power transmission with the latest ultra-high voltage AC and DC technology. Smart metering, efficient buildings, heat pumps, efficient motors, LED lighting and other applications can also contribute to higher energy efficiency. Life cycle analysis can help define the specific contribution of each technology and analyse which technologies are cost effective, i.e. reduction in total energy costs often provides positive returns on investments. Electric vehicles may be another example of future mobility solutions. It can also be a part of these solutions, depending on the electricity generation mix. However, cost-effectiveness still remains a considerable economic challenge when the cost of the battery is taken into account.

However, potential future cost savings alone are often insufficient to promote concepts supporting improvements in energy efficiency. There are still a number of barriers, such as

- lack of knowledge or skills to recognise and achieve potential savings;
- low priority relative to other costs;

- significant upfront costs, long pay-back periods and the risk that expected savings will not materialise;
- energy subsidies and currently not yet agreed externalities such as climate change.

According to WEC, energy consumption is growing less rapidly than the economic activity in all world regions, except the Middle East. This decreasing trend for the energy intensity (energy consumption per unit of GDP) accelerated since 2004 because of higher oil prices, technological enhancement and deployment of energy efficient technologies in appliances, bulbs, motors etc. and also the introduction of new policies: from 1.9% between 2004 and 2008 compared to 1.4% p.a. between 1990 and 2008. Additional energy policies and efficiency measures are needed to realise untapped energy savings. Their suitability varies due to differences in the ways decisions are made, such as:

- nature and location of potential energy savings;
- perception and culture related to benefits of energy efficiency;
- roles of key decision-makers: owners, tenants, operators, regulators, users; or
- electricity market and tariff structures, particularly subsidies and carbon costs.

2. Integrating Energy Efficiency Across the Entire Energy Value Chain

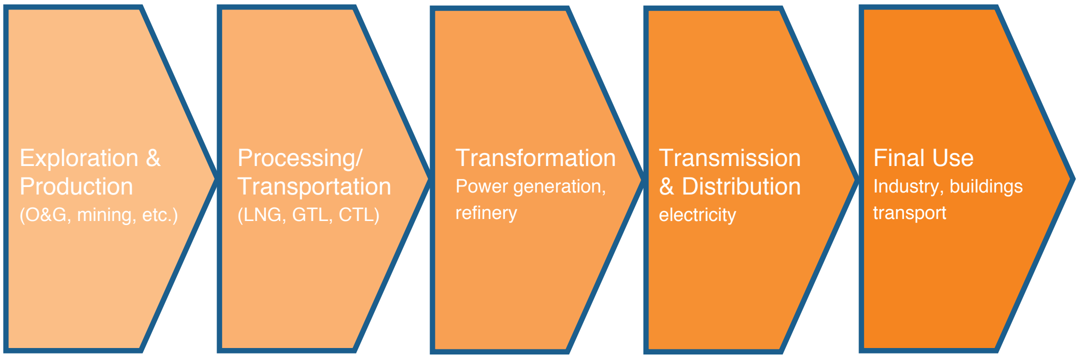
Whenever there is an energy or an environmental debate, energy efficiency never fails to be mentioned as something that can be easily implemented. For many people it looks like “a low-hanging fruit”, but the experience to date, both in the private and public sectors, does not support this assumption. There is a considerable technical potential for energy efficiency improvements along the entire energy value chain: from extraction of primary energy resources: oil, gas, coal, uranium and others, to their transformation into heat and electricity, transportation and distribution of energy, and ultimately to the final use by appliances, equipment and devices. Few research projects or studies have been able to estimate potentials with a required level of technical detail and produce reliable estimates of energy efficiency savings and communicate these findings in an easily understandable way.

Examination of Productivity/Output and Cost can produce useful insights into the efficiency of the entire process. It helps evaluate the impact of energy efficiency improvements and develop a common understanding of drivers behind these improvements. It helps reduce fuel consumption and increase the availability and the profitability of industry.

Measuring the impacts of energy efficiency

How can the impact of energy efficient technologies be measured and recorded? What savings can be achieved by deciding to use one technology, practice or appliance over another? To be able to answer such questions, it is necessary to define the reference point (baseline) to be used for measuring efficiency improvements. The baseline should also take into consideration ‘business as usual’ type efficiency improvements, i.e. the improvements that are due to take place anyway without adopting any specific efficiency measures.

Figure 6
Energy Value Chain



The energy value chain is a sequence of productive activities which starts with Exploration and Production (E&P) of the raw material (primary energy) for the subsequent processing, transportation, distribution and use. The more developed the value chain, the greater the benefits can be achieved through the improvements in energy efficiency.

There are a number of different approaches the industry has developed

In the last few decades, the recognition of environmental and socio-economic issues has increased significantly and not only amongst industry practitioners but also a wider range of stakeholders.

All assessment methodologies have their limitations. For instance, the nature of choices and assumptions made at the process outset may be subjective. Comparing results of different analyses (e.g. studies or modelling) is only possible if the assumptions and context of each analysis are the same. Generally, the information developed in an analysis should be used only as a part of much more comprehensive decision process or to understand the broad or general trade-offs. In this context it should be noted that industry develops energy efficiency guidelines for each specific design.

While conducting an assessment project, it is necessary to make assumptions, engineering estimates and decisions based on the values of involved stakeholders. Each of these decisions must be included and communicated within the final results to explain conclusions drawn from the data clearly and comprehensively. This will make the understanding of the pros and cons of each alternative easier.

What are the necessary steps?

A sustainable energy system based on the energy efficiency approach requires optimal integration of all components resulting in an integrated energy system. In order to setup the integrated energy system three tasks have to be completed:

1. Identify and specify your energy requirements.

2. Review possible options for efficiency increase along the entire energy conversion chain and select the most appropriate to match your requirements.

