IEC®

Coping with the Energy Challenge
The IEC's role from 2010 to 2030

Smart electrification – The key to energy efficiency

White paper

September 2010

2 INTRODUCTION

Over the next decades, the world will face increasing challenges to supply energy in sufficient quantities, while reducing carbon emission levels. Saving energy and using energy more efficiently are key to addressing these challenges. Ours is a connected world and energy efficiency solutions will need to work together, safely, everywhere to make a real impact. Not just in the developed world, but in developing countries as well.

However, without metrics all efforts to reduce and optimize energy consumption are doomed to remain small and insignificant. As the first IEC President, Lord Kelvin, always said: “If you cannot measure it, you cannot improve it!”. This statement is especially true here: without measurement you can’t credibly demonstrate energy efficiency improvements. The IEC provides and will continue to provide many of the measuring standards that are the basis for benchmarking, energy audits and compliance assessments.

But the IEC also holds an important piece of the solution for overall energy efficiency – smart electrification.

Electricity is the most easily controllable form of energy. The IEC believes that electricity will be the most important contributor to climate change mitigation. It is easily controlled and weightless. It is easier to transport and distribute and cleaner at the point of use than most other energy sources, and it can be produced cleanly at the point of generation. It represents the most efficient way of generating and consuming power and the most intelligent approach for future global efforts to economize energy.

With this paper, the IEC is laying the foundation for the electrical energy efficiency discussion.

To define where IEC’s work needs to be focused, the IEC has studied the wide array of energy efficiency opportunities and technologies that are available. Based on this the IEC has developed a model projecting what it believes is likely to happen in the next 20 years.

This document is a summary of those reflections and constitutes a roadmap and recommendations that will allow the IEC to develop the many standards that are needed to enable highest short- and long-term energy efficiency outcomes, today and tomorrow.

This document has been prepared by the IEC Market Strategy Board (MSB). The MSB was set up by the IEC to identify the principal technological trends and market needs in the IEC's fields of activity. It sets strategies to maximize input from primary markets and establishes priorities for the technical and conformity assessment work of the IEC, improving the IEC's response to the needs of innovative and fast-moving markets.

The MSB comprises 15 chief technology officers as members appointed from industry, and (ex officio) the IEC Officers.

Executive summary

In **Section 1**, the problem of energy demand, the energy challenge and the additional climate challenge are stated with a short summary of salient action points.

Section 2 summarizes available levers and their potential to reduce CO_2 emissions and increase energy efficiency.

In **Section 3** a definition for energy efficiency is provided, with a review of technology innovations that already today have the potential to significantly increase energy efficiency in power generation. This section also outlines the use of electricity and potential efficiency improvements in buildings and homes, industry and transportation.

Section 4 addresses the potential to reduce CO_2 emissions in power generation as well as carbon capture and storage.

Section 5 provides a sensitivity analysis regarding the overall impact of different energy scenarios and their ability to reduce long-term carbon emission levels.

Section 6 demonstrates what needs to change in the energy chain to achieve the CO_2 emission levels that can help humanity to mitigate climate change.

Section 7 offers a summary of critical success factors for implementing energy solutions, and in **Section 8** the MSB, author of the present document, presents key recommendations for the IEC.

CONTENTS

SECTION 1

Problem statement

The basis for much of the information in this section is the International Energy Agency's *IEA World Energy Outlook 2008* [1], augmented with information from the electricity domain.

1.1 Economy

The global economy is set to grow four-fold between now and 2050, and national growth could approach ten-fold in countries such as China and India.

This promises economic benefits and huge improvements in people's standards of living, but also involves much more use of energy. Unsustainable pressure on natural resources and on the environment is inevitable if economic growth is not de-coupled from energy demand, and energy demand from fossil fuel consumption.

1.2 Population

World population is expected to grow from an estimated 6.5 B in 2006 to 8.2 B in 2030, at an annual average rate of 1 %. This rate will probably slow progressively over the projection period in line with past trends: population expanded by 1.4 % per year from 1990 to 2006. The population of non-OECD countries as a group continues to grow most rapidly.

1.3 Energy demand

Growing populations and industrializing countries create huge needs for electrical energy. In the reference scenario of the International Energy Agency (IEA), which assumes that there are no new governmental policies other than those of mid-2008 (the so-called business-as-usual scenario, BAU), projected world primary energy demand increases by 45 % between 2006 and 2030 – an average annual rate of growth of 1.6 % – and doubles (i.e. a 100 % increase) by 2050. Electricity demand will triple by 2050.

1.4 Distribution of the population and energy demand by region

Today 1.6 B people have no access to electrical energy; however, they will require electricity in the coming decades. Furthermore, most of the new inhabitants of the planet will live in today’s developing countries. Therefore any measure envisaged affecting energy efficiency or consumption should take into account the fact that the new energy demand will be situated in those countries where energy distribution infrastructures are not yet at the right level to satisfy increasing demand.

In 2006, cities accounted for 67 % of the world’s energy consumption and 71 % of global energy-related CO_2 emissions, at a higher rate *per capita* than the countryside.

1.5 Distribution by type of energy produced

The combined power-generation and heat sector absorbs a growing share of global primary energy demand over the projection period. Its share reaches over 42 % in 2030 compared with 38 % in 2006.

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[1] The most recent edition, *IEA World Energy Outlook 2009*, does not present many significant differences.

Fossil fuels remain the leading sources of energy – roughly 80 % in 2030 (see Annex A). Coal remains the leading input for power generation and heat, its share of total inputs holding steady at about 47 % over the outlook period. Oil remains the dominant fuel in the primary energy mix, but its share drops to 30 % in 2030, from 34 % in 2006, while the share of gas rises from 21 % to 23 %. Nuclear power's contribution falls from 16 % in 2006 to 13 % in 2030. Hydropower's share remains steady at 6 %. Inputs from non-hydro renewables – photovoltaic (PV), wind, biomass and waste – will grow worldwide at an average rate of 6.2 % per year between 2006 and 2030, the fastest rate of all energy sources, with their share rising to 10 % but still remaining limited as a source of energy in 2030.

1.6 Distribution by type of energy used

According to the *IEA World Energy Outlook 2008*, industry, transport and buildings/services[2] are almost equal primary energy consumers ($^1/_3$ each). If we examine not primary but electrical energy, it is essential to note that almost half is consumed by industry, with all other uses making up the remainder.

In industry and buildings/services electricity is dominant, with the fastest rate of growth. In transport, on the other hand, electricity is almost absent, but its developing use could be one important part of the solution. Growth is most rapid in industry and slowest in buildings and services.

1.7 Carbon dioxide (CO_2) emissions

Today CO_2 emissions related to energy use are at a level of 28 Gt (Gigatonnes of CO_2 per annum), which represents 70 % of total greenhouse gas (GHG) emissions. Electricity generation represents something approaching a half of this, at about 11 Gt.

If no specific action is taken (in the so-called reference or business-as-usual scenario, BAU), the IEA projects in its *Energy Technology Perspectives 2008* that 42 Gt will be emitted in 2030 and 62 Gt in 2050; such a scenario could lead to a rise in global temperatures of up to 6 °C (see Table 1.1).

This is clearly not sustainable. The United Nations Intergovernmental Panel on Climate Change (UN IPCC) has demonstrated that, in order to limit the temperature rise to 2 °C, the concentration of CO_2 in the atmosphere must stay below 450 ppm (parts per million), and consequently **the world must not emit in 2050 more than half the GHG being emitted today.** Annex B and Annex C contain a comparison of three scenarios, the BAU, the 450 ppm and an intermediate one at 550 ppm.

Table 1.1 – CO_2 emissions in the BAU scenario (ref.: Table L.1)

	CO_2 emissions related to energy use	including:	CO_2 emissions from electricity generation
Today	28 Gt		10.8 Gt
2030	42 Gt		17.8 Gt
2050	62 Gt		29 Gt

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[2] In this paper, the phrase "buildings and services" also includes agriculture.

1.8 The challenge

We are faced with a double challenge: a purely energy challenge, and in addition a climate challenge. A new strategy is needed, which cannot be local but must be global. It must decouple energy consumption from economic development and growth.

In short: the challenge is ensuring energy availability and preserving the environment. The key elements are the following:

1) **Stabilizing climate impact from fossil fuel use**

2) **Meeting the energy demand of a growing global population**

3) **Bringing electricity to the 1.6 B people without access**

4) **Ensuring stable and secure energy access for all nations**

5) **Transporting electricity long distances from where it is generated to where it is used**

In figures, the challenge for the year 2050 is:

1) energy demand will increase by a factor of two,
2) simultaneously, CO_2 emissions must be reduced by a factor of two,

therefore the quantitative result to be achieved corresponds to a factor of four.

The present document is produced by an organization whose responsibilities do not extend to all forms of energy, but only to electrical. However, the coherence of the discussion requires that in certain contexts all forms of energy production and use should be treated together.

SECTION 2

Framework for solutions

2.1 Parameters for the response

1) **Climate change mitigation is economically meaningful, even essential**

   As indicated in the *Stern Review Report*[3], no action would cost from 5 % to 20 % of the global Gross National Product, where action will cost only 1 % of GNP.

2) **Climate change mitigation is politically supported**

   Political commitments for CO_2 emission reduction will frame action for the next 30 years:

   - Kyoto originally mandated a reduction of 8 % of emissions with respect to the 1990 level over the period to 2012
   - The EU Spring Council in March 2007 fixed a reduction of at least 20 % of the 1990 level as the basis, by 2020
   - Less than 50 % of the 1990 level by 2050 is the intention, according to some countries
   - Copenhagen follow-up, Bonn, Mexico, ...

3) **A key factor in the response must be electricity**

   - 31 % of global fossil fuel used each year goes to producing electricity
   - $^1/_3$ of final energy use in industry comes from electricity, with a growth rate of 2.7 %
   - Energy used in buildings/services also comes one-third from electricity, with a growth rate of 2.3 %
   - Introducing electricity into transport will enable economies by allowing control
   - Electrification of various other uses of energy will also increase efficiency

2.2 Targets for action

A useful statement of the problem might be the following: the more people there are, the more energy is used; the more energy is used, the more carbon dioxide is emitted; the more carbon dioxide is emitted, the more harm is done to the climate. A little more formally: at any point in time, total emissions of CO_2 are equal to the population, multiplied by the quantity of energy used per person, multiplied by the quantity of CO_2 emitted per unit of energy used:

$$CO_2 = P \times [E/P] \times [CO_2/E]$$

CO_2 = Quantity of CO_2 emitted
P = Population
[E/P] = Energy used per head of population
$[CO_2/E]$ = CO_2 emitted per unit of energy used

We will assume that P, population, is a given (see Section 1.2). We must therefore act on the [E/P] and $[CO_2/E]$ quantities in order to reduce CO_2 emissions (see also Annex C).

Acting on the [E/P] quantity is energy efficiency. It may be influenced in the short, medium or long term. Short-term action may already give significant results. The two strategic elements are efficiency in electricity use, and using electricity to replace a quantity of fossil fuel use.

Acting on the $[CO_2/E]$ quantity is decarbonization of energy, choosing energies which emit less or no carbon (renewables, biofuels, carbon capture and storage (CCS) and nuclear energy). Results are medium- and long-term.

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[3] http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

Some of the tactics which may be used are **investment** – investing to achieve reduction of energy use per person, and CO_2 emission per unit of energy used; **technologies** – identifying those technologies and strategies which are most cost-effective in achieving CO_2 reduction (note that these technologies and strategies will be different in different countries); and **individual action** – investment by individuals as well as by governments (e.g. buying energy-efficient appliances or paying a premium on electricity prices to be used for investment), and changing of behaviour to choose actions which use less energy.

2.3 Levers available

2.3.1 Inventory of actions and their potential

The following actions are available to reduce CO_2 emissions related to electricity generation and use. In most cases they concern mature technologies.

- Reduce energy used at end-use level by increased energy efficiency
    - Today available and proven technologies can bring savings of up to 30 %
    - The issue is massive implementation and not only with newly built but also with existing installations
    - End-use behaviour may be changed to reduce activities requiring much energy

- Reduce transmission & distribution losses (9 % today)
    - The benefit will be in line with the existing proportion

- Improve generation efficiency (only one third of primary energy used is available as electrical energy)
    - Existing power generation units will require time and resources to be converted
    - Coal is still available and cheap in many countries

- Increase renewable and specifically decentralized generation, almost CO_2-free
    - There are economic limitations (need to subsidize cost) and physical constraints (availability of land, wind, …)

- Change the fossil fuel mix towards less-CO_2-emitting fuels (less coal, co-generation, nuclear, Combined Gas Cycle Turbines, …)
    - As for generation efficiency, the existence of power plants which cannot be converted will delay real results

- Limit CO_2 emission at generation by capture and storage of carbon
    - The technology as well as a viable business model remain to be demonstrated

- Make transportation, today 99 % fossil-fuel (oil)-dependent, more energy-efficient with electricity

2.3.2 Measuring and evaluating possible responses

Electricity is a key factor in energy efficiency, on condition that its use is evaluated and controlled. Measurement and evaluation depend crucially on a few basic concepts. Calculations should be in terms of electrical energy as far as possible, and verified, so as to realize the benefits of control. For the whole electrical energy cycle from generation to consumption, i.e. for each of generation, transmission and distribution and in each application sector, EEE indicators should be defined and efficiency should be measured at each stage within each sector. For every value measured, the improvement which may be achieved by applying **Best Available Technology (BAT)** should be recorded. The reduction in CO_2 emissions should be based on full explanatory information on generation resources and any additional resources used; performance information, such as efficiency of generation, storage, and transmission; and CO_2 emissions calculated by life cycle analysis (LCA) of the infrastructure processes (see also Annex D).

In summary, two aspects are vital:

1) A systemic approach must be used which takes the whole cycle into consideration

2) Measurement and evaluation are necessary at each stage

The transport sector will gradually gain in importance, especially when electric vehicles become popular, but for the moment it has not been considered in this subsection.

2.3.3 Effects of electrification

Evaluation methods for energy efficiency should account for the effects of electrification, i.e. the conversion of energy-consuming tasks from another source (typically fossil fuel) to electricity. Substantial reductions may be expected, primarily because electricity can be extremely well controlled and measured, as well as through its versatility for different applications. In general, the net reduction in energy consumed is equal to the difference between the reduction achieved by electrification, and the energy consumed by the act of electrification itself (see Figure 2.1).

2.3.4 Effects of information & communications technology (ICT)

Evaluation methods for energy efficiency should also account for the intelligent introduction or extension of ICT. For example, if electronic communications replace the movement of people, the consumption of fossil fuel will decrease. In general, the net reduction in energy consumed is equal to the difference between the reduction achieved by the use of ICT, and the energy consumed by the ICT tools themselves (see Figure 2.2).

Total reduction in energy consumption = Reduction in useful energy consumption by electrification – Energy consumed in implementing electrification

Figure 2.1 — Reducing energy consumption by electrification

Total reduction in energy consumption = Reduction in useful energy consumption by use of ICT – Energy consumed by the ICT tools used

Source : “Deliverable 1 : Definition”, Focus Group on ICTs and Climate Change, ITU-T

Figure 2.2 – Reducing energy consumption by use of ICT

2.3.5 Behaviour changes

An enormous effect may be anticipated from behavioural changes on the part of individuals and society. This may run from the decision – as suggested above – to hold a “meeting” by electronic means, through the choice of environmentally neutral means of transport, to totally changing the population’s leisure pursuits, and will involve among other triggers spontaneous individual action out of concern for nature, emulation and changes in fashion, non-compulsory (e.g. financial) incentives and compulsory regulations. While from society’s point of view behaviour changes may prove to be the decisive lever and therefore must be stressed in all relevant contexts, this paper will not attempt detailed analyses or recommendations. This is because for the IEC, as in other technical contexts and in the domain of international standards generally, it makes no sense to act (or even to express opinions) in advance of the relevant signals from society and governments.

2.4 Perspectives for evolution

Energy generation today is mainly centralized, energy transmission and distribution take place in one direction only – from the generating plant to the consumer – and energy is used by consumers who only see the final result and have no information about energy usage in general. In Table 2.3 and a brief commentary we sketch some foreseeable developments.

For **electricity generation**, it may be expected that, by 2020, energy production will still be mainly centralized, using fossil fuels, but decentralized production at the place of consumption will be starting, using renewable energies (between 10 % and 20 %). Keeping in mind this evolution and plans for centralized renewable production, by 2050 it seems relevant to expect to progress from about 8 % of total energy consumption coming from renewable energy today, to about 40 %.

For **transmission & distribution**, major AC/DC grids will be interconnected and the consumer will combine consumption and production of energy. Grid design will evolve to a network of interconnected small and large grids. Figure 6.1 shows a grid diagram which illustrates energy generation, transport & distribution.

For **energy usage**, there will be a two-way relationship between the producer and the consumer, energy consumption measurement allowing flexible and negotiated strategies of use.

Regarding **buildings/services**, buildings will be active players, not only consuming but also producing energy. Thanks to information and communication technology (ICT) they will have the capacity to adapt to changes in internal conditions (e.g. different levels of activity) and to conditions in the grid. All building facilities will be integrated into an overall building and energy management system, using ICT and distributed sensors.

Electric vehicles will have interfaces to integrate them into the grid, and energy storage technology will be used.

Table 2.3 – Perspectives for evolution

		Today	2020	2030 and further
Generation		• Centralized	• Centralized (with more higher-efficiency thermal and nuclear) • Decentralized • Renewables (10 %-20 %)	• Centralized fossil and nuclear • Centralized & decentralized renewables (40 %-45 %) • Microgrids
Transmission and distribution	Large-scale	• Power flow : one-way, controlled by information technology (IT)	• Power flow: mostly one-way, UHVAC and UHVDC, optimally controlled by IT	• Major grids using UHVAC and UHVDC, optimally controlled by IT • Interconnected grids
	Small-scale	• Power flow: one-way • Starts changing from one-way to two-way	• Power flow: two-way • Development and introduction of control by IT	• Power flow: two-way • Interconnected and optimally controlled by IT
Usage		• Consumers have no information on usage	• Smart usage data • Consumers on the way to becoming producers also	• Consumers can optimize their consumption, production and CO_2 emission by energy management systems • Deployment of highly efficient end use

SECTION 3

Energy efficiency

3.1 Energy efficiency: a definition

Energy efficiency encompasses the overall efficiency of human activities using energy, not simply the measurable efficiency of a single process. It is therefore based on two complementary efficiencies: the efficiency of a given action or process – doing the same but with less energy; and the efficiency of the choices made – changing systems and social behaviour so as to use less energy altogether.

To illustrate the first aspect, optimization for electrical and electronic components may be achieved by developing minimum efficiency performance standards (MEPS). As a further example, both aspects will be needed to improve the energy efficiency of industrial activities: individual processes must be optimized, but in addition an overall architecture using a systemic approach will allow selecting and redefining processes so that global efficiency is augmented.

In *Energy Technology Perspectives 2008* the IEA has identified energy efficiency as the cheapest and, in the short and medium term, the most effective means of combating climate change.

