6 Energy Conservation

6.1 Energy – the Basis of Life and Society

6.1.1 World Energy Development

Over the last 100 years global energy use has increased 16 times, and the global economy 14 times, almost proportional. Energy has been seen as a key resource for development. This increase is still going on more or less linearly. The Energy Information Administration (EIA) of the US Department of Energy (DOE) has studied the energy development for the first 20 years in the new century. Their predictions are as follows:

Between 1999 and 2020, total world energy use is projected to grow from 403 EJ (ExaJ $=10^{18}$ J) to 645 EJ (Figures 6.1a-c), a 60% increase. Developing countries as a whole are expected to account for 60% of the increment in total energy use over this 20 years period, the western industrialised countries 30%, and Central and Eastern Europe and the former Soviet Union (EE/FSU) 10%.

Fossil fuels today account for 80% of energy provision at large, and are expected to continue to be the major source of energy. Oil is expected to remain the dominant energy fuel, with 40% of the whole, as it has for decades. In the industrialised world, oil use increase is due to a growing transportation sector. In the developing world, oil consumption is projected to increase for all end uses. Natural gas is believed to be the fastest growing primary energy source worldwide, maintaining a growth of 3.2% annually. Gas is increasingly seen as the desired option for electric power, given the efficiency of combined-cycle gas turbines relative to coal- or oil-fired generation. The fact that it burns more cleanly than either coal or oil, makes it a more attractive choice, also for reducing greenhouse gas emissions.

Coal use worldwide is projected to increase at a rate of 1.7% per year between 1999 and 2020. Substantial declines in coal use are projected for Western Europe and the CEE/FSU coun-