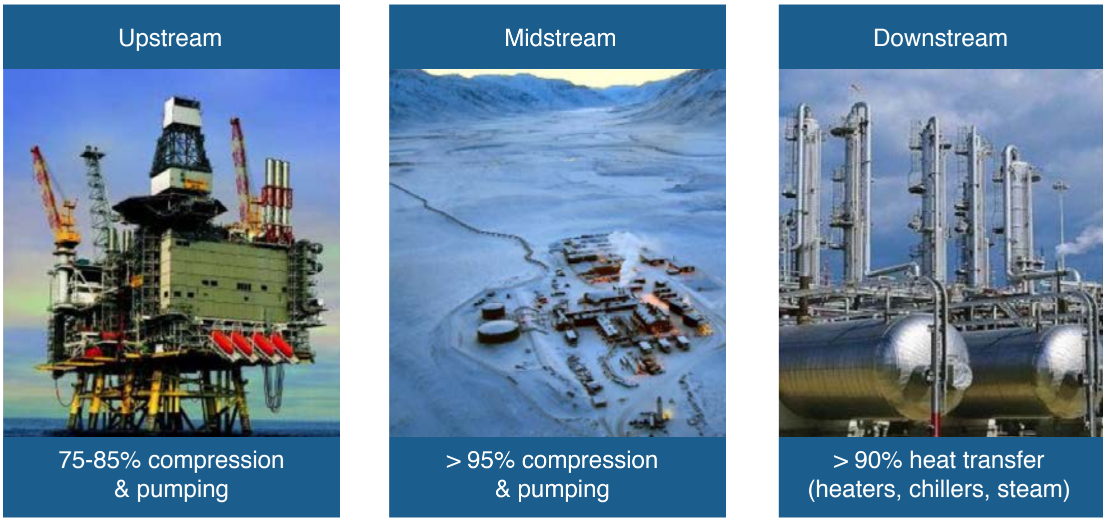
3. Optimise the system using tools such as Information & Communication Technologies, e.g. Control, Real Time Optimisation and Smart Grid Technologies across sectors and infrastructures along the energy chain and across regions.

Taking into account the many benefits provided by energy efficiency improvements, from reduced CO_2 emissions to billions of dollars in potential savings from lower energy bills, it is important to conduct specific assessment projects without further delay. To achieve faster progress in improving energy efficiency, guidelines, communication and information should take first priority, even more important than incentives. This is where governments can and should take a much more proactive approach. All energy investments and energy efficiency measures should be based on a cost/benefit analysis that includes environmental costs.

3. Energy Efficiency in Exploration and Production of Oil & Gas

The oil & gas (O&G) industry which is the most energy-intensive of all industrial processes has a great potential for efficiency improvements. The O&G is consuming about 20% of its output for its own process needs. Moreover, energy efficiency of O&G Exploration & Production (E&P) is low by any standards, as it hardly reaches 20%. Compared to the state-of-the-art power generation technology reaching over 60% efficiency, it is obvious that there must be a huge potential for the reduction of power demand for the E&P business. The reasons why the efficiency standard in E&P is so low need to be carefully analysed.

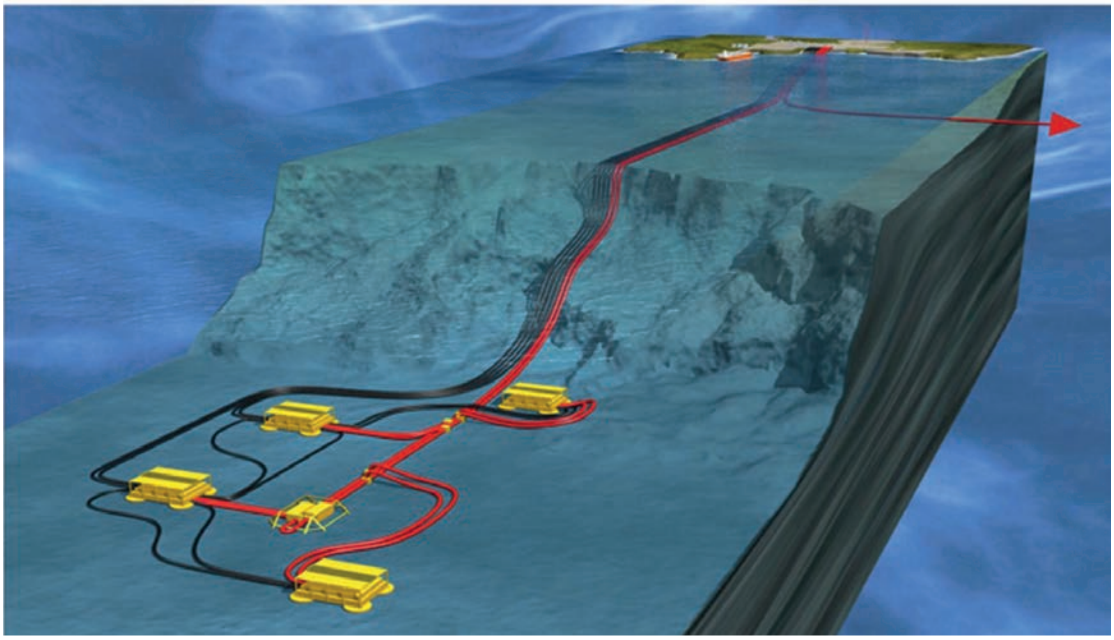
Figure 7
Oil and gas industry power demand in Upstream/Midstream/Downstream



The most visible activity in the oil and gas value chain is Exploration and Production (E&P). The E&P business is considered to be the most risky link in the energy value chain, both in economic and physical terms. At the same time, E&P generates the highest returns. This helps companies to diversify their activities and rely on multiple revenue streams. It is obvious that such business is dominated by large vertically integrated companies which can afford long-term investment cash flow.