Energy efficiency offers a triple-win outcome:

1) reduced CO_2 emissions,

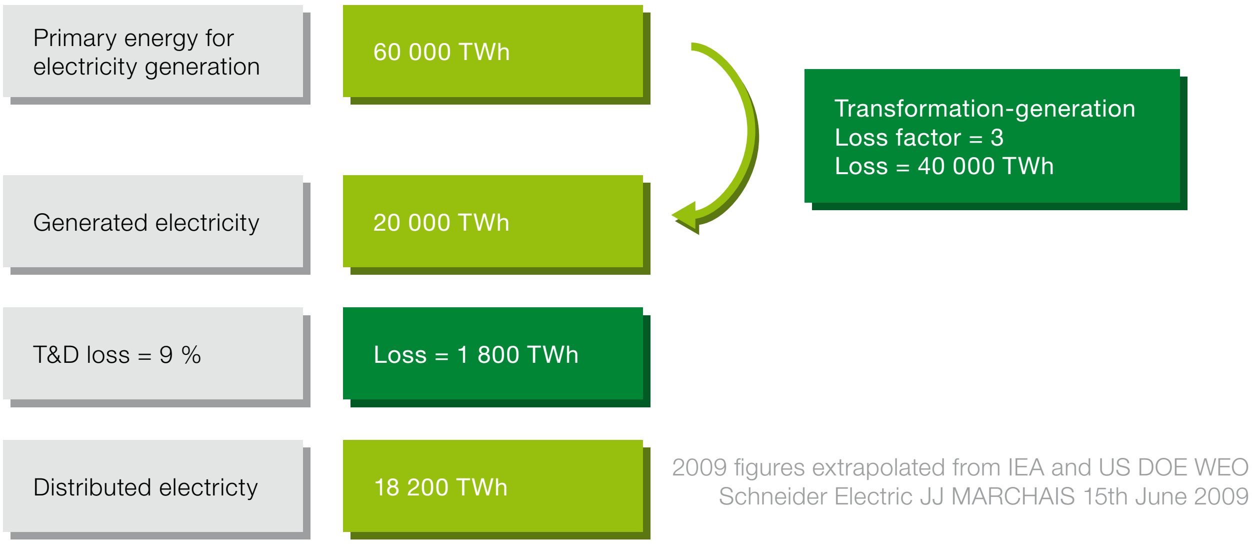
2) saving on scarce natural resources and reducing their depletion, and

3) reduced energy costs.

3.2 The current electrical energy chain

Electricity generation today represents 31 % of total global fossil fuel use, and around 40 % of all energy-related CO_2 emissions. However, of the fuel used to generate electricity, two thirds are lost in generation and another 9 % in transmission/distribution (see Figure 3.1).

In end use almost half goes to industrial applications, and of the rest residential buildings and service/commercial buildings each use about a half (see Figure 3.2).



2009 figures extrapolated from IEA and US DOE WEO
Schneider Electric JJ MARCHAIS 15th June 2009

Figure 3.1 – Losses in current energy chain

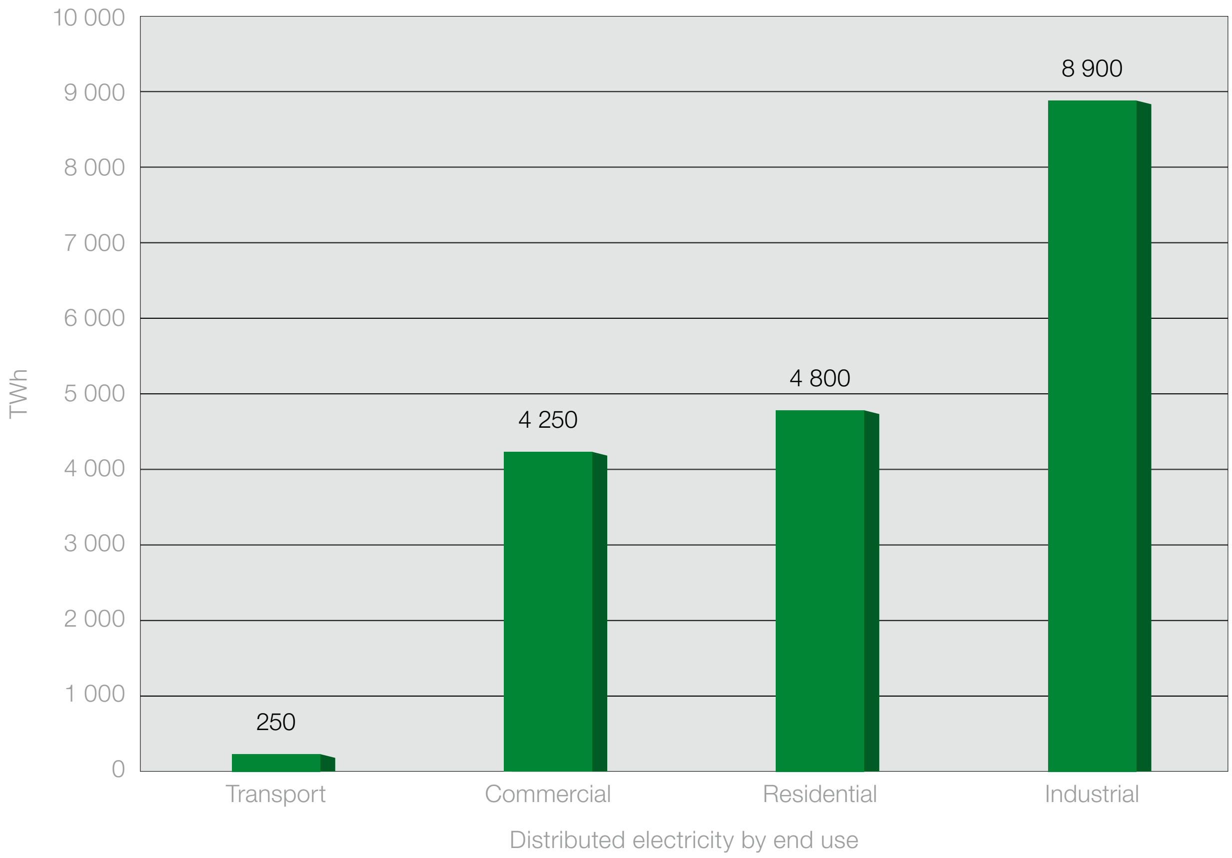


Figure 3.2 – End use of 18 200 TWh of delivered electricity

In summary:

- Only one-third of primary energy used in generation is transformed into electricity.
- Losses in transmission and distribution amount to about 9 %.
- In end use,
  - the quantities of electricity used in buildings/services and industry are almost equal;
  - the quantity of electricity used in transport is very limited at the moment.

The implications of this are as follows:

- Proven technologies can today save up to 30 %, so energy efficiency at end-use level should be implemented immediately and massively. The role of standards is to foster deployment.
- An increase in the efficiency of generation can give significant results, but research & development for new technologies need time to be implemented. The role of standards is to support the development of new technologies.
- In transmission and distribution (T&D) a proportional reduction in the percentage loss will not have much impact in the steady state, since the average loss rate is not high. However, as energy needs and especially the quantity of electricity distributed grows, each percent loss is significant. There are also specific situations where T&D loss is currently much higher than the average, where again a greater impact can be expected.

See Section 5 for an analysis of the effects of improvements at various stages in the energy chain.

3.3 Fossil-fuel power generation

Large-scale centralized generation will continue to have a key role in the production of electricity, and improvement of technology in this area – in addition to renewable energy – is therefore also important. The following are most significant for fossil-fuel generation:

- Improvements in the efficiency of thermal power generation
- Technology transfer of these improvements to all relevant countries
- Capture and storage of CO_2 (see Section 4.2)

Ideally less fossil fuel should be used, both in order to reduce CO_2 emissions and because of depletion of the natural resource. At the same time, in reality, fossil fuels will continue to play an important part in power generation in the future. It is therefore desirable to continue or expand R&D in fossil-fuel power generation in order to improve generation efficiency, reduce CO_2 emission to the atmosphere or both.

For the purposes of CO_2 reduction, spreading conventional but up-to-date technologies through international cooperation is also important, because the situation of thermal power generation varies by country.

3.3.1 Combined cycle (natural gas)

Combined cycle power generation is a method of generating electric power that combines a gas turbine with steam turbines. By employing a high-temperature gas turbine in the high-temperature section and by effectively recycling the exhaust energy of this section in the steam system, a higher thermal efficiency may be achieved in comparison with steam turbine generation. The most advanced type of combined cycle has achieved an efficiency of up to 59 %, mainly by raising the inlet gas temperature of the gas turbine to 1 500 °C. Combined cycle can follow fluctuations in demand as start-up and shutdown operations are straightforward. R&D is continuing in order to achieve even higher efficiencies, for example a thermal efficiency of up to 62 % with gas temperatures up to 1 700 °C (see Annex E).

3.3.2 Pulverized coal combustion (PCC) with supercritical steam

As many countries including developed countries are highly dependent on coal (e.g. USA: 50 %), and the coal reserves-to-production figure is assumed to be 147 years (higher than oil – 41 years – or natural gas – 63 years), improvement of thermal efficiency in coal-fired power generation may play a large role in the reduction of CO_2 emissions.

Various methods exist or are under development. Pulverized coal combustion (PCC) blows the pulverized coal with air to a boiler plant. PCC improves thermal efficiency through a higher combustion temperature, and also emits smaller quantities of polluting gases such as SO_x or NO_x. Thermal efficiency has been continuously improved mainly by raising steam temperature and steam pressure; an advanced type of PCC achieves a thermal efficiency of around 43 %-45 %. R&D for PCC is currently aiming to raise steam temperatures as high as 700 °C, which could improve thermal efficiency to 50 %.

3.3.3 Integrated Gasification Combined Cycle (Coal), IGCC

IGCC is a further innovation beyond pulverized coal combustion. IGCC presents slightly higher efficiencies of 45 %-48 %, compared with 40 %-42 % for conventional pulverized coal generation. Two types of IGCC, an air-blown system which enables lower auxiliary power consumption and an oxygen-blown system which enables easier CO_2 capture, are being developed and under field test by many countries, including US, UK and Japan. Some commercial IGCC plants are planned. For further application, some technical issues such as the combination with CO_2 capture and storage technology are being addressed.

3.4 Co-generation (combined heat and power, CHP)

Co-generation, which is also called Combined Heat and Power (CHP), produces electricity and hot water or steam simultaneously from the same power source. By this method fuel could theoretically be used to almost 100 % efficiency. Average performance would vary according to how well the relative demands for heat (e.g. hot water, steam) and for electricity corresponded to the supply. A higher average value for the efficiency would be achieved in regions where conditions require parallel supply of hot water or steam and electric power, such as the Netherlands or Scandinavia.

3.5 Fuel cells, including uses in combination with CHP & coal gasification

The fuel cell is a device which produces electricity from fuel and oxidant. Fuel cells are said to perform at a higher efficiency than heat engines as they are independent of Carnot efficiency. Though there are still many issues, such as a requirement for large cost reductions or longer life expectancy, the fuel cell has additional advantages such as quiet operation and modular construction that is easily scalable. Thus fuel cells are expected to be widely applied in many fields such as combined heat and power (CHP – see Section 3.4) or for mobile phones.

As for micro-CHP, which is expected to improve energy efficiency in the residential sector, an advanced residential cogeneration system exists in Japan (see Figure 3.3). In 2005, the New Energy Foundation (NEF) started a large-scale field test of a Proton-Exchange membrane Fuel Cell (PEFC) for introduction to the market. In four years 3 307 units were installed and provided a 1.3 t CO_2 reduction in the total of 5.2 t per year per living unit (household). The units started commercialization in Japan in 2009.

Many types of fuel cell are now in research and development to overcome the issues and find wide application. Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) is an advanced application of the fuel cell. It consists of an oxygen-blown coal gasifier, a gas turbine, a solid oxide fuel cell (SOFC) and a steam turbine, and is expected to achieve thermal efficiency of up to 60 %, which is much higher than conventional pulverized generation or even integrated gas combined cycle (IGCC). Field tests to develop the technology to produce coal gas for fuel cells are now going on in Japan (see Annex F).

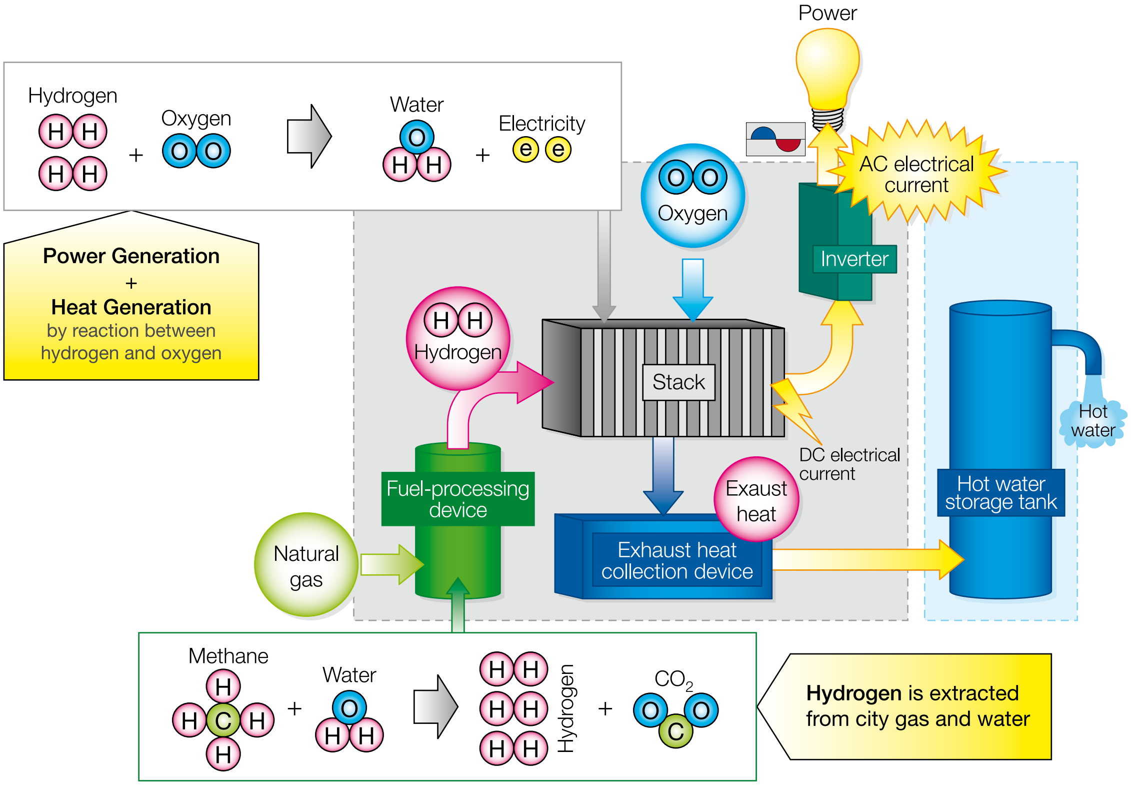


Figure 3.3 – Micro-combined-heat-and-power (micro-CHP) unit, Japan

3.6 Transmission and distribution (T&D)

We have seen that the effects on energy efficiency which may be expected from improvements in T&D are limited, given their comparatively small part in total energy use. It is however worthwhile to examine the situation, since today's well understood centralized network will soon be complemented by decentralized sources. Reduction of transmission/distribution loss plays a role in the reduction of CO_2 emission especially because the loss rate in many countries is high or may be liable to reduction. Upgrading transmission/distribution voltage, installation of power plants near the demand (including dispersed generation or on-site generation), development and adoption of low-loss-rate equipment are all assumed to be effective measures to reduce network loss.

However, the location and configuration of power plants and the intensity and distribution of the demand vary greatly by country and according to circumstances (e.g. resource availability, site acquisition). Consequently the configuration of the power system cannot be unified throughout the world, and those measures that will principally be effective will be quite different.

General alignment on best practices should lead to an improvement of about 3 % on losses. Ultra-high voltage AC, UHVAC (AC transmission whose highest voltage exceeds 1 000 kV) and UHVDC (DC transmission whose highest voltage exceeds 800 kV) are examples of advanced technology for loss reduction by upgrading transmission voltages. Superconducting cable may be mentioned as an example of low-loss-rate equipment.

3.7 Use of electricity in buildings

Energy use in buildings (residential & tertiary, i.e. services) is around 40 % of total energy consumption; the electricity used is about half of all electricity used anywhere (see Figure 3.2). Both are targeted for significant savings in the coming decade, through both electrical energy efficiency and electrification. Life-cycle analysis demonstrates how critical energy efficiency is throughout the lifetime of a building. Optimizing energy usage by allowing only the necessary energy and only *when* necessary is key during the whole life cycle.

In the residential sector (households) energy use and consumption are strongly driven by and correlated with income. The non-residential buildings segment covers a large range: office buildings, hospitals, commercial malls, railway stations, etc. Some of these contain heavy processes such as data centres. In fact, use of ICT equipment is increasing exponentially in both homes and offices: it can represent up to 1 000 KWh per year per household in developed countries, with up to 30 % consumed in standby mode. In non-residential buildings electricity represents around 50 % of energy used, and furthermore is key for control of the use of other fuels such as that for heating (see Annex G).

In both residential and non-residential buildings noticeable progress in energy efficiency has been made during recent decades, in heating or appliances for example. However, more effort is needed in the control of electricity usage in order to achieve efficiency. Electricity has therefore now become critical, not only in use directly as energy but also in measurement, automation and control, and in permanent monitoring of energy use. Proven technology is available, so that the issue is real implementation, specifically in existing buildings.

Existing levers to improve electrical energy efficiency today:

- Use of low-consumption, high-efficiency loads (lighting systems, motors, power capacitors, transformers, cables)
- Optimization of the use of these loads through intelligent automation and control (energy management systems)
- Implementation of procedures and tools to monitor and maintain the systems

Enabling efficiency and optimizing end use with automation & control: energy management systems are a fundamental part of the overall solution, since they allow optimized use of energy, general reliability and sustainability of performance. Low-consumption products functioning when not needed still consume energy (lamps, motors, electronics on standby, ...). A 2 °C variation in temperature setting on heating or cooling can consume up to 10 % additional energy, hence small drifts can have significant consequences. Automation and control are essential for optimization of energy usage:

- They allow consuming only what is necessary, when and where necessary
- They allow correcting “bad habits” and improving behaviour
- They can easily be installed in existing sites and improve existing performance
- They complement energy-efficient end-use products to improve overall usage performance

Examples of solutions: presence and light detectors, timers, variable-speed drives, electric motor systems’ automation & control, programmable logic controllers (PLCs).

Renovation of existing buildings for better energy efficiency is also critical. Because buildings have a long lifetime, construction of new buildings on existing sites proceeds slowly (typically less than 2 % per year are replaced). Renewable energy such as that from photovoltaic cells or heat pumps is well adapted to either residential or commercial/service buildings and should be extensively developed. Grid connection will need to be managed. More and more ICT-based applications are developing in commercial and service buildings, and some applications (such as health applications in hospitals) are becoming critical.

Strengthening energy efficiency through quality, reliability and continuity of supply can avoid expensive waste and restart costs. The constantly maintained high quality of an installation is a guarantee of optimized consumption. Examples of solutions: uninterruptible power supplies, generating sets and automatic transfer switches, filters.

Measuring and monitoring is the basis of diagnosis and control, and is therefore needed to guarantee durable energy efficiency and the limiting of CO_2 emissions. Examples of solutions: smart metering systems, monitoring systems and services, energy management systems and services.

The real issue today is to activate all levers and implement existing and proven technologies. As described above, the issue is not understanding what needs to be done, or finding new technologies and solutions. It is true that there is some progress with existing solutions in new buildings, but they are poorly implemented in existing buildings, and a key factor hindering progress is the slow construction rate. **This is why renovation is crucial.** (Note that 80 % of the buildings which will exist in 2020 have already been built.)

3.8 Use of electricity in industry

Industry uses almost half of all electricity produced, so it is vital that efficiency measures be taken. Many industry sectors are energy-intensive, and they have already economized energy (energy consumption per tonne of crude steel halved from 1960 to 2005, for example). With respect to these available methods, it is very important to identify the Best Available Technology (BAT) and best practices in each sector, and to spread them as widely as possible so as to realize the potential economies. However, many possibilities for further economies exist– most industrial processes still use 50 % more energy than the theoretical minimum. Reducing the amount of waste (which takes energy to produce) is also required.

A major barrier has been a complex of non-technological difficulties: even existing technologies have mostly not been implemented, sometimes for structural reasons (such as company-internal incentives for minimizing capital investment rather than running costs), sometimes for political reasons (policy incentives missing or misdirected).

Benchmarking is useful to identify areas where energy efficiency can be improved, but it is difficult, especially for whole systems, because it is subject to competition. However, it is urgent to develop the reference architectures (one example is given in Annex H, another in Figure 6.4) and best practices which will enable benchmarking, and publish these in standards or recommendations. One important component of EEE in industry is to use electricity (and ICTs, of course) to monitor and control the use of other types of energy; these other energies have to be incorporated in the reference architectures together with electrical energy.

