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Swedish energy research in a strong development phase

How do the driving forces behind present-day energy research compare with those of earlier years?
Thomas Korsfeldt, TK: – Sweden's modern energy policy started during the 1970s, and with it, the development of the energy research programme. At that time, the main emphasis was on replacing oil and reducing the use of energy. In the 1980s the discussion on phase-out of nuclear power production rose, and its associated environmental consequences. Today, it's the effects of energy supply and use on climate that provide the strongest driving force, together with the importance of securing a reliable supply of energy.

Birgitta Palmberger, BP: – There's also more pressure today for the results of research to reach implementation, through commercialisation or other means.

What's being done to increase the rate of commercialisation?
BP: – It's important to achieve an active dialogue with business, industry and other result-users, so that the direction of research is more determined by needs. We also demand from applicants to show how their results might be used, right from their initial programme and project proposals.

TK: – We are focussing our activities, for example through our new Department of Business Development and New Ventures, which deals with funding for various business ideas. The Agency's also actively involved in helping the providers of risk capital to make use of our unique overall competence and our networks of contacts.

What are the Swedish strengths?
BP: – The focus on sustainable energy has meant that Sweden is now a world leader in several research and development areas. Biofuels, heat pumps and solar cells are three areas in which Swedish research is at the forefront in an international perspective. Swedish industry has also come a very long way as far as improving the efficiency of energy use is concerned.

TK: – Yes, but we mustn't forget that the lead times between research and implementation in the real world are long. What we're seeing today are the results of projects that were started ten or twenty years ago. Energy research requires a long-term approach, an overall view and patience.

BP: – Research by itself isn't enough to create new energy systems: it needs to be backed by effective policy measures if some new technology is to reach the market.

What do you see as the future challenges for energy research?
TK: – An important issue is how we're going to be able to provide long-term financing for the development of demonstration plants, which are unavoidably large and expensive, but equally are absolutely essential. This requires both political will and a stable financial base if today's pilot plants are to be developed to full-scale production.

BP: – All our work focus on renewable energy, climate effects and the environment. The challenge will remain, of creating sustainable energy systems with a wide acceptance by society.

Finally, what are your intentions with this new publication, Swedish Energy Research?
TK: – We want to publicise the results of Swedish energy research, and show the high level of its attainment.

BP: – We want to show the range of our thematic areas, financing activities right from the basic research level through to large pilot installations within our six thematic areas. This is needed in order to achieve the results of research in terms of knowledge, competence and commercialisation.

Thomas Korsfeldt, Director-General, and Birgitta Palmberger, Head of Department for Energy Technology, head the funding of Swedish Energy Research.

The Swedish Energy Research Programme

The Swedish Energy Agency is responsible for Sweden's national energy research programme. Working closely with universities and business, it finances technical research and knowledge development. The results of this research are intended to support development of the country's energy system, while also finding applications in commercial activities and supporting robust energy and climate policy decisions.

"Targets for the Energy Research Programme are more effecient and cleaner tehniques on the market, lower costs, and competent people."

Energy research: part of the long-term energy policy

The energy system of any society is a key part of that society's development. We must reduce our impact on the global climate, while at the same time striving to achieve economic growth, not only in Sweden and the EU, but world-wide. Energy systems, both in Sweden and in other countries, must rise to these challenges. The target of Swedish energy policy is the creation of a safe and reliable energy system, with minimum environmental and climate effects, all at a reasonable cost and against the background of a healthy economy. Energy research can contribute to this through the acquisition of new knowledge, the development of new technology, the formation of new companies and the creation of competent persons who can contribute to helping the results find application in industry and society.

Knowledge, competence and commercialisation

The National Energy Research programme assists the creation of competence and knowledge of the energy system through support for research at university level, by other research institutes and in the public sector. It supports the development of new technologies, their commercialisation and introduction to the market. Research is also intended to reduce the costs of new energy technology based on renewable forms of energy. The overall aim is that, over the next 10–15 years, Sweden should greatly in-

The objective of energy research

The objective of energy research is to "acquire and develop such scientific and technical knowledge and competence within universities, institutes of technology, other research institutes, public authorities and industry as are needed to assist the shift towards a long-term sustainable energy system in Sweden through application of appropriate new technology and services, and to develop technologies and services that can be commercialised by industry in Sweden, thus contributing to the shift towards a sustainable energy system and to development both in Sweden and on other markets."

The Swedish heat pump industry is a good example of how research cooperation between the state and industry provides an excellent basis for successful commercialisation and growing export markets.

crease the proportions of its heat and electricity production from renewable energy sources, and that commercially viable means of improving the efficiency of energy use should be developed. Energy research is also intended to benefit industry as a whole by creating stable conditions for a competitive industry, assisting renewal and development of Swedish industry.

Achieving a sustainable energy system requires cost-effective policy measures

The development of a sustainable energy system requires more than just research and technical development. They need to be backed up by appropriate forms of taxation and grants, commercial incentives, information, legislation and regulations to help consumers and producers along the path to the specified objectives. An example of such a policy measure is carbon dioxide taxation, which is intended to encourage the use of biofuels by both domestic users and the district heating sector. Another example is that of the electricity certificate system, supporting increased production of electricity from renewable sources such as biofuels, wind power and small-scale hydropower.

Energy policy and energy research – hand-in-hand for 35 years

Energy-related research under a national umbrella programme started over 30 years ago, after the first oil crisis. It was, in fact, one of several measures intended to reduce not only the country's dependence on oil, but also its overall use of energy. The programme covered a very wide range, allowing all possible research areas to be included, as long as they related to improving the efficiency of energy use or to new technologies for moving away from the use of oil.

During the 1980s, growing pressure for phasing out nuclear power production provided a strong driving force behind energy research. Attention was also paid to the environmental problems associated with the production and use of energy. Depletion of the ozone layer and effects on climate are examples of global environmental problems that have strongly influenced the direction of energy-related research.

Over the years, the Energy Research programme has developed and changed. Today, it is concentrated on fewer thematic areas than before, although the driving forces are similar: reduction of carbon dioxide emissions and

The Energy R&D Board, EUN, is appointed by the government, and is the decision-making body for research funding. Members in 2006 were Tomas Hallén, Anders Schelin, Harald Haegermark, Christer Sjölin, Lena Neij, Birgit Bodlund, Eva-Katrin Lindman, Thore Berntsson and Thomas Korsfeldt, Chairman. Karin Kvist is missing from the picture.

reduced dependence on fossil fuels. There are clear requirements for the results of research to find implementation in industry and society as a whole. Work should also be concentrated on areas in which Sweden has the greatest potentials. Greater importance is therefore attached to working with industry and other intended users of the results.

Commercialisation has resulted in a more sustainable energy system

Research results have been commercialised and played an important part in Sweden's energy system today. Heat pumps, CFC-free refrigerators, energy forests, large-scale and small-scale biofuels combustion technology, flue gas condensation, district cooling and energy system models are some examples of products and services that have been successful on the market, and not just in Sweden. Earlier work in energy research has also resulted in Sweden today being in a relatively favourable position as far as fulfilling its climate obligations and other environmental objectives are concerned. The country is not as highly dependent on oil, natural gas, coal or other energy imports as are many other countries in Europe, which is partly due to the results of energy research. Swedish companies are successfully exporting both environmental and energy technology, making a substantial contribution to our national economy. For this reason, it is also vital that energy research should continue, in order to meet the continuing changes and challenges of the world around.

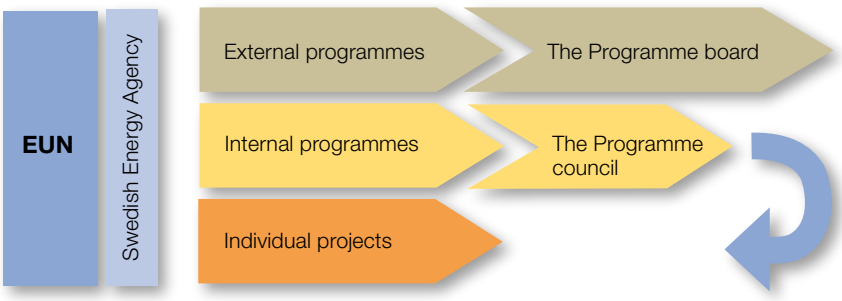


FIGURE 1: *The Energy Research and Development Board (EUN) makes the decisions concerning the Agency's financing of research and development, but can delegate decisions to the Director-General. For external programmes, project decisions are taken by the Programme Board: for internal programmes, project applications are granted by the Energy R&D Board or by the Director-General, after assessment by the Programme Council. Individual project applications are prepared by the Agency, with the financing decision made by the Board or the Director-General.*

Long-term energy research divided into six thematic areas

The Agency works with six thematic areas: Energy system studies, the Building as an Energy System, the Transport sector, Energy-intensive Industry, Fuel-based Energy Systems and the Power System. Within each of these areas, research is organised mostly into specific programmes, the number of which can vary with time, depending upon identified research needs. During 2006, about 40 programmes have been running. In addition to them, a number of individual projects are also in progress.

The members of the Energy Research and Development Board (EUN) are appointed by the government, and are the ultimate decision-making instance for the energy research programme. The Board decides on larger internal programme commitments, on participation in external programmes and on larger individual projects. Decisions on some programmes or projects are sometimes delegated to the Director-General.

Technology platforms – a means of identifying needs

Technology platforms have been established for each of the six thematic areas, bringing together experts from public authorities, industry and other parties, and supporting the Agency in its work of developing strategic research plans for each thematic area. They also assist the Agency in identifying and analysing the needs of energy-users, and in identifying obstacles that could prevent the energy system from operating effectively.

From basic research and technical development to demonstration activities and business development

Swedish energy research is carried out in all levels, from basic and applied research up to demonstration activities and pilot plants to test new technology. After this, new products and services must mature into feasible business entities. This provides added value, so that the results of research can develop into sustainable growth companies within the energy sector. It can often take between ten and thirty years for new technology to mature from the research and demonstration stage to that of practical introduction and use on a larger scale.

