ENERGY FORESIGHT – SWEDEN IN EUROPE

Synthesis and summary

REPORT OF THE PROJECT STEERING GROUP

Energy Foresight – Sweden in Europe is an IVA (The Royal Swedish Academy of Engineering Sciences) project, with the purpose of creating a foundation for a broad discussion around the possibilities and problems regarding sustainable development of energy in Sweden. The time perspective of the project is 20 years, with glimpses 50 years ahead.

Energy Foresight – Sweden in Europe is primarily targeted at broad context decision makers in public administration, industry, and research, but also aims at giving insight and knowledge to a wide group of people at central, regional, and local level.

During 2002 roughly one hundred individuals from business, public administration, and research, have worked in four so-called "panels" where they have studied and discussed different areas of the future, there have been various other groups with a connection to the project.

The results have been presented in four panel reports (in Swedish) and in this Synthesis and Summary Report.
The System Foresight panel: New energy era – a systems study.
The User Foresight panel: What happens next?
The Structure Foresight panel: Can we influence our future? Future scenarios for European Energy.
The Long-term Foresight panel: Energy in 2050 – closer to the sun.

The project has also produced some more accessible factual reports (in Swedish):

- *Oil – resources and price development*
- *Hydroelectric power in Sweden*
- *Electricity and cogeneration of heat and power from coal, natural gas, and biofuels*
- *Wind power on shore and off shore*
- *Energy transfer and storage*
- *Energy use in buildings*
- *Natural gas and coal – resources and price development*
- *Nuclear power of now and in the future*
- *Solar generated electricity and heating*
- *Economic incentives within the energy field*
- *Industrial energy use*
- *Energy use in transport*

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PREFACE

Availability of energy is a prerequisite for a modern industrial society as well as for a better quality of life in developing nations. The IVA-project *"Energy Foresight – Sweden in Europe"* deals with possibilities and problems associated with our energy future.

We take it for granted that various forms of energy will always be available for a multitude of purposes and at acceptable prices. Sweden also places high demands on health and environmental protection issues when it comes to the production of power and heat. During the last few years the climate issue has been highlighted, which in turn will change the conditions for the use of alternative sources of energy. Carbon dioxide is the most important of the greenhouse gases, and it is closely associated with the burning of coal, oil, and natural gas. These fossil fuels play dominant roles in the world's energy supply. Far-reaching measures to decrease carbon dioxide emissions will thus greatly affect the ways in which we use fossil fuels and non-carbon dioxide generating sources of energy.

We have chosen a global starting point for our energy study. From there we will zoom in on the energy systems of Europe and Sweden. The climate issue demands global approach. Deregulation of electricity and gas markets, and the development of integrated European systems related to these energy sources, requires an international perspective on the Swedish energy system.

Our project differs from earlier governmental energy studies in the sense that we are not trying to present the most likely, nor the most desirable energy future. Instead we have opted to draw up some illustrations of Sweden's future energy system, with Europe as a backdrop. The climate issue differentiates the scenarios. Our time perspective is 20 years, with glimpses 50 years ahead.

On the 18th of February 2003, the Steering Group of *Energy Foresight – Sweden in Europe*, presented its final report. The bulk of the work has been done in four panels. Their reflections and conclusions are presented in separate panel reports. The 12 factual reports present different sources of energy, how they are converted into electricity and heat, and finally in what way energy is used within various parts of society.

The Steering Group's final report presents starting points and driving forces, and sheds light on a number of prioritized issues concerning the development of the energy system. I hope that the conclusions drawn in the panels and factual reports will become springboards for continued reading.

We look positively on the energy future. Technological development creates possibilities to handle the climate issue without jeopardizing continued economic growth, and also makes it easier to narrow the gaps between countries. However, this positive basic outlook is based on the assumption that no serious international conflicts or disasters occur. The future will tell whether this condition is too simplistic.

In Sweden, we assume that our areas of technical and industrial strength develop, and that our advanced research within various globally growth-prone energy areas is enhanced. We also assume that clear and stable government energy policies, such as taxation and financial incentives, will continue to be important in the future.

The climate issue, as well as deregulated electricity and gas markets, require altered points of view. We welcome active Swedish participation in international forums to implement measures on carbon dioxide emissions, but Sweden should not single-handedly penalize itself, which will have no effects on climate but will damage the national economy. The development of a common European electricity market, and an expansion of transfer capacity create import and export requirements and open up new avenues to make best use of different countries' resources and conditions. The centrally planned system with total national balance between consumption and production therefore becomes obsolete.

Energy Foresight – Sweden in Europe caters to a broad public. It is my hope that our work will stimulate new ways of thinking, as well as spark discussions and actions in both major decisions and in everyday life.

Many dedicated individuals have been affiliated with this IVA-project. The panel chairmen have had central roles. My assignment as chairman of the project has been exciting and stimulating. I have been backed up by sound teamwork within the steering group, and by conscientious and skillful efforts at the secretariat. Many thanks to all of them!

Anders Narvinger

Chairman of the Steering Group

This report is a translation of the report "Syntes och Sammanfattning" but I have included Appendix "Energy in Sweden" with basic facts of the Swedish energy system as a service to foreign readers.

Göran A Persson, Project Manager

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Possibilities of more efficient energy consumption

- Hybrid vehicles result in lower fuel consumption and substantially better air quality in urban areas.
- New biologcal and material technology allows strong and light composites as well as material-efficient packaging, which, together with a lifecycle perspective decreases energy requirements for transportation.
- New diode-based lighting technology decreases the need of electricity for lighting, initially for different types of outdoor installations.
- Both basic and manufacturing industry move toward increased refinement and processing, and adjustments of the production systems – coupled with more efficient processes within energy intensive – industries limit the increase of electricity use.
- New technology for monitoring and controlling heat and ventilation, "smart" windows, and energy-efficient appliances result in a decreased energy consumption in primarily new, but also older buildings.

Less oil used for heating

- Forest fuels in district heating plants, pellets in multi-family buildings, and heat pumps and pellets in single-family homes replace oil, resulting in reduced carbon dioxide emissions within the heating sector. Increased use of solar heating, fuel cells, and in some areas natural gas, also contribute to the reduced emissions.

Solar based electricity grows in importance

- Hydroelectric power remains the most important component of the Swedish power system, but biofuel, wind, and solar power enjoy increasing market shares. The scope depends on the various incentives for change.

Nuclear power – to be or not to be?

- If the present form of nuclear power exists beyond 2020, we will study the cost and acceptance of a new and safer reactor generation, putting effort and money into "incineration" of radioactive waste through transmutation.
- If the present form of nuclear power is being phaseout in 2020, there will be natural gas network expansions with gas coming from the North Sea and Russia, and also a build-up of natural gas-fired, combined-cycle, power generation facilities (NGCCs).

FUTURE TO THE YEAR 2020

"Old" energy technology is revitalized

- Fossil fuel based electricity production becomes "climatized" through trapping of carbon dioxide, and ultimately stored in suitable geological formations (carbon sequestration). Coal-fired power plants utilizing this technique are in operation in Europe.
- The combustion engine has been further developed and can, in hybrid vehicles, offer much improved energy efficiency and zero-emissions at low speed, for example urban intra-city traffic.

Wider base for liquid fuels

- Liquid fuels still dominate the transport sector. They are to a greater extent tailor-made from natural gas, but they are also made from biofuels within the paper and pulp industry.

The hydrogen gas society on its way

- Fuel cell automobiles are used in local vehicle fleets, but a Swedish breakthrough awaits a hydrogen gas infrastructure development.
- An international research venture on automobile fuel cells has made the technology interesting for certain stationary applications, such as local electricity production with high demands on availability, microelectronics, and light and portable applications.

Structural change within the energy field

- Deregulation of gas and electricity markets, harmonized frameworks within the European Union, and expanded electricity and gas transfer capacities between the countries, make it possible to balance consumption and supply through import and export. This creates new business structures and decreases the need for a traditional domestic energy policy.

New energy technology – an area of growth

- The fact that Sweden lies at the forefront in three areas of research with large global market potential – development of solar cells, components for fuel cells, and gasification of biofuels – and also holds great experience and vast knowledge within production and consumption of forest fuels, should in at least one of these areas result in a successful Swedish industrial venture.

ENERGY FORESIGHT
– some starting-points

The information society depends heavily on a reliable energy supply. At the same time there are close to two billion people around the world who are in dire need of modern forms of energy. The challenge is thus to master the environmental problems and to create a long-term sustainable development of the energy system – not to limit the energy use as such.

Sustainable development is all about amalgamating economic and social development with protection of the environment and justice between generations. The core of the expression is the present generation's responsibility not to overuse and deplete the earth's resources. Since it was coined in the 1987 UN environmental report *Our Common Future*, the term has quickly world-wide spread. Sustainable development has become a political prestige word, an often proclaimed guiding star in environmental policies and environmental work throughout most types of organizations – even those within the field of energy.

A country's energy system cannot be viewed singularly

Earlier energy studies have focused on Sweden, with outreach views on the world. The scope of the Energy Foresight project is wider and has Europe and the world as a starting point. What does it mean to Swedish entrepreneurs, consumers, citizens, and politicians?

Aided by modern technology, mankind inflicts ever increasing traces on the environment. Feedback on, and connections between, global activities constantly grow stronger. Risks, as well as opportunities, become increasingly linked for all inhabitants of the world!

The different economies of the world become more and more intertwined, and deregulation and privatization have changed energy market rules. Older Swedish-based energy companies have become multinational – Sweden is one of many markets.

International cooperation on climate, development, trade, security, and defense will increasingly affect energy systems around the globe. The European playing field will thus be shaped by a continued development of the EU, in which a greater degree of common and harmonized EU-systems is one possibility – and more regionalized or national solutions another.

This is most evident with electricity and gas. For quite some time now, we have not had a Swedish electricity market, but rather a Nordic one. It, in turn, will develop into a Northern European market, and ultimately into a European one.

Energy systems do not shape society – they are shaped by society

Energy as such does not interest most consumers and citizens. Instead they want an abundance of goods and services, lit and heated buildings, and comfortable and inexpensive transportation. They show interest in protecting the environment, social justice, and in the protection of society from sudden disturbances. They basically look for combinations of convenience, security, and the environment, rather than specific combinations of energy resources.

Possible energy solutions must be placed in a larger social context. Energy technologies and energy systems are not developed in a vacuum. Radical infrastructure changes require alliances of influential players. Investments in the energy system's infrastructure are long-term by necessity.

> Energy is a resource for sustainable development – not a problem.

The traditional Swedish model of developing and building large technical systems has often seen close cooperation between Government and industry (e.g. Vattenfall and Asea, and Televerket and Ericsson). The model has undoubtedly been successful when it comes to the development and implementation of new technology, and it has, if not directly, shaped the Swedish industrial society, or at least influenced it greatly. This type of cooperation must, however, take on new shapes in today's deregulated and internationalized markets. The leading factors in a deregulated system will be its market, economy, environment, acceptance, and legislation.

What do the future developmental blocks look like?
Which political and institutional innovations can enable technology breakthroughs and new solutions?

These issues are brought up and discussed in the Energy Foresight project.

Transport, industry, and built-up areas – three integrated parts

Discussions on the development of the energy system often lead to a sectional polarization. We should instead seek common solutions within the supply and usage areas.

The processing industry accumulates considerable amounts of waste heat, which could be used for municipal district heating. This is already happening today, but there are still vast untouched resources.

Industry also has possibilities to use, and in some cases produce, electricity more efficiently. However, today's yield requirements in the process industry make these possibilities unprofitable. With the more favorable interest and better write-off terms within the electricity industry, it could be cheaper to produce new power rather than release it through more efficient use. With the emergence of deregulation and increased privatization of the electricity market, yield requirements within the electrical industry and other industries should approach each other.

When decentralized electricity production for separate buildings increases in size, suppliers focusing mainly on large-unit production and building-owners have to develop different forms of cooperation. The introduction of fuel cell automobiles might be easier if they could be used for electricity production during peak electricity periods. Each fuel cell car represents a 100 kW power plant and 10,000 such vehicles – a small part of the total cars parked – account for a 1,000 MW reserve capacity.

When it comes to reducing carbon dioxide emissions, the reductions have the same value regardless of societal position or geographic location. However, the costs involved in reducing carbon dioxide emissions may vary significantly. Reductions should therefore be imposed at locations where there is lower cost. Proposals that each sector carry out equal-sized reductions are not well-grounded.

The Technological Foresight requires other starting-points

In the Technological Foresight report three fields of technology were deemed especially significant: information technology, new biology, and material technology. What would these three areas look like if viewed through “energy glasses?”

IT will undoubtedly have great importance for developments within the field of energy. The possibilities of monitoring and controlling energy consumption – primarily electricity – create better and more effective conditions for both built-up areas and the industry sector. Experiences from individual monitoring in buildings show an average saving of 20 percent. These meter systems can also be hooked up to panic alarms and other functions of information exchange between landlord and tenant.

But IT-systems also require electricity. The electricity consumption of rolled-out 3G-systems needs to be acknowledged.

New biology opens up possibilities to use genetic engineering to grow plants or micro-organisms which efficiently produce substances and qualities of choice. It will be possible to manipulate wood and fiber qualities of trees, as well as their growth rates. The IT development and the use of sensors make it possible to classify different fiber qualities when harvesting.

If hydrogen production from genetically modified plants and micro-organisms leads to a viable process, it will be of great significance since hydrogen gas will be an important energy medium throughout the next few decades.

Material technology has the potential to trigger advances within the field of energy. Higher quality materials will significantly increase electrical efficiency of fossil-based power plants. Nanotechnology – the process of manipulating items at an atomic or molecular scale to produce precise structures – can result in totally new materials with new characteristics and functionalities, which subsequently can rationalize energy consumption.

So-called artificial photosynthesis requires advanced material synthesis at a molecular level. One objective is to be able to produce hydrogen using direct sunlight.

The combination of IT, new biology, and material technology is a promising field of research which can offer new functionalities in areas like process management, thus contributing to sustainable development and environmentally adapted products.

THE CLIMATE IS THE DIFFERENCE

Our two main scenarios reflect different views on climate changes, and thus of the respective measures needed to reduce carbon dioxide emissions.

The climate in focus scenario is one where the climate is the dominant driving force for the development of future energy systems. We assume that there is global backing for the perception that the growing carbon dioxide emissions pose a serious environmental threat, and that there are international agreements on global limitations. The industrial countries take the lead, with the EU as promoter, and will have reduced their climate emissions by 50 percent by the year 2050. This is in line with what The Royal Swedish Academy of Sciences regards as necessary to stabilize the level of carbon dioxide in the atmosphere at twice the pre-industrial level.

- Scenarios are tools for building various possible energy futures – not forecasts.
- Scenarios show thought-provoking, credible, and relevant pictures – not necessarily the most likely or desirable ones.
- Scenarios capture the deeper energy-developing trends – not merely individual events.

It is an optimistic scenario. The revenues per capita grow globally, the economic gap between countries narrows, and major wars and conflicts are avoided. Measures to improve environmental quality and to limit climate influence go hand in hand with economic and social development, especially in the developing countries. This subsequently makes it possible for them to accept binding commitments to decrease carbon dioxide emissions.

The proportions between market driven and government-initiated measures differs depending on where in the world you are. Some regions are introducing carbon dioxide taxes, while others use trade systems with emission rights. One way or another, what matters is reduced emissions. And perhaps the most important factor is to impose equally strict requirements on energy intensive industry regardless of physical location.