Probably 70 % of the electricity used by industry goes to driving electric motors, so an architecture approach to motor systems is a high priority. Many technical methods and optimizations already exist; their global and effective application is urgently needed. Examples of technologies that may need to be considered include permanent magnets, matrix converters, reluctance motors, *in situ* calibration of instruments and regeneration and harmonics in the supply.

3.9 Electrification of transport

In this area in particular, energy efficiency can be improved by electrification – increasing significantly the 1 % or so of electricity consumed by transport in the world and simultaneously decreasing net energy use and CO_2 emissions. Individual road vehicles are a promising candidate for electrification. A new-generation electric vehicle (EV) has been developed with the use of lithium-ion rechargeable batteries. EVs have the following advantages compared to cars using petrol:

- Less emission of CO_2: reduced CO_2 emissions even if the electricity is generated from oil
- Improvement of the urban environment: no exhaust gases, less noise

At the current stage of development, the following technological components need advances in order to resolve issues preventing the further spread of EVs:

- Expensive battery: cost reduction by R&D and mass production
- Large and heavy battery: downsizing and weight reduction by R&D

In addition to cars, (increased) electrification of public and freight transport needs also to be examined seriously in order to reduce energy use and emissions.

Electrification of transport will have an impact on grid and infrastructure design, but will also offer additional possibilities; aspects include load balancing, metering and the charging infrastructure.

SECTION 4

Reducing carbon dioxide emissions – "decarbonization"

4.1 Renewable energies (RE)

RE are those methods of obtaining energy which can operate indefinitely without emitting greenhouse gases, and they are important not only for energy efficiency and decarbonization. Many RE installations are categorized as distributed generation (DG). DG allows a single house to generate electricity, but also very remote areas to be electrically self-sufficient. Combined with advanced grid connection and control systems, energy storage systems and possible government incentives, this may allow new types of arrangement, leading to changes in the electric power industry, and possibly persuading areas that are not using electricity to do so. These secondary influences, which would allow a further reduction of CO_2, may include electric vehicles in cities and desalination in remote areas, for example.

The key to achieving the challenging goals in the medium to long term is the technology aspect rather than economics, according to the IEA report. A wide range of developments beyond currently popular RE technologies is needed. It extends from the material level, such as new solid-state power devices and new silicon purification technology, to highly integrated digital power distribution systems. Once these R&D activities take place properly, **the 450 policy scenario** (see 1.7 and Annex B) could be within reach.

4.1.1 Hydropower generation

Large-scale hydropower has been and will be taking a leading role among all renewable energies. Its increase in developed countries will be limited, because most areas suitable for hydropower have already been used. However, in large transitional and developing countries there is still a huge potential, and hydropower will contribute the most to clean power generation.

Mini-hydro systems have a history of long and stable operation in many countries. Some are reported to have been working for more than a century. The environmental load is much smaller than that of large-scale hydropower generation. In addition, mini-hydro systems are useful in remote areas and developing countries.

4.1.2 Wind power

Among renewable technologies wind power is the most successful one, and installed capacity exceeded 73,9 GW at the end of 2006. Wind power has been significantly popular in Germany, Spain, US, India, Italy, Denmark and so on. The cost is around USD 0,10-0,14/kWh. The connection to the grid is critical due to associated technical issues such as the frequency fluctuation of output by non-regular and non-control converters and non-matching of grid capacity. These issues are sometimes regarded as obstacles to wider exploitation of wind systems. Issues associated with maintenance and stable operation, which will grow with the market, may be standardized, with the scope of the standard expanding as it incorporates storage.

4.1.3 Solar thermal power generation

Solar thermal power is expected to provide inexpensive electricity, and relatively large-scale systems have been demonstrated in the US, the EU and the Middle East.

4.1.4 Solar photovoltaic electricity

Among renewable energy technologies, solar photovoltaic (PV) electricity is expected to be one of the most effective, not only in developing countries but in developed countries such as Germany, Japan, US, Spain and Italy. The adoption of PV has been dramatically promoted by various incentives such as feed-in tariffs, tax credits and government aid. Total world installed capacity exceeded 10 GW at the end of 2008.

The cost of the power generated may be as much as USD 0,45/kWh, which needs to be reduced.

4.1.5 Geothermal power generation

Geothermal power generation operates stably in commercial contexts in the US, the Philippines, Mexico, Italy, Indonesia, Japan and other countries, and large test systems have been demonstrated in various areas. Global capacity was roughly 8 900 MW in 2005.

4.1.6 Heat pump systems

Heat pump (HP) systems are not always classified as renewable energy, but the technology represents an efficient use of energy. In Japan HP systems have been becoming popular rapidly and have demonstrated an efficiency exceeding 60 %. Japan possesses a very large stock in gas air conditioning and there are more than 100 000 installations due to government aid.

4.2 Nuclear generation

Given global environmental problems nuclear power generation is a leading technology. The supply capability of nuclear energy is comparable to that of thermal power generation and it produces no CO_2 gas.

The emphasis of R&D for nuclear power generation has been on the improvement of safety and reliability, as well as generation efficiency. The results of R&D increase the value of nuclear power generation: increasing generation efficiency can extend the life of uranium resources, and improving safety and reliability can raise the utilization factor, which means lower generation cost. Thus generation IV, the successor to generations II and III which are presently used or under construction, is under development.

The Gen-IV International Forum (GIF) was established in 2000 for the development of the next generation of nuclear energy systems, "generation IV" (see Annex J). Now, ten countries (e.g. US, UK, France, Japan) are working together as members of GIF to lay the groundwork for generation IV and enable its deployment by the 2030s. Main goals for generation IV are to improve nuclear safety and resistance to proliferation, to minimize waste and natural resource use, and to decrease lifecycle cost. Recently six types of reactor have been discussed in GIF and considered to meet these goals:

- Thermal reactors
  - Very-High-Temperature Reactor (VHTR)
  - Supercritical Water-Cooled Reactor (SCWR)
  - Molten Salt Reactor (MSR)
- Fast reactors
  - Gas-Cooled Fast Reactor (GFR)
  - Sodium-Cooled Fast Reactor (SFR)
  - Lead-Cooled Fast Reactor (LFR)

4.3 CO_2 (carbon) capture and storage (CCS)

As mentioned by the IPCC, CO_2 (carbon) capture and storage (CCS) is one of the methods with a large potential to achieve considerable reductions in CO_2 emissions. There are two main potential options to store CO_2, the ocean and geological reservoirs (see Annex K). In the case of the ocean, technical and legal issues have been identified.

Field tests are planned or underway in many countries, for example in the UK, the US, Germany and Japan. The main issue in application of CCS to power generation is that it is expensive and causes degradation of thermal efficiency, and therefore technical innovations are expected if CCS is to be applied in the future. It should also be borne in mind that potential capacity for carbon storage differs greatly by region and country.

SECTION 5

Are these measures enough?
A sensitivity analysis

A large number of measures are outlined in Sections 3 and 4, mostly at a mature technology level (immediately implementable), which will contribute to economizing as well as decarbonizing electrical energy. Quite apart from whether these measures will actually be implemented and what steps are necessary to achieve that, the question arises whether – even if extensively implemented – these measures will prove adequate to attain the global goals set. This section answers the question in the negative, thus showing the logical progression from the measures described in Sections 3 and 4 to the more radical measures proposed in Section 6.

The approach adopted here is to concentrate on the final effect in terms of reduction of CO_2 emissions, whether it is through increased efficiency (including behaviour changes) or successful decarbonization. This is because climate change through greenhouse gases appears to be the first priority globally.

Quantitative assumptions are made, first, for what is likely to happen by 2030 and 2050 if no particular steps are taken – the so-called business-as-usual (BAU) scenario. This is based on a purely arithmetic projection of generally accepted estimates for the current rate of change of various quantities. Then various levels of improvement are assumed for the factors affecting CO_2 emissions, and the likely results quantified. This shows to which factors the end result is most sensitive – hence the expression "sensitivity analysis". More detail and a tabular presentation of the figures may be found in Annex L.

It should be stressed that these are not detailed predictive models; they do not set goals but simply describe them; and they do not imply any specific responsibilities for any organization. They do however give a significant glimpse through rough figures of the relative contributions of end-use energy efficiency, reducing transmission & distribution losses, renewable sources of electricity and generation efficiency.

5.1 Business as usual

Assuming growth of 2.5 % p.a. in generated electricity, **total emissions will practically triple** (increase by 170 %), from 10.8 Gt (Gigatonnes of CO_2 per annum) in 2010 to 29 Gt in 2050.

5.2 Improvements using immediate technologies from Sections 3 and 4

We assume optimally that immediately available technologies and strategies from Sections 3 and 4 will enable:

- a 30 % improvement through end-use efficiency and savings[4],
- increase of renewable and nuclear generation to 30 %,
- reduction of T&D losses from 9 % to 7 %, and
- a 5 % improvement in generation efficiency.

The result in 2050 would be an increase of 50 % of emissions over the 2010 level (not of 170 % as in BAU, but still an increase, not a reduction), from 10.8 Gt to 16.1 Gt.

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[4] "Efficiency" refers to the same task done using less electricity, whereas "savings" point to reducing or changing tasks so that there is less need for electricity. See Section 3.1.

Savings and efficiency in end use are the main contributors, renewables give a significant CO_2 reduction, whereas generation efficiency improvements as well as T&D loss reduction contribute smaller amounts.

5.3 More aggressive strategies in electricity generation and other areas

Assuming, for 2050:

- 40 % of efficiency/savings rather than 30 %,
- a 50 % share of renewables and nuclear (up from 30 %),
- reduction of T&D losses from 9 % to 6 %, and
- a 10 % improvement in generation efficiency (up from 5 %),

we have 8,9 Gt of emissions, which for the first time is a reduction from 2010 to 2050 (of around 20 %). However, 50 % renewables (with 40 % decentralized generation) is a clear challenge for the stability of the electrical system. For this and other reasons, this scenario depends on technologies still under development or in research.

Savings/efficiency in end use remain the most important: compared to BAU they provide a reduction of around a third, whereas the increase in renewable generation provides a 25 % reduction.

5.4 Results of the sensitivity analysis

With a full application of all mature technologies, and under the most favourable possible assumptions as to political will and level of agreed investment, CO_2 emissions will still grow between 2010 and 2050 (even if this growth is considerably less than what would happen if mature technologies were not fully applied). For climate change any growth in emissions is generally assumed to be unacceptable.

In order for any net reduction to be possible developing technologies must be fully used, in addition to entire application of those mentioned in Sections 3 and 4. (The greatest gains are likely to come from energy savings and increased efficiency. All other factors, even renewables and more efficient generation, have significantly smaller effects.) This is summarized in Figure 5.1 and serves as a basis for Section 6.

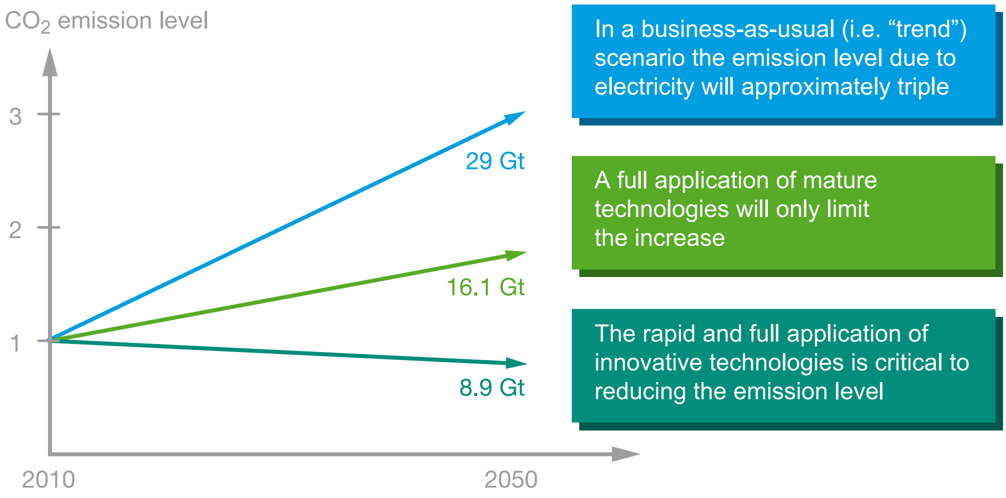

Figure 5.1 — Schematic of the effects of applying different technology levels

SECTION 6

Redesign: the future energy chain

6.1 The need for redesign and the role of reference architectures

The sensitivity analysis in Section 5 has demonstrated the need to go beyond the current energy chain, even as improved according to Sections 3 and 4, in order to effectively decrease CO_2 emissions in spite of increasing electricity generation and use. This will need significant changes in the overall architecture of the chain, as well as many interactions between end use and generation.

Main trends of the future energy chain will include the following:

- High-capacity centralized generation (including renewable power plants such as the DESERTEC project[5]) will coexist with decentralized generation of lower unit capacity but with a large number of installations

- High-capacity bulk power plants remote from the consumption area (power plants in the sea, in deserts, in space, …) may be established

- Renewable energy generation will represent a significant and constantly increasing share of overall generation; since this (solar and wind) will be largely intermittent, management of the stability of the overall system will be more difficult

- It will be essential to develop energy/electricity storage capacity, and electrical vehicles may present an opportunity to contribute capacity to a larger storage management system

- The electricity end user will not be just a consumer but a producer as well, which will expose critical issues in interfacing with the grid as well as in the management of the various sources:
  - tariffs will be linked to CO_2 emissions and time of use, for which adequate management systems must be available
  - demand response and load levelling (peak savings) will become a significant economic issue

Like any complex design task, energy chain redesign and its various sub-designs as listed in this section require competent planning, which by analogy with the design of buildings we refer to as "architecture". To map the abstract design on to real-world implementation, for example in order to apply technologies correctly and effectively, the various parts of the design and their relationships to each other must be referred to at each of the implementation steps. To summarize these two aspects – the overall design and the implementation of individual element – we use the expression **reference architecture.**

6.2 Grid architectures

The architecture of the power networks will have to integrate small power networks based on decentralized generation (basically renewable energies such as PV and wind). This must take place within large-scale power networks connecting heavy centralized power plants, with interconnections as schematically represented in Figure 6.1.

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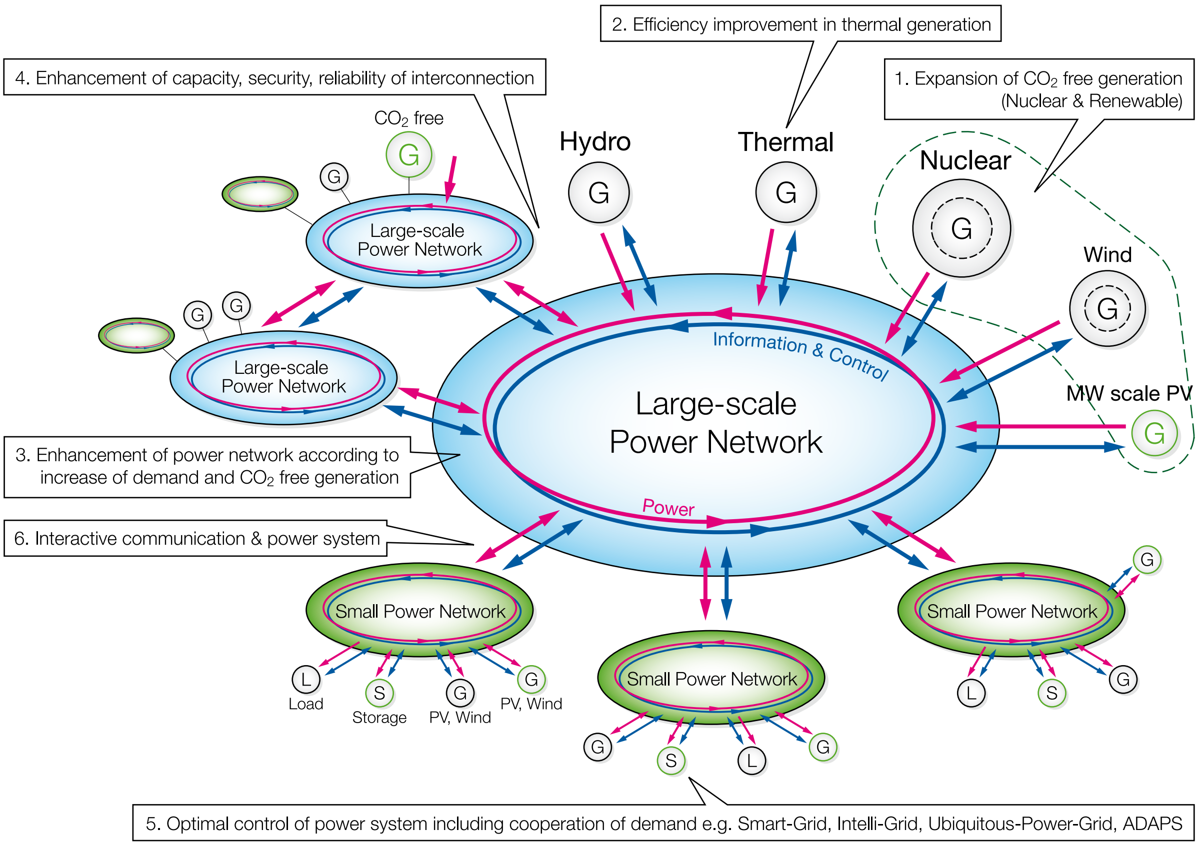
[5] See desertec.org and the figure in Annex M.

1) In large-scale power networks, their enhancement and interconnection will be key issues. UHVAC and UHVDC are expected to be the effective solution. They are planned in China to realize long-distance and large-capacity transmission systems, which will also enable utilization of large-scale hydropower generation in the western region. Some sections of the UHVAC system have started operation in China. In Japan, considering future needs to transmit large amounts of power, UHVAC transmission lines have been constructed and they are now operated at 500 kV. India also has plans for UHVAC and UHVDC.

2) In small power networks, optimal control of the network with demand, storage and dispersed generation is essential. Currently, many approaches are under development to achieve this concept, varying in their characteristics (e.g. Smart Grid, Intelli-Grid, Ubiquitous Power Grid).

3) The Smart Grid concept encompasses both of the following:
   a) An architecture for distributed generation, electricity storage, integrated sensors, ICT technologies on the consumer side
   b) Integration with bulk power systems with advanced control and protection


2. Efficiency improvement in thermal generation

4. Enhancement of capacity, security, reliability of interconnection

1. Expansion of CO_2 free generation (Nuclear & Renewable)

3. Enhancement of power network according to increase of demand and CO_2 free generation

6. Interactive communication & power system

5. Optimal control of power system including cooperation of demand e.g. Smart-Grid, Intelli-Grid, Ubiquitous-Power-Grid, ADAPS

Figure 6.1 – Schematic diagram of future power system

Key components in the Smart Grid include:

- Smart metering, which enables two-way communication between utilities and customers (including electrical energy storage facilities such as rechargeable batteries and electric vehicles) or dispersed generation (DG)
- Information technologies, which enable optimal control of the total grid even where very many DG units are integrated
- Energy management systems, which implement the most efficient possible use of electrical energy for customers
- Advanced control and protection systems, which improve the security and reliability of both small- and large-scale power networks

The technologies for Smart Grid have mainly been debated in the context of optimization of small power networks. However, the use of information technologies and advanced protection and control systems also improves the reliability and security of large-scale power networks and their interconnection.

6.3 Energy and electricity end use architectures

6.3.1 Buildings

Yesterday, a building was just a consumer of energy for heating, ventilation and air-conditioning (HVAC). Consumption was mainly determined by the building structure-envelope and the principal issue was thermal insulation.

Today, energy consumption for a building is significantly growing. Monitoring and control systems play an important role in efficient energy use.

Tomorrow (and the change has already started), a building will be an active player: not only a consumer but also a producer of energy. Thanks to information and communications technology a building will have the capacity to adapt automatically to changes in internal conditions (different types and levels of activity) as well as to external conditions; it will posses a demand-response capability linked with decentralized renewable generation and the "smart grid".