Cooperation with industry doubles funding

Research is carried out by universities, institutes of technology, various sector and research institutes and by industry. International networks within and between the Nordic countries, the EU and the International Energy Agency (IEA) are also important in the exchange and dissemination of knowledge and skills. See Page 38 for more detailed information on international cooperation in energy research.

Basic research and other energy research at universities and institutes of technology are often 100 %-financed by state funding. However, the closer to market some technology, product or service becomes, the higher the proportion of the costs financed by industry. More applied development work, for example, can receive only a maximum of 50 % of its finance from the state in the form of energy technology funding.

Universities, industry and public authorities working together in competence centres

Competence centres are forums for research cooperation between universities, companies and the Swedish Energy Agency. Research is concentrated on companies' long-term interests, and can often range over several disciplines. The intention is that the universities should become involved in meeting the research needs of industry, while at the same time delivering results of an assured high scientific quality. Such work covers fields such as improving the efficiency of internal combustion in engines, improved performance of materials and electric power technology.

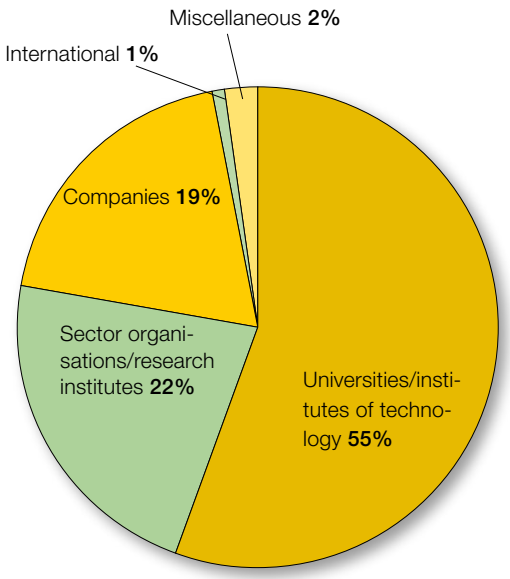
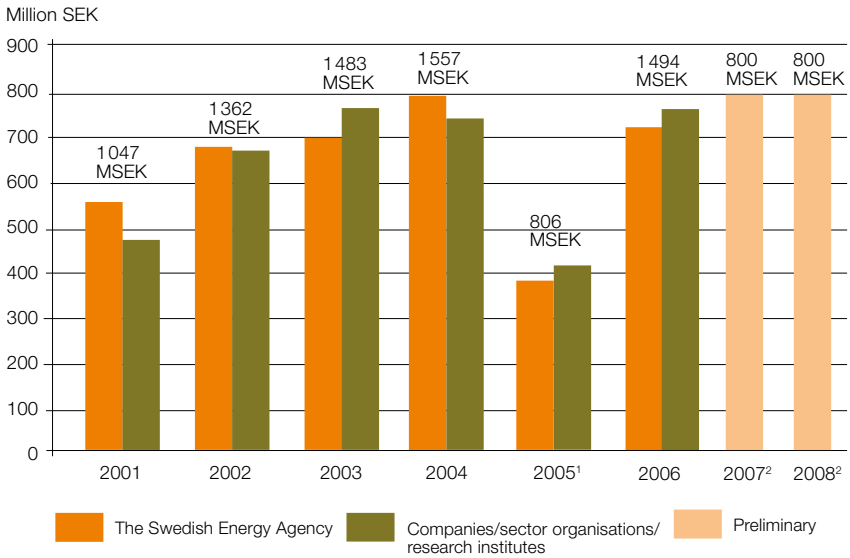


FIGURE 2: *Recipients of funding in 2006*

FIGURE 3: *Cooperation with industry effectively doubles financing*



1 2005 saw a temporary reduction in public funding of energy research activities.

2 The Figure for 2007 is as allocated in the national budget for the year, while that for 2008 is as presently expected.

Energy system studies

Why is the shift of the energy system towards improved sustainability not going faster? Why are energy policy objectives sometimes not being achieved? Energy systems research is concerned with the interaction between people, organisations, institutions and technology. It is often aimed at acquiring knowledge of synergies to provide a better decision-making basis for those involved in the energy system, regardless of whether they are politicians, companies, organisations or households. Sociologically-orientated system studies are of decisive importance for such purposes as the drafting of policy measures, negotiations on climate policy or the forming of future visions of the energy system.

Research direction

System research is focused on:

- studies of policy measures
- studies intended to provide material for climate policy negotiations
- future scenarios of the energy system
- studies to assess different technology alternatives

Man and technical systems affect each other

Both technology and social science use the term 'system'. Studying 'technology as a system' means different things, depending on the working area and views of those carrying out the study. For the Swedish Energy Agency, the energy systems studies thematic area includes not only system science research as often defined by scientists, but also investigations of the behaviour and actions of individuals or organisations, viewed from such perspectives as the national economy, legal aspects or sociology. Energy systems studies are often cross-disciplinary or multi-disciplinary.

The basis for this system perspective is that all technology can be seen as closely or loosely linked parts that create a whole. Technically, an energy system can be defined as consisting of a number of sub-systems, such as a district heating production plant with associated distribution network, or by geographical boundaries such as local authority or national electricity grids. But these technical systems are owned, controlled, developed, operated and used by many parties and organisations, all of whom affect the various systems and who can be regarded as parts of them.

Energy systems and those involved in or with them are also affected by taxation, legislation, regulations and events in the wider world. Most of these factors also have mutual effects upon each other. It is therefore not sufficient to look for one answer to a question at a time, as this fails to consider the underlying understanding of the relationships within the whole. If questions are, instead, put from a system perspective, it should be possible to build up a multi-faceted view of the energy system's function, and to develop conditions intended to work towards sustainable energy systems. An important element of the work in this thematic area is that it is individuals who construct and build the technical systems, while the technical systems in their turn affect society, organisations and individuals.

Energy system studies provide tools to achieve the system shift

Energy systems play a central part in the development of society, not least against the background of growing demands for efficient and long-term sustainable management of the earth's resources. Changing energy markets,

developments on the oil market and the threat of climate change – an environmental problem that must be solved at global level – are examples of factors that mean that we must increasingly regard energy matters from an international perspective. New energy and climate policy measures are being drawn up nationally and internationally. There are also requirements that energy supply in Sweden must be delivered on terms that are competitive against the rest of the world, as energy supply is so important for public wellbeing.

Objective: to acquire knowledge of the energy system and its dynamics

The Swedish Energy Agency's purpose with energy system studies is to acquire knowledge of the energy system and its dynamics from an overall point of view. Research is expected to provide, for example, material to permit assessments of different technological alternatives and their potential short-term and long-term importance for the energy system. It is also intended to provide knowledge of how energy and climate policy measures work, as well as of their cost-effectiveness. If we are to drive the international climate policy process forwards, we also need improved knowledge of climate policy means and conditions, which the investigations are also intended to provide. This working area will also investigate the importance of energy research as such, indicating what the relationship between research and other energy policy measures looks like.

"Individuals shape the technical systems, and the technical systems in turn affect society, organisations and people."

The General Energy Systems programme

The General Energy Systems programme has a long history. It is concentrated on a number of different main areas:

- The cost efficiency of policy measures and their suitability for purpose.
- Research into the energy markets and their actors, as well as technology shifts.

In addition, the programme carries out research into:

- Development of methods and models for energy system analysis and production of future scenarios.
- System-critical research and comparative investigation.
- Gender and generation perspectives.

Graduate school

The Energy Systems programme trains scientists with a broad system view of energy matters

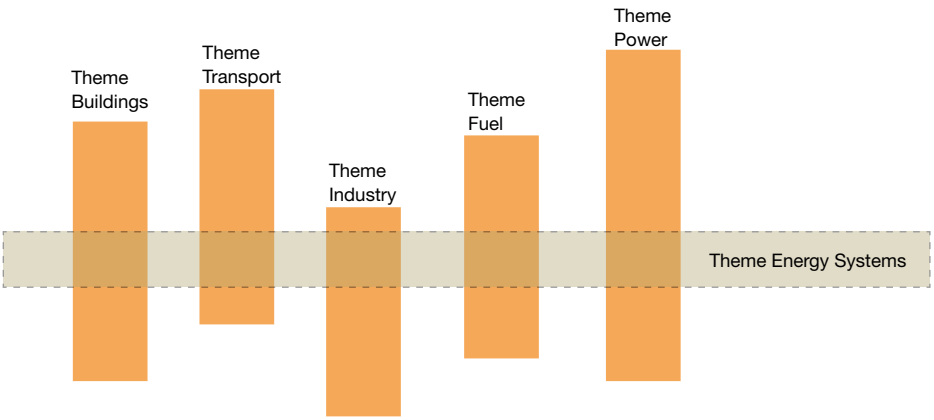
The Energy Systems programme is an initiative that brings together five departments at four Swedish universities to train PhD students and develop knowledge concerning the energy system. The programme has two main elements: a long-term research programme, and a graduate school in Linköping that trains groups of PhD students. Between ten and twelve PhD students are accepted every two years for training. The course is cross-disciplinary, with elements of both technology and social science, and aims to provide the future PhDs with a common level of general knowledge within the energy sector and a diverse basis for their continued work. At the same time, they acquire advanced specialist knowledge within their respective research areas. This will mean that, when their training is completed, they will have a thorough grounding in energy systems, enabling them to tackle complex problems. From an international point of view, the school is unique in its objectives. Many of those who have presented their theses continue to work in the energy sector, in key positions in industry and administration.

Climate Policy

Chalmers University of Technology analyses climate change policies

The Swedish Energy Agency has been involved, as the main financer, in the establishment of a research group for international climate policy at Chalmers University of Technology. The questions that are considered are: What technical solutions are being used to reduce emissions in order to prevent serious climate changes? How do the technical solutions relate to each other? How quickly can new technology find its way onto the market? What will it cost, and what policy measures are necessary? The group's research results give some hope that it may be technically and economically feasible to avoid serious climate changes.

FIGURE 4: *The systems perspective cuts through all technology areas.*



The basis of the system perspective is that all technologies can be seen as closely or loosely linked parts of a whole. Some research fields, such as gasification, fall within several thematic areas, and so technology advisory panels have been set up for them.