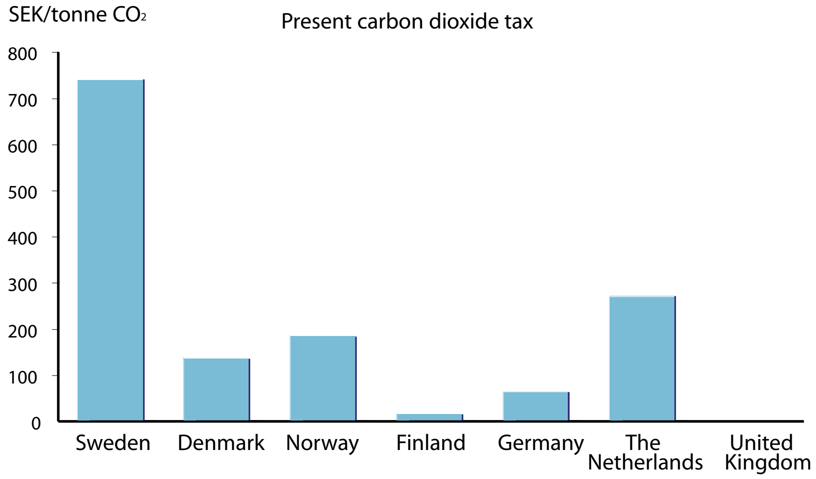
Any subsidies that may affect the climate negatively are removed. Traditional taxation on fuels within the transport sector is gradually replaced by systems that handle the societal costs involved more efficiently, for example kilometer fees. Various transport cost monitoring systems are coordinated within the EU. Congestion charges and toll-roads are introduced in urban regions. These measures enable faster and more attractive public transport systems. Even though urban transport continues to increase, it does not necessarily lead to corresponding increases in traffic jams and carbon dioxide emissions.

State and private interest in partnership paves the way for new vehicular technology and for new fuel infrastructures. Purchases within the EU, the states, and the municipalities create important niche markets for new technology.

New business structures and the use of IT to monitor and control energy consumption, as well as a European environmental and energy building certification, should lead to increased energy efficiency.

But a carbon constrained energy future also comes with a price. *The climate in focus* looks at a complex problem – the threat of global warming – which can lead to a changed and more intensive hydrological cycle and a rising sea level. The limitation requirements on climate emissions will increase the cost of fossil fuel based energy. The integration of electricity and gas networks, allocation of emission reductions, and the degree of harmonization within taxes and subsidies, will play a very important role when calculating the outcome for individual countries.

To sum up, an increase in the price of electricity and heating in Europe is likely if trade with emission rights, carbon dioxide taxes, or other EU-covered incentives are introduced. Sweden however, is in a situation where emissions of carbon dioxide in human settlements and in the transport sector are already highly taxed, which means that a transition to an alternative common EU-system will primarily affect the energy industry.



But since an industry-affecting European climate policy would be in line with corresponding policies in other parts of the world, the competitiveness of the Swedish industry does not have to deteriorate. On the contrary, harmonized actions and measures aimed at reducing carbon dioxide emissions would be beneficial to energy efficiency within the industry, as well as to its knowledge-intensive products.

The climate – one factor among others is a scenario where the climate is an important, but not comprehensive, driving force for future energy systems. Supply reliability and cost are equally important. The global community acknowledges that growing emissions of carbon dioxide are a serious threat but no additional worldwide agreements beyond Kyoto are in place.

This scenario is also an optimistic one in the sense that the per capita income grows globally and that the gap between industrial and developing countries narrows. Large international complications are avoided. Environmental improvements are carried out but the emphasis is primarily on the local scale.

Fossil fuels will still dominate in the year 2050. Certain measures to reduce climate emissions will be taken on a national level but international harmonization is limited to smaller groups of countries.

Far-reaching requirements on air quality will be introduced in some urban areas. This stimulates the use of zero-emission vehicles (energy efficient hybrid vehicles) in sensitive areas. Local congestion and toll charges will be introduced to counteract traffic jams and all kinds of emissions. Increased use of natural gas paves the way for combined production of electricity and heat in small units with high efficiency, good environmental performance, and low distribution losses.

In the absence of internationally harmonized agreements, voluntary commitments will play a bigger role. For example, establishment of codes of conduct on energy intensive products and processes multinational companies in close cooperation with governments.

The climate – one factor among others includes a high risk potential for negative climate effects. It represents the "wait and see" scenario. A delay in emission reductions in the industrial nations beyond the year 2020 could jeopardize the possibility of limiting future global temperature increases to 2°C, which is the EU long-term climate goal.

Great dependence on fossil fuels brings another type of risk. Not that the oil will run out during the next few decades, but in Europe we will experience a supply shift from the North Sea to the Middle East. This means an increased dependence on politically unstable countries. The situation for natural gas is different since there are vast resources available in the North Sea and in Russia.

The scenario represents a future with local and regional environmental improvements but with great uncertainty when it comes to climate change.

The climate in focus scenario implies a halving of carbon dioxide emissions throughout the industrialized countries to the year 2050, thus placing stiff requirements on the energy supply during this period. The Energy Foresight project primarily looks at the developments through the year 2020, which is one stage on the road to the long-term goal. To discuss the Swedish energy systems of 2020, the steering group has drawn up possible 2050 energy supply scenarios for *the climate in focus* and the *climate – one factor among others.* Both stem from the development of the European Union and are presented on the inside of the back cover page. The panels have had the liberty to add their own images.

The two supply scenarios have introduced new nuclear power and/or natural gas as a bridge to a solar and hydrogen society. Such a society requires a technological leap and can only be realized beyond 2020. And the bridge needs to be built by existing technically developed and climatically adapted technology.

PRIORITIZED ISSUES within Energy Foresight

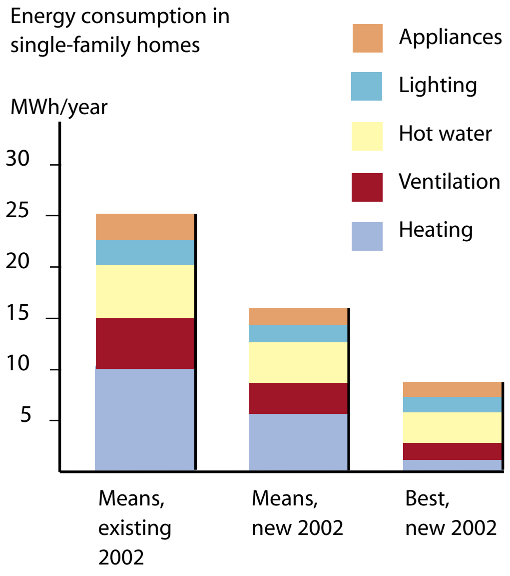
The energy need – level and composition

For a long time there has been a correlation between economic growth and energy consumption. In developed countries such as Sweden there are signs of maturity in the energy usage, and a weaker connection between growth and energy consumption but a continued increase in electricity use.

Energy Foresight has an optimistic view when it comes to economic growth in Sweden through the year 2020. GDP is assumed to increase by two percent per year, industrial output by three percent, and exports by six percent.

MORE ENERGY-EFFICIENT BUILDINGS – BUT LARGER SPACES TO HEAT OR COOL

Built-up areas have great possibilities to conserve energy. New single-family homes with only a third of the average energy consumption of existing houses can be built without any premiums. There are practical examples of how it is possible to accomplish 40 percent energy reductions by renovating existing apartment buildings, and there are corresponding findings in other types of premises. If all of these possibilities are realized the energy consumption in the building sector could decrease drastically in the long term.



But at the same time there is an increase in the area which needs to be heated or cooled – unless modern communication technology reduces the need for office space, warehouses, and stores, thus enabling a more effective use of existing areas. On the whole, energy consumption is assumed to decrease. The same however, is not the case for electricity consumption. The heat release of electrical appliances covers a large portion of the heating demands of energy efficient buildings and reduces the need for separate heating. It thus becomes natural to use only one source of energy – electricity.

The electricity savings attained by more efficient office and home equipment is counterbalanced by the growing number of appliances, even though this market will eventually reach maturity.

If we take the step into a hydrogen society seriously, a local implementation of the gas in both fixed applications and in vehicles could lead to a situation where it is produced in smaller units through the electrolysis of water. Such a development would lead to a dramatic increase in electricity consumption within the building sector.

INTEGRATED SOLUTIONS AND BETTER LOGISTICS – BUT INCREASED NEED FOR TRANSPORT

There is development towards more integrated transport solutions and improved logistics, but all prognoses point to an increased need for transport and fuel. To stop this trend, today's gasoline and diesel engines must be replaced by more effective alternatives. Great expectations are linked to the fuel cell but any large-scale implementation is more likely closer to the year 2050 than to 2020. Hydrogen, which is a fuel cell requirement, is first and foremost an energy medium. It has to be produced, transported, and stored, which requires substantial investments in new infrastructure. And until there is a viable marketplace, the energy industries will hesitate to make these investments. On the other hand potential users must have access to hydrogen, thus creating a "chicken and egg" situation. Something that additionally complicates the outcome is the fact that it is not obvious whether the gas should be produced by liquid fuels within the vehicles themselves, or if it should be available at hydrogen stations.

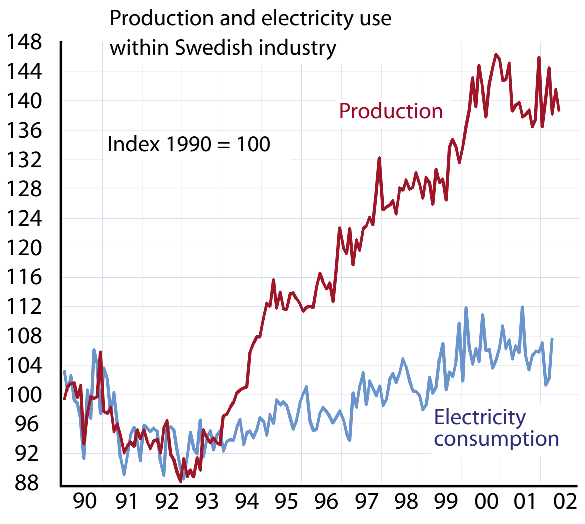
In the shorter time frame, hydrogen vehicles can bring a significant decrease in fuel consumption in the prevailing conditions of urban regions, since electric propulsion will replace the combustion engine. An electric motor is not only more energy efficient but also contributes to an emission-reduced environment. This could be a reason for stimulating the use of hybrid vehicles through the introduction of emission-free zones.

MORE ENERGY-EFFICIENT INDUSTRIAL PROCESSES – BUT AN ANNUAL GROWTH IN PRODUCTION

Process development in pulp production could render considerable revenues and ultimately make this industry a net producer of energy when it comes to electricity and biofuels. Such a development does not emerge purely because of energy reasons but rather in conjunction with modernization or expansion. It is thus a multi-decade change.

To sum up, with a long-range perspective there are substantial possibilities to lower the total energy consumption, but within the frame for such a development the electricity consumption might still increase.

The energy use is thoroughly discussed in the factual reports *energy use in buildings, transportation energy use in transport, industrial energy use*, and in the user foresight panel report.



Nuclear power replacements

The alternatives to Swedish nuclear power depend greatly on the timing of its decommisioning. If the use is limited to 40 years, as is the case in the *climate – one factor among others* scenario, it means that half of the reactors will have become outdated in 2020 and the rest five years later.

By that time there is probably not an electricity surplus on the North European market large enough to cover the decreasing domestic production. This is true even if the international transfer capacity increases. And we cannot count on lower electricity consumption, rather the reverse. Even with an expansion of wind power and combined heat and power (CHP) plants, more sources of power will be required to match domestic production with consumption.

NATURAL GAS – ONE ALTERNATIVE

Electricity from natural gas is what will be available if nuclear power is phased out in 2020. It will be supplied via a developed Swedish natural gas network. The natural gas supply is further discussed in the factual reports *Natural gas and coal – resources and price development and Energy transfer and storage.*

For every 10 TWh of electricity produced in this way, 3.5 million tonnes of carbon dioxide emissions are created. This represents approximately six percent of today's emissions. If we, for example, assume that 50 TWh of today's 70 TWh of nuclear power is replaced by natural gas in combined cycle (NGCC) the increase in carbon dioxide emissions will become too large to be compensated for by a biofuel and heat pump swap for oil, or by an increased use of biofuels within the transport sector. On the other hand, 30 percent of today's carbon dioxide emissions represent the annual amount absorbed by, and stored in, the net growth of forests.

NEW NUCLEAR POWER AND RENEWABLE SOURCES OF ENERGY ARE OTHER ALTERNATIVES

If the reactors are used for 60 years, as in the scenario *the climate in focus*, there will be real possibilities to replace the nuclear power with new carbon dioxide-free electricity production. Applications approved by the US supervisory authority show that the operational running-time can be extended by 60 years. Major overhauls and modernizations are required to accomplish this, but the electricity costs will still remain within the 15-25 öre/kWh range. The renovation of the Oskarshamn 1 nuclear reactor has shown that massive overhauls and control checks, even inside the reactor tank, are possible with respect to technology and radiation issues.

Solar-based alternatives other than hydroelectric power should be able to increase their market shares during the next 40 years. The only condition is that there must be a demand for carbon dioxide-free and renewable electricity production. This is especially true for wind power and electricity production based on the gasification of biofuels, as well as for different types of waste. A successful introduction and implementation of the gasification technology will enable larger quantaties of electricity to be produced at a given district heating base through combined cycle technology than is possible today using solid biofuel steam-cycle production. Some contributions might also come from solar cells, wave power, or fuel cells provided that costs can be decreased by technological development and by giving support to large-scale development.

Another alternative which will be realized within a few decades is a new generation of nuclear power, which will be economically competitive, safer, more fuel-efficient, and generate smaller amounts of long-lived nuclear waste. One reactor that presently draws much attention is the pebble-bed modular reactor. This is more closely described in the factual report *Nuclear power now and in the future*. This report also discusses a technology that radically reduces the amount of long-life nuclear waste through transmutation. The European aim is to have a smaller functioning transmutation prototype within 20 years, and a full-scale version in 40 years time.

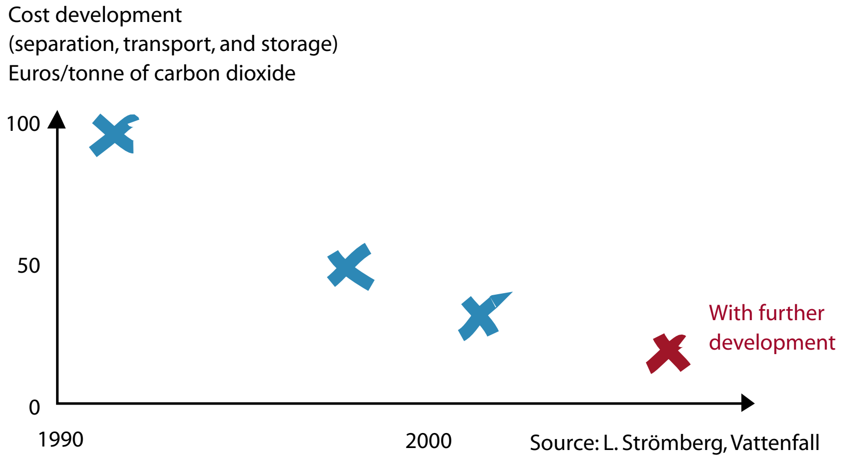
Can a new generation of nuclear power with decreased meltdown risks and shorter half-life for the bulk of the nuclear waste – from several hundreds of thousands of years to a few hundred years – gain widespread acceptance? Will we experience more reactor failures? Will nuclear power be a viable alternative in a deregulated and privatized electricity market? These are pivotal issues for the future of nuclear power.

A new generation of nuclear power in Sweden also assumes – as proposed by the Swedish National Council for Nuclear Waste (KASAM) – that the so called ”paragraph of thought” within the nuclear technology operations law (prohibits any preparatory work connected to nuclear reactor construction in Sweden) is repealed.

FOSSIL POWER CAN BE ENVIRONMENTALLY ADAPTED

Yet another alternative is continued electricity production based on fossil fuels but with carbon dioxide sequestration, which will be appropriately stored in suitable geological formations. This technology is further discussed in the factual report *Electricity and combined heat and power heating from coal, natural gas, and biofuels*, and it is technologically and economically realistic. The first coal fired power plant with carbon dioxide sequestration could be built within ten years, if the right incen-

Separation and storage of carbon dioxide from coal-fired power plants.



tives are provided. If coal burns with oxygen instead of with air, it is assumed that carbon dioxide and sulphur dioxide can be deposited together.