Deep water as well as applications in remote and Arctic regions strongly advance concepts that are fully automated and do not need operators. For instance, a concept is currently being developed by a company for deep sub-sea production by applying energy-efficient smart grid system technology. These so-called sub-sea systems will be fed by electricity transmission systems from above the water or from onshore power sources and they are capable of supplying and controlling fully autonomous exploration systems with electricity at depths of 2,000 meters and below.

Figure 8
Offshore and Subsea Smart Grid for Oil & Gas applications



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E&P investments ensure the liquidity of a market for petroleum services estimated at US$160 billion annually. These services include geophysical activities, such as drilling and associated services, engineering, construction, supply and maintenance of machinery and equipment. A systemic view promotes closer integration of the components of the energy value chain and taking into consideration the growing importance of energy to economies creates numerous opportunities for a number of related businesses to participate directly and indirectly in the industry.

4. Efficiency in Processing Industry

Energy efficiency in industry has improved significantly in the last decade, and additional improvements are still possible through the implementation of best available technologies (BATs) and design guidelines for existing assets. Moreover, efficiency measures offer some of the least-cost options for reduction of carbon dioxide (CO_2) emissions; however, a wider deployment of well-known, cost-effective policy instruments is needed to achieve this potential. Technologies such as carbon capture and storage (CCS), smelting reduction, separation membranes and black liquor gasification are expected to contribute massively to meeting these challenges.

Greater investment by both governments and industry is needed for research, development, demonstration and deployment of a wide range of promising new technologies and for identification and implementation of novel processes which will result in the CO_2-free production of materials in the longer term; for instance, induction (potential sectors: metallurgy, food industry), heat pumps for industry (potential sectors: food, chemistry, pulp and paper, iron and steel).

In the O&G Industry, the downstream business is strongly constrained by high crude oil costs, the required investments, increasing complexity of business processes and close monitoring of product prices, due to the huge impact of energy prices on national economies, in particular in developing countries. This can be attributed to the refining activity which has a long history of rigorous management of its operational costs, focusing on energy efficiency, maintenance practices, personnel management, etc.

In order to evaluate the energy performance of a refinery or petrochemical plant, analyse its performance trends and compare with other plants, it is important to consider performance indicators that take into account the complexity of the systems and its operations, and allow a critical analysis of its results by the manager, to bridge the gaps between the results and the proposed goals.

In general, the refinery energy management is based on the Energy Intensity Index (EII), developed by Solomon Associates, which developed standard consumption values for each refinery process plant, considering its impact, complexity, technological advances and good practices for operational excellence. The EII is calculated dividing the real consumption by the standard consumption, which is the sum of standard consumption values for each process calculated based on the unit supply and its specific standard consumption. Another methodology is the Energy Specific Consumption (ESC) dividing the real consumption by the sum of all refinery plants considering the complexity factor for each process.

In order to allow a critical analysis of its results with respective reporting and verification, the EII or the ESC must be implemented with three main priorities:

a. Measurement

b. Stratification

c. Optimisation of the plant thermal power balance

The importance of the Measurement and Stratification lies in their ability to filter available useful information and channel it to top management but also to the operators showing them the main variables influencing the results. The optimisation of the thermal power balance plays also a very important role, because it is necessary to adjust energy production and demand considering economics, feed flow rates and maintenance.

As a business index, the EII is also impacted by the fuel quality, flow rate and by the reliability of the systems, because it considers the operational capacity as its standard consumption unit. It is necessary that the Energy Manager shall not have a limited view of the business, but should also be concerned with the quality and priorities of maintenance and the maximum utilisation of the plants. The analysis of the index, the results and the implications of corrective actions should be routine work for the Energy Manager. Design guidelines also have to be a top priority in energy management of refineries and petrochemical plants, because it is very difficult to implement significant changes after the plant is in operation.

Based on the topics above, the following design and operational actions are usually considered to be good engineering practices to manage energy in a process plant:

- Optimise heat exchanger network, mainly in distillation units, using e.g. pinch technology
- Apply Total Site Analysis, searching for opportunities of plant integration and steam level optimisation
- Optimise Hydrogen Production, finding new catalysers, researching renewable feeds, pinch analysis, process control to reduce hydrogen losses, etc
- Analyze Columns Internals with low pressure drop and analyses integration with the heat exchanger network
- In heaters and steam generators, evaluate combustion air pre-heating, flue gas heat recovery and soot blowers distribution, taking into account NOx emissions.
- Consider Waste Heat Recovery and Cogeneration
- Evaluate Variable Speed Drivers for pumps and air coolers
- Implement Advanced Control and Real Time Optimisation
- Design Hybrid and Hijet Vacuum Systems
- Evaluate Refrigerant fluids and chillers for condensers, in order to reduce flaring
- Substitute big condensing turbines by electrical motors
- Implement Turboexpanders in Fluid and Hydro Catalytic Crackers and Hydrotreaters (FCCs, HCCs and HDTs)
- Elaborate action plan to prevent steam leaks and condensate recovery (steam traps)
- Reduce electric losses and improve thermal insulation
- Optimise service and instrumentation air system