Electrical vehicles will have interfaces with buildings, heat pumps may be widely used and energy storage technology will be installed for efficient energy use.

All building facilities will be integrated in an overall building management system using decentralized sensors and connectivity; energy management will change the game and transform a building into a safer, more reliable, more productive, more efficient and greener place.

Integrating all the new technologies (sensors, monitoring & control, open communications, energy production, ...) and the new functions (energy storage, energy management, ...) is a thorough challenge for the IEC. It goes far beyond the traditional supply of safe and reliable electricity.

Figure 6.2, an example of a future energy network in the home, shows that the future home will have not only home appliances which consume energy, but also energy-generating equipment such as photovoltaic cells, fuel cells or heat pumps, and energy storage equipment such as rechargeable batteries. Heat pumps will show that electricity is the cleanest and safest way to use energy even for thermal heating. Some houses may be equipped with LVDC wiring, to which fuel cells and batteries will be connected. Appliances that are suitable for direct connection to DC are also integrated.

6.3.2 Vehicle to grid

At home, in buildings and in parking places electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs) are a new load to manage, and their batteries will be used for stationary storage applications. This includes in particular the use of the local storage to help the larger grid with its load levelling – see Figure 6.3 and Section 6.4 on storage. The IEC has recognized the importance of standardization for the interface of EVs with the grid.

6.3.3 Industry

In industry, we should consider not only electricity but also other types of energy usage (e.g. heat) for total energy efficiency. Therefore reference architectures uniting all energy usage are required as a basis for energy management systems, opening the way for an overall improvement in energy efficiency. In addition, schemes for how to deploy best practices in energy-saving measures and processes in industrial companies are important for this sector. Figure 6.4 gives an example of an energy reference architecture.

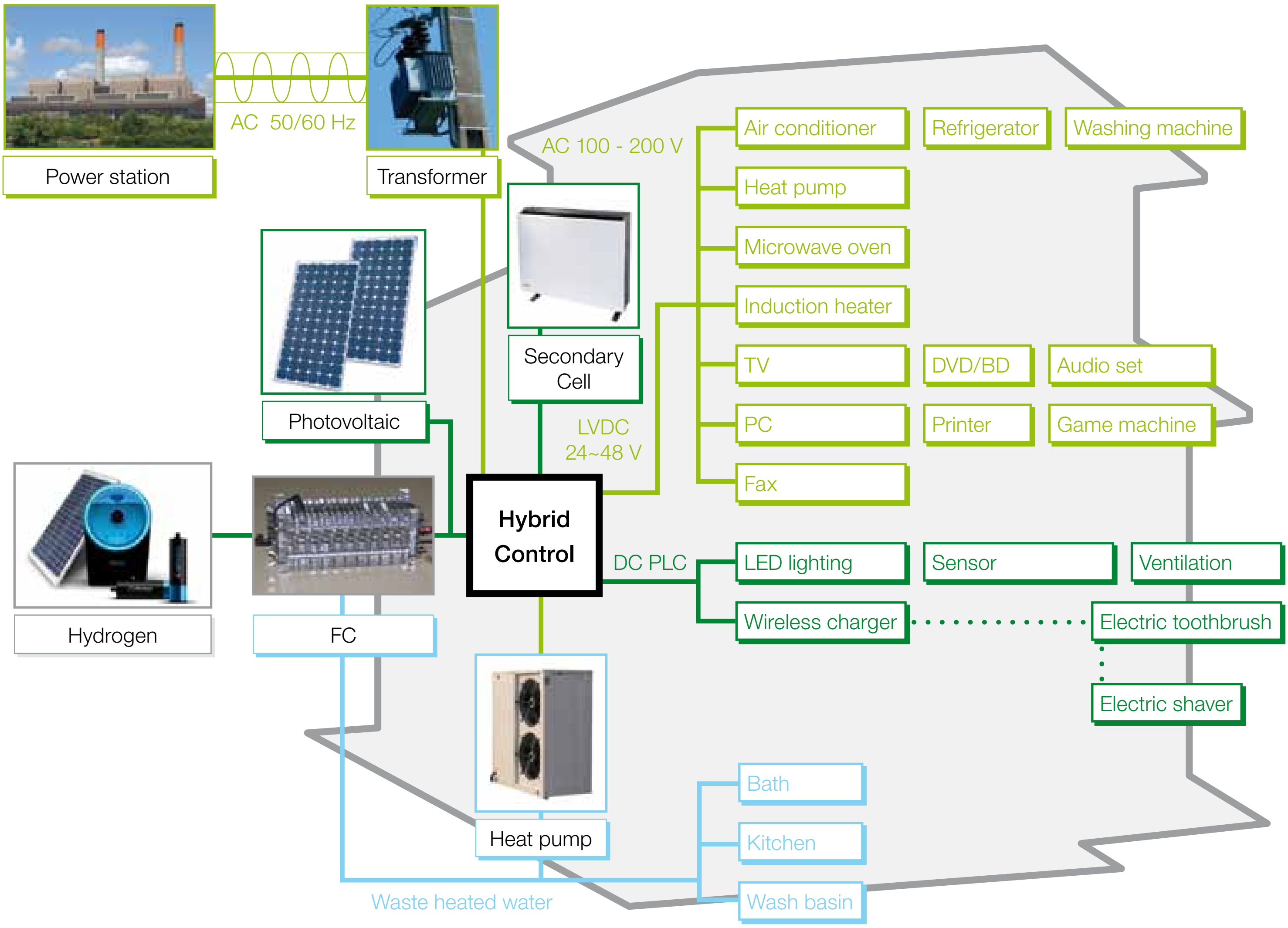


Figure 6.2 – Future home energy network

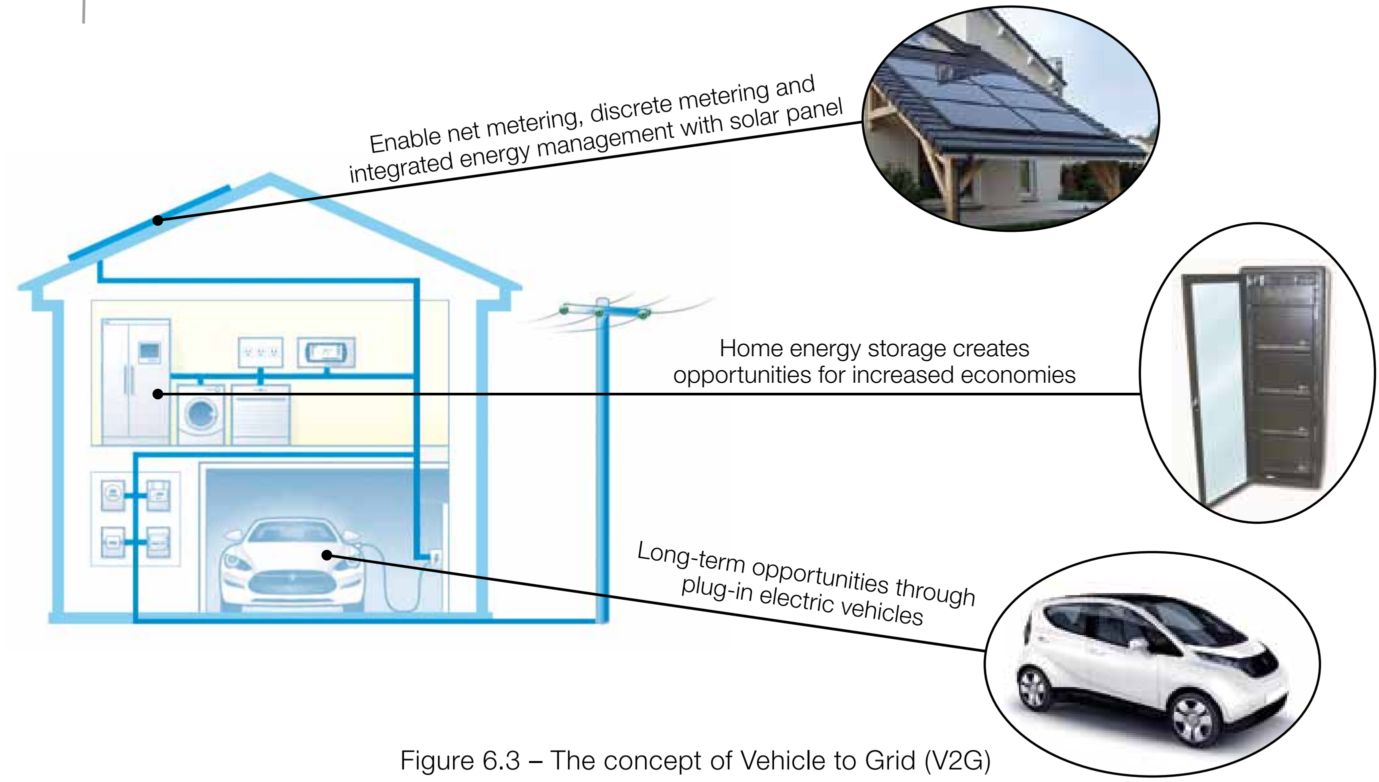


Figure 6.3 – The concept of Vehicle to Grid (V2G)

Source: Southern California Edison

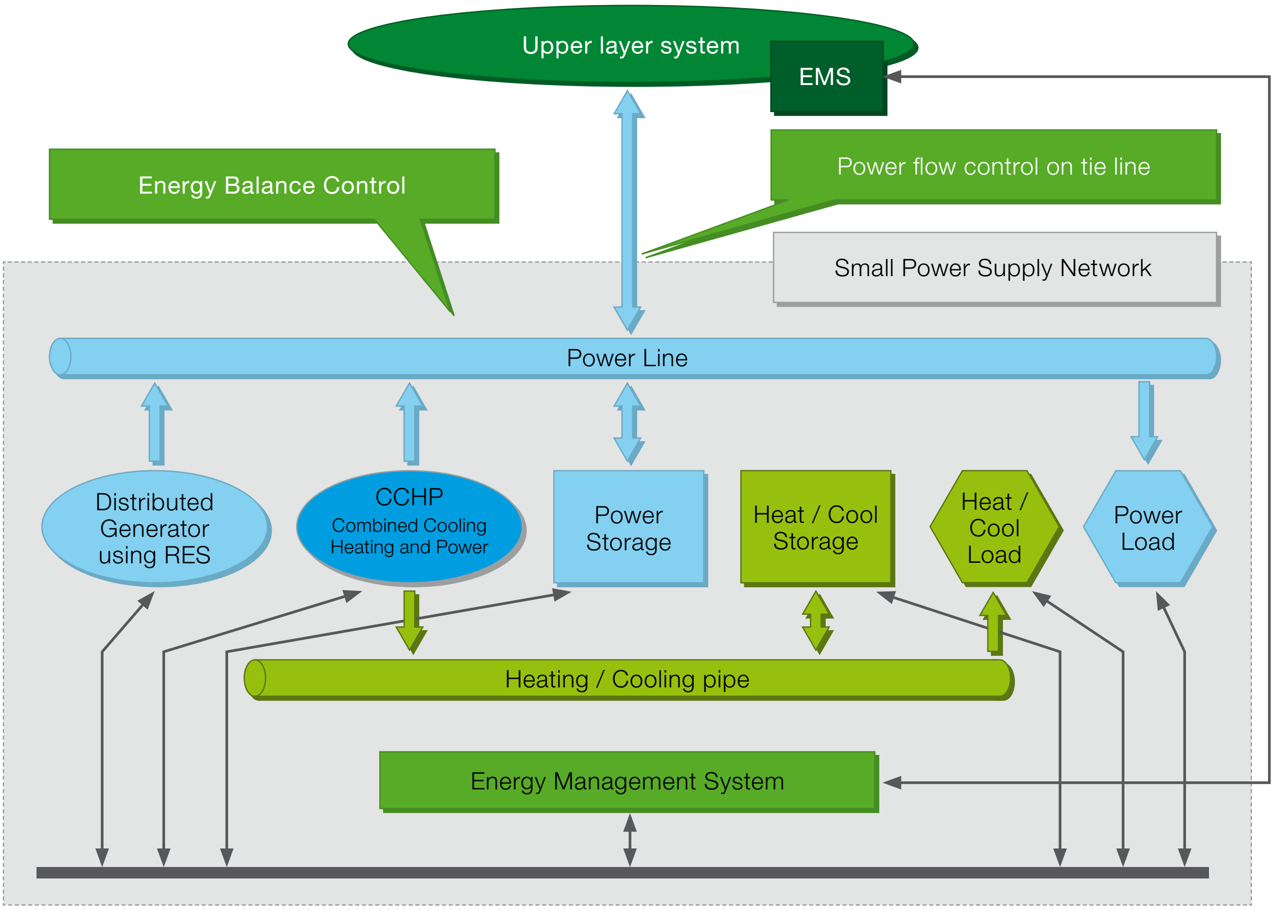


Figure 6.4 – An energy reference architecture for industry

6.4 Energy and electricity storage

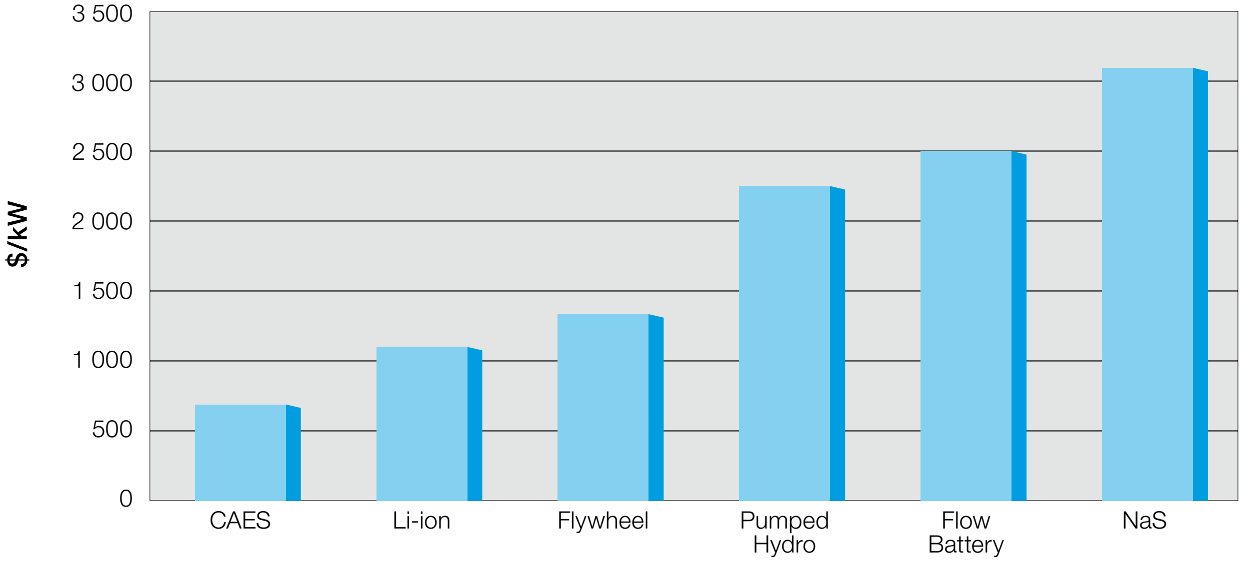
Electricity storage technologies (either in a distributed manner with possible aggregation, or as bulk storage interfacing to the energy system) will play an extremely important role. They can smooth out intermittent generation such as wind and solar, and allow consumers to optimize their consumption and local generation through their local energy management system.

Various technologies are in use currently, such as compressed-air energy storage, flywheels, pumped hydro and different types of battery: lithium-ion, sodium-sulphur (NaS) and a number of technologies under development. The elements in Figure 6.5 summarize the technologies and costs.

Technology development status

Commercial	Pre-commercial	Demonstration phase	Developmental
Pumped hydro	Flywheel	Electrochemical capacitor	Lithium-ion (grid applications)
Flywheels (local power quality)	Flywheel (grid device)	Hydrogen loop	Super-magnetic energy (storage applications)
Compressed-air energy storage (CAES)	Zinc-bromine battery		
Lead-acid battery	Vanadium redox battery		
Ni-Cd battery			
Sodium-sulphur battery			

Current Energy Storage Technologies Cost Estimates



Source: Figure created for *Bottling Electricity*: *Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid* by EAC Energy Storage Technologies Subcommittee 2008

Figure 6.5 – Technologies and costs of electricity storage

Electrolytic hydrogen is also a technology which could be developed, combining electricity storage with a hydrogen transportation fuel infrastructure – this co-production of electricity and H_2 could release significant synergies. (Hydrogen is generated by electrolysis of water producing an excess, which is later combined with oxygen from the air in either an electric engine or fuel cells.)

6.5 Micro-grids

A micro-grid is a small network that can work completely or almost completely isolated from other grids, by optimally controlling elements such as dispersed generation (DG), electrical energy storage equipment and the various loads.

Micro-grids could represent a solution to the unpredictable nature of power generation from DG (mainly from renewable sources). Additional possible advantages of micro-grids:

- To serve as a pattern for countries where electricity supply is not generalized: regions distant from the main grid can obtain electricity by DG and be served by a micro-grid

- To provide a back-up generation capability to its loads and survive an external black-out

Much R&D in many fields, such as power electronics, ICT, automation control as well as transmission and distribution, are required for the spread of micro-grids.

6.6 Issues raised by the future energy chain

6.6.1 Technical issues

The deployment of architectures as described in previous sections is expected to contribute to the reduction of CO_2 emissions, but will raise issues which can be serious for the whole system's safety, reliability and stability, such as:

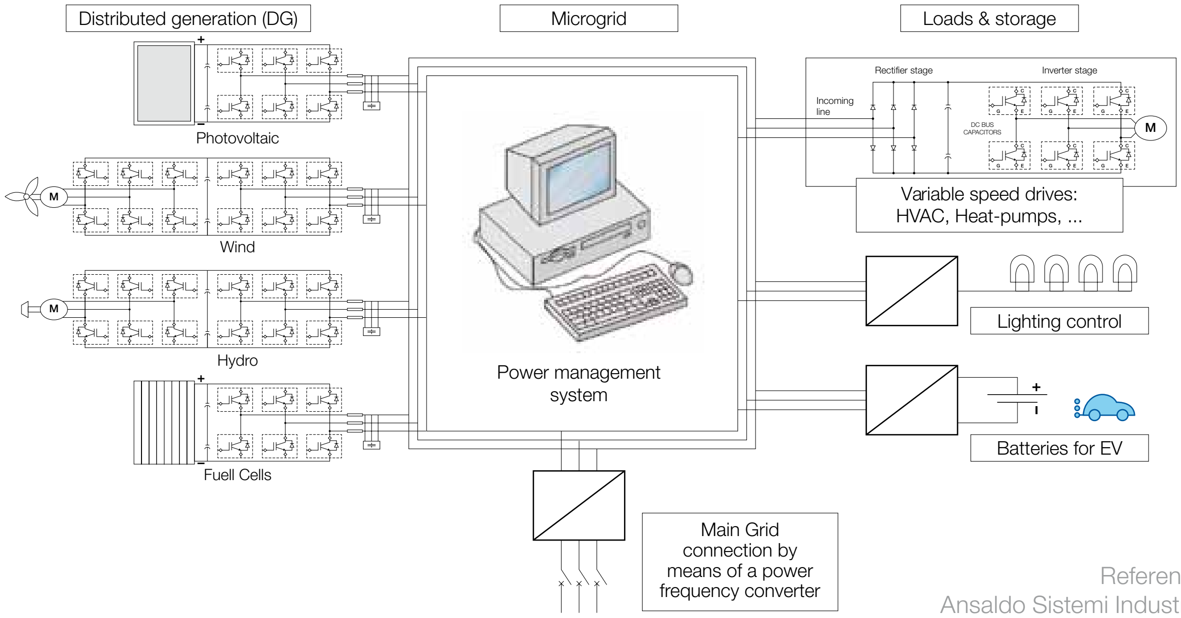
- Balancing between demand and generation (centralized and distributed)

- Power quality (harmonic current emissions, voltage flicker, voltage fluctuation)

- Prevention of unsafe islanding

- Insufficient coordination of control systems between the utilities' grid and decentralized generation (which may even cause blackouts and delays in power system recovery)

Figures 6.6 to 6.8 illustrate some of these issues.