In this Chapter

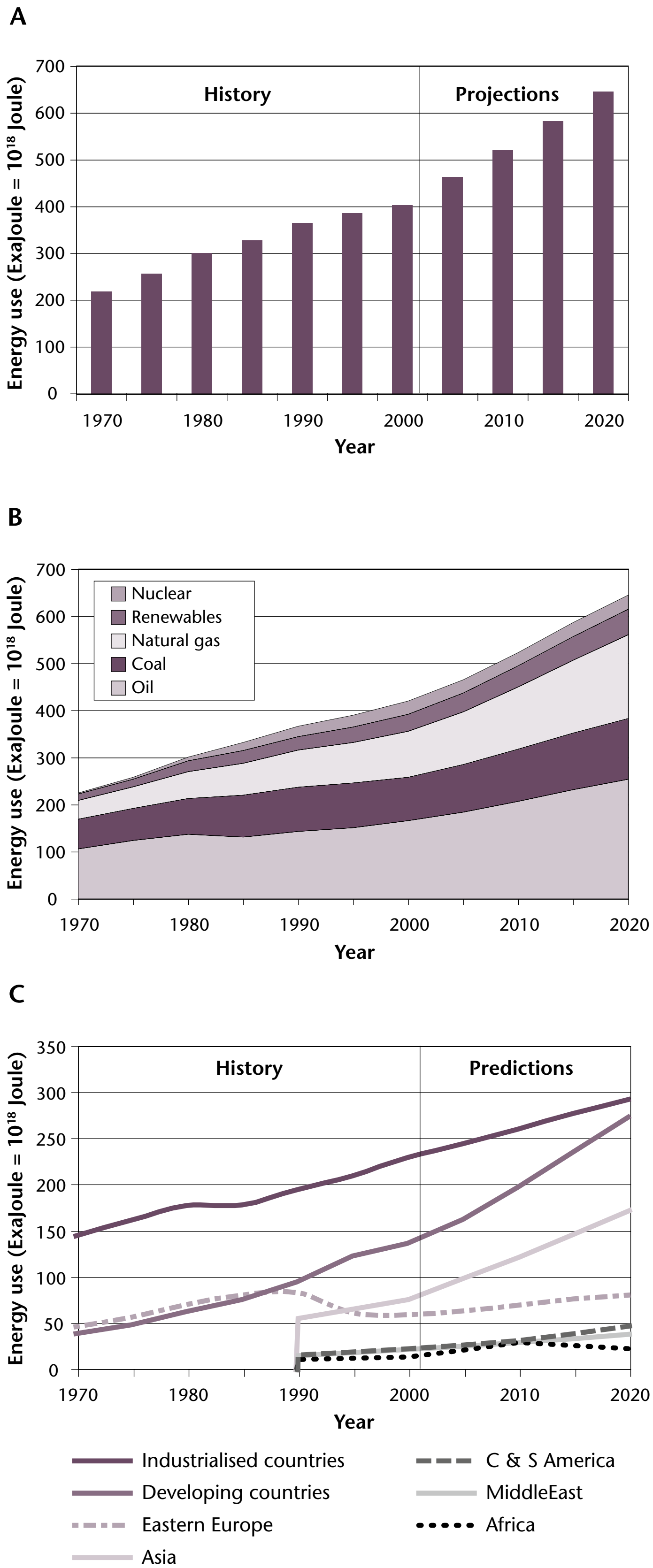

Figure 6.1 World energy consumption. The world energy consumption 1970-2002 as well as predictions by the Energy Information Administration (EIA) of the US Department of Energy (DOE) for the period 2003-2020. *A. World energy consumption 1970-2020. B. World energy consumption per fuel type 1970-2020. C. World energy consumption per region 1970-2020. The data are based on extrapolation of existing trends. A very different view based on the prediction of the Association for the Study of Peak Oil is shown in Chapter 2 of Book 3 in this series [Zibcinski et al, 2006]. [Sources. History: EIA, 2001 and EIA Office of Energy Markets and End Use, International Statistics Database. Projections: EIA, 2002].*

tries, where natural gas is increasingly being used to fuel new growth in electric power generation, and for the industrial and building sectors. In the developing world, however, coal use increases. 85% of the rise is projected for China and India.

Electricity generated from nuclear power is expected to increase by 11.3% in the period with the highest growth, 4.7% per year, in the developing world. Electricity from hydropower and other renewable energy sources is projected to grow by 2.1% annually. The renewable share of total energy use is expected to decline from 9% in 1999 to 8% in 2020. In the developing world large-scale hydroelectric power plants is expected to account for the largest share of growth, while wind, biomass and geothermal power will dominate in the industrialised world.

6.1.2 The Development in the EU and the Baltic Sea Region

The projection of the United States DOE is basically a projection of existing trends. This way to see the development is not shared by all.

First of all, independent researchers doubt that the oil reserves, which DOE assumes for its forecast, exist at all. They are not proven; it is just an assumption. Secondly, the limited oil supply and competition for the existing fossil fuel resources is believed to give a very substantial price increase. Peak Oil, the point in time when half of the existing resources have been used and production is declining, is projected to occur at 2008-2010. This is confronted with dramatically increased demand from China and other Asian countries. A new cost level for oil and gas will force western economies to look more seriously into energy saving measures and new sources of energy.

The increase in *total energy use* is obvious on a global scale but not on a national or regional. It is obvious that at some point in time energy use based on fuels have to stop increasing. In the more mature economies this is approaching. In the EU15 energy growth is declining. In Sweden the total energy use has been almost constant since the 1980s, if the surplus heat generated by nuclear power plants is not included.

For some time already, in fact since about the 1970s, economic value per used energy unit has been increasing. This is called *decoupling*. In the European Union the decoupling of the economy from energy has amounted to about 4% yearly. Increasing production without using more energy becomes more interesting as energy prices increase. A decoupling of economy from energy is very noticeable in housing, service and industry. It is still not obvious in the transport sector, but is expected to be so as oil prices soar.

The alternatives to fossils are also developing and become more interesting as oil prices mount. This is a question of *decarbonising* the energy flows, or, differently said, decoupling energy from carbon flows. This trend is visible in the industrialised world starting in the 1970s. In the EU the relationship of TWh/tonnes carbon has decreased 25% over the period. In Sweden, where a very clear policy to reduce oil dependency has been pursued since the oil price crisis in 1973, the share of fossils in the energy budget has decreased to less than half. The substitution includes nuclear power, hydropower and increased efficiency. In 2005 about 40% of the energy was based on oil.