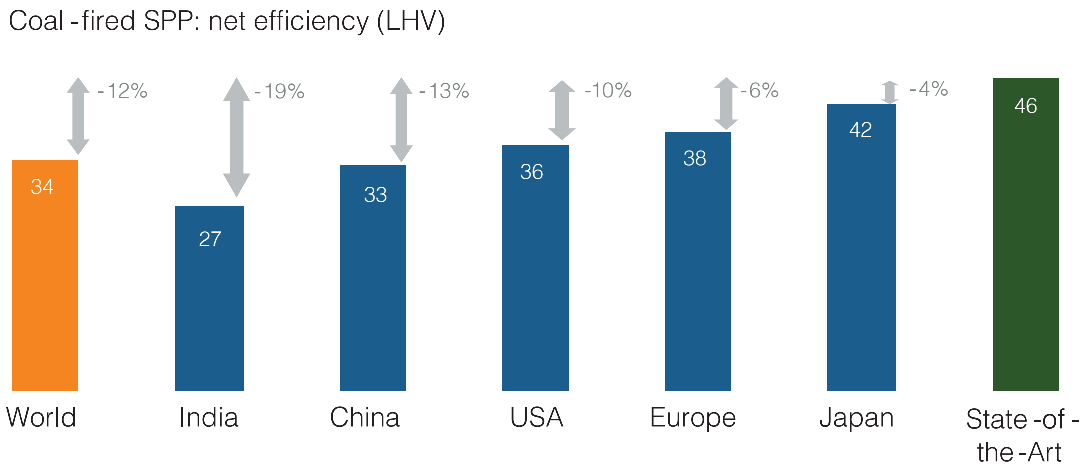
5. Efficiency in Thermal Power Generation

The transformation of thermal energy contained in the resource like hard coal, lignite, oil and gas, etc. into power has a long history. It all began with burning wood. Due to higher demands for heat and mechanical power and then electricity, coal became the primary fuel choice in the late 19th and in the 20th century. In addition, hydro power and in the second half of the 20th century, nuclear have been used for power generation. With the increasing use of natural gas in combined cycle mode the power generation efficiency could be raised significantly starting from the 1980's.

Increased operating efficiency as well as more efficient CO_2 capture and storage (CCS) in the medium term are the types of technology developments leading towards CO_2-free electricity production from fossil fuels. To give an example, Siemens has built a combined cycle power plant for E.ON AG in Irsching (Germany) with a capacity of 570 MW and an electric efficiency of 60.75%. This is the first plant in the world to exceed the 60-percent mark, and it will save over 40,000 metric tonnes of CO_2 annually compared with state-of-the-art power plants of existing design with an efficiency of 58%.

In coal-fired power generation, for example, efficiencies above 46% are being reached today with the aim to come close to the 50% level in the next few years. Although the state-of-the-art technology is at such high levels, the average efficiency of gas and coal fired plant across the world is approximately 41% for gas and 34% for coal. Looking at the coal fired power plant fleet, it becomes obvious that there is a huge efficiency potential. The total installed capacity of steam power plants in Europe is around 2,300 GW (2011) and 40% of them will be retired in the next two decades. That means roughly 1,000 GW of capacity needs to be replaced. In the USA, due to the availability and low costs of shale gas, old coal plants could be substituted by high efficiency combined cycles.

Figure 9
Net efficiencies [3] of coal-fired Steam Power Plants compared to state-of-the-art (2010)



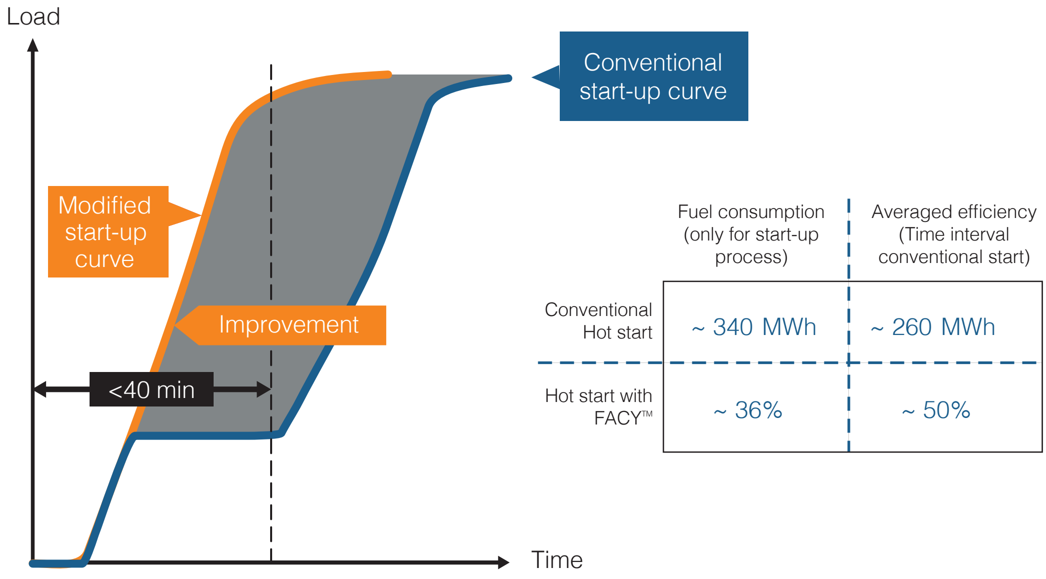
Carbon Capture and Storage (CCS) is the only large scale technology for mitigation of greenhouse gases emissions from fossil fuel power plants. Integrating CCS in fossil fuel plants leads today to a 6 to 10 % efficiency penalty.

Due to the increasing share of volatile renewable power generation from wind and solar, certain flexibility is needed with respect to controlling loads on the grid. Conventional power plants in the future must be capable of reacting even more rapidly to load changes by ramping the power plant output up or down. At the same time, more flexibility is needed at the load-side to react in a more elastic fashion, i.e. "load follows generation". This requires end-to-end detailed data from generation and via grid to load. How these requirements can be fulfilled together with a high level of efficiency can be demonstrated by the FACY (Fast-cycling) technology developed by Siemens. This technology improves the start-up efficiency of a gas-fired combined cycle plant by 14% during a hot start.

Figure 10

Start-up capability of a Combined Cycle Power Plant (CCGT) during hot-start

Source: Siemens



	Fuel consumption (only for start-up process)	Averaged efficiency (Time interval conventional start)
Conventional Hot start	~ 340 MWh	~ 260 MWh
Hot start with FACY™	~ 36%	~ 50%

In addition there are further possibilities to decrease the amount of fossil fuels and increase the efficiency of the overall power production e.g. in Combined Heat & Power (CHP) plants, by co-firing biomass in coal power plants or using sugar cane bagasse and straw in the ethanol processing industry.