Reference:
Ansaldo Sistemi Industriali

Figure 6.6 – Micro-grid working at frequency and phase different from those of the main grid

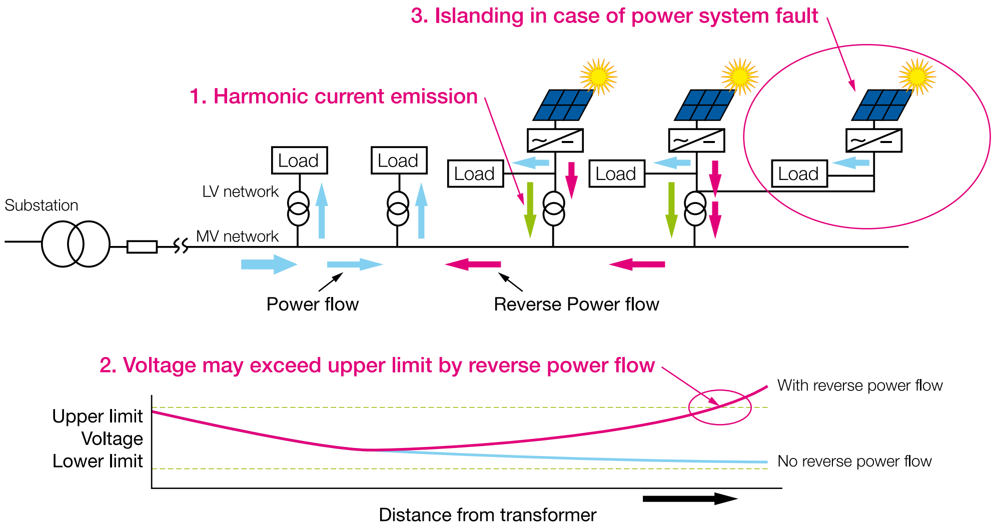
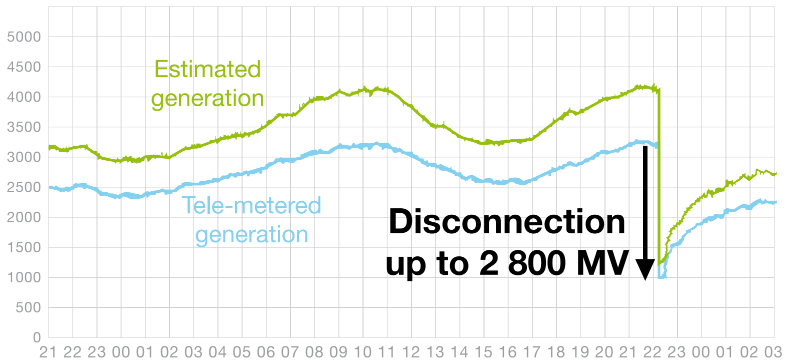


Figure 6.7 – Technical issues in MV/LV distribution network in clustered PV system



Source: Red eléctrica de España. www.ree.es

Figure 6.8 – Large disturbance caused by unintentional separation in Spain 2006

6.6.2 Systems approach issues

Sections 3 and 4 show the need for a systems approach to each element of the current energy chain (generation, transmission & distribution, end use).

Section 5 implies that to go further energy chain redesign is needed, which means more coordination between the three elements of the chain and a strong integration of information and communication technologies with electronic, automation & control and electrical technologies.

As an example, electricity distribution to groups of houses might include, as illustrated in Figure 6.9, **advanced metering, local renewable generation (wind & solar), electricity storage, electric vehicles, and a home energy management system.**

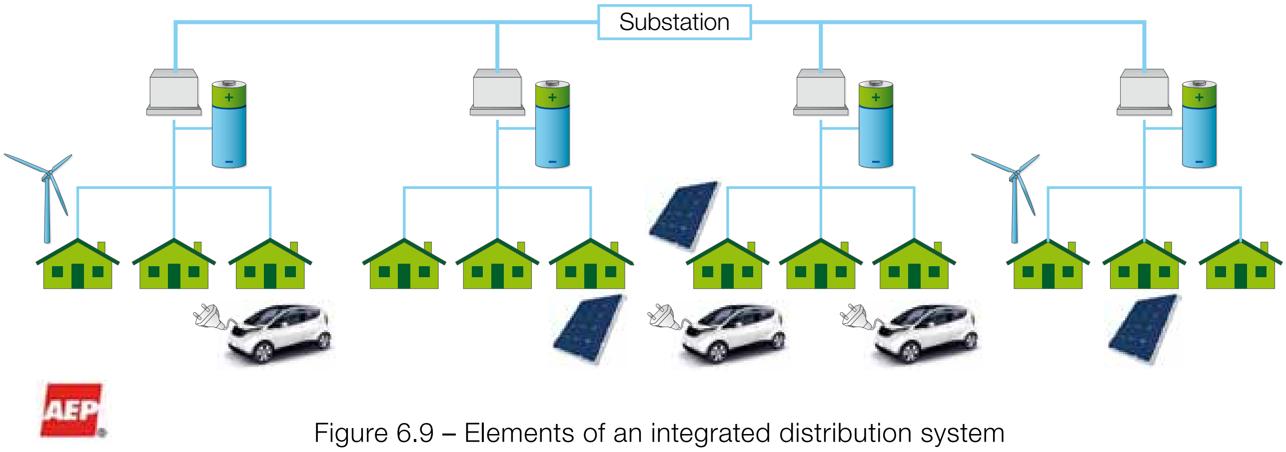


Figure 6.9 – Elements of an integrated distribution system

SECTION 7

Critical success factors for implementing solutions

To conclude just before giving our recommendations, we list four critical success factors. Some have been mentioned in relevant parts of previous sections.

1) We need reference architectures for electrical energy performance. Considerable investment from the electrical engineering community is required for this.

To take the example of buildings, in different parts of the world certificates for and ratings of the energy performance of buildings are in use. Methodologies have been developed based on thermal models and calculations and give an estimate of what the consumption of the building should be according to its shell structure. However, these certificates are more asset ratings (rating how the building was built – insulation, double glazing) than operational ratings (how the building is used). The energy performance ratings do not today include any electrical architecture and the related monitoring and control architecture, although these are key to the operational energy performance of a building.

Similarly, for the industrial example Sections 3.8 and 6.3.3 have shown that enormous progress needs to be made, from optimizing individual processes to optimizing whole production systems on the basis of reference architectures. **By defining these architectures together with the calculation and rating methodologies, The IEC will be able to provide extremely high added value.**

2) The standardized solutions must go beyond a simple product perspective to provide a real application perspective. Preferred electrical-energy-efficient solutions should be described in standards and other IEC deliverables, to be developed and widely promoted.

Development of standardization tools beyond products and in an application-solution perspective would accelerate electrical energy efficiency implementation by all the actors in the value chain.

Factors 1 and 2, architectures and an application perspective, are critical in particular because without them the many present and future technologies which can achieve efficiency and decarbonization cannot be effectively applied. **Only these factors can turn technologies into solutions.**

3) Electrical energy efficiency needs to become visible on the political agenda and in public incentive plans.

As a consequence of the political will to mitigate climate change effects and implement energy efficiency plans, building codes have been modified and incentive plans (tax offset, preferred loans, accelerated depreciations, …) are available in the market. Similar steps are needed, but have not yet been taken, for electrical energy performance, notably of buildings and of industrial plants.

4) Specifically, the IEC's electrical energy efficiency solutions should be made politically visible.

Factors 3 and 4 in turn are critical so that **society may make the investments necessary to achieve results, and so that consensual solutions – the only globally effective ones – may be applied.**

SECTION 8

Recommendations

8.1 Recommended evolution in the IEC's fundamental orientation

The IEC was historically safety and compatibility oriented.

We now have to take the lead in new areas where integration of different approaches is needed, such as energy efficiency, productivity and the environment.

More specifically for the current paper, the IEC now has to tackle the energy challenge.

The IEC has historically concentrated on product standards.

We now have to understand and base our activity on a systems approach and application-oriented global solutions.

Whether the IEC needs new TCs or needs to group existing TCs together is uncertain and not within the remit of the MSB. What is certain – and this is the task of the MSB – is that the thinking must start from the system and go on to the parts, and not start from the individual products and possibly progress to the system (as is the case today). This must include both systems of new products (new installations) and systems for retrofitting whole existing installations, with priority being given to the latter in some areas. It must also include revisiting existing product standards, where necessary, when new systems standards have been prepared.

In summary, in Figure 8.1, the IEC should start out by consideration of the application, and then go on to write standards for the services and products.

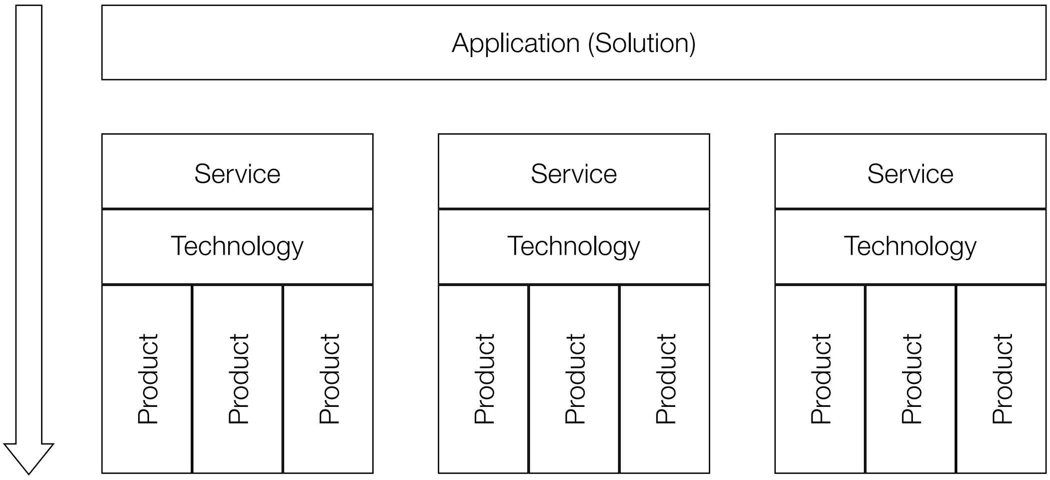


Figure 8.1 – Architecture for system-oriented standards development

The "applications" are defined by the market according to its needs, and are not necessarily limited to the IEC's areas of competence. **It is the MSB's task:**

- first, to listen and put questions to the market, in order to understand and describe the applications (solutions) that the market requires;
- to determine which aspects of these solutions are within the scope of the IEC;
- to recommend that the IEC invite ISO and other relevant standards development organizations to cooperate in working out the solutions;
- and finally to establish market priorities for standardization of the "services" and products needed by those solutions in the IEC's domain

The current paper, in Sections 3, 4 and 6, has attempted to complete the first two tasks for energy efficiency and CO_2 emission reduction. Section 8 seeks to launch efforts towards accomplishing the third and fourth.

On the basis of the proposed direction for the evolution of the IEC, and the other facts and arguments developed in this paper, the MSB makes the recommendations contained in Sections 8.2 and 8.3. Section 8.4 gives a technology list generated during the production of this paper which will be the basis of further work in the MSB.

8.2 General recommendations

Rec. 8.2.1 – Required research and development

The MSB recommends the IEC and its office-holders and experts to encourage progress to be made in all the research and development projects involving emerging technologies needed for electrical energy efficiency and decarbonization.

Rec. 8.2.2 – Political awareness and public visibility

The MSB regards it as essential that the IEC's energy efficiency solutions become visible on the political agenda and in public incentive plans. It recommends all relevant actors in the IEC community worldwide to use every opportunity to raise political awareness and the public visibility of IEC's standards for this purpose.

Rec. 8.2.3 – Liaison with international organizations

The MSB recommends the IEC to strengthen its ties with the following organizations in particular:

- The International Energy Agency (IEA), in the areas of statistics, indicators, benchmarking information in relation to the work done as part of Implementing Agreement (IA) on Efficient Electrical End-Use Equipment (4E)
- The Asia-Pacific Partnership for Clean Development and Climate (APP) Peer Review, for best practices in development, diffusion and transfer of clean and efficient technologies in power generation

- The World Energy Council
- The United Nations' Intergovernmental Panel on Climate Change (UN IPCC)

Rec. 8.2.4 – Cooperation with regulatory and political authorities

In the context of Recommendations 8.2.2 and 8.2.3, the MSB recommends the IEC to consider developing closer contacts with regulatory and political authorities in order to promote electrical-energy-efficient solutions.

Rec. 8.2.5 – Technology Watch and standardization Road Maps

The MSB will put in place a permanent Technology Watch function for electrical energy efficiency (EEE) and carbon dioxide emissions reduction (Decarb). An ongoing task of this function will be to create and update Road Maps showing the current and foreseeable development of various technologies available for EEE/Decarb and the corresponding timetables for standardization.

Rec. 8.2.6 – Reference architectures for electrical energy performance

The MSB recommends the IEC to develop standards giving reference architectures for electrical energy performance. Architectures will be needed for the different domains, such as buildings, services, industry and so on. Considerable investment from the electrical engineering community will be required and must be planned for.

Rec. 8.2.7 – Industry's urgent need for EEE

Industry uses almost half of all the electricity produced. It is therefore particularly vital for this area that reference-architecture and best-practice standards should be rapidly developed and implemented. These standards and other publications should promote advances in the following major areas: regulatory and financial incentives to encourage EEE (on the price of electricity, for example); subsidies and other incentives for new energy-/carbon-efficient capital investment; tools for benchmarking against best practices; facilitating the implementation of innovative technologies.

Rec. 8.2.8 – Use of an applications rather than product-oriented approach

The MSB recommends the SMB to ensure that the standards giving preferred electrical-energy-efficient solutions go beyond a simple product approach and consistently adopt a real application perspective. This will involve keeping in mind the global effects desired (e.g. for EEE), the functioning of the systems in which the products are integrated in practice, and in some cases revisiting current product standards once new standards for systemic solutions ("service" in terms of Figure 8.1) are in place.

Rec. 8.2.9 – Options and rules for connection, stability, intelligence and efficiency of electric grids

The MSB recommends the IEC, in close cooperation with CIGRÉ, NIST and other relevant organizations, to develop rapidly a full and detailed set of standards giving minimal performance rules and a full set of options for the operation of grids. This should be conceived as a part of the set of standards needed by "smart grids".

The standards should cover connection (especially of fluctuating sources), stability, “intelligence” (required functions of the IT applications controlling the grid), and minimum systemic efficiency as well as how to measure it. Aspects to deal with include balancing demand and generation, power quality, harmonic current emissions, voltage flicker, voltage fluctuation and islanding prevention. The standards should allow for the necessary differences in approach and choices made in different countries; thus some of the resulting publications may be non-normative.

In order to facilitate implementation, the MSB further recommends the IEC and cooperating organizations to organize a public symposium on what the necessary standards and other IEC publications on the “smart grid” should contain.

Rec. 8.2.10 – Best practices for electrical energy management

The MSB recommends the IEC to develop standards for best practices in electrical energy management. These standards should be specifications for the technical aspects of electrical energy management. They should not be based on products or individual installations but on the whole systems involved, and be built around the services to be delivered and the goals for energy efficiency and GHG reduction.

8.3 Detailed recommendations

Below are recommendations in various individual areas (mostly involving mature technologies) which the MSB has identified as advancing EEE and decarbonization.

Rec. 8.3.1 – Product standards suitable for a co-generation environment

The MSB recommends the SMB to ensure that all product energy-efficiency standards take into account the possible use of the product in an environment of co-generation. This may for example involve measuring efficiency partly in function of the source, the switching, the metering or the quality of the power supplied to the product.

Rec. 8.3.2 – Solar thermal power generation

The MSB recommends the SMB to examine the opportunity of developing standards on solar thermal power generation.

Rec. 8.3.3 – Energy architecture for buildings

The MSB recommends the SMB to develop standards for an energy architecture for buildings, including control, monitoring and rating methodologies, as tools for electrical energy efficiency implementation.

Rec. 8.3.4 – Energy-efficiency measurement methods for industry

The MSB recommends the SMB to develop standards for measurement methods in industry, needed for benchmarking, energy audits, assessing compliance with regulations, etc.

Rec. 8.3.5 – Electric-vehicle charging infrastructure

Insofar as they are not already under way, the MSB recommends the SMB to develop standards for the infrastructure for charging electric vehicles and its connections to the vehicles.

Rec. 8.3.6 – Micro-grids

The MSB will rapidly establish a technology watch and define a road map (see Rec. 8.2.5) for the elements and systems involved in micro-grids, including when each area is likely to be ripe for standardization.

8.4 Technology list

In the process of the data gathering and discussion which have led to this paper, the MSB members identified the need for clarity in the various technologies and political or social processes necessary for EEE, as well as for their prioritization. The present section is the initial result of the inputs received so far.

Much work remains to be done to complete, clarify and disambiguate the list below, and even more to make coherent proposals on priorities. **The list is therefore not intended to condition the current paper but to provide input for future steps.**

Solar energy
- Solar technology
- Solar photovoltaic
- PV : nano-3D-structured cells
- Solar thermal
- PV (the rest)

Nuclear power
- Nuclear power
- High-efficiency new-generation nuclear power-safety
- Extended-licence nuclear power-safety

Marine, Hydro and Geothermal
- Wave/ocean power
- Tidal generators
- Wave generators
- Hydro-electric power
- Geothermal power

Wind power
- Micro-wind power generation
- Wind turbines
- High-power wind turbines
- Large-scale offshore wind (transfer & storage)

Heat
- Integrated Coal Gasification Combined Cycle
- High-efficiency coal thermal power generation

CCS
- CCS (carbon capture & storage)
- Carbon capture
- Carbon storage

Fuel cells and Heat pump
- Stationary fuel cells, utility-scale
- Stationary fuel cells, residential/building-scale
- Solid-oxide fuel cells (duplication with above ?)
- Molten-carbonate fuel cells (duplication with above ?)
- Proton-exchange membrane fuel cells (duplication with above ?)
- Heat pumps

Storage

- Storage of electrical energy
- High-capacity battery technologies
- Magnetic storage in superconducting coils
- Capacitors
- Flywheel energy storage
- Compressed-air and electricity storage
- High-power permanent magnet motors
- Battery for EV (electric vehicles), PHEV (hybrid)

Energy transmission and distribution

- Ultra High Voltage transmission AC
- High Voltage transmission DC
- New types of conductors
- Gas-insulated lines (GIL)
- High-current composite conductors
- High-temperature superconductors
- Low-voltage DC supply

Grid

- Micro-grid and decentralized system
- Interface with grid
- Smart Grid
- Smart Home with Heating and Cooling
- Demand response
- Volt/var optimization

Sectoral approach

- Low-energy-consumption buildings / Building energy management systems
- Intelligent Transport System
- Lighting by LED
- Efficient appliances
- Efficient office equipment
- Inert anodes for aluminium smelters
- Reluctance motors

Energy-saving technologies

- Load balancing
- High-efficiency inverters
- High-efficiency filtering of harmonics
- Reduced standby losses
- Automated sensors and controls
- Adaptive presence detection
- Weather forecasting
- Recycling of electrical components

High-level verification

- Predictive maintenance (e.g. of transformers)
- Calibration of instruments

Management and process

- Road Map of innovative technology
- Administration of energy-saving management
- Introduce Top Runner method (JP) into white goods
- Education and notification activity (publicity)
- Energy Conservation Centre in each sector

Annexes

Annex A – World primary energy demand by fuel in the Reference Scenario

Figure A.1, from *IEA World Energy Outlook 2008*, shows the primary sources from which energy is obtained. Figures for future years are estimated using the Reference Scenario (business as usual, BAU), in which governments' policies continue without significant change. (Note: *IEA World Energy Outlook 2009* shows slightly lower figures because of the 2009 recession, but introduces no significant new parameters.)