This makes the investment cost, including equipment for carbon dioxide sequestration, no higher than for a power plant with flue gas desulphurization. A plant which produces oxygen out of air is no more expensive than the equipment normally required to remove sulphur dioxide from flue gases.

However, producing oxygen is energy consuming, reducing the electricity efficiency by 8-10 percent (i.e. from 43 percent to 35 or 33 percent for a lignite-fired power plant). There is an additional cost for transport and deposit, depending on the distance to a suitable deposit location. Vattenfall has calculated the total costs for a lignite-fired plant in Germany to be 12-15 öre/kWh. Costs have decreased during the last few years as a result of technological developments. The same technology can of course also be used with all fossil fuels, but coal remains closest at hand. Within a few decades when hydrogen reaches widespread implementation in both mobile and fixed applications, a scenario such as *the climate in focus* foresees the production of hydrogen from natural gas with carbon dioxide returning to the oil and gas fields. The question of whether carbon dioxide trapping will occur in conjunction with gas fields or in close proximity to large consumption centers, remains open. Electricity production in fuel cells, using hydrogen made without any carbon dioxide emissions, is another alternative for future carbon dioxide-free electricity production, particularly decentralized production.

THE BRIDGE TO A SOLAR AND HYDROGEN SOCIETY

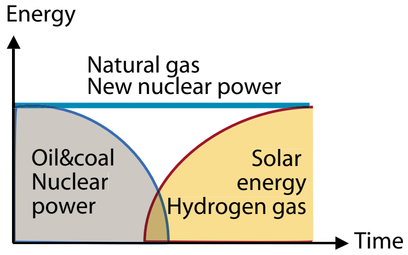
During a transitional period which stretches beyond the year 2020 – the project's primary time frame – both natural gas and nuclear power will be key elements in the bridge to a solar and hydrogen society.

The length of the transitional period will be different in *the climate in focus* and *the climate – one factor among others*, mainly as a result of the different incentives given in the scenarios.

With the right conditions, a European natural gas expansion could simplify the transition to hydrogen as an energy medium. While we wait for solar-based solutions, hydrogen can be produced from natural gas, and the natural gas distribution systems can be used for hydrogen at a later stage, pending design and choice of materials.

The use of natural gas can also be combined with more distributed systems – e.g. small scale CHP plants, often gas fired – which also creates the conditions for a gradual alignment with an infrastructure capable of supporting a hydrogen/electricity/solar network.

Natural gas and new nuclear power – a bridge to solar energy and hydrogen gas



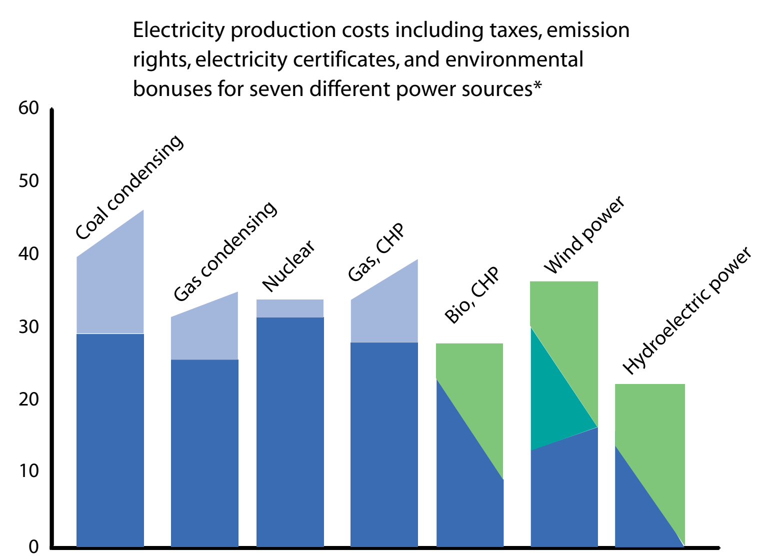
Nuclear power generates electricity free of carbon dioxide, but it is also controversial. The low costs taken into account, producers want to use nuclear power plants throughout their maximum economical life-spans. Some new nuclear power plants might be constructed in Europe (for example in Finland). Meanwhile there are nuclear phase-out decisions in several countries. This could mean that existing plants are shut down even though Swedish experiences show that this is difficult, since there are no realistic alternatives.

In conclusion, there are several alternatives to attaining electricity production with low carbon dioxide emissions, and these can contribute to a halving of the total emissions within the EU by 2050.

Countries will produce electricity in different ways. For electricity companies on the Swedish market a new generation of nuclear power combined with hydroelectric power and other types of solar-based electricity will become mainstream. Other countries with less nuclear power experience and lacking an infrastructure to handle the nuclear waste, will prefer other combinations.

EFFECTS OF INCENTIVES

The table shows the expected price effects on electricity using different power sources, where taxes and purchases of emission rights are added to the production cost and where earnings from electricity certificates and environmental bonuses are deducted from the same cost.



For the four non-renewable electricity production means – coal condensing, gas condensing, nuclear power, and gas-fired CHP plants (the first four bars) – the upper light-blue slanted section shows how the electricity price will be affected by taxes, as well as the trade with future emission rights. The higher value (i.e. the right side of the bar) indicates higher priced emission rights, whereas the lower value (i.e. the left side of the bar) represents lower priced emission rights. Nuclear power, which is carbon dioxide free, is not affected by the emission rights trade, and the bar thus has a horizontal top. In this case the light-blue part is tax only.

For electricity from biofuel-fired CHP plants, wind power parks, and hydroelectric stations (the last three bars), the electricity price will decrease as a result of the trade with electricity certificates, which benefit these sources of energy. The left side of the slanting green sections show the cost reduction attained by a low certificate price, whereas the right side indicates the cost reduction at a higher certificate price.

In addition, the pricing scheme of wind power-produced electricity is affected by a gradual de-escalation from today's environmental bonus of 18.1 öre/kWh (blue-green area).

To sum up, the blue parts of the bars show the future electricity price after add-ons (taxes and emission rights) and deductions (electricity certificates and wind power bonuses).

* Prerequisites: Policies and taxes brackets for 2003. 6% interest rate. Depreciation periods: Condensation and nuclear power 30 years, electricity and heat 20 years, wind power 15 years, and hydroelectric power 40 years. Heating revenue electricity and heat = 18.3 öre/kWh. Electricity certificates: max. SEK200/MWh, min. SEK60/MWh. Emission rights: max. SEK250/tonne carbon dioxide, min. SEK150/tonne carbon dioxide.

Fossil fuel reduction within the transport field

Traffic is a key sector. This is where the bulk of the expected increase in European carbon dioxide emissions will take place. However, issues concerning congestion, safety, and air quality are also widely discussed.

EU competition policies and principles with which to finance the traffic infrastructure are important. A harmonized kilometer tax – differentiated with respect to environmental effects, road wear, and accident risks – could become a very active tool towards a more environmentally adapted and safe traffic situation. Efforts to develop links throughout the European road and railroad network are of course also important. A common European high-speed train network could partly off-load road and air transportation.

But EU-level decisions are not definitive. They have to interact with national legislation, city planning, local congestion fee systems, environmental zones, and so on.

NEW VEHICLE TECHNOLOGY AND NEW FUELS

The ambition of car manufacturers to retain the automotive society and to sell cars in growing Third World markets is very strong, and new vehicle technologies, as well as new fuels, are being developed for the global market. Much emphasis is put on the development of hybrids and fuel cell powered vehicles, but also on the improvement of conventional technologies and fuels. The European Automobile Manufacturers Association agreement states that the manufacturers will reduce the average carbon dioxide emissions from new passenger cars by 25 percent by 2008/2009.

The average specific fuel consumption decreased in Sweden during the 1980s, but this development has since stopped. Goods and cargo transport on roads have become more energy-efficient, partly due to further refinements of the diesel engine and partly as a result of increased maximum payload allowances for trucks.

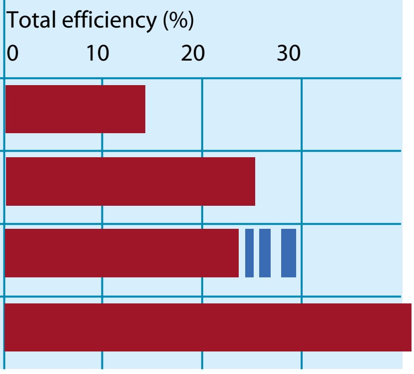
The possibilities to drastically reduce climate gas emissions from the transport sector are tied to more effective engine concepts and "carbon dioxide free" fuels.

Car manufacturers currently view hybrid electric vehicles as transitional alternatives, awaiting less expensive fuel cell-propelled cars and also a solution to the remaining technical issues. The hybrid vehicle has an electric motor with a battery pack and a combustion engine. The fuel reduction is between 30 and 50 percent in urban traffic, and the car can be driven emission-free through sensitive areas. The introduction of economic incentives or emission-free zones will result in reduced carbon dioxide emissions and also in improved local air quality. This can be achieved as early as this decade.

The question of whether hydrogen can be deemed a carbon dioxide-free alternative depends on how it is produced. Initially, hydrogen is likely to be produced from natural gas, but if carbon dioxide as a by-pro-

Efficiency from "Well to Wheel"

	Efficiency from source to tank (%)	Vehicle efficiency (%)
Gasoline vehicles	88	16
Hybrid (gasoline)	88	30
Fuel cell (FCV)	58	~50
Future FCV	~70	~60



Source: Toyota trial calculations

duct is not taken care of, the hydrogen is not carbon dioxide-free. Compared to today's gasoline-powered car the emissions are still reduced since the fuel cell vehicle is much more efficient.

Hydrogen can also be produced through electrolysis in small and large units. If the electricity comes from renewable energy or nuclear power, the hydrogen can be considered carbon dioxide-free.

The transition from combustion engines to fuel cells is a radical technological leap. It will have substantial impact on car manufacturing and fuel supply infrastructure. This is further discussed in the system foresight panel report. It is not likely that the number of fuel cell vehicles in Sweden will be enough to result in reduced carbon dioxide emissions by 2020, but the potential is much larger when extending the timeframe to 2050.

BIOFUELS

Replacing current fossil fuels with biofuels is also an alternative that will reduce the climate effects caused by the transport sector. New fuels are created by blending biofuels with existing fuels, whereby the new fuel can be used in existing vehicles and already established distribution networks.

Today there are few biofuels with large-scale potential. Ethanol and methanol are mostly used as gasoline additives, while dimethyl ether is an interesting alternative for heavy trucks. The cost of producing these today is high compared to gasoline and diesel or liquid fuels from natural gas, but the user foresight panel has an optimistic view.

Biofuel gasification is a promising technology with respect to flexibility and cost. This synthetic gas is the base for several fuels, such as dimethyl ether, methanol, and hydrogen gas. A related alternative which also seems promising is the manufacturing of these propellants in connection to black liquor gasification in bio-combinates within the pulp and paper industry.

Reports on different biofuel applications – especially on wood fuel which is the most important biofuel in Sweden but also a limited resource – show that the most cost-effective reduction of carbon dioxide emissions are attained in stationary sources rather than in mobile applications. The competitiveness of fossil fuels is strong within the transport sector.

The system foresight panel discusses the total energy system with respect to global development trends and also more comprehensive issues such as environmental policy prognoses, prerequisites for a hydrogen and solar society, and the need for various incentives and for R&D and educational efforts.

The radical reduction of environmental effects and simultaneous care for the energy needs of a global population, will subject the energy system to enormous changes. The challenge is to add energy as a resource for sustainable development – to create an energy system which benefits health and environment, economy, and safety.

Future solar and hydrogen based systems will have pivotal roles. And the interest in these types of systems is on the increase and there are already significant international ventures.

Sweden and the industrialized world should be able to reach the climate goals and at the same time have time to modernize their energy systems. The panel looks forward to a system where a more intelligent energy use, based on renewable resources, becomes an asset to a society which offers mobility, comfort, and a sound infrastructure.

Future energy system changes will take place in a world where most of the attention is shifting towards the developing countries. These densely populated and economically expanding nations will – pending a somewhat peaceful development – take an ever increasing part of the market growth. This is even more important to the energy markets. Even though access to modern technology enables a more energy-efficient cycle than in the earlier industrialized countries, there will be a significant increase in the demand for energy. However, the poorest nations will be dependent on aid, including energy aid. The lack of an established infrastructure could benefit new solutions, for example distributed systems for energy production instead of the large centralized systems that have become common.

Looking at developing nations, it is of the utmost importance that climate and development issues are collectively handled. The climate convention could create a platform for international cooperation that would contribute to sustainable development and at the same time solve the climate problem. Business relations can be developed in parallel through other channels.

Climate measures need an early start

The threat to the earth's climate is growing more serious. The 1.4-5.8°C temperature increase expected by the year 2100 (according to the Intergovernmental Panel on Climate Change), has had no equivalent during the last 10,000 years. The innate sluggishness of the climate system and the long periods of time that are required to realign technological and societal systems, mean that early measures have to be taken in order to limit the risk of a large temperature increase.

To achieve the 2°C temperature increase goal which has been flagged by many governments and organizations, it is necessary that the leading countries adopt emission-limiting measures as soon as possible. *The climate in focus* scenario – in which emission reductions outside the Kyoto Protocol receive a quick and efficient start – offers possibilities to reach this goal. A development according to the scenario *the climate – one factor among others* is likely to limit future action paths and expose coming generations to more radical climate effects.

On the road to a solar and hydrogen era

A sustainable energy system with a global and long-term perspective must have a broad focus on renewable energy sources, in combination with refined and pure energy mediums. Ahead of us we see a development towards a system with electricity and hydrogen as energy mediums – in a longer time-frame entirely based on renewable energy sources, i.e. solar energy. Such a system (based on solar electricity, solar heating, wind power, biomass energy, hydroelectric power, wave power, and other renewable energy sources) also gives the poorer areas of the world the possibility to gain access to energy for cooking, lighting, clean water, local production, and so on, with acceptable effects on health and environment. It enables substantial carbon dioxide reductions, and it breaks up the domination of fossil fuels, thus decreasing possible anomalies.

Spotlight on the system characteristics

The use of hydrogen in vehicles is a more complex issue. The major automobile companies are competing to be the first to present a zero emissions vehicle. The wish to preserve a structure with mass mobility and corresponding high-volume markets is an important driving force in most countries. Stricter environmental requirements and research, national and international, into new energy technologies is another driving force. But it is extremely difficult to predict the time-frame of such a shift. Less radical solutions such as hybrid cars and natural gas-driven vehicles could be preferred in a medium time-frame, thus delaying a solution using hydrogen. In the long-run, however, it is necessary to consider completely carbon dioxide free solutions, even within the transport sector.

A development towards hydrogen technology is anticipated in both scenarios. But the pressure to produce the gas without any carbon dioxide emission grows considerably stronger in *the climate in focus.*

There is a reason for raising the system aspects of new energy technologies such as hydrogen. A new energy medium needs a well planned framework and a professional culture around risk and safety issues. Material issues must be thought through. Large investments in partnerships between politics and industry could become necessary, to develop an infrastructure for storage and distribution in preparation for large-scale implementation, particularly in the transport sector.

The panel wants to stress that solar energy technology – which has a limited implementation in Sweden – also deserves to be studied from a system perspective. The cost of solar cells is liable to decrease faster than other costs related to already established energy technologies. But the anticipated cost reduction depends on a situation where development investments in, for example Japan, Germany, and the United States, are maintained in order to set the stage for large-scale manufacturing of solar cells. If this is the case it is estimated that, by the year 2020, solar cells would become competitive throughout large parts of the industrialized world. This would also pave the way for large-scale dissemination throughout the developing nations, which in turn would stimulate technology development and put further pressure on cost.

From natural gas to hydrogen?