The work of the group can be divided up into four areas:

- **Strategic aspects concerning the Kyoto Protocol.** A global energy system model has been developed and used to analyse the feasibility of achieving various concentration levels of greenhouse gases in the atmosphere. The model has also been used to investigate the cost implications, in industrialised countries in and developing countries, of achieving various specific per-capita emission levels in all countries by 2050.

- **Bioenergy, carbon sinks and strategies to reduce deforestation.** Research has shown that the use of bioenergy can be profitable if high rates of carbon dioxide tax are introduced, but emphasises that it is important to draft policy measures such that poor farmers and virgin natural environments do not lose out in the hunt for land for bioenergy cultivation. The group has also looked at the part that international climate agreements can play in creating incentives to reduce tropical deforestation.

- **Technical development and the flexible mechanisms.** Carbon dioxide taxes or emissions trading are of central importance in bringing down carbon dioxide emission levels, but research carried out by the group shows that additional technology-focused policy measures are needed in order to accelerate the development of energy technologies of interest in the long term, such as solar cells.

- **Greenhouse gases other than carbon dioxide.** This working area is concerned with investigation of the economic and climate-related consequences of including greenhouse gases other than carbon dioxide in the Kyoto Protocol.

Policy measures

Sensible policy measures diffuse renewable energy technologies

There is a clear need to understand the relationships between the development of new technologies and their establishment on the market. What political actions are effective when governments want to encourage achievement of political objectives such as technology and market development? Research at Chalmers is investigating how major changes in the electricity and transport sectors might be accomplished. Four case studies of the use of alternative motor fuels and biopower, wind power and solar power have been carried out, concentrating on the innovation system and its dynamics, technologies, institutional frameworks and function. By starting from this perspective, the scientists hope to identify the most important challenges facing the decision-makers. The investigations are also intended to provide insights into the various technology areas, which in turn provide a basis for discussion of which technologies as such, and of which policy measures, are suitable for their purposes. The work is intended to result in concrete advice on what policy measures can and should be employed in order to bring about a substantially increased proportion of renewable energy in the Swedish energy system.

The Kyoto Protocol

The Kyoto Protocol introduced three flexible mechanisms: International EmissionsTrading, 'Joint Implementation' and 'Clean Development Mechanism'.
A feature common to all the mechanisms is that they enable a country having emission reduction commitments to be credited with work carried out in other countries. The mechanisms assist commitments to be fulfilled in a cost-efficient manner.

The building as an energy system

Although research into the design and construction of buildings with higher energy efficiencies has been performed for many years, the results have been slow in finding their way on to the market. It is important that all parties involved in the sector work together if energy-efficient homes and other premises are to be built, and if existing buildings are to be renovated to produce intelligent designs with low energy demands.

The Swedish Energy Agency's vision for the built environment is that, in future, all energy should be used efficiently, and be supplied from sustainable sources. This means that interior heating in buildings must be provided with minimum losses through the building envelope. The amount of additional heat that may unavoidably be necessary must be efficiently provided from renewable energy sources. The correct choice of heating system for any particular building must be determined in relation to the particular circumstances, with efficiency improvement measures being applied at the correct time. The electricity used in buildings, too, must be from renewable sources.

The overall objective is that the use of energy in residential buildings and commercial buildings must be reduced by 20 % by 2020, and by 50 % by 2050, both in relation to the use of energy in 1995. These reductions shall additionally be accompanied by a drastic reduction in the use of fossil fuels for heating purposes. As the rate of new building in Sweden is only 2 % of the total building stock per year, it will be necessary, if these targets are to be reached, to achieve the energy efficiency improvements mainly in existing buildings. This can be done through more efficient maintenance and operation of buildings, or via renovation and conversion. There is a substantial need for maintenance of residential buildings constructed during the 1960s and 1970s, and it is essential to develop and spread the use of energy-efficient designs for ventilation, insulation, windows and lighting etc.

Research direction

The Building as an Energy System research sector is concerned with developing technical knowledge of the building envelope and building services systems, as well as with development of the necessary relationships between systems as needed in order to achieve the desired functions. Energy-efficient products and designs are needed both for new buildings and for conversion and renovation. Solutions must also be user-friendly, have a long life and as little environmental impact as possible.

The Processing and Policy Measures section is concerned with non-technical aspects such as the relationships between the various parties involved in the sector during design, construction and use stages. Better knowledge is needed in order to enable the many parties involved to work together in order to bring new, energy-efficient technology to the market.

Users' needs and improved construction processes determine the direction of research

Investigations of the construction process are concerned with how the various parties involved in the sector work together in connection with planning, construction, operation and renovation of buildings. Other areas of investigation are concerned with how the amount of energy used can be reduced, and with how well occupants' needs are met by the features of the building and by its services systems. How, for example, can buildings be designed in order to make optimum use of solar heating? Or, conversely, how can building services systems intended to distribute solar heat be best designed to suit the plan, construction and appearance of the building? Research into occupants' behaviour, and into energy policy measures and physical planning, are also important in aiding understanding of the entire energy system relating to buildings. It is important that all those who influence, and who are affected by, the design of a building – from architects, via construction companies, residents and building managers and operators – should be involved in the renovation and conversion process in order to ensure maximum effect of any improvement work. In this context, involvement of the management of construction companies is particularly important. The Swedish Energy Agency is therefore developing an overall programme for energy-efficient building construction, providing a forum for representatives of the construction sector, institutes of technology and other research organisations to investigate obstacles in the way of use of the best technical designs when constructing buildings. The objective of this work is to increase demand for such processes and buildings, in order to establish energy-efficient construction on the market.

Energy use

In 2005, energy use in the residential and commercial buildings sector amounted to 145 TWh. After correction for normal year weather statistics, this represented a reduction of 4 TWh relative to 2004 and 6.6 TWh relative to 2003. This Figuree also includes energy use in agriculture, amounting to about 9 TWh/year. 60 % of this energy was used for space heating and domestic hot water production, with the remainder being used for powering equipment and building services systems.

In the future, new buildings will use only a very small amount of purchased heating energy. Passive houses in Lindås outside Gothenburg show that the technology works.

Passive houses

– houses without heating systems

Although present-day technology can reduce the amount of energy used in buildings, new buildings are still generally designed and constructed in accordance with conventional principles and using conventional heat sources. However, residential buildings can be designed and constructed so that the amount of energy that they use is less than half of the amount specified in building regulations. What are known as passive houses need only a very modest input of additional heat over and above body heat from the occupants themselves, heat from electrical equipment and incident solar radiation. Instead, the reduced costs for a heating system are spent on well-insulated floors, walls, roofs and windows, in order to ensure comfortable indoor conditions. The heat in ventilation exhaust air also needs to be recovered. The Swedish Energy Agency has initiated a demonstration programme under the name of 'Passive houses and low-energy buildings', with the aim of showing how new buildings in the future can use a minimum input of purchased heating energy. This objective will be achieved by improving general levels of knowledge and encouraging development of the necessary skills and awareness in the building industry. The programme is linked to a number of demonstration buildings that will be constructed over the whole country in order to assure the best demonstration effect.

Passive houses

The first passive house was built in Germany in 1991, having been developed at the German Passive House Institute, and later at the Lund Institute of Technology. There are at present about 5000 houses built to passive house standards in Germany, Switzerland and Austria. In addition to houses in Sweden, the concept is also represented in Norway and Denmark.

The Anneberg housing development

– a solar-heated residential area

A residential area for 50 families has been built in Anneberg in Danderyd, on the edge of Stockholm. The houses have floor heating, which is supplied with heat from 2400 m² of solar collectors, which are combined with a seasonal heat store and individual electric immersion heaters for additional heating when required.

It is expected that solar heat should be able to supply about 70 % of the homes' total heat requirement. However, about 40 % of the heat supplied from the collectors to the heat store is lost to the rock surrounding the heat store. Reducing these losses requires either a larger heat store or a reduction in the store operating temperature. In this project, the heat store is constructed from 100 boreholes, 65 m deep, and encompassing a volume of about 60 000 m³ of rock. A preliminary evaluation of results after two years' operation has shown that the system is operating essentially as intended, although some sub-systems are not operating as well as expected. Heat storage

projects of this type are not economically viable today without investment support. However, using this particular heat storage concept for large commercial building applications is profitable, as the seasonal variations in the heat store provide cooling during the summer and heating during the winter. An example of such a scheme has been operating for some years at SAS' headquarters office development in Frösundavik in Solna.

The customer's needs

Energy to meet customers' needs

The 'Design for Awareness' project intends to look at energy use from the consumer's perspective. Its aim is to establish conditions for future product development by incorporating energy considerations in the design of everyday equipment. This can mean, for example, that domestic equipment could be designed so that, when it is in use, it displays, or provides information on, the amount of energy that it is using. Other examples include developing DVD, TV or entertainment centres that do not draw any current in the standby state. This project is one of five forming part of the recently started Energy, IT & Design programme. The objective of the programme is to develop modern IT methods, in combination with product design, capable of influencing domestic energy use levels, with particular emphasis on domestic electricity, space heating, domestic hot water and electric heating.

Nanotechnology

Reduced energy demand for heat pumps and refrigerators through nanotechnology

Efforts to develop more energy-efficient refrigeration and heat pump systems have resulted in a nanotechnology project for heat exchangers. Coating the thin plates of a heat exchanger with a porous surface consisting of small linked grains of copper, with diameters in the range 10-50 nanometre (nm), substantially increases the coefficient of heat transfer when the refrigerant boils, i.e. when refrigerant in the liquid phase is converted to the vapour phase. The porous layer encourages the formation of vapour phase bubbles, and provides a great increase in the number of nucleation sites, from which the bubbles start. The resulting improved heat transfer results in a higher evaporation temperature and improved efficiency. Using nano-surfaces of this kind should make it possible to reduce the amount of electricity used by refrigerators and heat pumps by about 10-15 %. Although the technology has been successfully tested in a full-size heat exchanger, it has not as yet been used commercially.