6.1.3 Environmental Issues and World Energy Use

In the coming decades, environmental concerns could significantly affect patterns of energy use around the world. Global climate change is a wide-reaching environmental issue that is receiving increased attention in recent years. Carbon dioxide, the most prevalent greenhouse gas in the atmosphere, has two major anthropogenic (human-caused) sources: the combustion of fossil fuels and changes in land use. Net releases of carbon dioxide from these two sources are believed to be contributing to the rapid rise in atmospheric concentrations since pre-industrial times. Because estimates indicate that approximately 80% all anthropogenic carbon dioxide emissions currently come from fossil fuel combustion, world energy use has emerged at the centre of the climate change debate.

Based on expectations of regional economic growth and dependence on fossil energy, particularly in developing countries, the DOE study expects global carbon dioxide emissions to grow more rapidly over the period 1999-2020 than they did during the 1990s. Factors such as population growth, rising standards of living, and further industrialisation are expected to have a much greater influence on levels of energy consumption in developing countries than in industrialised nations. Energy-related emissions are projected to grow most rapidly in China, the country expected to have the highest rate of growth in per capita income and fossil fuel use over the coming period.

The DOE study expects carbon intensity – the amount of carbon dioxide emitted per dollar of gross domestic product, GDP (the inverse of decoupling) – to improve (decrease) throughout the world over the next two decades. The steepest rates of improvement are, for the most part, expected to occur among the transitional economies of Central and Eastern Europe and the former Soviet Union (CEE/FSU).

6.1.4 Implementing the Kyoto Protocol

The world community's effort to address global climate change has taken place largely under the auspices of the Climate Convention. It was adopted at the UN Conference on Environment and Development in Rio in May 1992 and entered into force in March 1994. The ultimate objective of the convention is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The details of implementation of this goal were finally agreed on in Tokyo in 1997 (the Kyoto Protocol). The terms of the Kyoto Protocol call for the participating countries to reduce their overall greenhouse gas emissions by at least 5% (EU 8%) below 1990 levels to 2008 to 2012. The Kyoto protocol entered into force in March 2005, when the Russian Federation ratified it.

In addition to any domestic emission reduction measures that countries may choose to implement, the Kyoto Protocol allows the use of four "flexibility mechanisms" (sometimes called "Kyoto mechanisms"):

International emissions trading (Article 17) allow participating countries to transfer some of their allowable emissions to other participating countries, beginning in 2008, for the cost of emission credits. For example, a participating country that reduces its 2010 greenhouse gas emissions level by 10 million metric tons carbon equivalent more than needed to meet its target level can sell the "surplus" emission reductions to other participating countries. This trade would lower the seller's allowable emissions level by 10 million metric tons of carbon equivalent and raise the buyers' allowances by the same amount in total. In the Baltic Sea region the CEE countries, especially Russia, where industrial production had decreased since 1990, will be able to sell emission rights.

Joint fulfilment of commitments (Article 4) allows participating countries that are members of an established regional grouping to achieve their reduction targets jointly, provided that their aggregate emissions do not exceed the sum of their combined Kyoto commitments. For example, EU countries have adopted a burden-sharing agreement that reallocates the aggregate Kyoto emission reduction commitment for the EU among the member countries.

The Clean Development Mechanism (CDM), (Article 12) allows participating countries, either through the government or a legal entity, to invest in emission reduction or sink enhancement projects in non-participating countries, gain credit for those "foreign" emissions reductions, and then apply the credits toward their own national emissions reduction commitments. The CDM, in principle, redistributes emission reductions from developing country parties to participating parties.

Joint implementation (JI), (Article 6) is similar to the clean development mechanism except that the investment in emission reduction projects must occur within the participating countries.