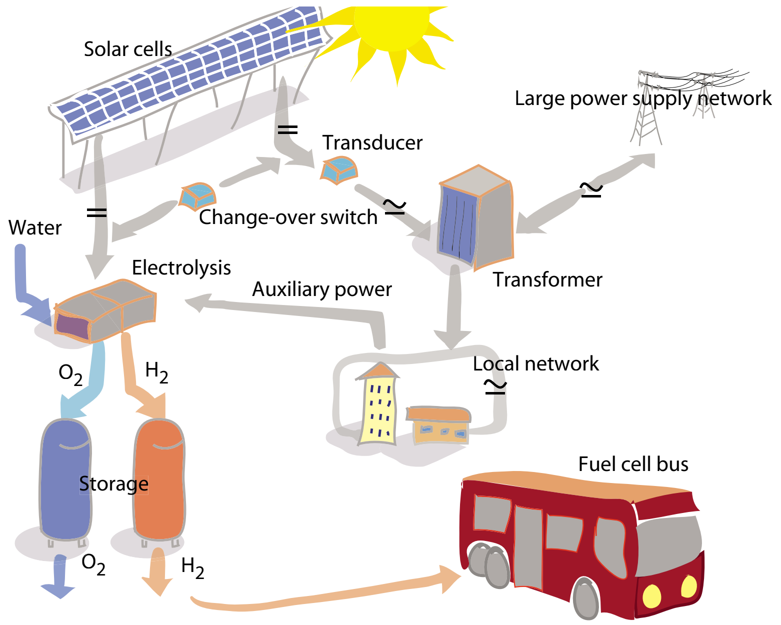
Appropriate conditions would strengthen natural gas expansion in Europe, simplifying the transition to hydrogen as an energy source. Hydrogen can be produced from natural gas while waiting for solar-based solutions. The distribution systems can, after some adjustments, be used for hydrogen at a later stage. Natural gas can also be coupled with an increased level of distributed systems – small-scale power and heating, often gas-fired – which also create conditions for a gradual adaptation to an infrastructure capable of supporting a hydrogen/electricity/solar energy system.

During a transitional period it is probable that both natural gas and – in some countries – nuclear power will be integral parts of a bridge to a society based on solar energy and hydrogen. In the long-term the panel believes that nuclear power expansion will come to a halt, partly due to the fact that its cost structure does not work in deregulated markets, and partly because the complex issues of safety, reliability, and nuclear waste management, which are difficult to communicate, will continue to limit public acceptance.

Biofuels are expected to gain a leading role in Sweden, more so than in the rest of Europe. In the scenario *the climate in focus* these fuels are likely to continue dominating the district heating sector. Biofuel-fired CHP plants will be an important boast for electricity production. In the scenario *the climate – one factor among others* it is more likely to see the natural gas network expand in central Sweden. In this scenario biofuel is used for CHP plants and district heating outside the gas networks. Some parts, however, are still included within the gas networks.

A more intelligent energy consumption

The emergence of the information society means that future electricity demands must be discussed and understood in terms of reliable power and mobile applications. The large power supply network is required for large volume and high-voltage feeds. But the requirements on an a safe power supply could, perhaps, in the future be fulfilled by a medium power backup network, generated by solar cells, hydrogen, or other local energy sources. Mobility and the ample availability of small electronics



Solar cell powered systems that produce hydrogen for city buses will be demonstrated in Visby in a project backed by the EU. The aim is to show how innovative systems which combine solar cells, hydrogen production, and means of transportation, can be used to reduce carbon dioxide emissions and to protect a valuable urban environment. Source: USCHER (Urban Integrated solar Hydrogen Economy Realisation Project).

brings us further away from the large power supply network. Accumulators or miniature electrical plants powered by solar energy or fuels could become additional components in a distributed electricity system.

People must be prepared to change their way of life – avoiding hardship or retrogression, and instead focus on more intelligent ways of using energy. A switch-over needs to be supported by clear incentives to hold back emissions and other unwanted effects of energy consumption, by better public transport, and by other changes that will simplify the choice of low carbon dioxide solutions.

Increasing electricity prices combined with more efficient and less expensive solar cells, fuel cells, and controlling and monitoring technology could – particularly in *the climate in focus* scenario – benefit new and more distributed electricity supply solutions. The pressure to create more effective solutions and the development of energy efficient technology are strongest in this scenario as a result of effective climate-related incentives. In *the climate – one factor among others*, the incentives are more connected to the modernization of the energy sector and to a more intelligent energy consumption in general.

New business opportunities

Within Swedish industry there are several areas of technology, products, and services which enjoy good growth potential in an energy-focused scenario. Knowledge of forest biomass processing could become an asset in a climatically adapted development. Other examples are district heating systems, ecocycle-adapted waste management, and biogas processes. The building sector's knowledge of energy conservation could also create new business. Swedish companies have already successfully deve-

PHOTO: TOMAS HAMMAR

Only 80 years ago reading lamps were uncommon in our country. The introduction of electricity was immensely beneficial to reading and education as a whole. Source: Energihistoriska Samlingarna

Darkness falls at 6 p.m. in the West African country of Burkina Faso. Most homes lack electricity. The Swedish aid organization Diakonia and the soccer tournament Gothia Cup have jointly funded an illuminated soccer facility in a poor neighborhood of the capital Ouagadougou. Many children take advantage of the floodlighting and go there in the evenings to do their homework

loped components for fuel cell systems. Innovative companies with foresight can be advantageous to growing markets, in particular in developing nations

Institution-building and research are required

A long-term and comprehensive shift in the energy system will require changed institutions and organizations. In much the same way as the environmental interest was mobilized by the Swedish Environmental Protection Agency (Naturvårdsverket) and by other environmental organizations, the change in direction of the energy system must be established and maintained through powerful organizations, professions, networks, and interest groups. Shifts of this magnitude require broad cooperation between government and industry.

A European pilot-project on hydrogen would enable the mapping of the possibilities and limitations of a hydrogen economy. It would also make it possible – for a wide group of interested parties – to discuss research requirements, possible development cooperation between politicians and industry, the balance between domestic measures and EU measures, and so on. Considering the European Union's active role in climate discussions, it is natural to pay special attention to the carbon sequestration issue.

It is necessary for Sweden to incorporate a European level strategy and – in parallel – tackle the issues concerning supply structures, safety thinking, etc. which emerge nationally and locally. There are solid arguments for an early start, not least the fact that Swedish industry can occupy interesting high-technologicy niches in the emerging hydrogen economy.

The outlined system change-over also requires a new research strategy. The system foresight panel indicates that system aspects of this breakthrough have to be acknowledged within energy research. There is a need to study the links between the old and the new. Research is required on policies, regulations, and institutions. Small-scale systems could require a partly new business logic and new policies – supranational systems as well. All new systems require attention to standards, safety, and economy.

The panel stresses that a major system shift will take time and also requires a great deal of consistency. The Swedish power supply network was gradually constructed throughout more than half a century. Oil gradually replaced coal and wood. The implementation of nuclear power was preceded by research, legislation, and corporate formations from as early as 1946, a full 26 years before the technology was ready to be launched. Wind power has increased in Sweden, but at a slower rate than in Denmark and Germany where legislation has been more beneficial. There are many other examples.

Up to the year 2020, which is the panel´s primary time perspective, much will have to happen. The panel´s conclusion is that there is a current need for a broad societal dialog, reliable frameworks for carbon dioxide emissions (among other things), and Swedish, European, and international organizations that can carry the burden of change for the coming decades.

The user foresight panel discusses prerequisites for more efficient energy consumption and bottlenecks (other than purely technical ones).

The panel establishes that energy is used to create good living conditions in a periodically dark and cold country but also to refine domestic resources, thereby creating opportunities for industry, trade, and economic growth. Availability of energy is, in essence, a question of societal well-being. But a question with a reverse side. All production of electricity, heating, and mechanical labor is connected to a certain amount of negative environmental impact. Therefore a continuing energy efficiency increase is important to sustainable development.

The challenge to keep on increasing efficiency and to improve energy consumption is difficult within certain areas – such as finding competitive alternatives to gasoline and diesel within the transport sector – but easier within others for example, reducing oil consumption in urban areas. Sometimes the market leads development, and other times political incentives are key to making changes.

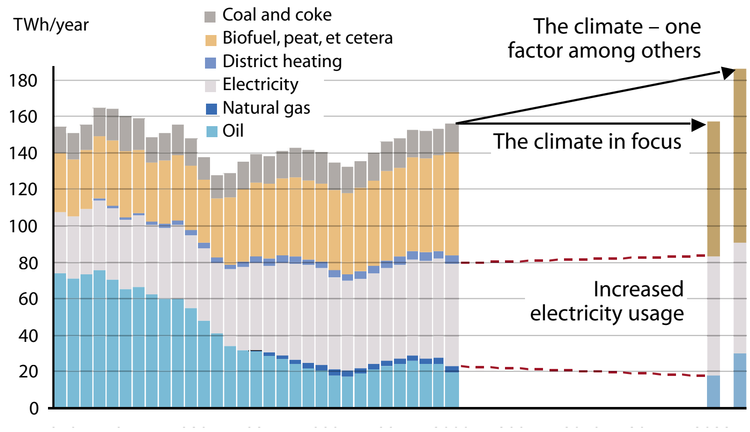
Industry

Industrial energy consumption through the year 2020 is based on a positive vision with a development of all industry including the service sector, in which energy intensive industry continues to be competitive. Energy intensive industry in this case means the pulp and paper industry, the iron and steel industry, the mining industry, and large parts of the chemical industry.

Growth is normally correlated with increased energy consumption, however it is not proportional. Within energy intensive industry there is a development towards continuing concentration, increasing product refinement, and a far-reaching process integration. This enables more efficient energy consumption in relation to the degree of refinement, but the total energy consumption will continue to increase. Fuel requirements will, however, decrease. This means that industry's oil consumption will continue to go down, in part as a result of a transition from oil to other energy sourses – electricity, biofuels, or natural gas. A large part of the growth will also take place in non-Core industrial areas, such as electronics, IT, and biotechnology, as well as the entire service sector. Massive growth is achievable without any significant increase in energy consumption.

Industrial energy consumption continues to grow in the scenario *the climate – one factor among others*. With an annual growth of two per cent, the energy consumption will continue to grow, increasing the electricity use by 15-20 percent during the next 20-year period. This relatively moderate increase assumes continued restructuring and efficiency promotion. *The climate in focus* scenario describes a situation where the industrial sector increases its efficiency to the extent that it becomes possible to retain current energy levels. Higher energy prices create a larger-scale transition to refined energy medium, i.e. the share of electricity further increases. Higher electricity prices also mean that the entire industrial sector is motivated to implement the best technology available, and this will unleash potential currently unavailable to us. The climate scenario also implies that industrial waste heat deliveries increase and that these are subtracted from the industry's energy consumption when assimilated into built-up areas.

To realize a large-scale industrial energy efficiency program – at the same time as we reach the growth predicted in the scenarios – all measures taken must be internationally harmonized. Efficient energy use within industry is achieved by active corporate energy management and by technology development in controlling and monitoring, experience



Industrial energy usage could change over the next 20 years, according to estimates by the user foresight panel.

feedback, and production. Research is necessary to produce new materials and technical solutions. Recently established local universities and polytechnic institutes have to be developed so that they are able to reinforce the local industry with competence and well-educated personnel, as well as to enhance the appeal of the respective regions. Sweden also has to be an attractive country in order to attract necessary future investments in international competition. Carbon dioxide emissions are decreasing in both scenarios.

Built-up areas

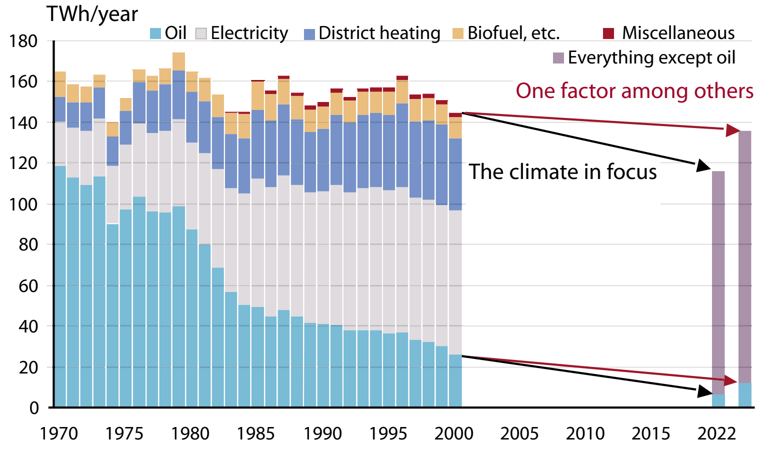
More than 90 percent of the houses and buildings we will have in 20 years are already built. The real challenges thus lie within the already available stock. There is great potential in increasing the efficiency of energy consumption. Much is done while undertaking major renovations and when switching important installations, for example ventilation and heating systems. It is also important to give to the house-owners financial incentives to choose the most energy-efficient solution at each renovation or refurbishment. If the houses are environmentally classified and if the classification can be linked to tax reductions on well-maintained and energy-efficient houses, the development can be influenced in the right direction.

Much unnecessary energy consumption comes from technological ignorance, for example in the ways ventilation equipment should be adjusted or which light fittings require the least amount of energy. Besides more effective technical solutions and efficiency incentives, increased knowledge is thus an important factor that could limit energy consumption in built-up areas.

Despite the population increase and the fact that the total building area will increase, the energy consumption of built-up areas decreases in both scenarios. *The climate – one factor among others* describes, using current conditions, a situation where the energy consumption will decrease by ten percent. *The climate in focus*, incorporating incentives and/or higher energy prices, increases the share of solar panels and heat pumps, and the measures with which to increase energy efficiency are further stimulated. Energy consumption in built-up areas can thus be reduced by as much as 20 percent. However, the possibilities to increase energy efficiency will not come into full effect for another 20 years. This is a result of the low turnover rate within the building sector. Carbon dioxide emissions decrease in both scenarios.

In the climate – one factor among others scenario, natural gas will be readily available throughout most parts of the country. Areas that are outside the district heating networks can thus use natural gas for heating purposes as an alternative to both oil and electricity. Natural gas also paves the way for fuel cells in buildings and enables local and small-scale production of electricity and heating.

It is also important to have long-term and reliable rules. A home owner, private building society, and all others whose housing is linked to large costs, must be able to trust that it will be beneficial to invest in a slightly more expensive piece of equipment (at the time of purchase) that could lead to an annual energy saving.



Energy consumption in built-up areas according to estimates by the user foresight panel.

Transport

Transport is a collective term for a number of different activities, all with the purpose of moving people or goods from one point to another. Today's transport runs almost entirely on fossil fuels. Trains, i.e. the railroad traffic, run on electricity, but only account for 2.5 percent of the transport sector's total energy consumption. And since today's alternative fuels – ethanol, electricity, and natural gas – have a market share of just half a percent, a full 97 percent of the transport sector's energy consumption comes from fossil fuels.

The structural change within the industry will lead to an increased need for transport. Specialization leads to more refinement steps within the production chains, and to a situation where more companies get involved and where many semi-manufactured products are moved many times before final assembly. Despite the fact that an ever-increasing number of people move into the cities, an even greater number of people will face longer commuting distances. The metropolitan regions grow geographically and this is also where many of the new jobs will be found. Fast train connections and high-volume freeways give people the chance to live in small towns, or even in the countryside, despite the fact that they work in the city.

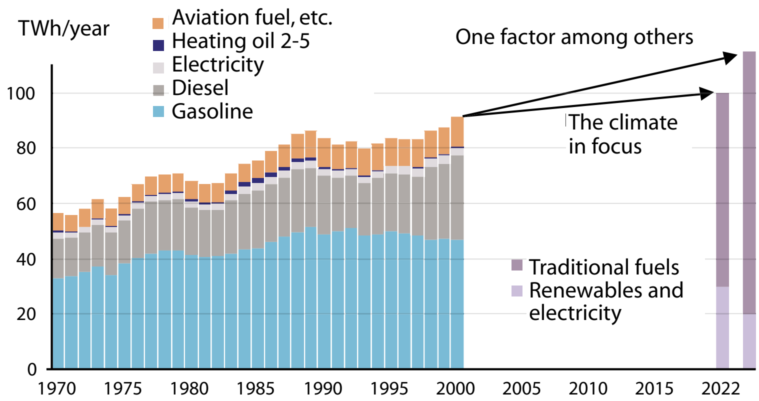
Over a 20-year perspective the panel does not identify a specific solution that would rationalize the transport sector's energy consumption finding a way out of its fossil fuel dependency. Several interacting factors could mean much, but on the whole the panel's opinion is clear – the energy consumption within the transport sector will continue to increase.