FIGURE 5: *Energy use in residential buildings and the service sector is relatively constant, although its mix of sources has changed considerably over the years.*

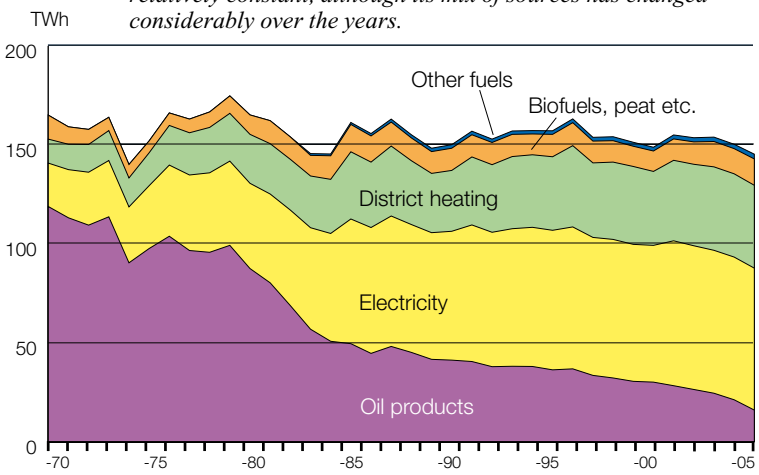
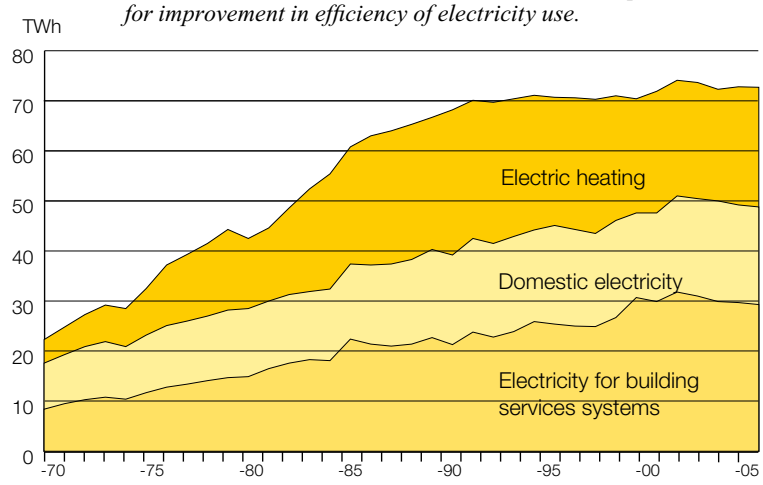


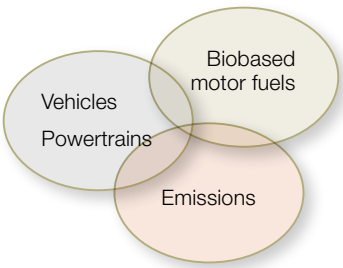
FIGURE 6: *The residential and service sector has a substantial potential for improvement in efficiency of electricity use.*



SOURCE: ENERGY IN SWEDEN, 2006

Transport

How can Sweden do away with its dependence on oil without hindering essential transport? The Swedish Energy Agency is supporting long-term research and development focussing on the production of motor fuels from renewable sources and of more efficient vehicle engines running on alternative fuels.



Research direction

Research in the transport sector is focused on:

- Alternative motor fuels, entire chain from production to use
- Energy-efficient vehicles, particularly for use in heavy traffic with considerable potential for improvement

It is expected that the need for transport and fuels will continue to increase at a rapid rate in all parts of the world. In order to help reduce the use of fossil motor fuels, reduce greenhouse gas emissions and assure a future supply of transport fuels, the Swedish Energy Agency is financing energy research aimed at creating a strategic whole of the individual research areas of renewable motor fuels, vehicles and emissions. This research is being carried out in close conjunction with other public authorities and the Swedish automotive industry. It includes, for example, methods of producing motor fuels and constructing vehicles, while system research into infrastructure and logistics is financed mainly by VINNOVA and the Swedish Road Administration.

Alternative motor fuels and energy-efficient vehicles

One objective of the Agency's work is to develop Swedish production technology for carbon dioxide-neutral motor fuels, with a high overall production efficiency. A second objective is to contribute to the continued development of the country's successful automotive industry, which also includes the production of energy-efficient vehicles. It is important that Sweden is a driving force in this work, in order to be able to influence EU harmonisation of new specifications and requirements for motor fuels and vehicles.

The Agency is financing several large research projects covering the entire chain from cultivation of raw materials for biobased motor fuels to the use of new fuels. One example is the research into the production of motor fuels in future industrial combines.

Several futures studies of transport have been carried out over the years, and research is in progress on both innovation systems and policy measures to encourage the use of alternative motor fuels. Sweden is also involved in the EU Refuel project, the objective of which is to develop strategies for the introduction of cost-effective alternative motor fuels. The project is also investigating the potential effects on stationary installations using biofuels.

ALTERNATIVE MOTOR FUELS

Second-generation biobased motor fuels are energy-efficient

Energy-efficient and carbon dioxide-neutral are the wanted properties of the second-generation biobased motor fuels now being developed. The concept includes the conversion of resource-efficient raw materials, such as forest raw materials and short-rotation crops, into biobased motor fuels. In addition, it involves the use of advanced new technology in efficient processes aimed at increasing the energy yield from the biomass. Gasification of biomass, for example, permits flexibility in the choice of raw materials as well as of the form of the end product. Second-generation motor fuels deliver a significantly better energy yield throughout the production chain than do traditionally produced biobased motor fuels.

Can gasification of biomass deliver the future's motor fuels?

Today, recovery boilers in pulp mills burn black liquor to supply about 30 TWh of energy per

year. It is primarily used as steam in the pulp production process, but about 3 TWh is used to generate electricity via steam turbines. The overall efficiency would be higher if, instead, the black liquor was gasified. Burning the resulting gas in a gas turbine would allow electricity production from black liquor to increase by 60-70 %, or about 15 TWh per year. Alternatively, the gas could be used to produce motor fuels, equivalent to about 25 % of present-day consumption of fossil motor fuels in the transport sector. However, in this case, the pulp mills would need to compensate the loss of process energy from recycled black liquor, which could be done by gasifying low-grade biomass such as branches and crowns, or by reduced sales of electricity and heat. Future developments will be decided by several factors such as the results of research, economic policy measures and international competitiveness.

Forest alcohol as a motor fuel?

Today, ethanol manufacture is based on a method that goes back thousands of years; fermenting sugar from starch-rich crops to alcohol. Ethanol can also be produced from ligno-cellulosic material such as wood, but it is much more difficult to produce fermentable sugars, as the raw material is more chemically and structurally complex. In general, less energy is required in the form of fossil fuels in the production process to produce ethanol from forest raw materials than is required to produce it from agricultural crops, which means that the former source is therefore preferable in terms of energy efficiency. Production of ethanol from forest raw materials has been the subject of research for many years, including at the University of Lund laboratories.

Pilot plants are an essential stage in testing new research results and methods before production can start in commercial plants. The Swedish Energy Agency is financing the plants in Värnamo (left), Örnsköldsvik (top right) and Piteå in order to further the development of alternative motor fuels.

Piteå

Black liquor gasification facility

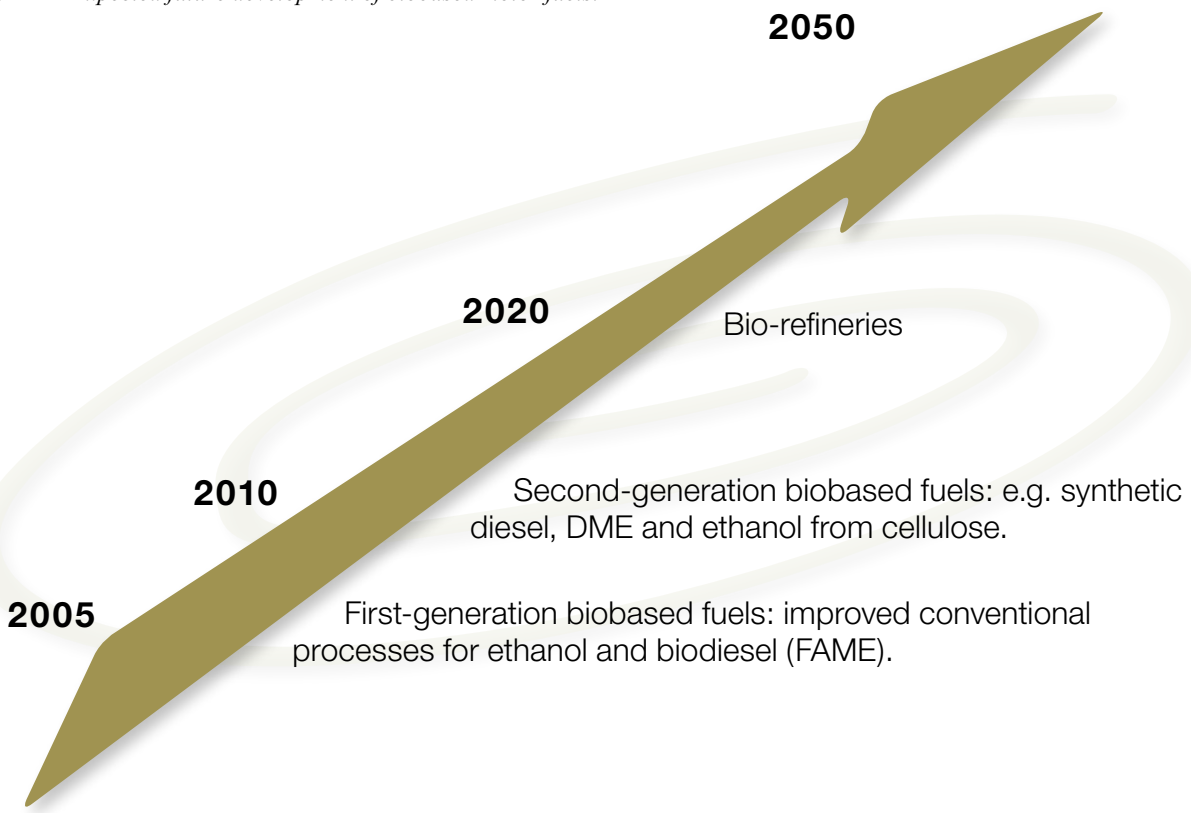
The Agency is partly financing a development facility at Piteå for black liquor gasification. The plant, which is linked to the Smurfit Kappa Kraftliner pulp mill, was started up in 2005 with the aim of developing gasification technology and recovering and supplying chemicals, electricity, heat and possibly motor fuels. This development plant has a capacity of 3 MW of fuel. The objective is to collect and evaluate research data, in parallel with acquiring experience of operation and requirements for commercial development. Experience from continuous operation in this small development plant is needed in order to move on to the next stage, or to a demonstration phase plant.