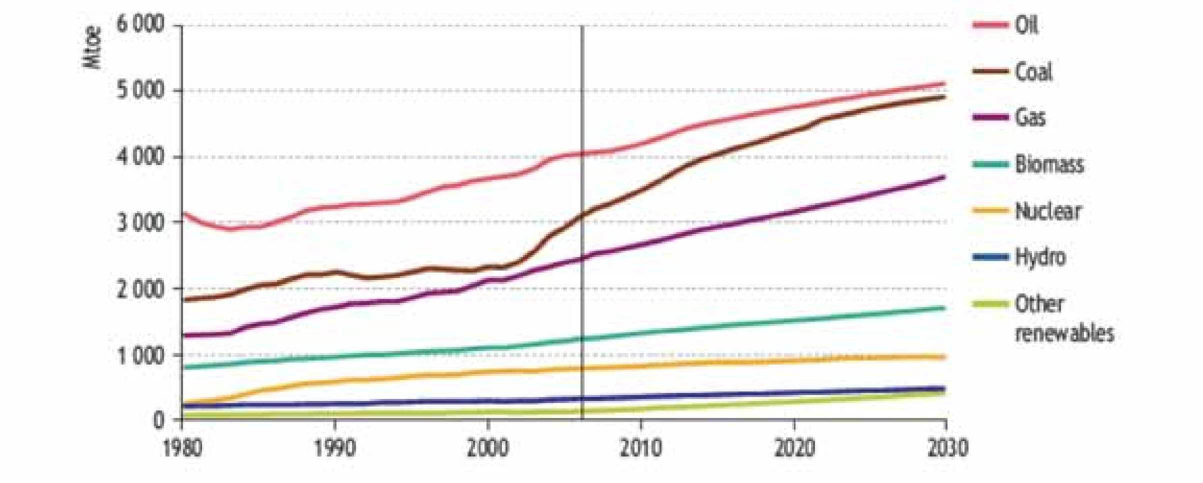


Figure A.1 – Energy sources (fuel) 1980 - 2030 (in Mio. tons oil equiv., Mtoe)

Annex B – Scenarios for greenhouse gas emissions and temperature rise

If nothing is done, the situation will get worse. **Without a change in policy, the world is on the path towards a rise in global average temperature of 6 °C.** According to the UN IPCC, the consequences of such a rise would be “significant change in all aspects of life and irreversible change in the natural environment”.

IEA World Energy Outlook 2008 assesses the implications for the energy sector of efforts to put the world on to a different trajectory, by means of a 550 Policy Scenario, in which greenhouse gas concentration is stabilized at 550 ppm CO_2-equivalent with a temperature rise of about 3 °C, and of a 450 Policy Scenario which results in a 2 °C increase. These scenarios are illustrated in Figure B.1 (Note that *IEA World Energy Outlook 2009* omits the 550 Scenario.)

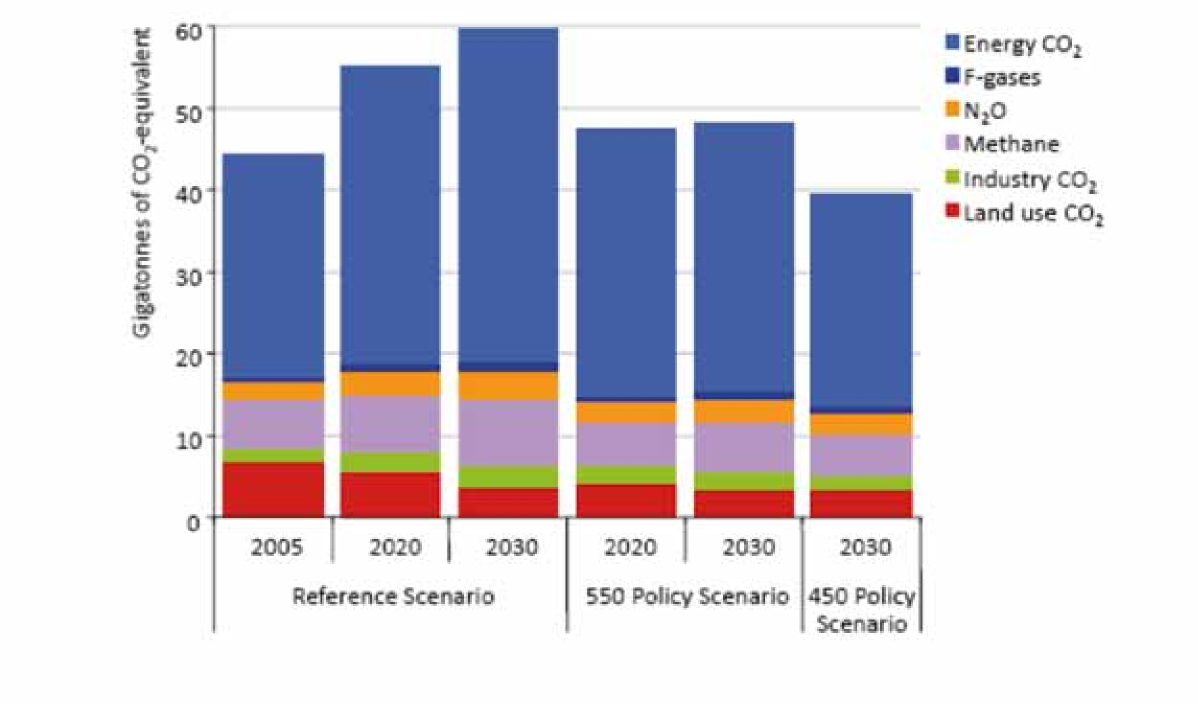


Figure B.1 – Policy scenarios for greenhouse gas emission reduction

Annex C – Energy-related CO_2 emission reductions in the 550 and 450 Policy Scenarios

Figure C.1 shows some possible effects of different available means (sources) of reducing CO_2 emissions, relative to the Reference Scenario, as well as the potential timescales.

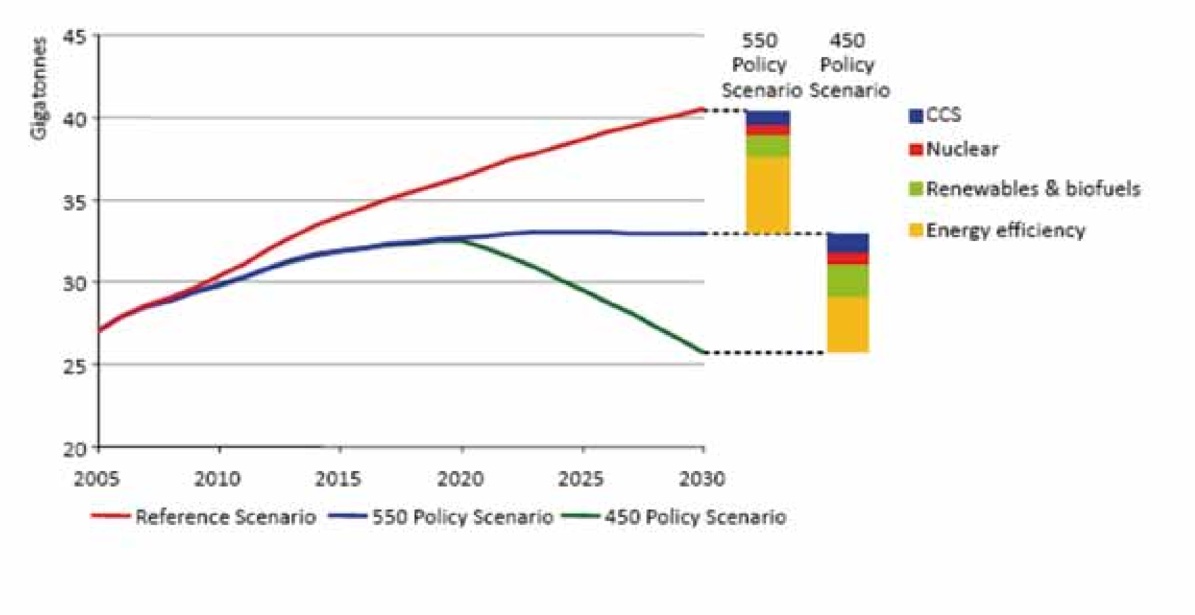


Figure C.1 – Potential sources of CO_2 reduction in 450 and 550 Scenarios

Annex D – Systematic evaluation of efficiency and CO_2 reduction

The concept shown in Figure D.1 can be applied to all electrical energy systems, i.e. power systems, local generation, generation in the home, independent generating plants, transmission, distribution and applications. Renewable energies such as solar photovoltaic, wind power, mini-hydro systems, geothermal power, solar thermal power, heat pumps and large-scale hydropower[6] are also included.

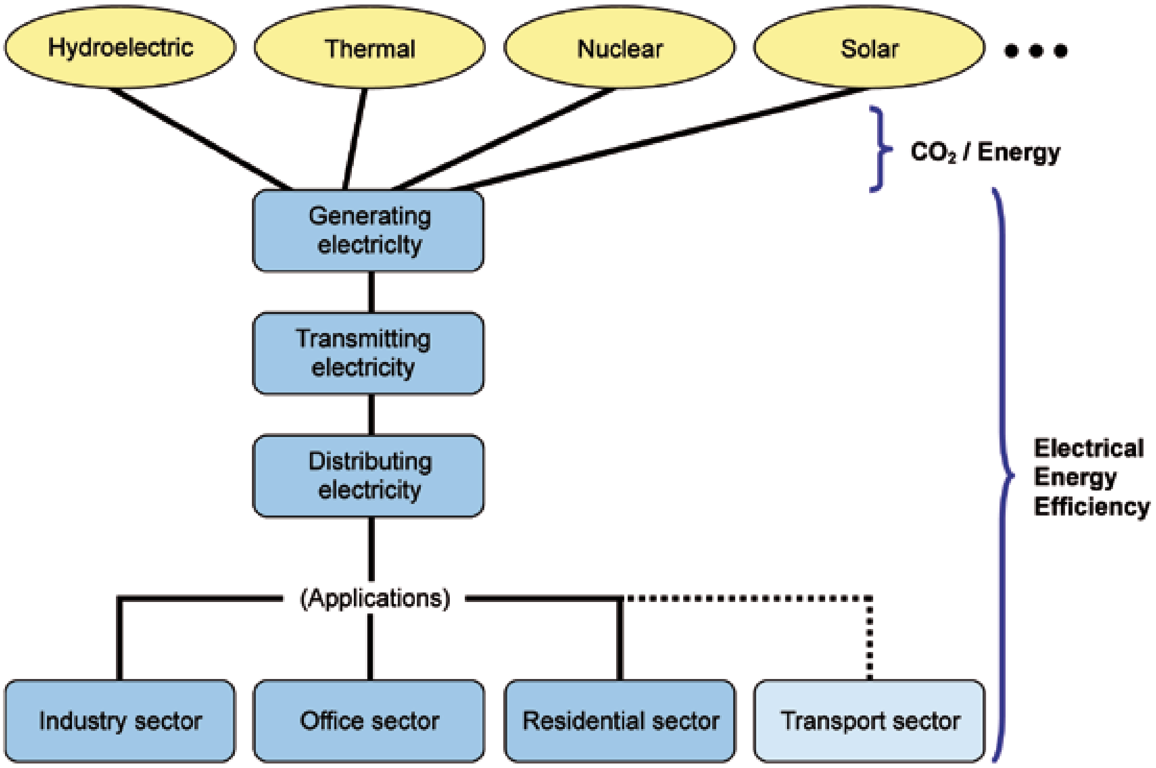


Figure D.1 – Schema for measurement and evaluation of electrical energy efficiency

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[6] See Section 4.1, *Renewable energies (RE).*

Below a step-by-step approach is given. See also Section 3.2, *The current electrical energy chain*.

D.1 – Generation

CO_2 emissions (GHG emissions) largely depend on power generation methods. Therefore it is desirable to define the CO_2 indicator for generation methods and input energy and, when evaluating electrical energy efficiency, to begin with the processes in the cream-coloured ovals in Figure D.1, as follows (the result will influence every stage after generation):

$$\text{Indicator of } CO_2 \text{ at generation} = \\ CO_2 \text{ / IE (Input Energy)}$$

The efficiency of generation independently of CO_2 is the amount of electricity per unit of input:

$$\text{Indicator of efficiency of generation} = \\ \text{GE (Generated Energy) / IE}$$

The efficiency of steam power generation is described by the IEA[7].

D.2 – Transmission

The efficiency of transmission depends on transmission loss:

$$\text{Indicator of efficiency of transmission} = \\ \text{TE (Transmitted Energy) / GE}$$

D.3 – Distribution

The efficiency of distribution is determined by controlling load changes, the structure of the grid system to end-users, and management of the grid system, including smart grid. Considering total losses, the efficiency can be described as:

$$\text{Indicator of efficiency of distribution} = \\ \text{DE (Distributed Energy) / TE}$$

---

[7] *Worldwide Trends in Energy Use and Efficiency*, IEA.

D.4 – Applications

Applications should be dealt with in all the sectors mentioned in this paper (e.g. buildings/services, industry), at the relevant level of detail. For each sector CO_2 reductions through changed behaviour (see Sections 2.3.1, 2.3.5 and 3.1) and "electrification" (see Section 2.3.3) should be taken into account, in addition to improvements in electrical energy use by best available technology (BAT).

D.4.1 – Industry

The industrial sector includes steel, cement, power generation, chemical, pulp and paper, among others[8]. Each has various characteristic processes, and the concepts of this section may be useful in analysing the electrical energy aspects of those processes.

D.4.2 – Buildings: commercial and service buildings (incl. offices)

Buildings should be separated into a commercial/service sector and a residential sector. There are two methods in the first sector to improve efficiency: to increase the efficiency of pieces of equipment such as air-conditioners, lighting or office machines; and to improve the management and the usage schedule of that equipment[9].

D.4.3 – Buildings: residential sector

There is a method for the residential sector in Japan called the "Top-runner method", which encourages improvements in equipment so as to use BAT[9].

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[8] *Japan Energy Conservation Handbook 2008*, The Energy Conservation Center, Japan.

[9] See for example Section 3.7, *Use of electricity in buildings*.

Annex E – Combined-cycle generating plant

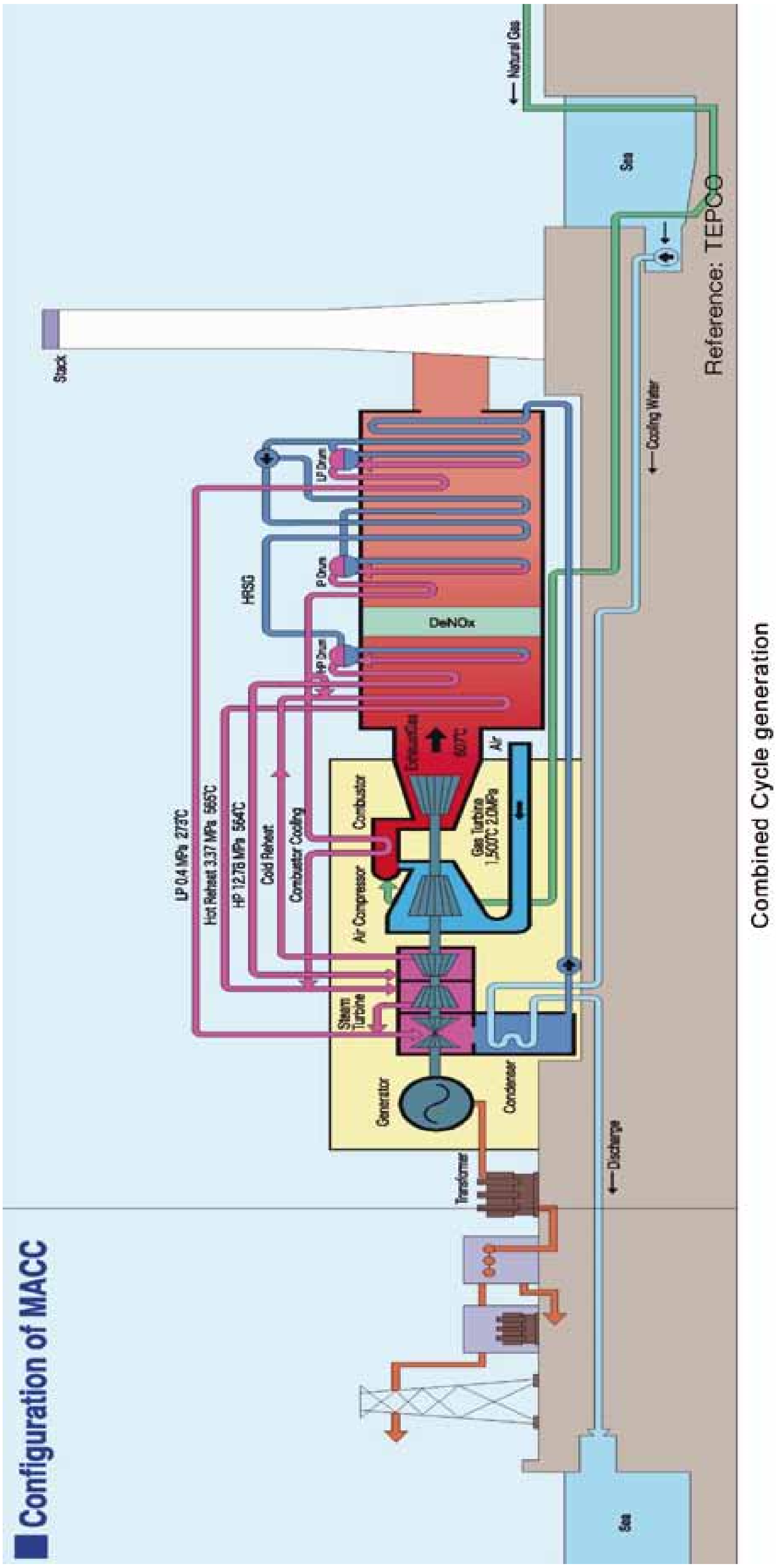
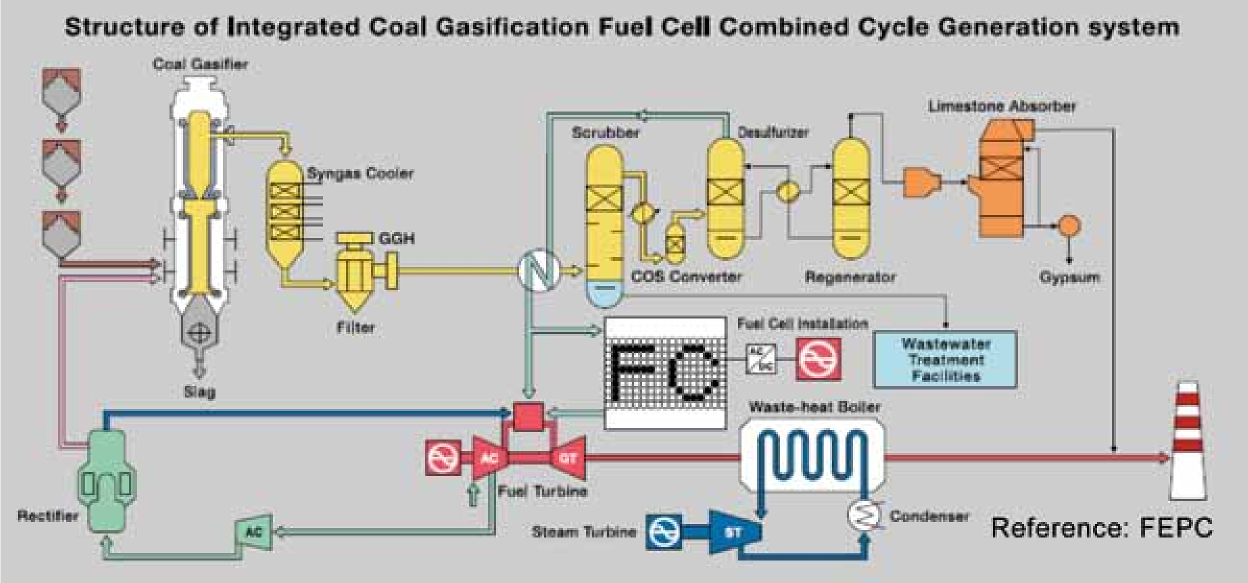


Figure E.1 – Combined-cycle schematic from Tokyo Electric Power Company

Annex F – Integrated coal gasification and fuel cell, IGFC

In Figure F.1, a schematic is provided of the IGFC technology under field test, mentioned in Section 3.5.