In *the climate in focus* scenario the energy consumption will increase by approximately 10 percent and in *the climate – one factor among others* by nearly 25 percent. This happen because since both goods and personal transportation will increase, and also because the theoretically possible efficiency measures will not have had the chance to come into full effect.

There will be many more alternatives in 2020 than today. *The climate – one factor among others* scenario envisages natural gas operation in more parts of the country than just the south. Alcohol cars, hybrid cars, and pure electric vehicles will be available, but they will be primarily used within commercial fleets since there will be no obvious replacement for gasoline and diesel. There will also be a peripheral number of fuel cell vehicles.

The development of new technology will also drive existing technology to develop further. The panel does not see any obvious solution to the transport sector in *the climate – one factor among others* either. Fuel cells will meet competition from new high-efficiency diesel engines with flexibility for all types of fuels.

It is likely that several alternatives to gasoline and diesel will continue to be developed, but the traditional fuels still dominate the market in 20 years. In *the climate – one factor among others* scenario the panel estimates the share of renewable fuels to be 20 per cent, compared to about 35 per cent in *the climate in focus* scenario. The increasing share of renewable fuels dampens carbon dioxide emissions.



Transport sector's energy consumption over the next 20 years, according to estimates by the user foresight panel

The structure foresight panel discusses the structures of the energy system and in what ways these might change during the next 20 years.

The panel considered three structures to be of more interest to the future energy system: the institutional, the (energy-) industrial, and the technological. Since these structures subsequently are affected by other broader contexts, the panel has chosen to study two different paths of development, each of great social importance. The first one deals with Europe's development and the other with development in the IT area. Both of these areas are characterized by uncertainty during the 20-year period which the panel has chosen to study. Will Europe continue to pull together? Will the IT development emulate the industrial revolution?

Three structures of importance to the field of energy

The panel has decided to study three structures which influence and interlink with energy: institutional structures, industrial structures within the field of energy, and technological structures. The panel quickly discovered that there is considerable sluggishness in the changes to the technological structures within the field of energy. The structures will not have enough time to change radically within the coming 20-year period. There are also conservative forces which counteract change, such as difficulties in finding new physical sites for power production plants or new power routes. New power plants will, to a great extent, be placed in direct connection to the already existing ones, and this will lead to a conservation of today's geographic and technological large-scale structures.

Even though the established technological energy infrastructures have not changed much, other technological infrastructures could increase in importance within the field of energy as well. The development towards more interwoven IT systems naturally plays an important role within the field of energy as well. The question is: which role?

The other two structures selected by the panel, the institutional and the industrial ones, are more social in character and are thus prone to change faster – although there is some sluggishness here as well. One example of an institutional structure change is the de-regulation which led to competition within the electricity markets. This regulatory change has led to a number of changes, one being the emergence of marketplaces for electricity and climate data. It has also changed the energy industries' operations, since they have been forced to split the companies and filter out the monopolized operations from the ones exposed to competition.

Another institutional change is Sweden's EU membership which means that we are, in a number of areas, no longer able to act based on purely domestic conditions.

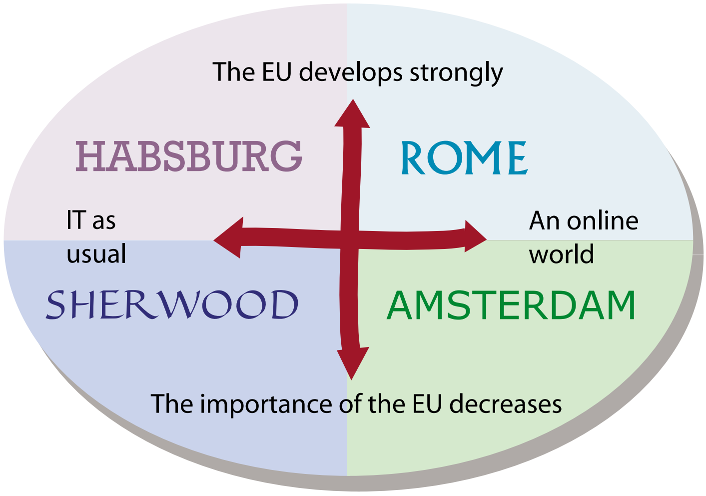
The third structure chosen by the panel is the industrial – within the field of energy. Energy companies adapt their operations to the surrounding changes. One such important change has been the exposure to competition which in turn has led to corporate rationalization. Several energy companies have also exercised the possibility to expand in Europe by purchasing other energy companies. As a result capital, expenditure has become an important issue. Government and publicly owned companies have sometimes been able to benefit from low capital expenditure and low yield requirements, and have thus been able to make substantial acquisitions.

Two developments resulted in four scenarios

Two developments have been identified as sufficiently important to create substantial implications for a number of fields, one being the energy field. The first development deals with the issue of Europe's future. On the one hand there are unidirectional forces towards a more unified Europe, but on the other hand there are forces that point away from central and unified solutions. The recent expansion of the EU could also put more strain on the willingness to cooperate. At the same time there is a great deal of uncertainty which enhances the first dimension of our scenarios.

Another development – independent of the European development – concerns the IT area. New means of communication are rapidly deployed. These could mean a paradigm shift of the same magnitude as when we started to use electricity a hundred years ago. Very few people back then realized the consequences and the possibilities of an electricity expansion.

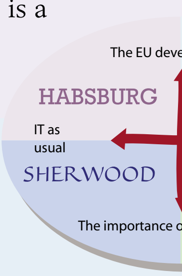
In what ways will society be affected by the fact that billions of embedded and intercommunicating computer chips constantly surround us? Perhaps it will change our very way of life and the way we organize our society and industry? Or maybe the implications will be of less significance. This question raises the other dimension of the panel's scenarios. These two dimensions make up four scenarios which have been given names from different historical eras:



The Habsburg era symbolizes the European time period which ended with the outbreak of World War 1. The Austrian dual monarchy was a great empire, but finally got stuck in its own mold. The rulers did not want to “shift the balance” but instead keep it for as long as possible.

The importance of the EU has grown in **Habsburg**. At the same time the IT development has failed to create any substantial social changes. The citizens of Europe increasingly regard themselves as Europeans and act accordingly. Policies and taxes partly converge, and framework policies are often used as tools to create unity. Increased harmonization benefits European trade, which grow significantly.

Within many business areas the companies tend to become fewer but larger, and these mega-companies often opt to control several levels of their own value chains. A large intra-European capital market with stable policies results in low capital expenditure. The EU’s ambitions to link the countries’ infrastructures are characterized by subsidies granted to these ventures. New infrastructure and new energy technology will be large-scale and developed jointly between the EU and industry. The carbon dioxide issue is handled within allEU systems through internal negotiations about the distribution of labor. There is a outward European front.



In Nottingham there was law and order, but only as far as the sheriff’s power reached. Just outside was the wild Sherwood Forest, with a different set of rules. Some people could live well by using the regional differences in rules. Robin Hood lived to take from the rich and give to the poor, whereas the sheriff of Nottingham used rather the opposite principle.

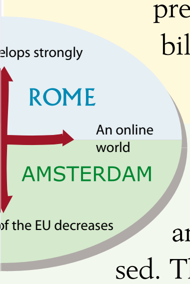
The EU’s importance is decreasing in the Sherwood scenario. National and regional considerations outweigh the common European alternatives. The EU is good, but with limitations. It is more important to promote the home country and its products. Global crises and problems are handled by multinational ad hoc groupings. Policy convergence is avoided since the countries use taxes and legislative measures as competitive means when trying to attract industrial activities. There is regional and international trade. There is no particular European trade.

The value chains are often nationally collected since it is easier to administer them in an environment with local and national regulations. Capital expenditures grow as the capital markets are decreasing. However, this is manageable by governmental guarantees or other forms of cooperation. Infrastructure investments are often locally packaged in order to make best use of the local conditions. This is done through cooperation between the industry and political institutions. Similarly, new technology is often locally adapted and integrated with nearby industries and communities. The carbon dioxide issue is handled differently depending on location. Local opinions and interests focus on local issues such as emissions and air quality.

The **Rome** scenario is characterized by a situation where the EU grows in strength while IT is changing society. A kind of European pragmatism characterizes the values of many citizens. In relation to the rest of the world, the EU's ambition is to be a neutral part, and open to constructive cooperation. Taxes and policies have quickly converged into a common European standard. Tax neutrality has been the guiding star. There is a large inter-European trade but with a considerable international component.

The companies are often characterized by large-scale and specialization. The specialization has led to a situation where many earlier value chains have been split up and absorbed by several different companies. The capital market is substantial and offers both stability and risk spreading opportunities. This, in turn, makes it easier to finance large-scale infrastructure investments. Technology development is influenced by prevailing market conditions and is often characterized by the possibilities of the communication technology. The carbon dioxide issue is handled internally by the companies, but under EU supervision.

Historical Rome had standardized measurements and weights, a common legislation, and a common market. The empire was in many ways an early EU but with a smaller central administration and a considerable delegation of power to the provincial governors. We have borrowed some of these characteristics in our scenario.



IT has changed society in **Amsterdam** and the importance of the EU has decreased. The speedy globalization process means that the advantages of a European territory will decrease. Many people consider themselves world citizens and prefer to be identified as supporters of certain globally spread trends or movements, rather than just citizens of a country. New networks are formed based on interests, work, hobbies, or global issues of great importance. Personal networks or values are much more important than an incoherent European community.

Global crises and problems are handled by multinational ad hoc groupings. A number of countries try to attract companies by offering tax brakes and favorable policies whereopon a complex set of rules and laws develop as global trade adjusts to regional differences. There are many "multilocal" network enterprises with global networks, but with distinct local presence to cover this very important sector. The companies are influenced by the global capital market which shows signs of varying stability, but which also enables spreading of risk.

Infrastructure investments are often local – in line with the multilocal companies' strategies. Technology is developed for a global market. The economic considerations taken into account with decisions on new technology, often deal with whether the technology is flexible and adaptable enough. Various plug and play concepts (allowing simple connection to the existing infrastructure) are mainstream. The carbon dioxide issue will be differently prioritized – in some countries public opinion could force widespread measures to be taken, whereas in other nations it could cause the opposite.

Amsterdam illustrates the mercantile idea. In the 17th century the merchant ships of the Dutch East India Company brought home goods from all corners of the world, and the city became a hub where merchandise was traded and shipped onwards throughout Europe. Our scenario replaces this physical trading arena with others of electronic nature.

	HABSBURG	AMSTERDAM	ROME
What is the importance of the EU?	The EU grows in size and importance	The EU idea begins to wither	The EU is reformed and grows in strength
How is the climate issue handled?	Common EU systems with internal negotiations	Different priorities in different countries. Trade systems common	The companies assume responsibility. The EU monitors
How are new infrastructure investments handled?	Large, partly EU financed projects consolidating the European sub-systems	Locally adapted projects. The need for investments is brought to surface thanks to better systems knowledge	Large projects with little EU involvement. The EU sets the agenda
How do new technology markets emerge?	Through cooperation between the EU and the industry	Technology is developed for a global market	Technology develops based on the market conditions
Which are the energy supply technologies?	Technology adapted to existing large-scale structures is benefited	Technology is developed for a global market. Plug-and-play concepts common	Flexible and possible to integrate with existing systems. Plug-and-play concepts common

In what ways are there similarities between the panel's four scenarios and the two main scenarios of the Energy Foresight project?

The importance of the EU is substantial in Habsburg, Rome, and in the scenario *the climate in focus*, while its importance is decreasing in Amsterdam and Sherwood. In the scenario *the climate – one factor among others* the role of the EU is unclear. This can be interpreted as though the EU does not play an important role in this scenario.

The other issue, concerning the climate, contains some similarities between *the climate in focus* scenario and Habsburg. *The climate – one factor among others* shows similarities with Sherwood, since the initiatives are in, essence, local.

New infrastructure is established through cooperation between government and industry in Habsburg, Sherwood, and the *climate in*

SHERWOOD	The climate in focus	The climate – one factor among others
The EU diminishes in importance	Great importance to establishing common social systems, e.g. regulations and standards	N/A
Different in different countries. Local environmental opinions force local measures	The EU is an international driving force and procedes with measures	Primarily via local initiatives and cooperation between groups of countries
Locally designed projects in cooperation between government the industry	Through cooperation between government and company	Through local initiatives
New technology is locally adapted. Often integrated with industries and nearby communities	Partly through EU/governmental/municipal purchases of new technology (50-year EU perspective)	Markets for new locally adapted technology emerge (50-year EU perspective)
Locally adapted, integrated with industry and society	Solar-based electricity based on wind, solar cells, and biofuels. A new generation of nuclear power, natural gas with carbon dioxide separation	Limited part of solar based electricity. Natural gas and coal with carbon dioxide separation

focus scenario. In *the climate – one factor among others* a new local infrastructure is established, and this is the case in Sherwood as well.

New markets for new technology emerge as joint efforts between government and industry in Habsburg, Sherwood, and *the climate in focus* scenario.

On the whole, there are many similarities between Habsburg and *the climate in focus* scenarios. There are also similarities between the Sherwood and *the climate – one factor among others* scenarios, but Sherwood has also borrowed some characteristics from *the climate in focus.*

The long-term foresight panel discusses two future scenarios for the year 2050 and describes their development. The panel stresses the difficulties in making such long-term predictions and mainly focuses on technology development and the positive effects it might have on different parts of society, but also touches upon more general issues concerning social and political development.

Growth, increased prosperity – and more efficient energy use

Both Energy Foresight scenarios describe a favorable Swedish and European development, with continued growth and increased prosperity, consumption, and travel. The population increases moderately and there is continuing movement towards growth regions across Europe.

Increased consumption and growth results in higher energy consumption. At the same time there are powerful forces working in the opposite direction. New technology creates unique possibilities, climate, environmental, and health requirements act as driving forces, and efficient use of energy all become parts of an important global strategy to become less vulnerable.

IT development, new biology, as well as nano- and material technology will render much more effective solutions. Miniaturization and portability require energy efficient technology, IT alters the production systems and new and less complex materials make it possible to reduce weight, thus lowering fuel consumption within the transport sector.

Built-up regions controll and monitor technology, and make use of diode lighting, effective and smart windows, and energy efficient electronics, thus rendering more efficient solutions and applications. One outcome is reduced cooling of various premises – but comfort requirements could result in increased air-conditioning and heating in homes. Built-up areas change slowly, but within 50 years most areas will be new or at least have replaced heating systems.

Industry is becoming more geared towards refinement and service. Large parts of manufacturing industry are looking at vast efficiency possibilities through the year 2050. The forest products industry will benefit from new process technology – which makes better use of the raw materials in addition to delivering chemicals, fuels, and electricity – but will of course also continue to produce paper, composites, packing materials, and so on.

A significant increase is expected for all types of *travel and transportation*. Requirements on reduced emissions and lower fuel consumption is expected to lead to a transition to hybrid vehicles with combustion engines and fuel cells. Pure fuels and new propulsion systems could achieve a 50 percent reduction in fuel consumption and a substantial reduction in vehicle emissions.

Energy supply: paradigm shifts and possible breakthroughs

Several current developments could have different impacts on the energy systems. The panel has identified three paradigm shifts which could become of great importance, but which also require cooperation between different energy players, society, and consumers:

- The United States, Japan, and Europe invest greatly in hydrogen and fuel cells in automobiles and for electricity generation. This is done as an attempt to reduce climate gases and also to lower the dependency on imported fuels.
- The process of carbon dioxide trapping appears (according to present estimates) to have only a limited impact on cost when producing "carbon dioxide free" electricity from coal and natural gas.
- IT increases the possibility to achieve cooperation between the major players, the small-scale suppliers, and the consumers.