Värnamo

Major effort in Värnamo for gasification of biomass

A demonstration facility for gasification of biomass was built in Värnamo during the 1990s, with the aim of producing electricity via an Integrated Gasification Combined Cycle (IGCC). The gasifier, and the technology it used, are still of interest in connection with the production of synthetic gas for further conversion to motor fuel. The Swedish Energy Agency in co-operation with the EU has financed the project Chrisgas for restarting the plant. Work is at present in progress on conversion of the plant to produce synthetic gas that can be used as motor fuels. In particular, the gas cleaning process is important. If it can be demonstrated that the process works,

FIGURE 7: *Expected future development of biobased motor fuels.*



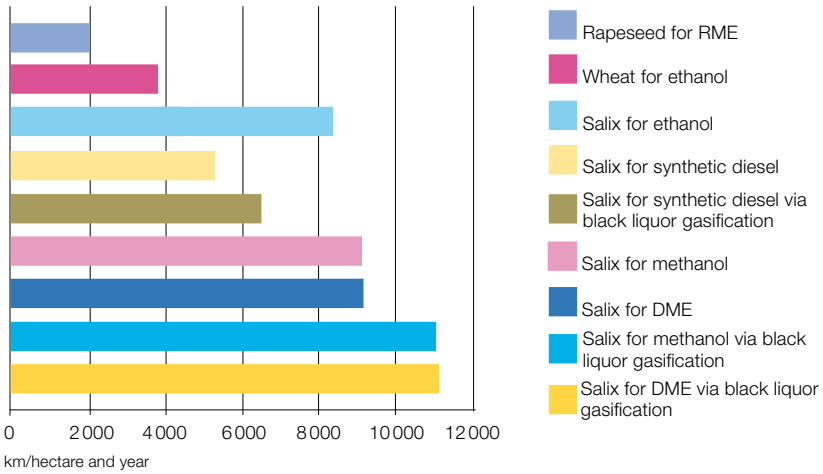
it can be scaled up from its present size, which would be important in the context of profitability of a commercial process. In the longer term, the vision is to create a European research centre at Värnamo for development of biomass gasification processes. This would mean that the Swedish expertise in gasification, which has been steadily accumulated since the 1980s, would be utilised even further.

Örnsköldsvik

Ethanol pilot plant in Örnsköldsvik test results on a large scale

A pilot plant was inaugurated in Örnsköldsvik in 2004 in order to investigate the entire process chain on a larger scale than had previously been possible. Experience and problems from the pilot project will be fed back to the university world for new laboratory trials. Much of the research is concentrated on finding ways of reducing operating costs, such as cheaper enzymes, improved strains of yeast and optimisation of processes in such ways as reducing water consumption and energy requirements. The Örnsköldsvik plant will therefore be a test bed for the results of university research for several years.

FIGURE 8: *Specific fuel energy yields: distance driven per hectare and year (heavy goods vehicles).*



SOURCE: WELL TO WHEELS, 2006

➜ More information on Well to Wheels is available on the EU website **http://ies.jrc.cec.eu.int/index.php?id=346**

The EU Biofuels Technology Platform

The Swedish Energy Agency has been one of the initiators of a technology platform for biobased motor fuels within the EU, with the aim of enabling industry and the member states to develop a common research agenda. This work will be an input to the direction of the EU's Seventh Framework Programme. There is a considerable need to harmonise development of biobased motor fuels at EU level: harmonisation and cooperation are essential if the results of research are to be commercialised, as both the automotive industry and the motor fuels industry operate on an international market. It is also essential, as vehicles must be able to use fuels bought in any country. Together with its German counterpart, the Swedish Energy Agency operates the platform's secretariat, and is thus also responsible for setting up the necessary networks of contacts.

ENERGY-EFFICIENT VEHICLES

Alternative motor fuels and more fuel-efficient vehicles

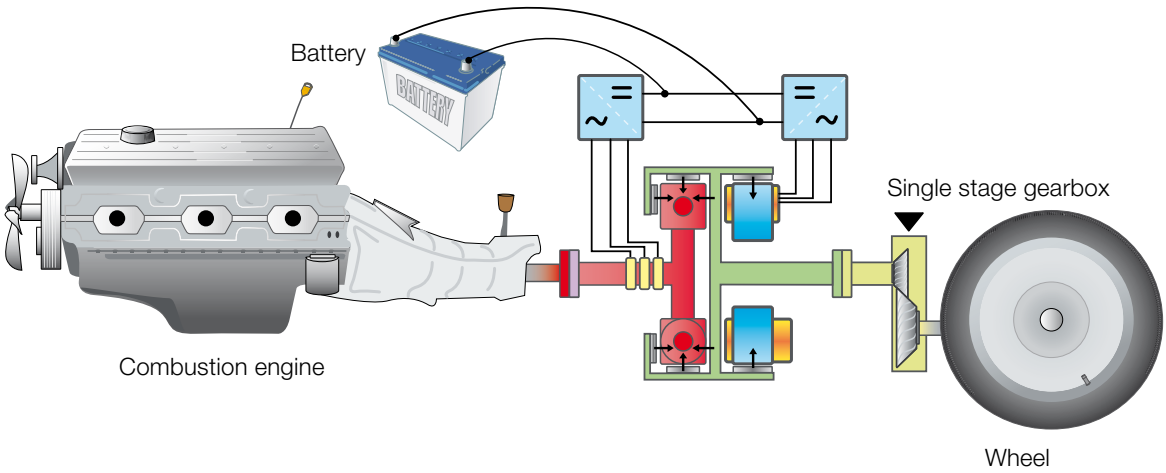
The Swedish Energy Agency supports research aimed at reducing vehicle fuel consumptions. Both new technologies, such as fuel cells, electric and hybrid vehicles, and conventional petrol and diesel vehicles, must be made more efficient, with reduced emissions and suitable for use with alternative fuels such as alcohols, gases or electricity. The greatest potential for energy efficiency improvement is to be found in vehicles used in urban traffic: through the use of electricity, electric hybrid and/or fuel cell vehicles, energy use can be reduced by up to 50 %. The energy-saving potential of vehicles used in long-distance traffic is less, as present-day engines are already relatively energy-efficient with conventional technology. However, as it is heavy traffic that is responsible for the greatest proportion of the increase in traffic, even small improvements are significant.

DME vehicles

Volvo tests DME vehicles

Volvo has started development work on new engines that can run on di-methyl ether, DME, produced from synthetic gas from gasification of renewable or fossil fuels. Volvo believes that DME has a good potential for becoming competitive with fossil fuels. The company also believes that the use of DME is best seen in an overall system perspective, looking at energy efficiency, carbon dioxide emissions and particle emissions as a whole. The latest technology, in third-generation DME vehicles, will be tested in a large field trial involving 30 goods vehicles in four different towns. In parallel, the necessary technical facilities for the fuel infrastructure will be investigated.

FIGURE 9: *4QT – Four Quadrant Energy Transducer, a new hybrid engine technology.*



The homogeneous engine

– more sensitive, but a better alternative to present-day vehicle engines

Sweden is a world leader in development of a new type of vehicle engine, the Homogeneous Charge Compression Ignition (HCCI) engine, which can replace current petrol and diesel technologies. Present-day petrol engines have a low efficiency, and therefore consume considerable quantities of fuel. The diesel engine, on the other hand, has considerably better efficiency and therefore uses less fuel, but requires expensive, complicated catalysts as well as particle filters in order to keep down its NOX and particulate emission levels. HCCI brings together these two traditional technologies, to produce results with the best features of both. Scientists at Lund University have succeeded in producing engines with an efficiency twice that of ordinary petrol engines. Expensive exhaust treatment systems are not needed, as is the case with diesel engines, as the exhaust gas quantities are reduced as the compression is increased. The drawback of the engine is that ignition may occur either too early or too late if the temperature of the engine induction air varies too widely. This therefore requires an accurate and responsive control system. The Lund scientists have shown that it is possible to control the air temperature sufficiently quickly, and to adjust it to the driver's driving style. There is already substantial international interest in this work.

Hybrid systems

Improved hybrid system uses less fuel and is cheaper

Hybrid systems can be designed in many ways, but consist essentially of a conventional combustion engine, electric motors/generators and batteries. In all cases, the objective is the same: to produce systems that are cost-efficient and energy-efficient. Present-day hybrid systems have fuel consumptions of about 25 % less than those of ordinary petrol engines. The combustion engine can operate at essentially constant load and at its optimum working point, as the electric motor/generator and battery can largely deal with acceleration and braking. Applications in which hybrid technology provides the greatest benefit are traffic systems requiring frequent starts and stops, such as for taxis, urban buses and waste collection vehicles.

The Four Quadrant Energy Transducer, 4QT, is a cheaper, recently developed technology that is expected to further reduce fuel consumption in comparison with present-day hybrid systems. Manufacturing costs are less than for present-day hybrid technology, which is a prerequisite for any large-scale introduction of hybrid vehicles. The new technology, which has been developed at the Royal Institute of Technology in Stockholm, is at present operating in a demonstration Volvo heavy goods vehicle.

Energy-intensive industry

Sweden's energy-intensive industries produce major export revenues, and are therefore important for the country's economy. Although the pulp and paper industry and the iron and steel industry are constantly improving their efficiency, there are still major opportunities for further reducing the amount of energy that they use. The fact that government and industry are co-operating, helps the industry to reduce its energy costs, improve its competitiveness and contribute to a better environment. This also makes important contributions to sustainable growth and upholding of economic welfare.