Improving the reliability of power plant is another possible way of achieving higher overall efficiencies in power generation. It has been calculated that if all power plants in the world could operate with the same degree of availability which is today achieved by the top 25% of plants, the world could save at least US$80 billion per year and avoid CO_2 emissions of 1Gt and corresponding amounts of other pollutants.

6. Efficiency and Power Grids

Power grids play an important part in delivering electricity to the consumer. The grid uses a transmission system to transport large quantities of power at highest voltage levels, either with direct or alternating current (DC, AC). The distribution system secures transport of power at medium and low voltage levels. During this transport there are losses of power amounting to 12% which today is the global average. Therefore it is crucial to minimise the losses through an optimised set up of a grid structure combined with latest technologies.

However, the massive expansion of wind and solar generating capacity with its volatile output – is pushing the present supply infrastructure up towards the limits of its maximum performance capability. For instance in Germany and in the USA, grid constraints make it increasingly difficult to provide an adequate balance between generation and load due to the high renewables share, resulting in disconnection of generators in order to maintain stability of the electricity grid. A new challenge appears as a consequence: identify and implement the best solution amongst the possible options: electricity storage, high voltage transmission lines, optimisation on a broader area, etc.

Another consequence is the volatility of prices on the spot markets for electricity, which increasingly often reach very low or even negative values under strong wind and low load demand conditions. Today's grids in some regions are at the limit of being able to handle any additional volatile input. The IEA, for instance, estimates the investment required for electricity grids by 2030 to be as high as US$ 6.5 trillion.[1]

The European Wind Energy Association (EWEA[2]) estimates that the EU27's total generation capacity will reach 300-350 GW by 2030. Wind turbines will be built on land and, to an increasing extent, off-shore in the open sea. This means that it will be necessary to transport large amounts of electricity with minimum losses over long distances and therefore High-Voltage Direct Current (HVDC) transmission technology becomes an important issue for consideration. The highest-capacity electricity highway in the world has been built in China and more are in the planning: it will transport GWs of power from hydropower plants in the interior of the country over distances of thousands of kilometres to the coastal cities, with only minimal losses. This is possible by utilising transmission voltages of +/- 800 kV, the first time that a voltage level of this magnitude has been deployed anywhere in the world. Even higher voltage levels – up to and above 1,000 kV – are feasible with HVDC technology to transport large amounts of electricity over long distances, with transmission losses of about 3–4 percent per 1,000 kilometres. HVDC may become a part of the overall solution: HVDC is cost-effective compared to HVAC for distances above 100 km. However there are some drawbacks related to this technology, such as establishing a real network for example, today, HVDC is mainly a point-to-point solution.

In addition to the upgrade and expansion of the transmission grid, it will be necessary to adapt the distribution network structure for the new challenges. The one-way network of the

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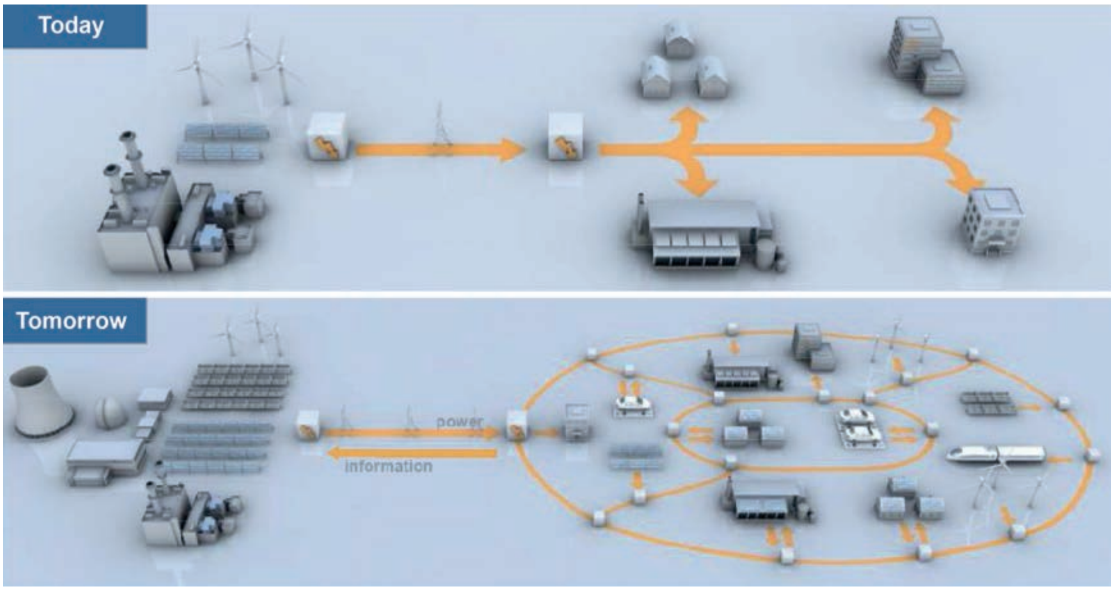
[1] International Energy Agency, *World Energy Outlook* 2009

[2] EWEA Report March 2008: *Pure Power – Wind Energy Scenarios up to 2030*

past will now have to be equipped for two-way load flow. This will call for increased use of information in the power network especially at the distribution level: in other words, a Smart Grid. This will be absolutely necessary assuming that the generation / load dependency will be transformed in the energy system of the future. The previous rule, that "generation follows load," will no longer apply. Power generation will fluctuate to such a large extent that this principle will be reversed into "load follows generation".