Reference: FEPC

Figure F.1 – Integrated coal-gasification/fuel-cell combined cycle (IGFC)

Annex G – Analysis of energy use in buildings – some figures

Energy consumption in residential and tertiary buildings represents around 40 % of total consumption and is targeted for significant potential savings through energy efficiency in the coming decade.

In the residential sector (household) in a given country several segments can be differentiated (flats/ apartments, private houses, condominiums, …). However, in a global perspective, Figure G.1 shows that energy use and consumption is strongly driven by and correlated with income. The more income grows, the more electricity is used as an energy source.

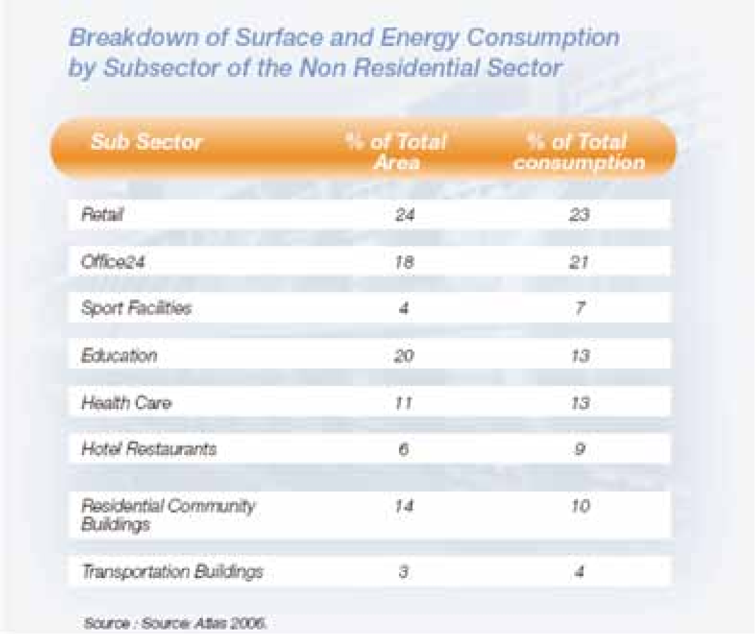
Source: IEA 2002.

From UNEP, Buildings and climate change 2007; source IEA 2002

Figure G.1 – Relationship between income and residential energy use

The non-residential buildings segment covers a large scope of applications such as office buildings, hospitals, commercial malls, train stations, etc.

Some of these contain heavy processes such as data centres. The relative energy use according to type is shown in Figure G.2.



Breakdown of Surface and Energy Consumption by Subsector of the Non Residential Sector

Sub Sector	% of Total Area	% of Total consumption
Retail	24	23
Office24	18	21
Sport Facilities	4	7
Education	20	13
Health Care	11	13
Hotel Restaurants	6	9
Residential Community Buildings	14	10
Transportation Buildings	3	4

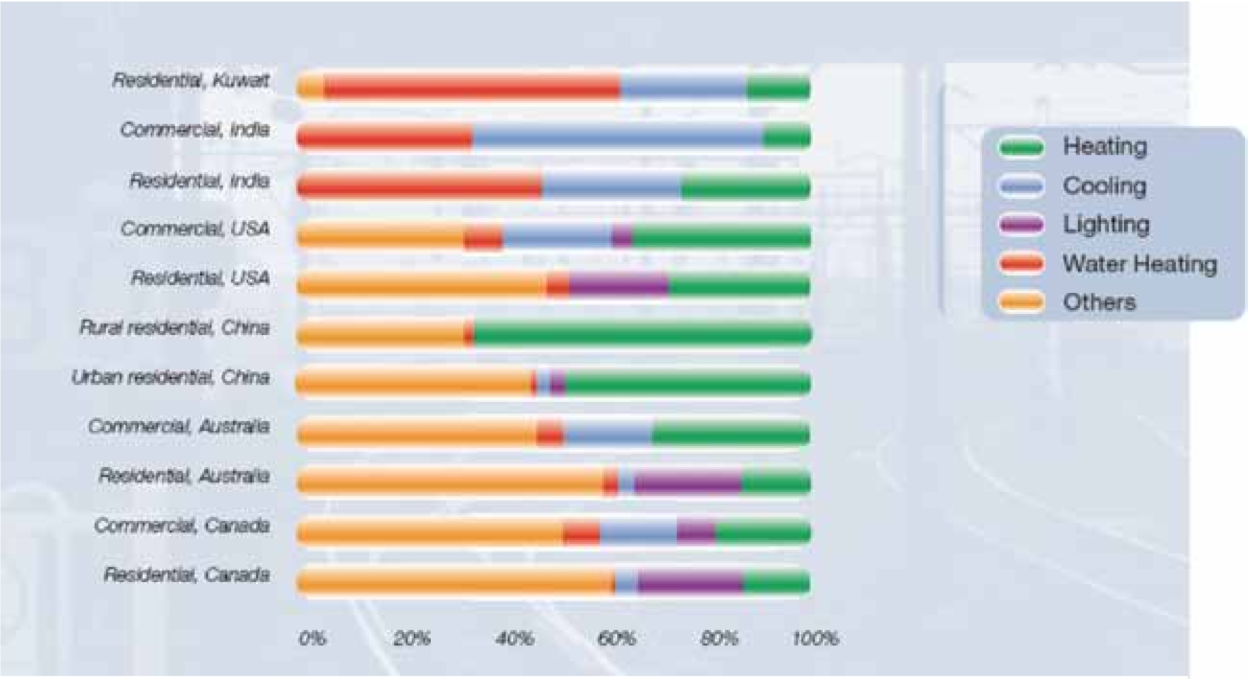
Source : Source Atlas 2006.

From UNEP, Buildings and climate change 2007; source Atlas 2006

Figure G.2 – Relative non-residential-building energy use by type of building

ICT equipment is increasing exponentially in both homes and offices. Ten years ago this was almost non-existent in residential facilities. It can now represent up to 1 000 kWh per year in developed countries, with up to 30 % consumed in standby mode (source: France ADEME 2008).

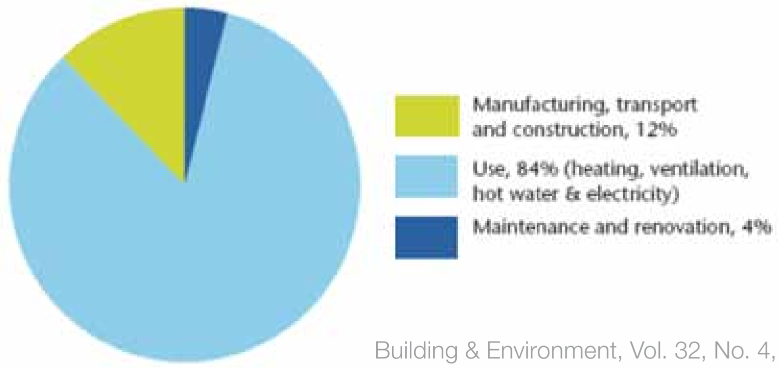
Analysis by usage gives a good framework. However, from one country to another notable differences exist, as shown in Figure G.3, so that for a useful benchmark it is important to have consumption data by usage available for a given country. Even though technology allows economic measurement of consumption by usage, this is seldom in place, and data are estimates rather than true measurements.



From UNEP, Buildings and climate change 2007

Figure G.3 – Country comparison of uses of energy in buildings

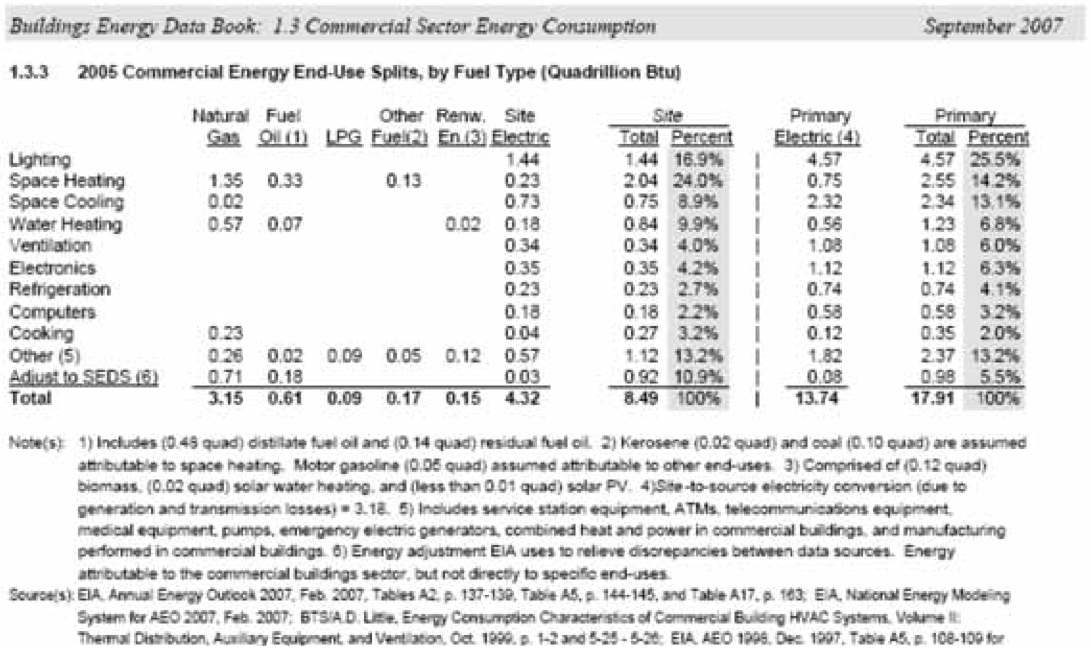
Life-cycle analysis demonstrates how critical energy efficiency is, throughout the lifetime of buildings (see Figure G.4). Optimizing energy usage by allowing only the necessary energy and only when necessary is key during the whole operational life of the buildings.



Building & Environment, Vol. 32, No. 4, pp. 321-329 (1997)

Figure G.4 – Energy use by stage in the life cycle of a building

In non-residential buildings electricity represents around 50 % of energy used, and furthermore is key for control of other fuel usage such as that for heating. Figure G.5 shows numbers for the US, Figure G.6 for France.



Buildings Energy Data Book: 1.3 Commercial Sector Energy Consumption — *September 2007*

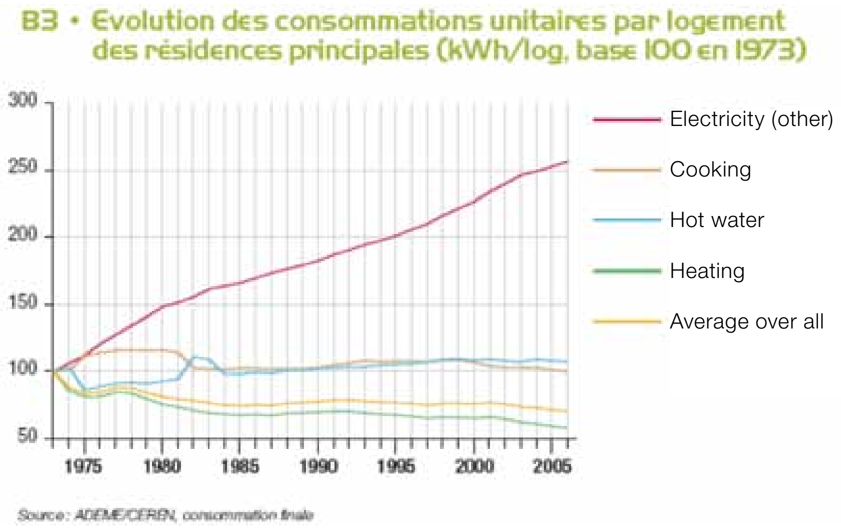
1.3.3 2005 Commercial Energy End-Use Splits, by Fuel Type (Quadrillion Btu)

	Natural Gas	Fuel Oil (1)	LPG	Other Fuel(2)	Renw. En.(3)	Site Electric	Site Total	Site Percent	Primary Electric (4)	Primary Total	Primary Percent
Lighting						1.44	1.44	16.9%	4.57	4.57	25.5%
Space Heating	1.35	0.33		0.13		0.23	2.04	24.0%	0.75	2.55	14.2%
Space Cooling	0.02					0.73	0.75	8.9%	2.32	2.34	13.1%
Water Heating	0.57	0.07			0.02	0.18	0.84	9.9%	0.56	1.23	6.8%
Ventilation						0.34	0.34	4.0%	1.08	1.08	6.0%
Electronics						0.35	0.35	4.2%	1.12	1.12	6.3%
Refrigeration						0.23	0.23	2.7%	0.74	0.74	4.1%
Computers						0.18	0.18	2.2%	0.58	0.58	3.2%
Cooking	0.23					0.04	0.27	3.2%	0.12	0.35	2.0%
Other (5)	0.26	0.02	0.09	0.05	0.12	0.57	1.12	13.2%	1.82	2.37	13.2%
Adjust to SEDS (6)	0.71	0.18				0.03	0.92	10.9%	0.08	0.98	5.5%
Total	**3.15**	**0.61**	**0.09**	**0.17**	**0.15**	**4.32**	**8.49**	100%	**13.74**	**17.91**	100%

Note(s): 1) Includes (0.48 quad) distillate fuel oil and (0.14 quad) residual fuel oil. 2) Kerosene (0.02 quad) and coal (0.10 quad) are assumed attributable to space heating. Motor gasoline (0.05 quad) assumed attributable to other end-uses. 3) Comprised of (0.12 quad) biomass, (0.02 quad) solar water heating, and (less than 0.01 quad) solar PV. 4)Site-to-source electricity conversion (due to generation and transmission losses) = 3.18. 5) Includes service station equipment, ATMs, telecommunications equipment, medical equipment, pumps, emergency electric generators, combined heat and power in commercial buildings, and manufacturing performed in commercial buildings. 6) Energy adjustment EIA uses to relieve discrepancies between data sources. Energy attributable to the commercial buildings sector, but not directly to specific end-uses.

Source(s): EIA, Annual Energy Outlook 2007, Feb. 2007, Tables A2, p. 137-139, Table A5, p. 144-145, and Table A17, p. 163; EIA, National Energy Modeling System for AEO 2007, Feb. 2007; BTS/A.D. Little, Energy Consumption Characteristics of Commercial Building HVAC Systems, Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation, Oct. 1999, p. 1-2 and 5-25 - 5-26; EIA, AEO 1998, Dec. 1997, Table A5, p. 108-109 for

Figure G.5 – Energy use breakdown in US commercial buildings:
electricity is almost half of all end use, but more than 75 % of primary energy



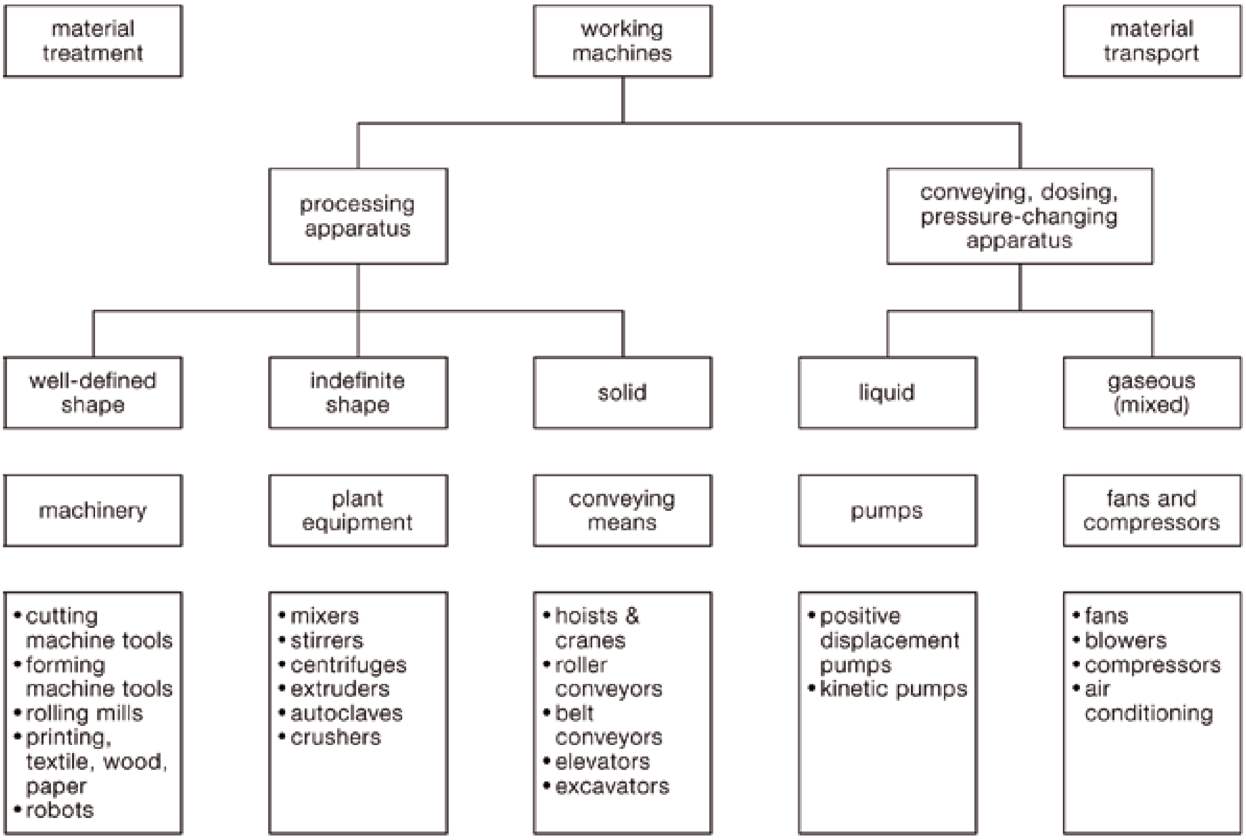
B3 • Evolution des consommations unitaires par logement des résidences principales (kWh/log, base 100 en 1973)

Source : ADEME/CEREN, consommation finale

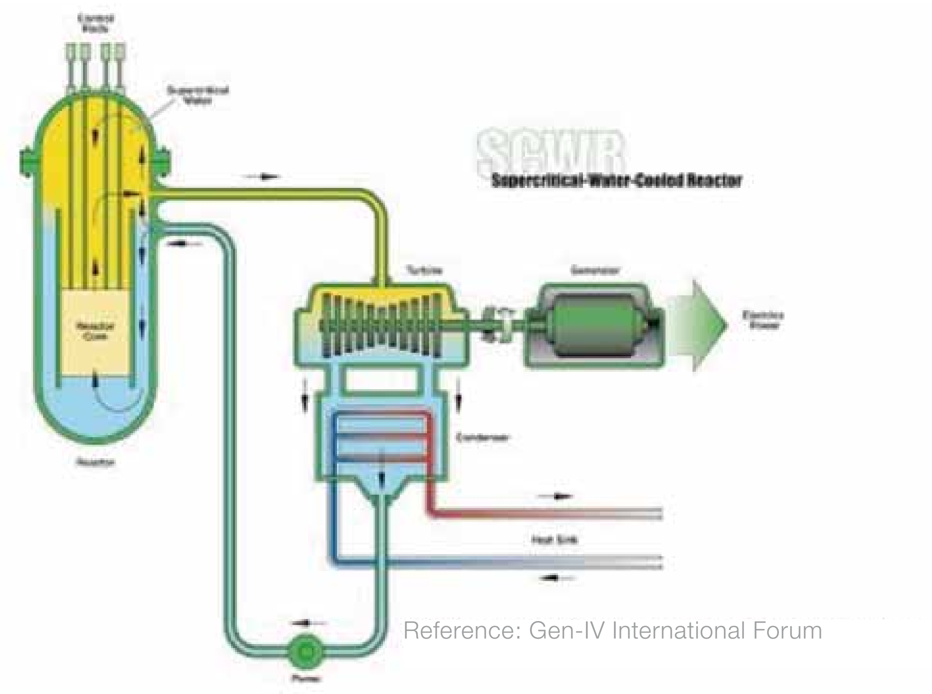
Figure G.6: Relative changes 1973-2005 in electricity consumption of French households,
by type of use (1973 = 100)

Annex H – Example of a reference architecture for material handling

There are several ways to classify the processes in industry. For the development of EEE one approach is to take machinery that is used for the conversion of electrical energy into other forms of energy as the basis for the classification. The level of abstraction of the classification scheme must be high enough that the list of processes is manageable, but not so high as to prevent the scheme being used to formulate best practices or give practical guidelines. The classification scheme described by the diagram below, provided as an example, places machines for working and conveying solid, liquid and gaseous material into a hierarchy.