Swedish industry is reducing its use of energy, but can do more

Major parts of Swedish industry are energy-intensive. In total, Swedish industry accounts for almost 40 % of the country's energy use. The pulp and paper industry, the iron and steel industry and the chemical industry are collectively known as energy-intensive, and account for over two-thirds of total energy use in industry.

Many sectors of the process industry converts/upgrades indigenous raw materials and contribute to valuable export revenues to the country. Their markets are characterised by strong global competition, so they are constantly improving the efficiency of production in order to maintain competitiveness and profitability.

The base industry is characterised by high capital costs, which means that it is cautious in introducing entirely new technology, as disturbances in production would put companies' competitiveness at risk.

Since the 1970s, Swedish industry has improved its production efficiency at about 2 % per year. Although the total amount of energy used has remained more or less constant, the output production value has more than doubled. Nevertheless, there are still substantial potentials for improvements.

More efficient factory energy flows through process integration

The Swedish Energy Agency's research priorities for industry are concentrated on the energy-intensive process industries, with the aim of reducing the use of energy through various process improvements and reducing greenhouse gas emissions. One research area suitable for an overall systems-related approach is that of process integration, which provides opportunities for making better use of energy. Other important research includes the development of models and economic research concerned with the effects of energy policy measures on individual industry sectors.

Research direction

Research is concentrated on problems and potentials such as:

- improving the efficiency of electricity use
- improving the efficiency when using fossil and renewable fuels
- increasing industry's own supply of energy to its processes, by better utilisation of waste heat, by-products and refuse material, as well as through own production of electricity
- supplying energy in the form of heat, fuels and electricity to nearby areas

Process integration

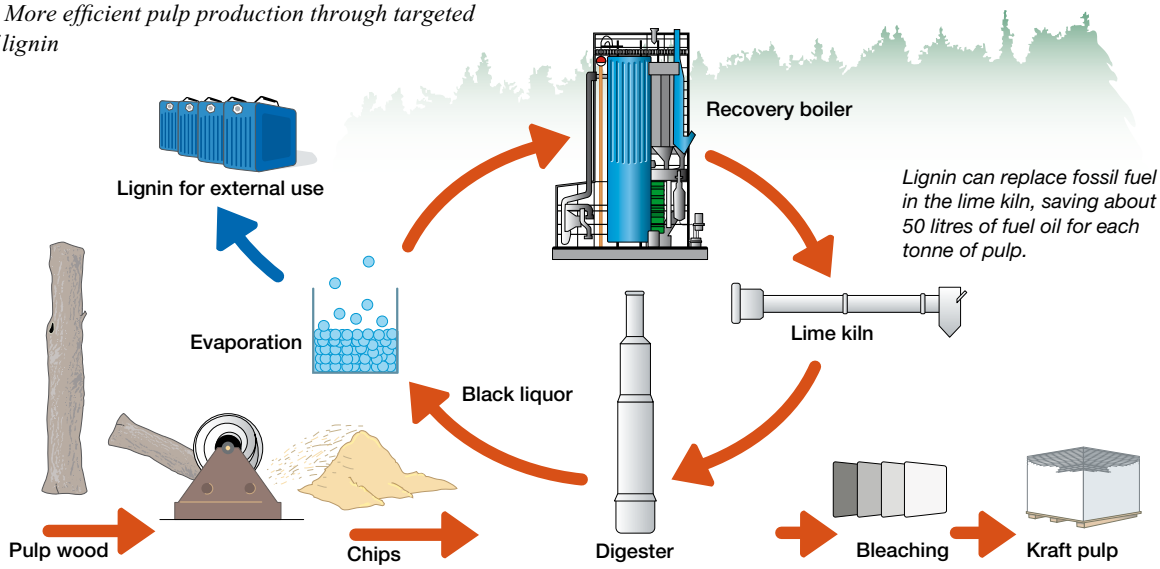
Process integration is concerned with overall energy analyses not only of the interaction between different parts of a process, but also of entire industrial processes. It involves mapping energy flows in factories. It identifies potentials for structuring and modifying industrial processes in order to make more efficient use of energy and reduce environmental impact. Process integration methods are being applied in the pulp and paper industry, the iron and steel industry, the food processing industry and in other sectors.

Cleaner iron production

Cleaner iron with lower energy consumption

LKAB in Luleå is involved in the major ULCOS (Ultra Low Carbon diOxide Steelmaking) project, co-funded by the EU. The aim of the project is to reduce carbon dioxide emissions from steel production by 50%. Another steel project is concerned with improving the efficiency of the blast furnace process. Blast furnaces are technically complicated, with several chemical reactions taking place at high temperatures. The interaction between the crude iron and the slag is particularly important. Controlling the formation process of the slag and its final composition allows a cleaner crude iron to be produced with lower energy consumption. Slagging agents are traditionally loaded into the top of the furnace, but research being carried out at the Foundation for Metallurgical

FIGURE 10: *More efficient pulp production through targeted extraction of lignin*



Lignin is a constituent of wood. Modifying the kraft process for extraction of lignin in solid form for use as a fuel has several benefits. It replaces the use of oil in certain process stages and increases the production of pulp. The new LignoBoost process is the result of ten years of research.

Research (MEFOS) in Luleå is now concentrated on also injecting the slagging agent at a lower level in the furnace. This procedure has two advantages: the ability to employ different types of slagging agents, customised for the respective zones in the furnace, and smoother and more stable operation, which is energy-efficient.

Fuels from lignin

FRAM, for more efficient pulp mills

The Swedish Energy Agency is supporting a number of ideas following from earlier research on the closed-loop pulp mill, known as the KAM project. Work in the FRAM project (Future Resource Adapted pulp Mill) is today concentrated on producing solid fuel from lignin in the kraft mills' black liquor. A development plant was recently (2007) inaugurated at Bäckhammar. The project is investigating how fuel may be produced as efficiently as possible, and how it should be customised to suit the needs of various users, such as combined heat and power plants. The fuel will also be tested in the lime kiln of a kraft mill, where it can replace oil. One benefit of lignin is that it can be recovered with a low moisture content, which gives improved efficiency. This technology is particularly attractive for pulp mills suffering from production limitations due to insufficient recovery boiler capacity. The removal of lignin provides an opportunity for increased pulp production. The programme has therefore attracted substantial interest, as it makes it possible for paper mills to supply an additional product, while at the same time improving the efficiency of the pulp process. The work involves representatives from several stakeholders, ranging from pulp mill owners via equipment manufacturers to final users of the fuel. The Swedish production potential for lignin fuel is estimated to 5–10 TWh.

Pulp

More efficient refining of paper pulp saves electricity

A major advantage of mechanical pulp production is that almost 100 % of the raw material is converted to pulp. On the other hand, the Achilles' heel of the process is its high electrical energy requirement, amounting to 2-2.5 MWh per tonne of pulp. A project carried out in Holmen Papers' Braviken mill has shown that it is possible to reduce electricity consumption by about 20 % per tonne of pulp. The concept is based on beating the wood chips in two stages; first at high and then at low pulp consistency. Holmen has optimised the process by increasing the temperature and modifying operation to produce high-strength fibres despite a reduced energy input. Basic research into this process was started during the 1980s at STFI-Packforsk research institute. In subsequent development projects the technology was studied on intermediate scale. The entire work has been completed within a time period of 20 years from initial basic research to successful demonstration of the technology, which is a common time horizon for technical research and development.

Energy efficiency

New energy-efficient process for recycled paper-based products demonstrated

EcoFracSmart is a new process for reusing recycled fibre for paper manufacture. The process consists of two parts. The first part, EcoSmart, uses patented equipment to break up and recover the recycled paper in a gentle, energy-efficient manner that retains the fibre quality. The energy savings in this stage may reach 50 % in comparison with present-day recovery processes.

In the second part of the process, FracSmart, the recovered fibres are separated into different grades. As a result of the efficiency of the new technique, the number of process stages can be reduced, which improves the strength of the fibres. At the same time, energy requirements for pumping and processing are reduced, as fewer stages are involved. The whole process has been demonstrated on industrial scale through cooperation between paper manufacturers Smurfit Lagamill and Holmen Paper, equipment suppliers NOSS AB and PURAC, the STFI-Packforsk Research Institute and the Swedish Energy Agency.

Filters

Filters in the chemical industry save 25 % of electricity use

Akzo Nobel at Skoghall has demonstrated an improved method for chlorine-alkali production with reduced energy input and less environmental impact. The company installed a new membrane filter which reduced energy consumption by 25 %, or 60 GWh per year. Operating costs were also reduced, as the life-time of the membrane was longer than expected. As a result of this successful full-scale demonstration of the new environmentally friendly membrane technology, several paper mills in Europe have now abandoned the elderly and environmentally hazardous mercury process that has traditionally been used, thus giving substantial global environmental benefits. The Skoghall plant has now been in operation for seven years.

”Since the 1970s, Swedish industry has improved its production efficiency at about 2 % per year. Although the total amount of energy used has remained more or less constant, the production value has more than doubled. Nevertheless, there are still a substantial potential for improvements.”

Fuel systems

Fuels of various kinds are used for the production of heat, electricity, cooling and motor fuels. Both in Sweden and internationally, there is pressure to reduce the use of fossil fuels and to increase the use of biofuels. Research is concentrated on fuels from forests and agricultural land. A greater quantity of biomass needs to be produced in an ecologically and economically sustainable manner. Costs need to be reduced in all parts of the various system chains, from fuel production to delivered heat, electricity or motor fuel. Efficiency needs to be improved and resources used more efficiently.

Use of bioenergy increasing worldwide

Forests and agricultural land are gigantic solar collectors as a result of the ability of green plants to capture and store solar energy. Plant biomass is an excellent fuel, and returns no more carbon dioxide to the atmosphere when it is burnt than it has absorbed while growing.