Electricity becomes increasingly important as an energy medium. The panel discusses possible electricity production from fuel cells, solar cells, wave power, bio-energy, and fusion besides commenting on technologies such as hydroelectric power, wind power, new nuclear power, and so on.

Natural gas becomes the most prominent energy medium in Europe during the transition to a renewable energy supply, in which hydrogen could hold a pivotal position. Hydrogen can be derived from natural gas – done on a daily basis within the chemical industry – but will eventually be produced directly from solar energy through, for example, electrolysis of renewable electricity, artificial photosynthesis, or biological processes.

The climate in focus 2050

This scenario incorporates massive changes in energy consumption and energy supply, not only in Europe but throughout the entire industrialized world. Internationalized and harmonized incentives aiming at reducing emissions have led to significant efficiency gains and adaptations. Energy prices have increased, but efficiency measures and environmental improvements compensate for the growing cost.

Societies based on electricity, solar energy, and hydrogen are emerging within the world's densely populated and developed regions. Hydrogen is distributed via gas networks in larger regions and is used as a vehicular propellant as well as a fuel to generate electricity and heat. Most new cars run on hydrogen/fuel cells. However, in many areas around the world, including the more sparsely populated areas of Europe, liquid fuels are used in combustion engines or fuel cells.

Multiple sources generate electricity: fossil fuels, solar energy, wind power, hydroelectric power, waves, biofuels, hydrogen, and nuclear power. Fossil fuels are still used for heat and electricity production and as vehicular propellants around the world. In industrialized countries fossil fuels are mostly used in conjunction with carbon dioxide trapping in large power plants, and also in manufacturing of propellants. Natural gas dominates the European market.

The total *Swedish* energy consumption is approximately the same as at the turn of the century, in spite of a higher material standard, increased travel, and greater production. The increases have been balanced out by more efficient technology. The most significant change is a widespread transition towards renewable sources of energy within the transport sector, and also the phase-out of oil for heating purposes.

District heating is almost entirely based on biofuels and waste, and outlying areas are mostly heated by biofuels and heat pumps. Hydroelectric power is a cornerstone of electricity production, and biofuels in CHP plants are important additions. There are several alternatives for additional power: ocean-based wind power, new nuclear power, import, wave power, solar cells, combined power and heating from hydrogen gas/fuel cells, natural gas combinates, as well as more hydroelectric power.

In 2050 hardly any electricity is generated by fossil fuels that produce carbon dioxide emissions. Natural gas is used primarily in connection with today's gas networks. Oil and liquefied petroleum gas are used marginally, primarily in industrial furnaces. The forest industry has become a net supplier of electricity and fuels.

Transport fuels are imported, free of carbon dioxide and based on natural gas (hydrogen), but also domestic and renewable from gasification and anaerobic digestion of biomaterials and waste. In conclusion, this scenario shows how renewable energy and more efficient solutions and applications result in drastically reduced carbon dioxide emissions

The climate – one factor among others 2050

In this scenario, economic and technological developments have greatly influenced the energy systems. New technology has brought about many efficiency improvements, at the same time as the energy consumption – electricity consumption in particular – has risen sharply in some areas. The biggest difference between this scenario and *the climate in focus* is that the driving forces for change and for a transition to renewable energy have not been as prominent as in *the climate in focus*.

Passenger car density is high and transport has increased sharply since the turn of the century. Environmental and health requirements, as well as the congestion problems, have resulted in efficient vehicles with low emissions.

This scenario also sees an increase in solar-based energy and hydrogen, but the increase is slower than in *the climate in focus*. The driving forces in this scenario are technological development and an ambition to reduce the amount of imported energy in the US and Europe.

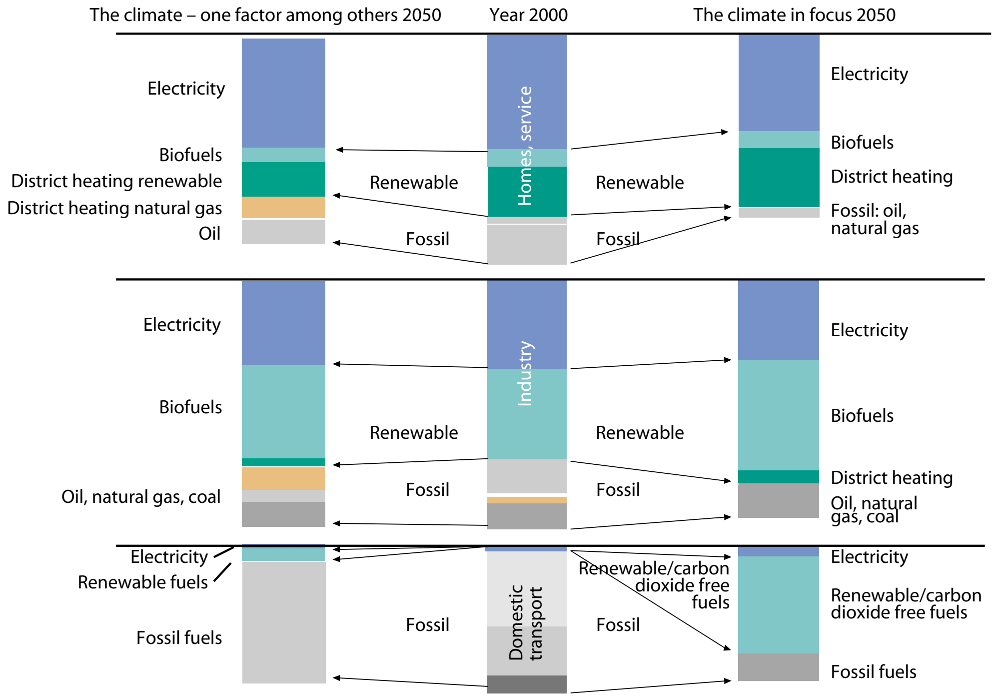
In 2050 natural gas holds a central role within *The European* energy supply. This includes the generation of electricity and heat, as well as the production of fuels. One important driving force for the development of natural gas has been the desire to reduce the dependency on imported oil. Another driving force has been the possibility to extend combined power and heat production, both large and small scale. A third driving force has been the demands for better air quality in densely populated regions.

Combined-cycle gas turbines and coal power plants account for a large part of the European electricity production. Solar-based electricity, e.g. wind power, solar cells, and bio-based, has a limited but growing market share. Vehicles run on liquid and gas fuels derived from natural gas or from biological raw materials via gasification.

What characterizes *The Swedish* energy system is its vast implementation of natural gas in CHP plants, connected to a substantial expansion of district heating networks. Natural gas networks have been extended in central Sweden. Biofuels are used in electricity and heat stations and in districtheating systems outside the gas networks.

The Swedish electricity supply uses hydroelectric power as a base. Electricity from natural gas (NGCC) and from CHP plants in district-heating systems and within industry provide important contributions. Limited but growing contributions come from wind-, wave-, and solar power.

In conclusion, this scenario still relies on fossil fuels – but is heading towards renewable sources via natural gas.



Two illustrations of the total Swedish energy consumption in 2050. *Today's energy supply has been condensed into electricity, renewable, and fossil. District heating has been arranged so that biofuels, waste, and electricity are shown in dark green, while fossil is included in the gray fields. The bars the climate in focus and the climate – one factor among others show the panel's assumptions. Renewable fuels include hydrogen produced with carbon dioxide trapping*

Conclusions and reflections

The panel's most important conclusion is that there are several ways to manage a future sustainable energy supply at a reasonable cost and without threatening growth and well-being. The sun supplies the earth with far more energy than will ever be needed. The challenges are surmountable since politics and society create rules and incentives for energy systems in a broad context. Society and industry can thus invest in development and infrastructure – global, European, and Swedish.

A few specific conclusions concerning Sweden are that the area of transport fuels is key in the climate discussion and that bio-energy can sustain the heat production – the alternative is natural gas.

During a transitional period, fossil energy will be required. Environmental consequences can be reduced if built-up areas, industry, and transport use energy more efficiently, and also through a shift towards pure fuels, engines, and electricity production technologies.

The panel has attempted to describe a positive view of the future, common for this type of work. It is an image where "points" regarded as too prominent have been smoothed out. The future is unpredictable and gloomy future scenarios are not attractive. The panel has not made any specific efforts to study the consequences of terrorism and political conflicts.

Also, the panel had no common view on whether the integration of Europe is turning towards increased nationalism and fragmentation or if it is actually the other way around, and the panel did not discuss the possibility of re-regulation as a counteractive measure to deregulations and free markets. These issues are discussed in the reports by the system foresight panel and the structural foresight panel.

Issues related to energy, and nuclear power in particular, have been on the Swedish agenda for many decades. Panel sessions have naturally been diverse in nature, especially the ones concerning the earth's reserves of oil and natural gas, electricity consumption in the future, new nuclear power, and the development of protected rivers.

The report ends with a few comments on areas worthy of deeper investigation, such as research needs.

Energy Foresight factual reports

The following factual reports have been derived within the framework of the IVA project Energy Foresight – Sweden in Europe. There is a principal person responsible for each report and he or she has been assisted by others when it comes to factual material and comments. Draft reports have – for commenting reasons – also been published on the IVA home page and the project's home page.

Gas and coal – resources and price development

Gunnar Agfors

This report discusses the availability of gas and coal over the next few decades, and also looks at the anticipated changes in factors that affect price.

Natural gas is much better for the environment than oil and coal, and the resources are vast. Sweden has the lowest share of natural gas of any European energy system, in spite of its proximity to the large deposits in Norway and Russia. New pipelines will run both east and west of Sweden and will thus create conditions for competitive pricing. Natural gas is also commercially and environmentally promising as a motor fuel.

Coal can hardly ever be more than a backup fuel on the Swedish market, unless today's technology is replaced with one that is less detrimental to the environment. The often expensive local coal mining in Western Europe is slowing down and is replaced by large-scale and rational mining, increased international coal trade, and uniform price setting. This will probably act as an effective counterweight against high prices of oil and natural gas.

Transfer and storage of energy

Åke Ekström

This report discusses the development of electricity and gas transfer and storage over the coming decades, as well as future moves towards cooperation between these two energy mediums.

The electricity transmission capacity will be increased between the Nordic countries, as well as between Northern Europe and the rest of Europe. The electricity supply system will become more efficiently monitored and controlled by the introduction of new voltage and output components.

Gas will probably become more common within the Swedish energy system and its infrastructure will be develped. Gas is an energy medium which can be stored, while electricity is mainly a direct form of energy. They are interchangeable, i.e. electricity is stored as hydrogen when there is an electricity surplus, and generated from gas when there is a lack of electricity.

Hydrogen increases in importance as an energy medium of electricity from renewable energy medium.

Oil – resources and price development

Gunnar Agfors

This report discusses the availability of oil over the next few decades, as well as the anticipated changes in factors that influence price.

During this period the world will be forced to adjust to the decreasing availability of crude oil. This will result in a historical break-up of the energy trend, and will have many implications, particularly within the transport sector.

The balance between supply and demand narrows. The best viable temporary solution appears to be a greater exploitation of Middle Eastern oil and gas fields. The political instability of this area however increases the risks of supply disruptions.

The North Sea countries have for a long time accounted for a large part of the Swedish crude oil supply, but the region's production has reached its maximum and is now decreasing. The quality of available crude oil will therefore deteriorate, and the risks of supply disruptions are increasing due to the dependency on more remote and politically unstable regions.

Electricity and cogeneration of heat and power from coal, natural gas, and biofuel

Mats Höjeberg

This report discusses the next few decades development of Swedish fuel-based electricity production, i.e. condensing power, cogeneration, and industrial back-pressure.

The technology to use coal, natural gas, and biofuel to produce electricity is focusing increasingly on combined-cycle gas turbines. In addition to natural gas, gasified coal or biofuel become viable fuel alternatives. Gasification appears to be one major path to increased efficiency and flexibility within power generation.

Future technology costs have been conservatively estimated. The availability of coal and biofuel is expected to be sufficient, while the role of natural gas within Swedish power generation depends on the development of a gas network.

An attachment to the report describes the possibilities of trapping carbon dioxide when burning fossil fuels. Carbon dioxide is then transported to safe and long-lasting depositories, such as exhausted gas and oil wells, or other geological formations.

During the last few years carbon sequestration has been widely reevaluated. Both separation and compression, as well as carbon dioxide transportation, can be done using existing technology. Storage in, for example, exhausted gas and oil fields is made possible by the fact that these safely contained gas and oil prior to their exploitation.

Energy Foresight factual reports

Nuclear power now and in the future

Lars Högberg

At normal operation the radiation from a nuclear power plant has an almost non-existent effect on the individual risk of cancer, but emissions caused by a reactor failure could result in radiation injuries, and the psycho-social aftermath could become extremely difficult. Vast areas might have to be evacuated for a long time.

A basic problem concerning nuclear waste is to estimate the reliability of the models which calculate the influence of certain processes throughout the extensive periods of time that they are dealing with. A possible but expensive technology that reduces (but not eliminates) the amounts of long-lived radioactive waste is known as an accelerator driven system (ADS).

The EU estimates that its reliance on nuclear power will have decreased by 50 percent by the year 2030, due to the member countries' domestic energy policies and also as a result of the existing plants having reached the end of their life-spans by then. During the same period a large number of fossil-fired power plants will have been phased-out, while electricity consumption is expected to increase. Addressing these two trends will become a key issue within nuclear power.

Present reactor types are further developed with the objectives to be safer and more economical. A longer-term outlook could include completely new reactor types (for example cooled by gas or melted metal, and with new fuel cycles) developed for commercial use.

Hydroelectric power in Sweden

Gunnar Hovsenius

Hydroelectric power, which has played a substantial role in the development of Swedish prosperity, today accounts for almost half of the nation's electricity production. Moreover, hydroelectric power assures that the qualities of electricity stay within a certain interval. This has become increasingly important in our computerized society.

The possibilities for increased production aided by an extensive environmentally adapted development are estimated at 5 to 7 TWh/year at a minimum cost of 27 öre/kWh. The Swedish Parliament has however limited further expansion to 2 TWh/year.

The early development of hydroelectric power resulted in a local and regional depletion of biotopes and species. A research program aimed at providing a foundation for environmental improvements in already exploited rivers, is expected to show positive environmental results towards the end of this decade. Some of the desired actions could however lead to severe economic, legislative, and technological problems.

If wind power is developed according to the ambitions set out in the Energy Bill of 2002, there might be an increased need for an instantaneous capacity backup, and possibly also for further capacity development within the field of hydroelectricity. An increased instantaneous capacity need corresponds to faster flow fluctuations, which are detrimental to the environment.

Industrial energy use

Camilla Sundlöf

The industry accounts for 40 percent of Swedish energy consumption. In spite of a dramatic increase in production since the 1970s, industry's total energy consumption has not increased, thanks to a series of concurrent factors. Energy consumption has become more efficient but there has also been a change in product composition to products with lower energy requirements. The conversion from oil to electricity has resulted in a situation where some losses have been moved from industry to the power plants. Sweden's energy-intensive industry accounts for 70 percent of industry's total energy consumption, compared to 25 percent of production value. These lines of business are similar in the way that energy, primarily electricity energy, is one of the main resources. Energy costs thus account for a large part of the value-added costs.

In addition to the development of industry processes there is a potential for savings in normal process-equipment. Energy-effective engines, pumps, and compressors create a savings potential within the manufacturing industry as well.

Energy use in buildings

Agneta Persson

The buildings sector accounts for roughly one third of total Swedish energy consumption and causes approximately 15 percent of the carbon dioxide emissions. The knowledge and technology for more efficient energy consumption already exists today, but there is a lack of incentive to invest in more efficient solutions. Presently, less expensive technology is most often selected instead of the best technology, electric heating is increasing, and electric appliances are growing in number.