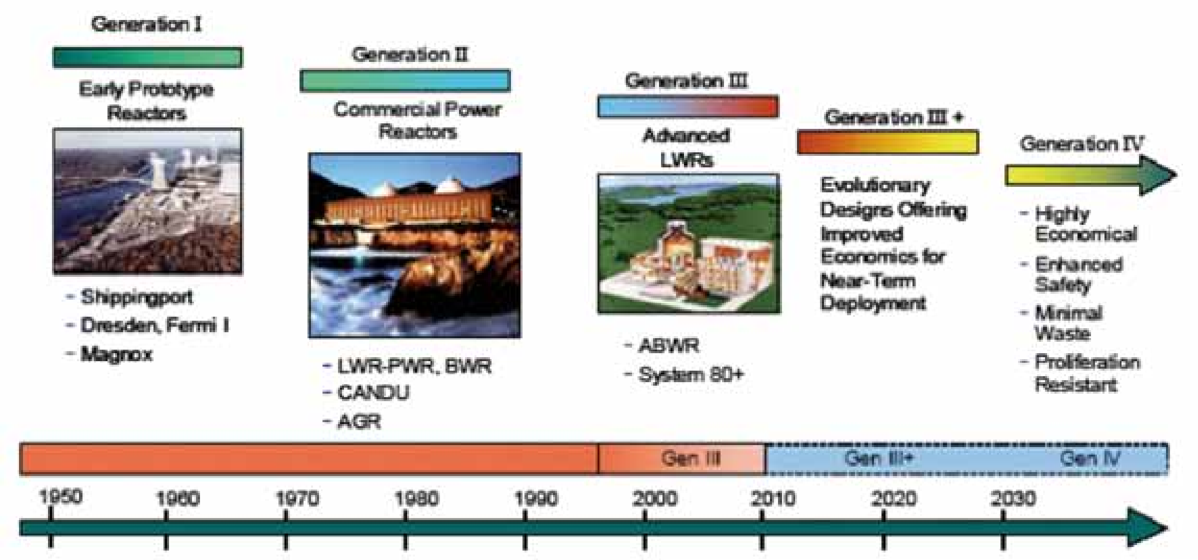


Annex J – Generation IV nuclear energy



Reference: Gen-IV International Forum

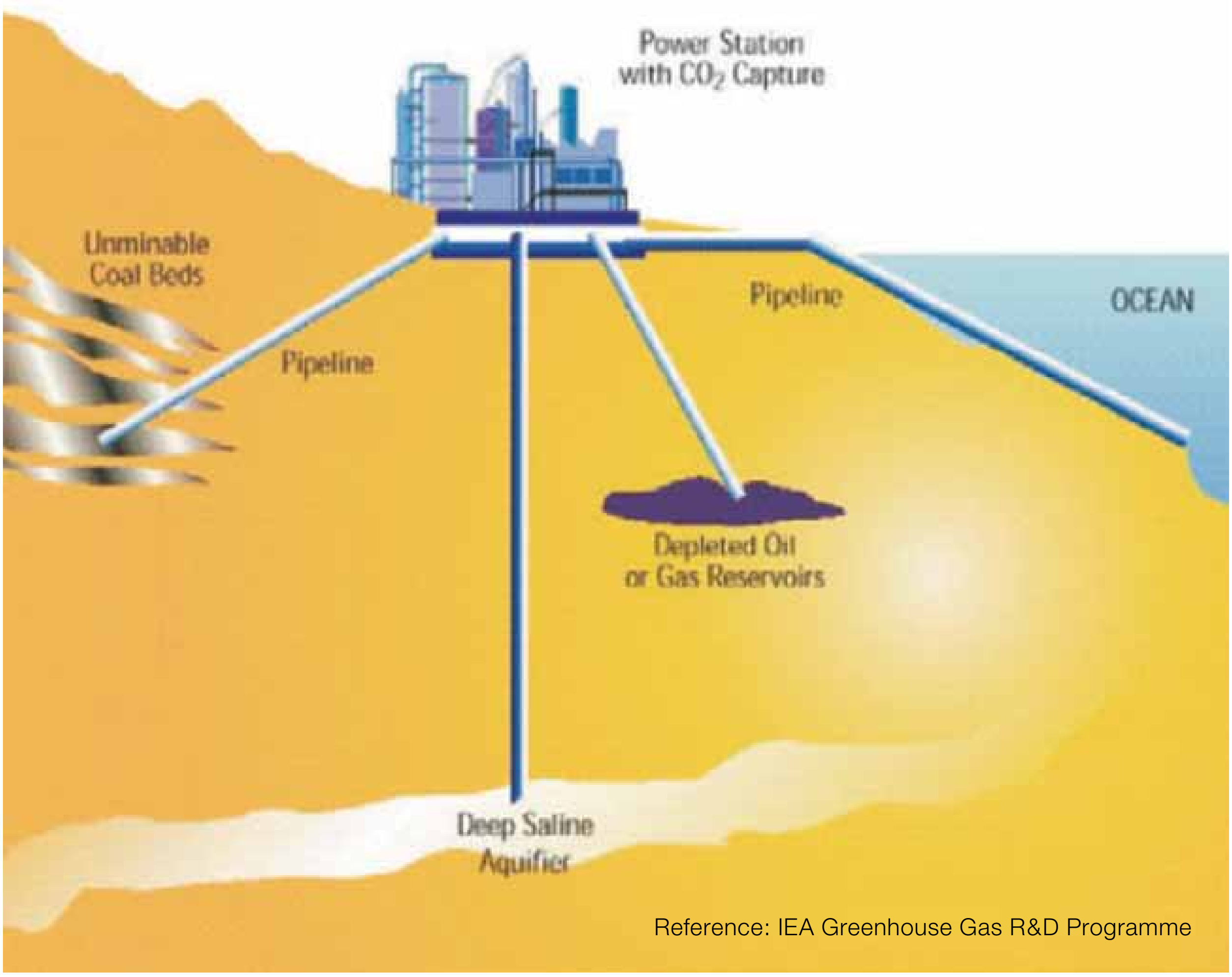
Figure J.1 – Supercritical Water-Cooled Reactor (SCWR)



Reference: Gen-IV International Forum

Figure J.2 – Transition in generations of nuclear energy production

Annex K – Carbon capture and storage



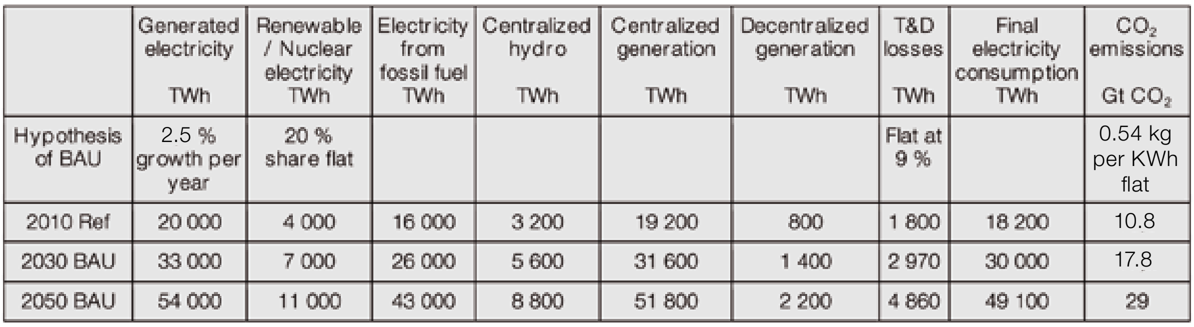
Reference: IEA Greenhouse Gas R&D Programme

Figure K.1 – Options for carbon capture and storage, CCS

Annex L – Sensitivity analysis of CO_2 reduction measures

In a business-as-usual scenario, shown as BAU in Table L.1 below, **CO_2 emissions due to electricity generation would almost triple by 2050.**

Table L.1 – Electricity generated/used and CO_2 emitted in business-as-usual, 2010-2050



	Generated electricity TWh	Renewable / Nuclear electricity TWh	Electricity from fossil fuel TWh	Centralized hydro TWh	Centralized generation TWh	Decentralized generation TWh	T&D losses TWh	Final electricity consumption TWh	CO_2 emissions Gt CO_2
Hypothesis of BAU	2.5 % growth per year	20 % share flat					Flat at 9 %		0.54 kg per KWh flat
2010 Ref	20 000	4 000	16 000	3 200	19 200	800	1 800	18 200	10.8
2030 BAU	33 000	7 000	26 000	5 600	31 600	1 400	2 970	30 000	17.8
2050 BAU	54 000	11 000	43 000	8 800	51 800	2 200	4 860	49 100	29

A first scenario could limit emissions to less than doubling CO_2 by 2050. Table L.2 below (for 2030) and Table L.3 (for 2050) show the improvements possible in green and yellow: in order, from top to bottom, end-use efficiency improvements of 30 %, increase of renewable/nuclear generation to 30 %, reduction of T&D losses from 9 % to 7 %, and a 5 % improvement in generation efficiency. After each improvement the new totals (energy used, CO_2 emitted) are shown on a new line where they are different.

Table L.2 – Effects of end-use efficiency, 30 % renewables and 2 % T&D loss reduction, 2030

		Generated electricity TWh	Renewable / Nuclear electricity TWh	Electricity from fossil fuel TWh	Centralized hydro TWh	Centralized generation TWh	Decentralized generation TWh	T&D losses TWh	Final electricity consumption TWh	CO$_2$ emissions Gt CO$_2$
	2010 Ref	20 000	4 000	16 000	3 200	19 200	800	1 800	18 200	10.8
	2030 BAU	33 000	7 000	26 000	5 600	31 600	1 400	2 970	30 000	17.8
Less 30 %	EE end use reduction								-5 500	-2.9
	2030 after EE end use								24 500	
30 % renewable (16 % H & 14 % DG)	Renewable effect	27 000	10 200	16 800	5 600	22 400	4 600		24 500	-1.7
	T&D losses	27 000	10 200	16 800	5 600	22 400	4 600	2 430	24 500	
7 % T&D losses instead of 9 %	T&D losses reduction effect							-540		-0.3
5 % improvement in generation efficiency	Generation efficiency improvement									-1.45
	2030 SC 1	26 400	10 200	16 800	5 600	22 400	4 600	1 890	24 500	11.5

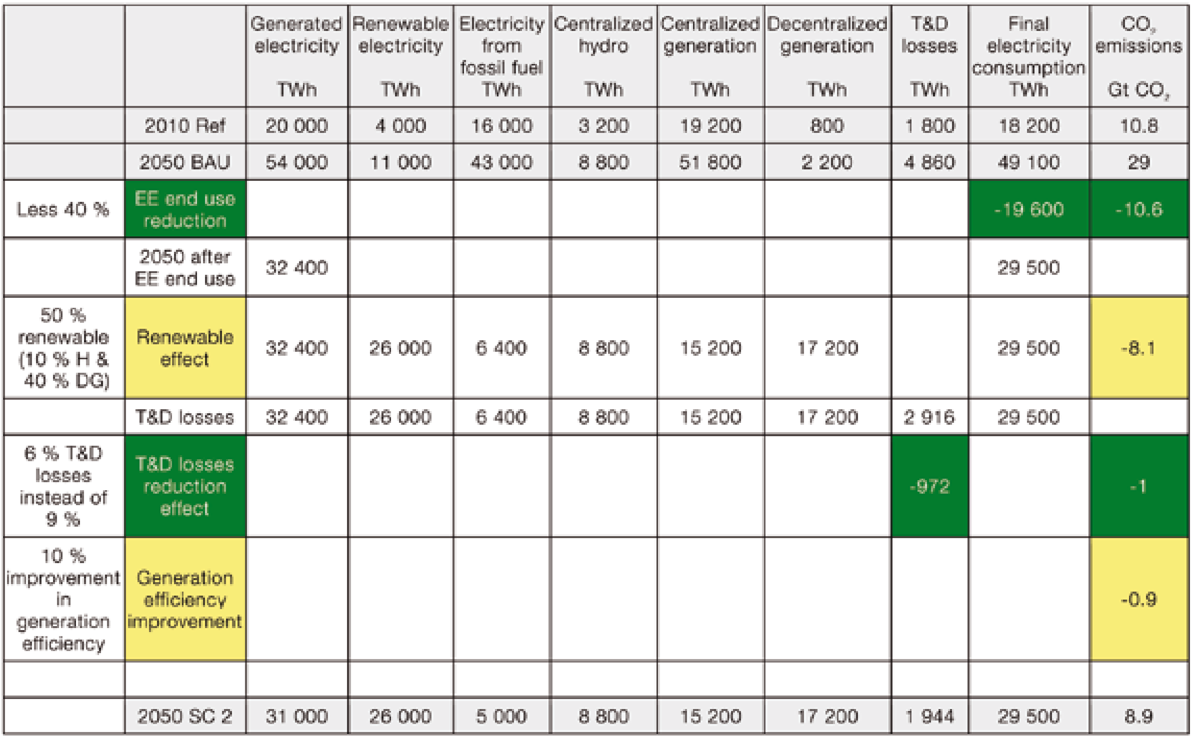
Table L.3 – Effects of 30 % end-use efficiency/renewables and 2 % T&D loss reduction, 2050

		Generated electricity TWh	Renewable electricity TWh	Electricity from fossil fuel TWh	Centralized hydro TWh	Centralized generation TWh	Decentralized generation TWh	T&D losses TWh	Final electricity consumption TWh	CO$_2$ emissions Gt CO$_2$
	2010 Ref	20 000	4 000	16 000	3 200	19 200	800	1 800	18 200	10.8
	2050 BAU	54 000	11 000	43 000	8 800	51 800	2 200	4 860	49 100	29
Less 30 %	EE end use reduction								-14 700	-8
	2050 after EE end use	37 800							34 400	
30 % renewable (16 % H & 14 % DG)	Renewable effect	37 800	16 400	21 400	8 800	30 200	7 600		34 400	-2.9
	T&D losses	37 800	16 400	21 400	8 800	30 200	7 600	3 400	34 400	
7 % T&D losses instead of 9 %	T&D losses reduction effect							-760		-0.4
5 % improvement in generation efficiency	Generation efficiency improvement									-1.7
	2050 SC 1	37 000	16 400	21 400	8 800	30 200	7 600	2 640	34 400	16.1

Energy savings and efficiency in end use are the main contributors, renewables/nuclear give a significant CO_2 reduction, whereas generation efficiency improvements as well as T&D loss reduction contribute smaller amounts.

A more aggressive scenario is necessary to decrease CO_2 emissions from electricity generation, and Table L.4 below shows the effects of a 10 % generation efficiency improvement as well as the other factors shown.

Table L.4: Effects of 40 % end-use eff., 50 % renewables & 3 % T&D loss reduction, 2050



		Generated electricity TWh	Renewable electricity TWh	Electricity from fossil fuel TWh	Centralized hydro TWh	Centralized generation TWh	Decentralized generation TWh	T&D losses TWh	Final electricity consumption TWh	CO_2 emissions Gt CO_2
	2010 Ref	20 000	4 000	16 000	3 200	19 200	800	1 800	18 200	10.8
	2050 BAU	54 000	11 000	43 000	8 800	51 800	2 200	4 860	49 100	29
Less 40 %	EE end use reduction								-19 600	-10.6
	2050 after EE end use	32 400							29 500	
50 % renewable (10 % H & 40 % DG)	Renewable effect	32 400	26 000	6 400	8 800	15 200	17 200		29 500	-8.1
	T&D losses	32 400	26 000	6 400	8 800	15 200	17 200	2 916	29 500	
6 % T&D losses instead of 9 %	T&D losses reduction effect							-972		-1
10 % improvement in generation efficiency	Generation efficiency improvement									-0.9
	2050 SC 2	31 000	26 000	5 000	8 800	15 200	17 200	1 944	29 500	8.9

Energy efficiency and savings in end use remain the main contributor. Combining 50 % renewables/nuclear with 40 % decentralized generation is a clear challenge for the stability of the electrical system. A 10 % improvement in generation efficiency has a limited effect since fossil-fuel use has been reduced.

The vision of 50 % of power being generated by methods which emit no CO_2 at all is shown graphically in Figure L.5.

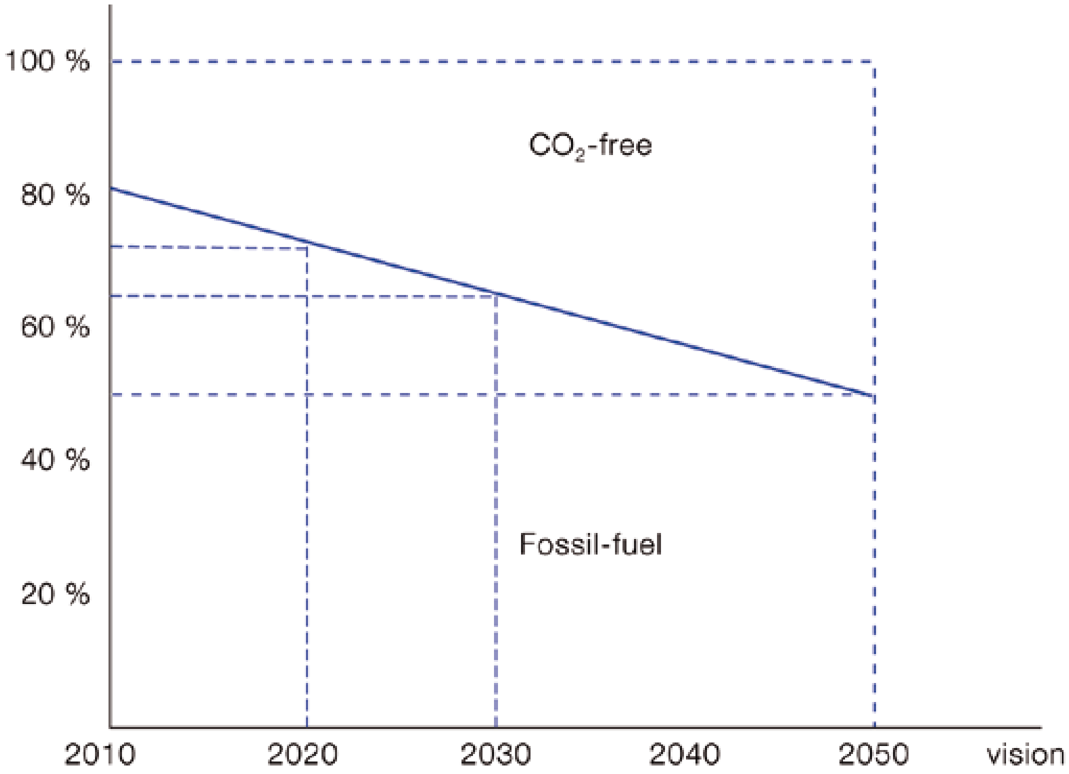


Figure L.5 – Schematic evolution towards 50 % CO_2-free generation in 2050

Annex M – The DESERTEC project

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