The Kyoto targets refer to overall greenhouse gas emission levels, which encompass emissions of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Hence, a country may opt for relatively greater reductions of other greenhouse gases emissions and smaller reductions of carbon dioxide, or vice versa, in order to meet its entire Kyoto obligation. Currently, carbon dioxide emissions account for the majority of greenhouse gas emissions in most participating countries, followed by methane and nitrous oxide.

The governments will have to implement various incentives, such as carbon dioxide taxes or energy taxes, to reduce emissions in their countries. Some of these will be of significance to industry.

6.2 Improving Energy Use in Society

6.2.1 Energy for Transport – Alternatives

Transport is today using about 40% of the energy budget of industrial societies, a share that is increasing. In a car engine the heat released when combusting the fuel (gasoline or diesel) is used to generate the mechanical work needed to drive the car forward. This is a quite inefficient process. Up to 18% of the energy content in the fuel becomes kinetic energy. The yield is slightly higher in a Diesel motor in which the combustion temperature is higher.

Efforts to reduce energy use in transport have priority, but are the least successful today. A few measures are the following: Car motors can be made much more efficient and the mileage of a car can be improved by up to 50%. Alternative renewable fuels include ethanol and biogas. Today petrol in the European Union has 5% ethanol content. This may increase. Cars which can take either ethanol or petrol (flexi fuel cars) are increasing in popularity, and a conventional motor may easily be converted into one that runs on ethanol. So-called environmentally friendly cars have a number of advantages, no tax on ethanol, no parking fees in some cities etc. which will make them less expensive to drive. Electric cars, and hybrid vehicles (with both an electric and a combustion motor), are increasingly used. Electric energy can be transformed to movement (and vice versa when braking) with high efficiency. Drawbacks include the lack of efficient batteries, and high cost.

Transport on rail is at least one order of magnitude more energy efficient than road transport in traditional cars.

More efficient use of cars should be mentioned as a separate measure. This includes car pooling, but also that transport in industry not is dependent on owned cars, but rather that the service is bought from the car provider. A complete reorganisation of transport in society is the most far-reaching measure. A society in which the need for transport is decreasing, and the remaining transport is using mainly rail, would decrease energy use in this sector dramatically.

6.2.2 Electric Energy – More Efficient Lighting, Motors and Processes

Electricity accounts for close to 50% of national energy budgets. Electric energy is used for *lighting*, *movements* in electrical motors and a number of *industrial processes* such as electrolysis in which the final energy form is electricity. Industry spends more money on electric energy than on any other energy source. Big total savings can be realised through small savings in electricity consumption practices, thus increasing the ratio between production volume to energy costs.

In a house, electricity is used to heat the kitchen stove as well as in many cases for direct or indirect heating of the house. In industry many energy intensive processes rely on heat from direct firing of fossil fuels, but electricity is used in induction ovens where it is converted to heat.

But electricity is a higher form of energy. This becomes clear with the concept of *exergy*. Exergy expresses the capacity of energy to do work. Electricity has 100% capacity to do work and thus its exergy is 1. For heat the capacity to do work is dependent on temperature. Low temperature heat, which may be excellent to heat a building, has very little capacity to do work and has little exergy. It is clear that electric energy has to be carefully used and only exceptionally used for heating.

The equipment using electricity in industry as well as in households has developed to become more efficient. This is a considerable source of energy saving. In cities the local electricity companies may inform and encourage the inhabitants to buy and use more energy-saving products in order to lower the consumption of electricity.

The use of low energy *lamps* may reduce energy costs considerably. It is also important to turn off lamps when they are not needed. *Electric motors* – that is, movement – are often used less carefully in that they are either on or off. If the work output from the engine is regulated by rotation speed control, considerable savings are possible. Electricity using *processes* is more difficult to change.

6.2.3 Heating Energy – Saving, Upscaling and Downscaling

In many cases the final use of energy is in the form of *heat*. It is thus crucial that the use of heating in society is optimally organised. The largest share is the heating of housing, about 30% of total energy use in society. Traditionally heating was done independently for each house or even household, by an individual boiler using wood, coal, coke, etc. These burners were seldom efficient (temperature too low) and often gave rise to considerable pollutants in the flue gases, especially particles.