Oil, coal and natural gas supply 87 % of the world's energy needs, in comparison with which the use of biofuels is low. However, demand is increasing for a number of reasons, such as many countries wanting to reduce their dependence on oil and their carbon dioxide emissions. Various policy measures are being used which, together with the high price of oil, encourage industry and consumers to use more biofuels. The EU has set targets for the use of renewable energy, with bioenergy playing a major part. Farmers are now also better paid for the production of biofuels. The use of biofuels in Sweden has doubled since the 1970s, with substantial research programmes having contributed to this development. Sweden now has access to fuels and technologies that are available, efficient and environmentally benign, but there are still substantial needs.

The supply of biofuels can be doubled

Increasing the use of biofuels necessitates supply from sustainable sources. On the basis of various investigations and assumptions, it should be possible to increase the supply of biofuels in Sweden from 112 TWh in 2005 to about 170 TWh by 2020. By 2050, it should be possible to double the supply, to about 230 TWh. More efficient forestry should make it possible to increase the production of forest fuels, both from primary production as well as in the form of by-products from the forest industry, while agriculture can deliver crops such as Salix, hybrid aspen, grains, oilseeds, energy grass such as reed canary grass, and various by-products from the foodstuffs chain. Some scenarios assume a significant increase in production from arable land.

Many want to use biomass

Bioenergy is a priority research and development area. One area of research is concerned

Research direction

Targets for research in the Fuel thematic area are:

- increasing the availability of fuels
- improving the cost and resource efficiency of the entire chain from raw material to finished product
- increasing electricity yield
- commercialisation of the technology.

In addition, biobased motor fuels must be produced in an environmentally friendly manner, in response to the market and policy measure requirements.

Bioenergy

Sweden and Finland use the highest proportion of biofuels of any EU state. The Nordic countries use mainly forest biofuels, while agricultural crops are most common in other EU states.

In 2005, bioenergy supplied about 112 TWh, or one-fifth of Sweden's total energy supply. The forest products industry uses half of the biomass energy, while over 30 % is used for district heating. Bioenergy in the form of fuel wood and pellets is also used for heating homes.

with the competition for raw materials between various sectors, as seen in the overall context of the public economy. Other research is concerned with the trade in wood fuels around the Baltic, and how it might change against the background of policy measures and international market developments. Competition between users arises against the background of a steadily increasing demand for biofuels and a good, but nevertheless limited, availability. Those concerned in the agriculture and forestry sectors, the pulp and paper industry, motor fuels and energy sectors are all watching their respective areas of interest. There is therefore a need to find synergies between the various parties in order to establish healthy markets.

Research for expanded bioenergy resources and the environment

Forestry produces by-products that can become fuel, including branches and felling residues. However, removing biomass from the forest means that there will be environmental consequences to consider. How will remaining trees, the ground, water and the forest's plant and animal life react? The ash from biofuels contains nutrients and minerals: can it be returned to the forest, and what will be its ecological effects? Answers to many of these questions are now becoming available as a result of long-term research. As the demand for fuels is still increasing, research is now looking at new areas: can stumps be used as fuel? Can forest production be increased through more intensive care and application of fertilisers?

"Felling residues are already today used as biofuels, but there is a considerably greater potential. Research is also being carried out into the consequences of using stumps."

Wood fuel potential, 2006, TWh	SLU, Parikka 2004	SLU, Hagström 2006	SFIF 2005
Felling residues, first thinning (net)	6,1	-	-
Felling residues, other thinnings (net)	9,6	13,1	-
Felling residues, final felling (net)	25,8	44	15,0
Stem parts and small trees left behind	3,9	-	-
Whole tops, small trees from cleaning and early thinning	12,5	12,7	6,8
Fuel wood, miscellaneous sources	7,8	9,3	9,0
Timber from non-forest land	2,9	2,8	-
Cull from sawmills and the pulp industry	4,9	5,8	2,7
Forest fuels total (not stumps)	**73,5**	**87,7**	**33,5**
By-products: bark, sawdust, chips etc.	16,7	26,8	
Recycled wood from Sweden	3,9	4,4	
Total	**94,1**	**118,9**	

FIGURE 11: *Different calculation bases result in substantial differences in estimates of available wood fuel quantities.*

Swedish University of Agricultural Sciences (SLU), Parikka 2004
Swedish University of Agricultural Sciences (SLU), Hagström 2006
The Swedish Forest Industries Federation (SFIF), 2005

SOURCE: NYLUND, SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES (SLU), 2006

What will be the environmental effects be? What are the best methods of harvesting and logistics? It may be necessary to develop systems capable of bundling and handling felling residues, as well as cost-efficient means of long-distance transport of fuels. There is also a need for research into the storage and processing/upgrading of biofuels, into efficient methods of producing pellets from raw materials other than sawdust, and into improved pellets quality.

On the agricultural side, the research activities funded by the Swedish Energy Agency are concentrated on multi-year crops that are efficient from a life cycle perspective. Production conditions need to be improved in order to strengthen the competitiveness of fuels.

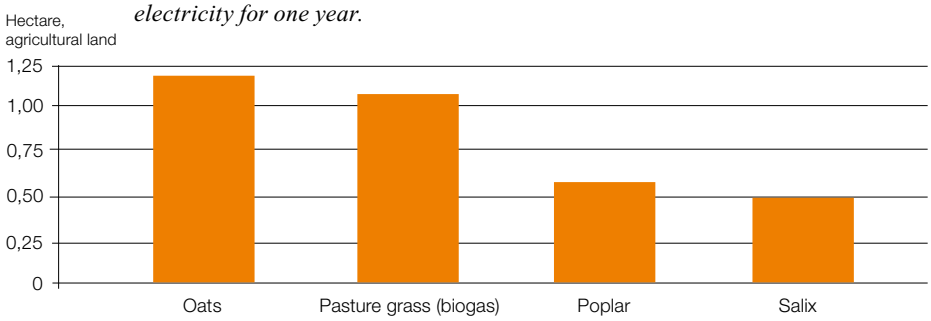
Efficient biofuels are those that provide the most energy output in proportion to the work input

Bioenergy is normally very energy-efficient. The efficiency depends on how the fuels are produced and how they are used. The input of energy needed to produce the fuel must be compared with the energy content of the end product. Losses that occur during transport to the final point of use must also be included. One way of comparing different energy crops is to see how many hectares of ground they require in order to provide a house with heat and electricity. Forest fuels and short rotation crops such as Salix are examples of energy-efficient biofuels, delivering about twenty times more energy than required for their production and transport.

Bioenergy for several purposes

If the objective is to reduce carbon dioxide emissions, then the most effective way of doing so is to use biofuels for heat and for combined heat and power (CHP) production. This provides excellent energy efficiency, particularly if the latent heat in the flue gases is recovered through condensation. As the electricity systems of the Nordic countries are linked, and as some of the electricity is produced in Danish coal-fired power stations, the climate benefit of increasing the use of biofuels for district heating and CHP production is very considerable. If, instead, the purpose is to reduce the use of oil, biofuels must be used for the production of motor fuels, despite the fact that, with present-day methods,

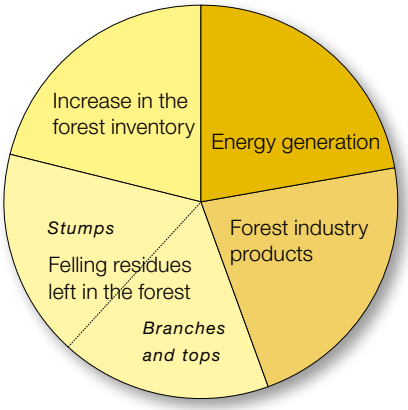
FIGURE 12: *Land area requirements to provide a single house with heat and electricity for one year.*



Based on net energy harvest and cultivation on good agricultural land in southern Sweden.

SOURCE: BERNDES, BÖRJESSON AND ROSENQVIST, 2006

FIGURE 13: *A large proportion of forest biomass is already used for energy production, although the potential is considerably greater.*



Biomass proportions from forest production per year

Annual growth of all biomass: 75.9 Mtdry solids (Megatonne dry solids)

Annual felling of biomass: 61.0 Mtdry solids

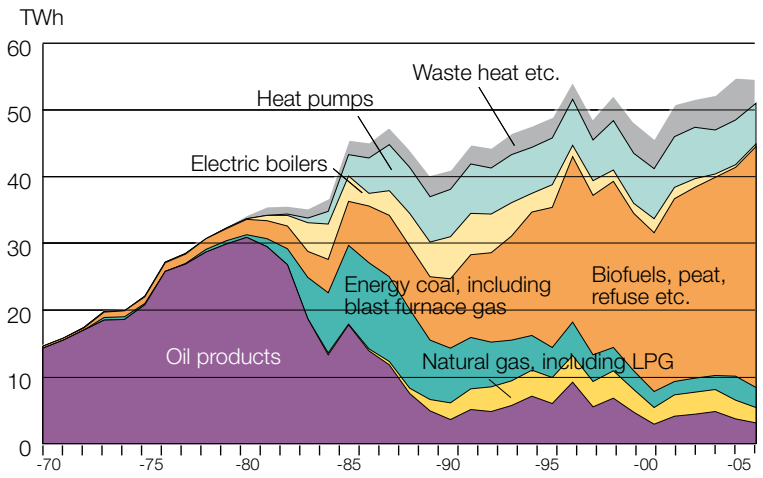
SOURCE: NILSSON, NATIONAL BOARD OF FORESTRY, 2006

a relatively considerable quantity of energy is required for production, so that such processes are not likely to be energy-efficient in the near future. Nevertheless, as a large proportion of Sweden's CO_2 emissions arise from transport, it is important to investigate alternatives to the use of oil as a motor fuel. It can be seen that both the climate and the oil reduction objectives result in a reduced use of fossil fuels, but the reasons for this reduction are only partly similar. Users and decision-makers therefore have every reason to attempt to find a carefully considered balance for the use of biofuels in order to achieve the greatest possible overall benefit. This presents a challenge to create efficient policy measures that consider the needs of various objectives, while at the same time observing the efficiencies of the various fuels and their application areas.