Figure 11
The paradigm shift in the electricity system



The Smart Grid will be the next step of development in electrical generation, transmission and distribution. Power in the old electrical grid flowed one way from generation through to the last load. The smart grid will allow two-way transfer of information between power provider and customer and even power transfer to the grid from users capable of providing electrical generation. Advanced Metering Infrastructure will allow greater efficiency and accuracy in billing while eliminating error and significant labour costs of manual meter reading. The communications infrastructure can also enable new advanced functionality such as, for instance, smart home appliances, electric vehicle recharging, data acquisition systems, etc. Smart Grid deployment will have direct impacts on greenhouse gas emissions through more efficient operation of the grid and optimal integration of distributed energy resources. Additionally, Smart Grid deployment will provide the customers with the right price signal and introduce incentives, which as it has been demonstrated result in an overall reduction in consumption: the customer becomes the main stakeholder in the search for efficiency and contributes to peak shaving.

The Smart Grid will therefore be critically important for the development of a sustainable energy system with its increasingly complex mechanisms. Monitoring and control of the current flow is the core function of the smart grid. Without these data, the power supply grid of the future will not be capable of absorbing large amounts of renewable energy and providing optimal control performance for maintaining the balance between fluctuating generation and load. In addition, Smart Grids will allow more rapid system restoration after outages and also the reduction of non-technical losses. With the integration of Information Technology (IT) in the grid structure for monitoring and managing the operation a Smart Grid becomes reality. The elements needed for Smart Grids are

- smart meters for small energy producers and consumers as well as for electric car infrastructure and
- efficient information and communication technology and sensors along the entire energy chain.

This will make electricity consumption more transparent and easier to control and therefore will help to save energy. The introduction of smart control systems also makes it possible to interconnect a variety of power generation, or to decouple individual supply areas from the rest of the system, so called Micro-grids. These micro-grids using distributed generation like PV, wind, biomass or micro-CHP could be developed towards independent systems where the connection to the grid is only used for back up reasons.

7. Efficiency in Industrial Use of Energy

Industry uses a large amount of energy to power a diverse range of manufacturing and resource extraction processes. Many industrial processes require large amounts of heat and mechanical power, most of which is delivered by natural gas, petroleum fuels and as electricity. In addition some industries generate waste streams that can be recovered to provide additional energy.

Because industrial processes are so diverse from the cold or low temperature required process to the high temperature required process, it is impossible to describe the multitude of opportunities for energy efficiency improvements in industry. There are a number of processes and energy services that are widely used in many industries. Many depend on the specific technologies and processes in use at each industrial facility. However effective energy management in industry, irrespective of size, technology or process, will increase energy efficiency by at least 5%.

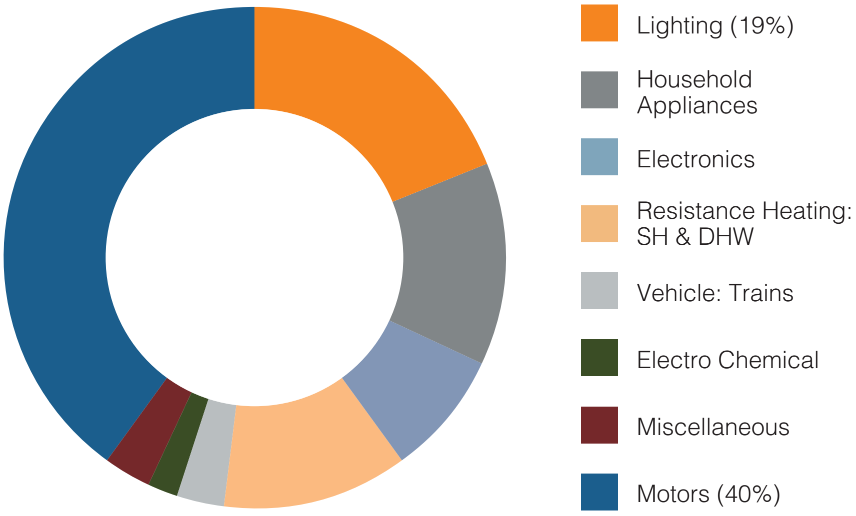
To implement co-generation, decrease process heat level and amount or recover the waste heat from process or utilities provides important Energy Efficiency opportunities in many countries.

Various industries co-generate steam and electricity for subsequent use within their own facilities. When electricity is generated, the heat that is produced as a by-product can be captured and used for process steam, heating or other industrial purposes. Co-generation converts up to 90% of fuel into usable energy.

Advanced boilers and furnaces can operate at higher temperatures while burning less fuel. These technologies are more efficient and produce fewer pollutants. Over 45% of the fuel used by US manufacturers is burnt to produce steam. The typical industrial facility can reduce its energy usage by 20% (according to the US Department of Energy) by insulating steam and condensate return lines, stopping steam leakage, and maintaining steam traps.

Figure12

Global electricity demand [4]



Electric motors are by far the most important type of electric load in industry using about 70% of the consumed electricity. In the tertiary sector, electric motor systems use about one third of the consumed electricity.

Electric motors usually run at a constant speed, but a variable speed drive allows the motor's energy output to match the required load. This achieves energy savings ranging from 3 to 60%, depending on how the motor is used. Motor coils made of superconducting materials can also reduce energy losses. Moreover, motors can also benefit from voltage optimisation.

Industry uses a large number of pumps and compressors of all shapes and sizes and for a wide variety of applications. The efficiency of pumps and compressors depends on many factors but often improvements can be made by implementing better process control and better maintenance practices. Compressors are commonly used to provide compressed air which is used for sand blasting, painting, and other power tools. According to the US Department of Energy, optimising compressed air systems by installing variable speed drives, along with preventive maintenance to detect and fix air leaks, can improve energy efficiency by 20 to 50%.