One measure which has proven to give large environmental gains in urban areas is district heating, that is to replace all small household heating systems with a large power plant, that is *upscaling*. By building a central power plant with improved process control, as well as cleaning equipment, and with an energy distribution net instead of a number of small household heaters, the amount of air pollutants drastically decrease. Central power plants may also use a fuel, which is difficult to use for a household, such as household waste or peat.

There are also a number of other ways to *save* energy, economise with the produced energy, as for instance controlling the temperature in our flats and houses. These measures are dependent on incentives, for example increased cost of heating. With proper insulation it is today possible to build houses which use very little or even no heating at all, so called passive energy houses (< 15 kWh/m²/year) or low energy houses (< 40 kWh/m²/year). Energy use in residential areas has been decreasing for several years.

It is also possible to save by finding proper local solutions, that is, *downscaling*. These include solar panels and heat pumps. Solar panels, producing hot water, in many cases are enough to provide a household with warm water. Solar panels are usually added to roofs and then do not require extra space. Of course these measures also apply to the heating of industrial buildings. Heat pumps use electricity to extract heat from the surrounding. The possible savings, compared to electric heating, are up to 2.5 times or a reduction of 60%. Here it is important that the electricity does not come from combustion. Then there is no systems gain. Alternatives include e.g. hydropower. Heat pumps may be very profitable if the heat is extracted from e.g. wastewater or surface water. Alternatives are so-called rock heat (from great depths) or even from the air.

6.2.4 Integrated Solutions

Energy together with materials, waste, and water make up the flows of a society, its metabolism. Considerable gains can be made by coordinating these flows. E.g. wastewater always carries some heat, which may be extracted by a heat pump. The sludge from a wastewater treatment plant may be fermented to produce biogas, which is an excellent source of energy, for example for buses or cars. Solid waste may be incinerated to produce district heating and cogenerated electricity.

Integrated solutions include the coordination of several facilities, sometimes referred to as industrial symbiosis. The steam produced in one factory may be sold to another factory, instead of just emitted. Several factories use extra heat for the district heating system in the city where they are located. Many times the waste in one production can be used in the next production. Slaughter house organic waste may be fermented to produce biogas.

Special solutions are also possible. In cities in the north of Sweden snow, collected when cleaning the streets in wintertime, is deposited in one place to be used for local cooling e.g. in a hospital during the rest of the year.

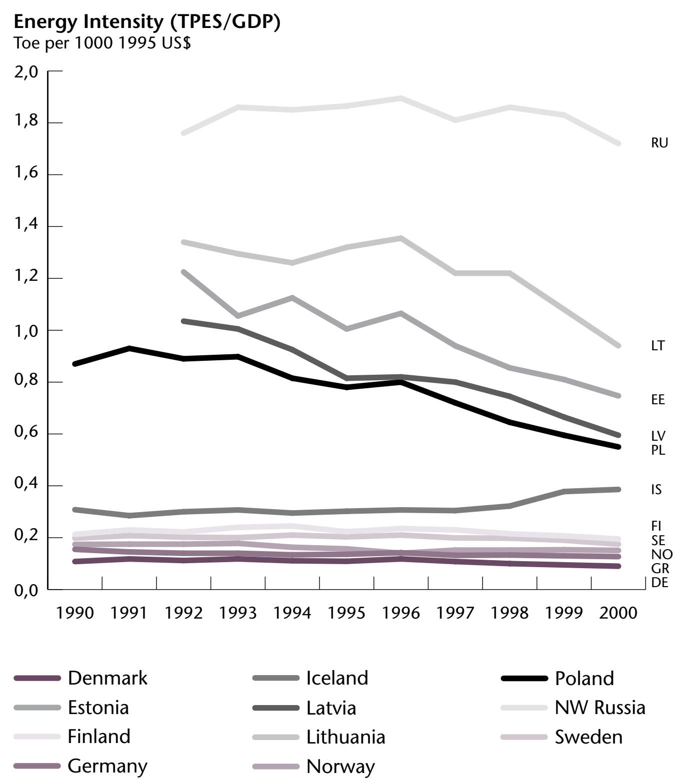

Figure 6.2 The development of energy intensities in Northern Europe, 1990-2000. *The development shows a general decline in the eastern european countries while the western countries exhibit a more stable situation. (TPES=Total Primary Energy Supply.) [Adapted from Baltic 21, 2003].*