More than 90 percent of the buildings in use20 years from now have already been built. Therefore it is important to take all possible measures to make existing buildings more energy efficient. It is important to give the house-owners financial incentives to choose the most energy efficient solution at each renovation or refurbishment.

Energy use in transport

Maria Stenkvist

The need for transport has risen sharply during recent decades, as a result of a growing economy and increased globalization. Road transport is increasing at the expense of railroad transport and shipping. A consequence of this development is that the transport sector in most countries becomes the sector where energy consumption increases most rapidly. Since fossil fuels dominate energy consumption, carbon dioxide emissions within the transport sector also increase.

More stringent environmental requirements have been one driving force for the development of more efficient vehicles and cleaner fuels, even though the automotive technology primarily has led to more powerful engines and larger vehicles. However, the automotive industry drives the development towards more fuel-efficient cars, and older technologies improve while new ones are developed.

Energy Foresight factual reports

Economic incentives within the energy field

Erik Larsson

This report discusses the development of economic incentives within the field of energy.

The principal task of taxation is either to provide government revenues, i.e. fiscal taxes, or to act as incentives to reach certain goals. Taxes are often geared towards both of these at the same time.

Subsidies are used to support operations at, or construction of, certain preferred plants. All subsidies have one thing in common. They come at a monetary cost and the money comes out of the public treasury.

The purposes have varied over time, but the primary purpose of taxation has always been to provide revenues to the government while subsidies have primarily been used to support new sources of energy. Lately, the need to influence energy consumption has become more important.

Today's free market requires harmonization of support and control in order not to disrupt competition. Market-based incentives provide no revenues for the government, but they do not come with a cost either. In addition, they can be handled internationally.

Presently, the most discussed support system for renewable electricity production is a green certificate system. To reduce carbon dioxide emissions, trade with emission rights is introduced.

Wind power on shore and off shore

Mats Leijon

This report discusses the development of wind power over the next few decades. If placed in the right location and if properly constructed, wind power could become a substantial addition to the nation's electricity supply system.

Large wind power stations have a much higher output than smaller ones at the same installation cost. New technological developments make it possible to construct robust, simple, and reliable wind power stations which can be placed both at sea and in mountainous regions, where wind conditions are especially favorable.

Wind power is environmentally friendly but not unproblematic. With the erection of wind power stations or wind power parks, their direct and indirect influence on flora and fauna needs to be minimized. This area requires more research.

Since wind cannot be stored, it must interact with other sources of energy in order to be used efficiently. With a widespread development of wind power, hydroelectric power (with its storage capacity) becomes an important key component of the entire power supply system.

Energy Foresight factual reports

Solar-generated electricity and heating

Tomas Kåberger

This report discusses the development of technologies for direct conversion of solar energy to electricity and heat.

The amount of solar energy which hits dead areas on earth is many times greater than the total energy consumption of mankind. Materials exist for the construction of solar panels and solar cells which could supply society's entire energy consumption without polluting or infringing on nature.

Technological development results in greater efficiency and lower costs. The amount of electricity-generating solar cells is growing at an accelerating pace, however from a current low level. Solar heating is already a significant source of hot water in many countries. Legislative policies influence markets depending on geography and manufacturing development.

When solar panels have saturated the market for hot water in Sweden, we will be able to increase the size and scope of the panels in order to heat buildings. The solar panel industry so plays an important role for Sweden. Solar cells face a global expansion and thus become an important industrial policy issue. For the research findings to be used to create a competitive Swedish solar cell industry, a local solar cell market with demanding customers is required.

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ENERGY FORESIGHT
a continuous process

The Technological Foresight project, with its visions of a future Sweden, received much justified attention when the results and conclusions were presented in March of 2000. The future scenarios depict a period of great change and express positive expectations but also uncertainties about future development.

Future energy systems were only discussed briefly and generally. Considering the great importance to social development, requests were made to supplement the Technological Foresight project with a specific Energy Foresight project.

The IVA Energy and Environmental Committee initiated such a project with the aim to view the Swedish energy system primarily as one entity within the European perspective, but also from a global perspective. The European perspective was considered as important because of the ongoing deregulations and also as a result of the electricity and gas networks becoming interlinked in continuously expanding regions. Energy is well on its way to becoming just like any other commodity. The climate issue and the ubiquitous globalization of the energy consumption sectors also necessitate a global scope.

Energy supply and energy consumption in Sweden have certain national characteristics, particularly within the area of heating. We are however, critically dependent on many developments in other countries. We import fuels for transport, for many industrial applications, and for parts of the heating sector; our products must be marketable in other countries, and we have (via EU membership) entered a marketplace in which we must abide by common rules. The EU also creates a new home market for our products, and deregulations and increasingly free trade clears new paths for the energy industry. Moreover, the energy consuming sectors currently operate on a defined global market – perhaps most noticeable within the transport sector.

The international work on climate was judged to result in a strong movement towards "carbon dioxide free" energy systems and renewable energy. One important task of the Energy Foresight project has thus been to present the pros and cons of such a development, as well as discussing developmental strategies.

The Technological Foresight project chose a perspective of 10 to 20 years. This is a long period of time when related to developments within IT, biology, and material technology, but much shorter when related to an energy system change.

The Energy Foresight project has worked with two time perspectives. Firstly, the 20-year scope which was used in the Technological Foresight project, and secondly a 50-year outlook in which new, visionary, and alternative energy solutions will have had enough time to emerge and replace much of today's technology. The longer perspective has obviously been treated more generally.

Considering the deadlocks and the polarizations which have often characterized the Swedish energy debate, it is important that the Energy Foresight project is perceived as independent, legitimate, and unaffiliated with any interest group. It is thus natural for the project to cover both existing lines of business as well as technology disciplines. It is also important to accumulate knowledge and competence from different social areas. In addition, representation from both industry and research becomes natural. Participants have been selected based on their character and competence, and not as representatives of any organization.

> Instead of saying "This is the way it's going to be!" or "This is the way we want it to be!" the Energy Foresight project has aimed at stimulating discussion and debate.

Instead of saying "This is the way it's going to be!" or "This is the way we want it to be!" the Energy Foresight project has aimed at stimulating discussion and debate by drawing up thought-provoking, credible, and relevant future scenarios.

The project has been run by The Royal Swedish Academy of Engineering Sciences (IVA) with financial backing from several authorities and organizations.

Foresight with hindsight

It is difficult to predict the pros and the cons of new technology and new ideas. The Technological Foresight project carried out a specific study of various sources of error and obstacles which need to be acknowledged. This study is also of relevance to the Energy Foresight project and points to these factors:

- A belief in a scenario where new technology will replace the already available, and that this transformation will be comparatively swift. In reality several competitive technologies often exist in parallel over an extended period of time.
- A belief in a scenario where new technology simply solves old problems and adds to existing technological systems. Instead, new technology often paves the way for entirely new systems.
- A belief in a scenario where technology functions as a universal solution to various social problems.
- The difficulty in identifying important links between various fields of technology, where the combination becomes the real enabler of developmental possibilities.
- That the individuals who have tried to predict the future have drowned in the actual technology, thus omitting several economic aspects.
- That we have been caught in the spirit of the time, having believed that today's important issues also will be tomorrow's.
- That not only rational and economic considerations influence choice of new technology. Irrational considerations are often decisive.
- That the foundation of information concerning future studies has often been insufficient. Much technological development takes place behind the scenes, especially within the military sector.

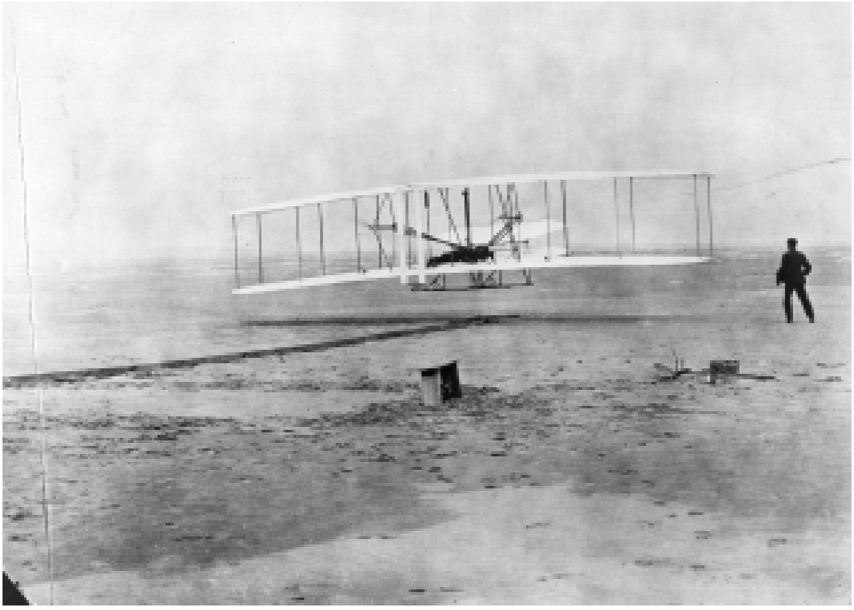
The insight of the impossibility to draw a reliable picture of what the Swedish energy system will look like in 20 years, and even more so in 50 years, as well as the scope of the estimations and the perceptions, brought us to the onset of the scenarios. We present basic data and draw up scenarios which will stimulate discussions that could lead to alternative scenarios.

Meanwhile it is important to realize that Sweden will not be entirely different in 20 years. There is only a slow replacement of the infrastructure which influences energy requirements. Industrial profile, built-up areas, and transport systems will not be entirely different in 20 years from what it is today but there are ongoing processes of change. While technological structures change slowly, much can happen within institutional and business structures since they are influenced by EU-development and by globalization and deregulation.

The Energy Foresight project has not submitted any worst-case scenarios, such as the effects of widespread terrorist activities or the implications of political upheaval in countries which are of importance to European oil and gas supply. Perhaps our future scenarios are too optimistic?

There are not so many foreign examples of the Energy Foresight – Sweden in Europe project. There is a British report – *Energy for Tomorrow Powering the 21st Century* – prepared by the Energy Futures Task Force within the Foresight Energy and National Environment Panel. Another report, from Finland – *Energy Visions 2030 for Finland* – is prepared by VTT Energy. There are also future global energy studies prepared by Shell. The most recent one is *Energy Needs, Choices and Possibilities.*

"Heavier-than-air flying machines are impossible."
Lord Kelvin, President of the Royal Society, London, 1890 – 1895.



Thursday, December 17, 1903. Wilbur and Orville Wright's famous first flight. On the historic day, it was Orville's turn to pilot. Just after the Wright flyer lifted off the monorail, the famous picture was taken, which Orville had set up (having asked one of the men simply to squeeze the shutter bulb after takeoff). Wilbur is running next to the plane. Photograph: Pressens Bild.

Energy Foresight – Sweden in Europe project realization

The fact that the energy issues received a very limited amount of space in the Technological Foresight project, sparked the idea to create a specific Energy Foresight project. This was done by the IVA Energy and Environmental Committee during the fall of 2000. A first project specification was developed with the cooperation of Mr. Leif Magnusson, EnerGia, who had been involved in the Technological Foresight project.

Following several contacts with different parties during the first half of 2001, the project's funding was secured. Unlike to the Technological Foresight project which incorporated four different project trustees, IVA has been the sole organization responsible for the Energy Foresight project. The project has been realized within a budget of SEK11.2 million. The contributors are:

Energimyndigheten (The Swedish Energy Agency) 5
Svensk Energi 2
ÅFs forskningsstiftelse (ÅF's Foundation for Research and Development) 1
VINNOVA (Swedish Agency for Innovation Systems) 1
Fjärrvärmeföreningen 0.5
FORMAS (The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning) 0.5
SBUF 0.5
Svenskt Näringsliv och SKGS (Confederation of Swedish Enterprise and SKGS)..........0.5
LRF 0.2

To lead the Energy Foresight – Sweden in Europe project, the CEO of IVA appointed this Steering Group:

Chairman, *Anders Narvinger*, Director, Sveriges Verkstadsindustrier
Program Manager, *Henrik Blomgren*, IVA
Investment Manager *Sigrun Hjelmquist*, BrainHeart Capital
Director-General, *Thomas Korsfeldt*, Statens Energimyndighet
Director, *Lars-Gunnar Larsson*, Swedish International Project/Statens Kärnkraftinspektion
Professor, *Bruno Nilsson*, Kungliga Skogs- och Lantbruksakademien
Director, *Monica Ulfhielm*, Svensk Energi

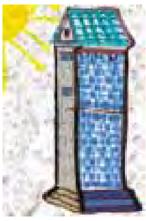
A project secretariat was assigned to the project. *Göran A. Persson*, Director, was appointed overall project manager with *Ann-Margret Back* as his assistant.

The Steering Group appointed chairmen and project managers for the individual panels.

The system foresight panel
Bengt Söderström, Chairman.
Kerstin Lövgren, Project manager

The user foresight panel
Bertil Pettersson, Chairman.
Karin Byman, Project Manager

The structural fore-
sight panel
Peter Nygårds,
Chairman.
Fredrik Lagergren,
Project Manager



The long-term fore-
sight panel
Minoo Akhtarzand,
Chairperson.
Leif Magnusson,
Project Manager

The panels were suggested by the panel chairmen and project managers, and appointed by the steering group. The aim of each panel was to achieve the broadest representation possible from different disciplines and social areas. Most of the project work was carried out within the four panels.

A number of different groups were also tied to the project in order to get the best representation from "Energy Sweden." All groups have been invited to the project's joint meetings.

The interest group was established in order to spread the work of the Energy Foresight project more widely and to convey comments from influential players within the field of energy, and also to help distribute the results.

The reference group was established to follow the project in its entirety and to comment on the work by studying the panel and factual report drafts.

Regional energy offices have committed themselves to help distribute the results.

An important part of the Energy Foresight project are the factual reports which have been produced. The aim has been to present up-to-date information within the field of energy, partly for internal use within the project but also to a wider group of people working with energy issues. The factual reports are presented from page 41 to page 46.

The "kick-off" event took place on January 24, 2002. Representatives from Shell's global energy foresight group were present, as well as members of the British energy foresight project. A follow-up session, in which everyone participated, took place on June 12. The theme of the IVA Royal Technology Forum of October 24, was *Energy for Tomorrow – Prepare for the Future with Energy Foresights.* On this occasion the chairman of the steering group presented the Swedish Energy Foresight. Glimpses from other related projects were given by the EUcommission, Finland, the United States, Russia, and China.

The panel reports of the Energy Foresight project and a summary were presented at a final conference on February 18, 2003. During Spring of 2003, the Energy Foresight – Sweden in Europe project will be presented at a number of meetings throughout Sweden.

THE PROCESS MOVES ON nationally and internationally

One goal of the Energy Foresight project has been to offer a foundation for broad information and discussions regarding the possibilities and the obstacles of sustainable development within the field of energy in Sweden. The project is primarily targeted at broad context decision-makers in public administration, industry, and research, but also aims at giving insight and knowledge to a wide group of people at central, regional, and local level.

In the directives for the Government's study of the long-term program on energy policies (2001:122) it is stated that the Energy Foresight – Sweden in Europe project shall constitute one of the points of departure for preparing proposals for guidelines for the program in question related to the planning period starting in 2003. The prospects of the material from the Energy Foresight project being used by the investigation are deemed good since the appointed investigator Peter Nygårds, in his capacity as panel chairman, has direct insight into the work. Moreover, representatives from the secretariat of the project have also been members of the interest group.