8. Energy Efficiency in the Transportation Sector

The estimated energy efficiency for an automobile is 280 Passenger-Mile/106 Btu. There are several ways to enhance a vehicle's energy efficiency. Using improved aerodynamics to minimise drag can increase vehicle fuel efficiency. Reducing vehicle weight can also improve fuel economy, which is why composite materials are widely used in car bodies.

More advanced tyres, with decreased tyre to road friction and rolling resistance, can save gasoline. Fuel economy can be improved by up to 3.3% by keeping tyres inflated to the correct pressure. Replacing a clogged air filter can improve a car's fuel consumption by as much as 10% on older vehicles. On newer vehicles (1980s and later) with fuel-injected, computer-controlled engines, a clogged air filter has no effect on mpg but replacing it may improve acceleration by 6–11%.

Energy-efficient vehicles may reach twice the fuel efficiency of the average automobile. Cutting-edge designs, such as the diesel Mercedes-Benz Bionic concept vehicle have achieved a fuel efficiency as high as 84 miles per US gallon (2.8 L/100 km; 101 mpg-imp), four times the current conventional automotive average.

The mainstream trend in automotive efficiency is the rise of electric vehicles (all electric or hybrid electric). Hybrids, like the Toyota Prius, use regenerative breaking to recapture energy that would dissipate in normal cars; the effect is especially pronounced in city driving. Plug-in hybrids also have increased battery capacity, which makes it possible to drive for limited distances without burning any gasoline; in this case, energy efficiency is dictated by whatever process (such as coal-burning, hydroelectric, or renewable source) generates the power. Plug-ins can typically drive for around 40 miles (64 km) purely on electricity without recharging; if the battery runs low, a gas engine kicks in allowing for extended range. Finally, all-electric cars are also growing in popularity.

9. Efficiency in Commercial and Residential Use of Energy

A building’s location and surroundings play a key role in regulating its temperature and illumination. For example, trees, landscaping, and hills can provide shade and block wind. In cooler climates, designing buildings with south-facing windows increases the amount of sun (ultimately heat energy) entering the building, minimising energy use, by maximising passive solar heating. Tight building design, including energy-efficient windows, well-sealed doors, and additional thermal insulation of walls, basement slabs, and foundations can reduce heat loss by 25 to 50%.

Dark roofs may become up to 39 C° (70 F°) hotter than the most reflective white surfaces, and could transmit some of this additional heat inside the building. US Studies have shown that lightly coloured roofs use 40% less energy for cooling than buildings with darker roofs. White roof systems save more energy in sunnier climates. Advanced electronic heating and cooling systems can moderate energy consumption and improve the comfort of people in the building.

Proper placement of windows and skylights as well as the use of architectural features that reflect light into a building can reduce the need for artificial lighting. Increased use of natural and task lighting has been shown by one study to increase productivity in schools and offices. Compact fluorescent lights use two-thirds less energy and may last 6 to 10 times longer than incandescent light bulbs. Newer fluorescent lights produce a natural light, and in most applications they are cost effective, despite their higher initial cost, with payback periods as low as a few months.

Effective energy-efficient building design can include the use of low cost Passive Infra Reds (PIRs) to switch-off lighting when areas are unoccupied such as toilets, corridors or even office areas out-of-hours. In addition, lux levels can be monitored using daylight sensors linked to the building’s lighting scheme to switch on/off or dim the lighting to pre-defined levels to take into account the natural light and thus reduce consumption. Building Management Systems (BMS) link all of this together in one centralised computer to control the whole building’s lighting and power requirements.

The choice of space heating or cooling technology in buildings can have a significant impact on energy use and efficiency. There are also district heating and cooling systems which can use city wastes. For example, replacing an older 50% efficient natural gas furnace with a new 95% efficient one will dramatically reduce energy use, carbon emissions, and winter gas bills. Ground source heat pumps can be even more energy efficient and cost effective. These systems use pumps and compressors to move refrigerant fluid around a thermodynamic cycle in order to “pump” heat against its natural flow from hot to cold, for the purpose of transferring heat into a building from the large thermal reservoir contained within the nearby ground. The end result is that heat pumps typically use four times less electrical energy to deliver an equivalent amount of heat than a direct electrical heater does. Another advantage of a ground source heat pump is that it can be reversed in summertime and operate to cool the air by transferring heat from the building to the ground. The disadvantage of ground source heat pumps is their high initial capital cost, but this is typically recouped within five to ten years as a result of lower energy use.

Smart meters are slowly being adopted by the commercial sector to focus staff on energy issues and for internal monitoring purposes the building's energy usage in a dynamic presentable format. The use of Power Quality Analysers can be introduced into an existing building to assess usage, harmonic distortion, peaks, swells and interruptions amongst others to ultimately make the building more energy-efficient. Often such meters communicate by using wireless sensor networks.

Conclusions

Energy efficiency sometimes is considered to be an easy solution for achieving immediate energy savings. Efficient technical solutions are available already today for most applications and uses. Technological developments are offering and will offer in the future a range of technical solutions for improving energy efficiency, but there are barriers: organisational, financial and behavioural which need to be addressed in a holistic way.

The ambitious goals for energy efficiency are reaching beyond purely technical solutions and go much further in terms of cost-effectiveness, financing, acceptance, innovation and environmental impact assessment.

- **Cost-effectiveness of technical solutions**: profitability of investing in energy efficiency technologies are often unknown or questioned. Governmental agencies should promote unbiased comprehensive studies of profitability, including cost/benefit assessments.
- **Financing** Energy efficiency requires a long-term commitment, and the financing framework should take this into account. The loan terms should be covering the entire lifetime of the solution.
- **Acceptance** Energy savings do not always turn out as expected (rebound effect). Acceptance and willingness to adapt to new consumption patterns are essential for successful implementation of policies and measures.
- **Innovation** Technology roadmaps can be useful tools for design of possible futures and help decision-makers to agree on short-term solutions.
- **Environmental impact assessment** should be based on a full life-cycle analysis, and also be realistic and achievable.