6.3 Power Generation

6.3.1 Kinds of Energy Sources

There will always be a demand for primary energy. To meet the need for primary energy there are basically three classes of energy sources:

1. Fossil fuels – Coal, Oil, and Natural gas.
2. Nuclear power.
3. Renewable energy sources, i.e. energy from the sun. These are:
   - Hydropower, Biomass.
   - Wind, Solar energy, Wave and tidal energy, Geothermal energy.

It is useful to distinguish between *dispatchable* and *intermittent* sources of energy. Dispatchable sources can be stored – to be used later – and to some extent transported to the place where the energy is converted to heat or electricity. Power plants that convert solar radiation, wind or wave power directly into electricity cannot be dispatched since the flowing energy will be lost unless it is utilised when it is available. Solar radiation, wind, wave and tidal power sources are therefore considered as intermittent sources. To some extent the energy generated by an intermittent source can be stored however. Thus hot water can be stored as such, and electricity can be stored in a battery or used e.g. to pump water to a high level reservoir.

Fossil- and biomass-fuelled power plants – as well as other energy converters such as vehicle engines – are dispatchable since the energy is stored in the fuel. The use of biomass, especially in the form of wood chips and biopellets, has increased much recently. Biomass is produced in forestry, where the residual is taken care of, from energy forests and recently also from oat.

Hydropower stations are mostly dispatchable since they often have dam-capacity to allow storage of water so that the production of electricity can be regulated according to the demand. It is not likely that there will be any additional large hydropower plants in the Baltic Sea region. The capacity was taken into use in the early part of the 20th century. Proposals for new large hydropower plants have been developed for River Daugava close to Daugavpils in Latvia, and in River Wisla in Poland, but protests against these plans have been voiced, as they would destroy much of the natural beauties of these rivers. In northern Norway, Sweden and Finland expansion of hydropower also meets protests. In Sweden the four remaining large rivers are protected against exploitation by a parliamentary decision. The technology of small scale hydropower, to provide e.g. a neighbourhood with electricity, has developed recently in an interesting way.

Wind power stations and wind farms are increasing since the 1990s. Wind power will provide some 10-25% of electricity in many parts in the region, e.g. Denmark and north Germany. Wind energy is more efficient on a water surface and many wind farms are located outside the coasts. Wind power electricity is fed into the general net of the country and in this way can be stored, as hydropower is resting. As with hydropower, wind farms disturb the landscape.

Wave power technology is now developing in an interesting way and may have the capacity to be just as important as wind power in the future. Tidal power is of very limited significance generally and not at all possible in the Baltic Sea region. In regions with high tidal differences it is however a feasible technology. The Rance Valley Tidal Power Station close to St Malo in Normandy, France has an installed capac-