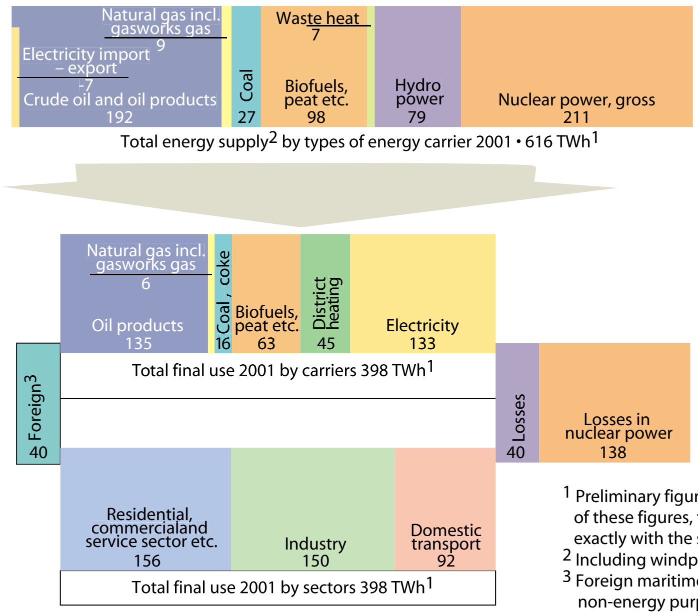
The Royal Academy of Sciences (KVA) has also been active in the field of energy. In the periodical *Akademien anser*, no. 1/2002, a contribution by the KVA was published on energy, health, and environment. IVA intends to initiate a discussion on cooperation within those fields where the academies enjoy particular expertize and where an in-depth discussion beyond that which was possible in the work on the energy foresight appears urgent.

IVA collaborates with 18 European academies of engineering sciences within Euro-CASE. A committee on energy and environment was recently established. IVA has been asked to take the lead for this work and there is great interest in bringing the work to a European level, based on the Energy Foresight project, in particular with regard to a technical evaluation of various sources of energy.

ENERGY IN SWEDEN

In international terms, the energy supply of Sweden includes a relatively large proportion from renewable sources. Hydro power and biofuels account for 29 % of the country´s total energy supply. The electricity supply system based on hydro and nuclear is almost free of carbon dioxide emissions.The energy supply and use in Sweden 2001 is shown in Figure 1.

Figure 1 • Energy supply and use in Sweden 2001, TWh



[1] Preliminary figures. Due to rounding up or down of these figures, total figures may not always agree exactly with the sums of the individual items.
[2] Including windpower, 0,45 TWh.
[3] Foreign maritime trade and energy for non-energy purposes.

Electricity use in Sweden is linked primarily to two sectors, the residential and service sector and the industrial sector (Figure 2). The substantial increase in the use of electricity in the residential sector up to 1987 was the result mainly of a change from oil to electricity for heating purposes. Industrial use is is closely linked to conditions in a small number of sectors. The pulp and paper industry, for example, uses about 40 % of all the electricity used in industry.

The production mix of electricity has changed over the years (Figure 3). At the beginning of the 1970s, hydro power

Figure 2 • Use of electricity in Sweden 1970–2001

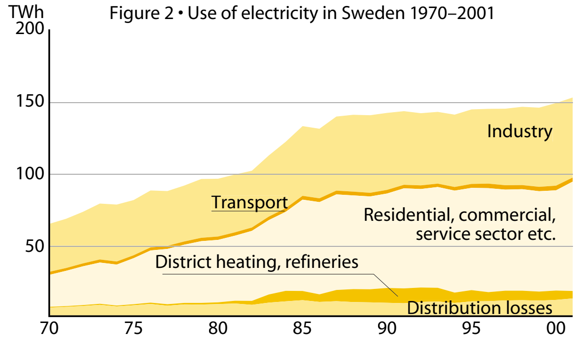
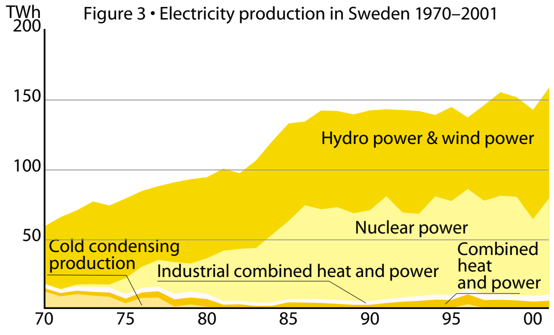


Figure 3 • Electricity production in Sweden 1970–2001



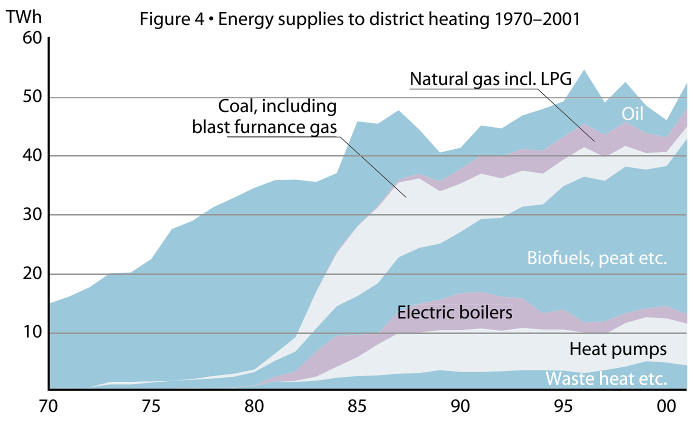
and conventional thermal power produced most of the electricity. The oil crisis of the 1970s provided a strong impetus for nuclear power. Today hydro and nuclear supply most of the electricity, amounting to somewhat over 94 % in 2001.

This production structure is once again in the process of change. Sweden has decided to phase out nuclear power production but without a time limit. The first reactor was closed in 1999 and a second will be closed when the conditions set by the Parliament are fulfilled. These conditions include "the loss of electricity production being compensated by the introduction of new production capacity and reduced use of electricity".

Today, there is a joint Nordic power exchange, Nord Pool, on which all the Nordic countries except Iceland trade. The prime factor in determining power trading is annual precipitation to the Swedish, Norwegian and Finnish reservoirs, coupled with the marginal production costs of electricity.

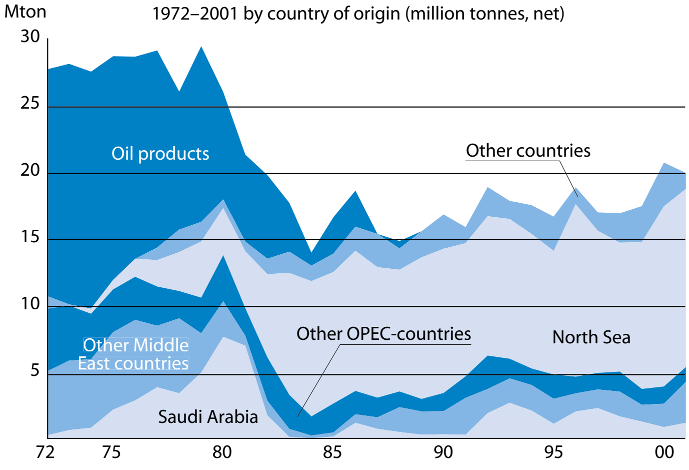
In Sweden, per-capita electricity use is relatively high in comparison with that of other countries. Only Norway, Iceland and Canada have higher uses. All these countries have plentiful supplies of cheap hydro power, a cold climate and highly electricity-intensive industries based on forest and ores.

Figure 4 • Energy supplies to district heating 1970–2001



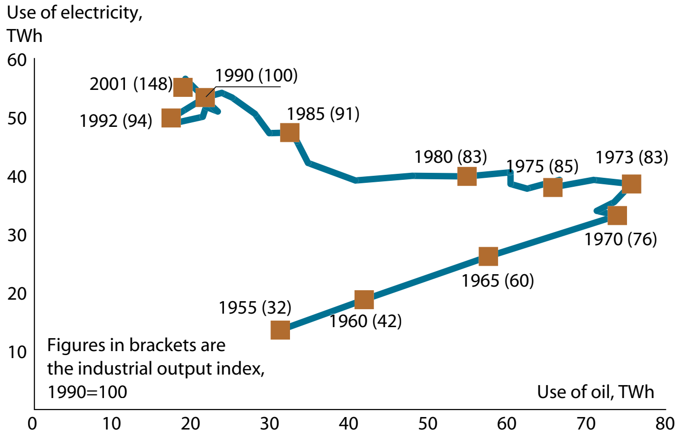
In 2001, the use of biofuels amounted to over 97 TWh. These fuels consist mainly of wood fuels and black liquors in pulp mills. The use of wood fuels by the district heating sector is about 30 TWh in 2001 and has increased by a factor of five since 1990 replacing fossil fuels (Figure 4).

Figure 5 • Swedish imports of crude oil and petroleum products, 1972–2001 by country of origin (million tonnes, net)



The import of oil (Figure 5) has two main features. The decline in the use of oil and the high dependance on import from the North Sea. When the production in the North Sea decreases in the next ten years oil has to be imported from other more politically unstable areas.

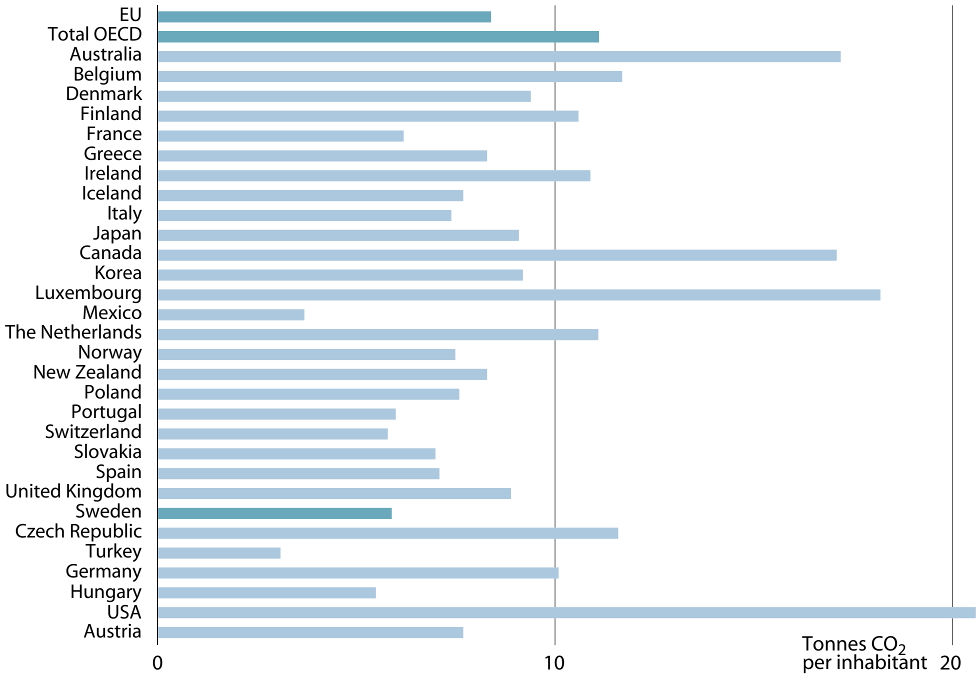
Figure 6 • Use of oil and electricity in industry 1955–2001



Despite rising industrial output, the use of oil has fallen substantially since 1970, due to greater use of electricity and improvements in the efficiency of energy use (Figure 6).

Environmental conditions have improved. Sulphur dioxide and nitrogen oxides have decreased by 90 and 30 % respectively, from 1988. The decline in the use of oil has resulted in reduced emissions of carbon dioxide and the per-capita emissions are among the lowest in EU and OECD-countries (Figure 7).

Figure 7 • Emissions of carbon dioxide (CO_2) per inhabitant 2000 in EU and OECD-countries



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About scenarios

The climate in focus is a scenario which describes a halving of the carbon dioxide emissions in the industrialized countries up to the year 2050, and therefore places high demands for changes in the energy supply during this time period.

The climate – one factor among others does not require large reductions of carbon dioxide emissions, but the technological development will induce extensive changes within the energy supply up to the year 2050.

In order to discuss the Swedish 2020 energy system, which is the primary time perspective of the panel, we need illustrations of long-term international development. As a common base for the panels the steering group has submitted the following depictions of possible energy supply within the EU and Sweden in 2050. They do not claim that these are the most likely or desirable, and the panels have been free to add their own views and scenarios.

EU 2050 – The climate in focus

- Solar-based electricity (e.g. wind, solar cells, bio) and hydrogen gas powered fuel cells have a considerable and growing market share.
- A number of countries have replaced nuclear power after 60 years in operation. A new generation of nuclear power offers increased safety and a bridge to a solar and hydrogen gas powered society.
- Natural gas with carbon sequestration is the dominant fossil fuel for electricity production.
- A majority of vehicles have hydrogen fuel cells produced from natural gas with carbon sequestration and from renewable energy. The social infrastructure for hydrogen is complet.
- Heating and cooling with natural gas and electricity.

Sweden 2050 – The climate in focus

- Hydroelectric power ass today.
- Solar-based electricity other than hydroelectric power (e.g. bio, wind, solar cells) and hydrogen powered fuel cells have a considerable and growing market share.
- Present nuclear power plants have, after 60 years in operation, partly been replaced with a new generation of nuclear power plants, which offer increased safety and a bridge to a solar and hydrogen gas society.
- A majority of vehicles have hydrogen fuel cells produced from natural gas with carbon sequestration and from renewable energy.
- Heating by bio, heat pumps, and electricity (low-energy houses).

EU 2050 – The climate – one factor among others

- Solar-based electricity (e.g. wind, solar cells, bio) have a limited but growing market share.
- Present nuclear power plants have been phased out after 40 years in operation.
- Electricity production using natural gas and highly efficient coal-fired power plants with carbon sequestration.
- Many vehicles use fossil fuels with a large influx of natural gas and liquid fuels from natural gas. Only vehicles without emissions are allowed in the central parts of urban areas.
- Heating and cooling by natural gas and electricity.

Sweden 2050 – The climate – one factor among others

- Hydroelectric power as today
- Solar-based electricity other than hydroelectric power (e.g. bio, wind, solar cells) have a limited but growing market share.
- Present nuclear power plants have been phased out after 40 years in operation. Replaced by natural gas-based electricity.
- Many vehicles use fossil fuels, of which some use natural gas-based liquid fuels and natural gas, where available. Only vehicles without emissions are allowed in the central parts of urban areas.

Steering Group synthesis and summary report

With this report the Steering Group wants to draw attention to possible changes within the field of energy up to the year 2020, and also offers more general views in a longer time-frame. The starting-point has been the development in Europe and the world in general and in the way this development affects Sweden's energy future. Two main scenarios are presented: The *climate in focus* and *The climate – one factor among others*. What differentiates the two scenarios is their reactions to the climate issue.

Three prioritized areas are discussed: energy use levels and composition, replacement alternatives to current nuclear power, and replacement/reduction of fossil fuels within the transport sector.

The report expresses the Steering Group's positive outlook on the possibilities of achieving sustainable and climate-aware development of European and Swedish energy systems. The report also includes panel and factual report summaries as well as a description of the background and realization of the project.

Energy Foresight – Sweden in Europe

The Royal Swedish Academy of Engineering Sciences (IVA) is an independent forum for information exchange. Through initiating and stimulating contacts between various competence areas and across national boundaries, the academy acts as a transboundary link between industry, research, administration, and various interest groups.

This IVA project sheds light on the Swedish energy system from a global and a European point of view. The climate issue necessitates a global perspective. The European perspective is important because of the ongoing deregulations and also as a result of the electricity and gas networks becoming interlinked in continuously expanding regions.

By looking to the future, the ambition of IVA is to stimulate interesting and balanced discussions through offering insights and thought-provoking, yet credible and realistic, future scenarios of the Swedish energy system as one part of the total European system.

The project's results and conclusions are presented in four panel reports and in one synthesis and summary report. These can be ordered from *IVA, Box 5073, SE-102 42 Stockholm* (bokh@iva.se) and will be available in PDF-format at the IVA home page www.iva.se and at www.energiframsyn.nu.

The project factual reports can be ordered in printed form from *Energimyndigheten, Box 310, SE-631 04 Eskilstuna*. They are available in PDF-format at www.stem.se, www.iva.se and www.energiframsyn.nu where they also are available in PDF-format.

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