Case Study for the United States:

The Electric Power Research Institute (EPRI) has conducted field assessments of emerging energy-efficient technologies within the Energy Efficiency Demonstration project (see the EPRI final report 1025438). EPRI identified six categories of energy-efficient technologies with the potential to significantly reduce energy usage in US buildings and homes. These technologies were commercially available, but each had limited penetration in the US market. The Demonstration was launched to gain experience with these technologies and to gather data on their energy savings and performance in the field. The Demonstration also focused on validating applicability in North America.

The objectives were to

- Examine the efficiency and performance of the technologies.
- Assess energy savings for different climatic regions and different building designs and constructions.
- Identify and quantify different qualities of products within the technology category and effects when compared with traditional technology.
- Understand technical obstacles such as the possible impact that the technologies may have on the performance of the electric grid.

Heat Pump Water Heaters (HPWHs) for Residential Applications

Compared with the energy consumption that was calculated for baseline electric-resistance water heaters, the heat pump water heaters in this study used on average 50% less energy. The HPWHs were observed to provide minimal reduction to utility peak-day, on-peak demands. The average daily load shapes for the mixed-humid climate showed significant reductions in power during the morning and evening peaks, with reductions at the peak hour ranging from 47 to 56%, even in winter. Analysis of the small sample of cold-climate water heaters showed that in winter, those units provided only minimal reduction in peak power (10 to 25%) on average, although full-day energy consumption was 33 to 34% lower.

Variable Refrigerant Flow (VRF)

Variable refrigerant flow (VRF) is a family of air-conditioning and heat-pump products that expand the capabilities of traditional heating and air-conditioning systems with the incorporation of variable capacity and distributed control. VRF may emerge as a leading technology for managing both short-term load variations and long-term load growth. VRF operates on the same thermodynamic cycle as other heat pumps and air conditioners and is limited by the same overall efficiency constraints of ambient temperatures. Manufacturers claim for energy efficiency indicate savings over traditional HVAC equipment of 10 to 40% (depending on the building type, climate, and installation details).

Ductless Heat Pumps (DHPs) – Heating and Cooling of Residential Buildings

In the United States, space cooling accounts for about 18% of a residential electricity bill. Most people in the United States rely on central systems that feature a network of hidden air ducts that can become leaky and therefore inefficient. Ductless mini- and multi-split systems distribute cooled or heated refrigerant to one or more indoor wall- or ceiling-mounted fan-coil units, which transfer heat between the refrigerant and the room air. DHPs may thus reduce the energy consumption by up to 40% by eliminating air resistance and leakage, reducing fan power, eliminating unintended heat exchange between air ducts and the surrounding unconditioned air, and enabling zone-by-zone temperature control to avoid conditioning unoccupied spaces.

Light-Emitting Diodes (LEDs) – Street and Area Lighting

High-intensity discharge (HID) lighting prevails in illuminating streets. But high-power LEDs promise a brighter future with energy savings between 20 and 70%. The variation is largely due to differences in design constraints such as pole spacing, use of security cameras, and adequacy of existing designs. Although the cost of installing LED lighting is greater than the installation cost for conventional lighting (up to ten times higher in some cases), maintenance costs of conventional lighting far exceed the initial costs of their installation. LEDs also last longer than HID lighting – a lifespan as much as to 100,000 hours according to some manufacturers – which also reduces the maintenance costs.

Energy Efficiency in Data Centres: Efficient Power Supplies, Airflow Management, DC Power.

Energy usage at data centres doubled between 2000 and 2006, and it is poised to double again, costing data centres billions of dollars to power and cool information technology (IT) equipment. To reduce the energy consumption of data centres, various energy-saving concepts are being considered, from innovative technologies to best practices that have been verified to cut energy consumption. Replacing the standard AC power system with DC systems, data centres can reap the benefit of eliminating multiple AC-to-DC and DC-to-AC power conversions, resulting in a potential energy savings of 15%.

Residential Appliances Demonstration: Washers, Dryers and Refrigerators

EPRI targeted several important “white goods” – refrigerators, clothes washers, and electric clothes dryers for an energy-efficiency demonstration. Together, these appliances use about 15% of the residential electricity consumed in the US. Although the potential energy performance of washer/dryers is ambiguous, the potential for refrigerators is clear. Today’s average size unit uses less than a third of the electricity required by its counterpart of the 1970s – 1800 kWh/yr in the 1970s compared to less than 500 kWh/yr for today’s high-efficiency model.

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1. WEC Energy Efficiency Database (2010), www.worldenergy.org

2. Richard C. Dorf, *The Energy Factbook*, McGraw-Hill, 1981

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4. Institute for Industrial Productivity (w-iipnetwork.org) 2011: "Best Practices in Energy Efficient Industrial Technologies"

5. Electric Power Research Institute (EPRI): *Energy Efficiency Demonstration report*: Palo Alto, CA: September 2012. 1025438

Detailed Annexes (available on WEC website www.worldenergy.org)

1. Energy Efficiency Potentials and Barriers for Realization in the Industry Sector, Technical report prepared by Dr. Klaus Willnow, Siemens

2. Energy Efficiency Solutions for Existing Communities, Technical report prepared by Alexander Jeandel, GDF-Suez

3. Energy Efficiency Solutions for Thermal Power Plants, Technical report prepared by Dr. Klaus Willnow, Siemens

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Further details at **www.worldenergy.org** and **@WECouncil**

World Energy Council
Regency House 1–4 Warwick Street
London W1B 5LT United Kingdom
T (+44) 20 7734 5996
F (+44) 20 7734 5926
E info@worldenergy.org
www.worldenergy.org

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ISBN: 978 0 94612 125 0