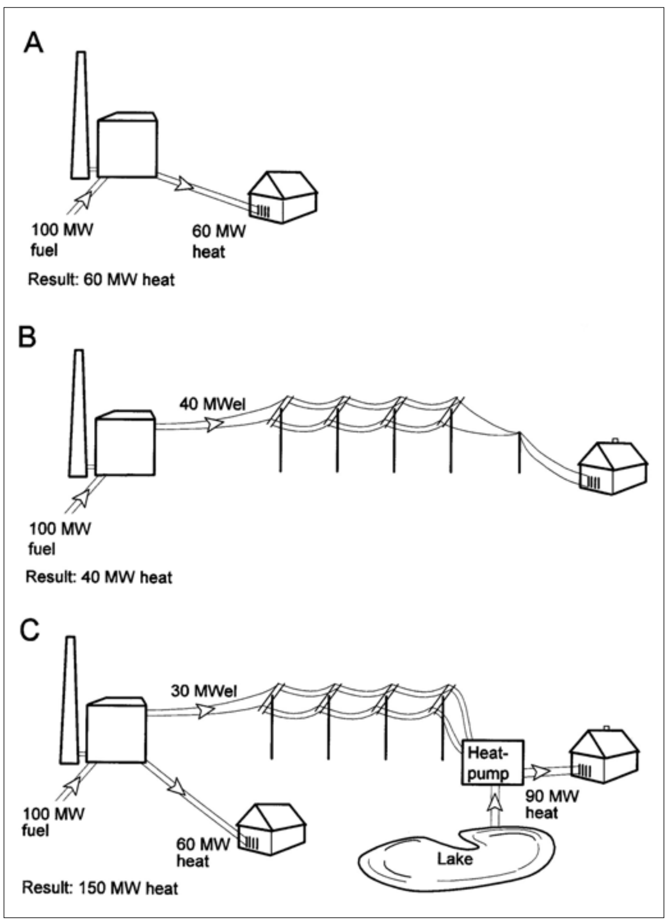

Figure 6.3 Comparison between three different alternatives for production of heating energy for households. *A "bad" energy plant (A). An energy plant where all produced electricity is used for heating purposes (B), and an energy plant where the produced electricity is used to run a heat pump (C). (Illustration: Gunnar Svedberg, Royal Institute of Technology)*

ity of 240 MW, distributed on 24 turbines. The amplitude of the tide here is in the order of 13,5 m.

Solar panels have been mostly known as solutions for individual buildings, but solar panel fields also exist and are a growing energy sector. The largest today seem to be the one at Aeroe in southern Denmark. It provides all district heating needed for the town of Aeroe from March to November. Large solar panel fields are also working in Kungsbacka and Uppsala in mid Sweden. The technology for solar panels develops. Today they are quite efficient also in winter as long as the sun is shining. Heat may be stored as warm water in large spaces in the rock. In this sense they are semi-dispatchable. It provides much more heat per surface area, up to 50 times, than growing of biomass which then is incinerated. Geothermal energy, where it is available, is similar. Large geothermal power plants are found outside Szczecin in Poland and in Denmark.

Figure 6.4 Wind power is now rapidly expanding in the Baltic Sea region. *It is expanding in Denmark, northern Germany, and southern Sweden, where this wind power park is found. The environmental costs of wind power are mainly related to landscape intrusion. If fully exploited, wind power could not, it is projected, provide more than up to 7% of Sweden's electricity requirements.*

Photovoltaic cells convert sunlight to electricity. Recently the cost of the electricity, measured as euro per kWh, has decreased and is more competitive. Still photovoltaic is expected to be used mostly is special circumstances, for example in distant areas to which distribution of electricity is not practical.

6.3.2 Power Plants

Power plants are mostly based on burning of fuels. These are fossils, biomass (wood or peat), or waste. In general fossil fuels totally dominate the picture in most countries in the region.

When burning a fuel, the remains are generally various gases and a solid waste. What gases are produced and the amount of each depends on the fuel used, as well as the conditions during the combustion. The emissions from a combustion plant are thus influenced by the choice of fuel and conditions under which combustion takes place, i.e. process integrated measures. Another possibility is, of course, to use external cleaning technology.

The aim of a power plant is to supply us with energy in the form of heat and electricity. We can also use some other source of energy instead of the fossil fuel, for instance nuclear power. We must then realise that we have other environmental problems to consider.

Figure 6.3 shows some alternatives which gives very different results regarding the consumption of raw materials and, consequently, emissions of pollutants. From an environmental point of view the above mentioned outlook on the problem of supplying us with energy is considerably more important, compared to the discussion of how to increase the efficiency in an exhaust cleaning process by some percents.

6.3.3 Cogeneration

Cogeneration, also known as combined heat and power (generation) or CHP, is an efficient, clean, and reliable approach to generating (electric) power and thermal energy from a single fuel source. Cogeneration uses heat that is otherwise discarded from conventional power generation to produce thermal energy. This energy is used to provide cooling or heating for industrial facilities, district energy systems, and commercial buildings. By utilising this waste heat, cogeneration systems achieve typical effective energy efficiencies of 50% to 70%, a dramatic improvement over the average 33% efficiency of conventional fossil-fuelled power plants.

Cogeneration's higher efficiencies reduce air emissions of nitrous oxides, sulphur dioxide, mercury, particulate matter, and carbon dioxide, the leading greenhouse gas associated with climate change.

Case Study 6.1 Co- and Trigeneration

A factory requires 1 MW of electricity and 500 refrigeration tons* (RT) of heat/cooling. The gas turbine generates electricity required for the on-site energy processes as well as the conventional vapour compression chiller.

Assuming an electricity demand of 0.65 kW/RT, the compression chiller needs 325 kW of electricity to obtain 500 RT of cooling. Therefore, a total of 1325 kW of electricity must be provided to this factory. If the gas turbine efficiency has an efficiency of 30%, primary energy consumption would be 4417 kW.

A cogeneration system with an absorption chiller (thereby making this a "trigeneration" plant) can provide the same energy service (power and cooling) by consuming only 3,333 kW of primary energy, thereby saving nearly 25% in primary energy usage.

** Note: A refrigeration ton (RT) is defined as the transfer of heat at the rate of 3.52 kW, which is roughly the rate of cooling obtained by melting ice at the rate of one ton per day.*

Another example of a cogeneration process would be the automobile in which the primary fuel (gasoline) is burned in an internal combustion engine. This produces both mechanical and electrical energy (cogeneration). These combined energies, derived from the combustion process of the car's engine, operate the various systems of the automobile, including the drive-train or transmission (mechanical power), lights (electrical power), air conditioning (mechanical and electrical power), and heating of the car's interior when heat is required to keep the car's occupants warm. This heat, which is manufactured by the engine during the combustion process, was "captured" from the engine and then re-directed to the passenger compartment.

6.3.4 Trigeneration

Trigeneration is the simultaneous production of cooling, heating and power, in one process. Trigeneration, when compared to (combined-cycle) cogeneration, may be up to 50% more efficient than cogeneration. When found in a hospital, university, office-campus, military base, downtown or group of office buildings, a trigeneration plant has also been referred to as a *district energy system* or *integrated energy system* and as previously mentioned, can be dramatically more efficient and environmentally friendly than *cogeneration.*

The trigeneration energy process produces four different forms of energy from the primary energy source, namely, hot water, steam, cooling (chilled water) and power generation (electrical energy).

Trigeneration allows greater operational flexibility at sites with demand for energy in the form of heating as well as cooling. This is particularly relevant in tropical countries where buildings need to be air-conditioned and many industries require process cooling.

When a trigeneration energy and power system is installed *on-site*, that is, where the electrical and thermal energy is needed by the customer, so that the electrical energy does not have to be transported over long distances, and the thermal energy is utilised on-site, system efficiencies can reach and surpass 90%.

6.4 Saving Electric Energy

6.4.1 Strategic Choices

In the power industry, energy efficiency involves getting the most usable energy out of the fuels. At its best, energy efficiency improvements in the power industry can lead to postponing – or altogether avoiding – the construction of new power plants.

The efficient generation of power is only one way a power plant can pursue energy efficiency. New technologies, applied to the storage of energy and the transmission of energy, contribute to energy efficiency. For instance, the copper wires used in typical transmission lines lose a percentage of the electric energy passing through them because of resistance, which causes

Figure 6.5 Cogeneration. *Combustion for heat production may be coupled to electricity generation in turbines, as in this turbine hall. When the hot steam is pressed through the turbines electricity is generated. The steam is cooled to temperatures appropriate for the district heating system. With this combined system efficiency is close to the theoretical maximum. (Photo: Kjell-Arne Larsson)*