More electricity from new materials

Sweden has a large number of combined heat and power plants designed for operation on biofuels. Initially, when only biofuels were burnt, they suffered from corrosion problems. In order to produce as much electricity from the fuel input as possible, boilers need to operate at high temperature and pressure, but internal corrosion in the boilers forced a reduction in temperature and thus also in electricity production. Research has considerably reduced these problems. More suitable materials for use in the boilers and new fuel additives have been developed. The addition of sulphur changed the chemistry of the flue gases and reduced corrosion. The sulphur combines with the ash in the boiler and is removed from the flue gases. A similar beneficial effect can be achieved by mixing peat with the fuel. Research continues into further raising the boiler pressure and temperature in order to increase electricity production. Other research is also concerned with entirely new technologies, such as gasification of biomass and using the gas in combined cycles, i.e. combining steam and gas turbines to produce electricity. For a given district heating load, this enables the amount of electricity production from a combined heat and power station to be doubled.

FIGURE 14: *Two-thirds of district heating is supplied by biofuels, an example of successful joint action of research and policy measures.*



SOURCE: ENERGY IN SWEDEN, 2006

Synergy in practice. Salix plantations are used in Enköping to purify sewage effluent, which reduces the costs of effluent treatment and increases the production of biofuel. The Salix is then burnt in the town's district heating power station, to the overall benefit of the environment and residents of the town. Mr Eddie Johansson, manager of Enköping Energi, leads the development.

Salix in the fuel system

World-leading knowledge

Salix is the energy crop that best combines production profitability, cost levels, combustion performance and energy yield. Sweden is the world leader in commercial cultivation of Salix. Research is therefore concentrated on plant breeding and semi-industrial development. The objective of the work of plant breeding is to develop means of producing improved species of Salix with, for example, higher yields and improved resistance to disease. This will mean that new species can be modified to suit new future markets. In western Northern Europe, for example, resistance to fungal attack is important, while frost resistance is particularly important in the Nordic countries. Research into industrial aspects covers areas such as methods of cultivation and use of mechanical equipment.

Salix synergy

Salix purifies and heats

An example of research that has found practical application can be found in Enköping, where sewage effluent and sludge are being used to fertilise Salix plantations. In addition to nitrogen, the Salix absorbs heavy metals in the sludge. The fuel is then used in the town's combined heat and power plant, concentrating the heavy metals into the ash, which is then disposed of in landfill. In this way, the town treats its sewage at low cost, collects the heavy metals in the sludge and provides fuel for the power station. The scientists have also monitored the environmental effects of the entire system.

Intensive cultivation

Should we optimise the forest nutrient cycle?

Controlled experiments have shown that production from young forest can be increased up to four times as much if carefully measured nutrient doses are applied. This can be done without significantly increasing leakage of nitrogen compounds to waterways. It is now time to apply the results to practical forestry. What types of ground are most suitable? What will production and costs be like in reality, and how should cultivation be practised without having harmful environmental effects? There are considerable potentials: if 10 % of the suitable forest land is intensively cultivated, and if 50 % of the additional production is used for fuels, the overall result could be an additional 24 TWh of fuel per year. Converted to ethanol or DME, this would meet about 10 % of the transport sector's requirements.

Research into small-scale fuel wood firing is concentrated on user friendliness and low emissions.

Small-scale firing

Research for improved environmental performance of small boilers

Small-scale firing of logs in detached houses in older boilers, and unsuitable firing methods, can result in emissions of health-hazardous particles and hydrocarbons. Research has shown how emissions from log firing spread, how individuals are exposed and how log firing affects health. Intensive development work has resulted in improved ways of firing logs and pellets. Research is now concentrating on intelligent system designs, such as biofuels in combination with solar heating. The technology must also become more robust and user-friendly, with emissions being reduced in order to meet future, stricter requirements.

Skellefteå

Intelligent combinations needed for overall efficiency

Skellefteå combined heat and power station is an example of the production of several services while at the same time making more efficient use of raw materials. The power station produces electricity and district heating, and also dries raw material for the production of pellets, which means that there is a heat sink for electricity production in the summer when the demand for district heating is low. More such combined services plants will be needed in the future, producing various combinations of electricity, heat, cooling, steam, pellets, motor fuels, chemicals, animal feeds and biogas. This is an area for which research and development are required, leading to demonstration installations.

Waste

Waste into energy

Another research area is that of energy recovery from sorted combustible waste. Some fractions can be burnt, while sludge and manure can be digested to produce gas. Biogas technology needs to be further developed in order to increase process efficiencies and to be able to deal with waste products containing contaminants.

Research successes in bioenergy

- Research in the field of gas turbine technology has largely been concentrated on increasing efficiency by developing new materials and advanced methods of cooling in order to increase overall efficiency. Öresundskraft has demonstrated a new gas turbine based on earlier research, which has a very high efficiency compared to similar products. The Rya power station in Gothenburg has installed three of these turbines, and the improved turbine has become an export success for the producer, Siemens. The turbines are at present powered by natural gas, but investigations are in progress with the aim of using gas from biofuels.
- Technology is now available to allow logs and pellets to be used as domestic fuels in urban areas.
- Salix cultivation has now been commercialised, and both plant materials and cultivation systems have been exported, including to the UK.
- As a result of research financed by the Swedish Energy Agency, the National Board of Forestry has published guidelines on fuel abstraction and ash return in an environmentally appropriate and sustainable manner.

The power system

The use of electricity is increasing everywhere: industrialised countries are still finding more application areas for electricity, while developing countries need electricity for their development. Renewable electricity from wind power, solar energy and wave power is the way forward. These energy sources need to be complemented by hydropower and electricity from biofuels. As new technology is developed and comes into practical use, costs fall and the prospects for commercial uptake improve.

Research Direction

Swedish research into electricity from renewable sources is well to the fore in an international perspective. Work is concentrated on wind power, hydropower and wave power, solar cells and power transmission. Cross-disciplinary research is also carried out into areas such as the use of electricity, behavioural responses and the effects of deregulation of the electricity market and various policy measures.

Research needed to maintain adequate electricity systems in the future

The Swedish power system is changing. Carbon dioxide emissions must be reduced, and renewable alternative production facilities must be built. About 90 % of Sweden's electricity production, which at present supplies almost 150 TWh of electricity per year, comes from nuclear power and hydropower, with the remaining 10 % being supplied by fossil-fired and biofuel-fired production, and a small proportion of wind power. The government's target is that electricity production from biomass, wind power, solar energy and possibly wave energy shall increase by 17 TWh by 2006 in comparison with the production quantity in 2002.

Sweden has good prospects for production of renewable electricity

Today (2006) Sweden produces about 1 TWh of wind power per year, although conditions are favourable for increasing this production. The government target is that it should be possible to increase wind power production to 10 TWh by 2015. The overall potential for wind power is many times larger than this. There are several other possible methods of renewable electricity production, such as solar cells and wave power, but the costs of such production are still far too high for such methods to be competitive. As electricity production methods that are more vulnerable to the vagaries of the weather start to provide an increasing proportion of a country's electricity, so is there a greater need to trade electricity with neighbouring countries and physically to transfer electricity between different regions. Development of new transmission technologies, such as HVDC links and other controllable links, allows the power system to be developed in a cost-efficient and energy-efficient manner, while at the same time meeting the basic requirement of a reliable supply of electricity. Pressure is increasing for greater security against major power supply failures, which requires development of technology for local production and for standalone production and supply in emergency conditions.

Sweden has a very strong electrical power industry, both in terms of various production technologies and in terms of transmission. Most of the industry's products are exported. As industry is involved in research at an early stage, the power industry can show several excellent examples of commercialisation of research results.

Wind power

Research is this area is concentrated on reducing production costs and finding ways of more easily establishing wind power. Research into various environmental effects, and into individuals' acceptance of wind power, are also important working areas. Another research area is concerned with how new parts of the country's transmission and distribution system should be

built in order to allow wind power production to be connected at low cost but with high standard in respect of electricity quality and availability.

Solar cells
The Swedish Energy Agency is giving priority to research into more efficient solar cells with low manufacturing costs, in order to bring forward commercial viability of producing solar electricity on a large scale. Solar cells with high efficiency have been developed at the Ångström laboratory in Uppsala, and the technology is now being commercialised by a spin-off company that has attracted venture capital from both Swedish and international sources. Work is also being carried out on how solar cell systems could be used both as an energy source and as a building component, e.g. how solar cell panels could be designed and integrated into buildings in an aesthetic manner, without sacrificing performance.

Hydropower and wave power
In order to ensure the continuation of hydropower as an important resource in the Swedish energy system, the Swedish Energy Agency is concerned both with maintaining existing, and developing new, knowledge and competence within this sector. Work is needed, for example,

Wind power

A modern 2 MW wind power unit can produce about 4500 MWh per year, equivalent to the amount of domestic electricity used by 750 households. It would have a rotor diameter of 80-90 m and, to produce this amount of energy, would need to be on a suitably windy site. With over 2000 wind power plants of this size, total production would meet the government's planning objective of 10 TWh per year.

Solar cells

Covering half the area of the island of Gotland with present-day solar cells would provide sufficient electricity on an annual basis to meet all Sweden's demand for electricity. Correspondingly, only 5 % of the Sahara's surface would need to be covered with these cells to meet the entire world's electricity demand. However, the problem is that such electricity would have to be stored from day to night, and from summer to winter. With present-day solar cell technology, only 15 %of the energy in sunlight is converted into electricity, with the rest being converted into heat. The world record for solar cell electricity production is at present 39 %, but such cells are extremely expensive.

on the safety of dams, on how existing hydropower stations can supply more energy, and on the environmental effects of hydropower. Research into wave power is concerned primarily with verification of the technology.

Power transmission

Most electricity today is produced in power stations that are a long way from where the

Wave power

A typical wave power park with 1000 generators over an area of 800 x 800 m could have an installed capacity of 10 MW. If suitable wave heights are available for about 4000 hours per year, the total energy output would be sufficient to supply 2000 electrically heated houses with all the electricity that they need.

electricity is used: hydropower production in the north of Sweden is an example. In future, local production of electricity in smaller power plants may become more common. However, this will require new ways of controlling the electricity transmission and distribution systems, which will require research and development of new components and materials.

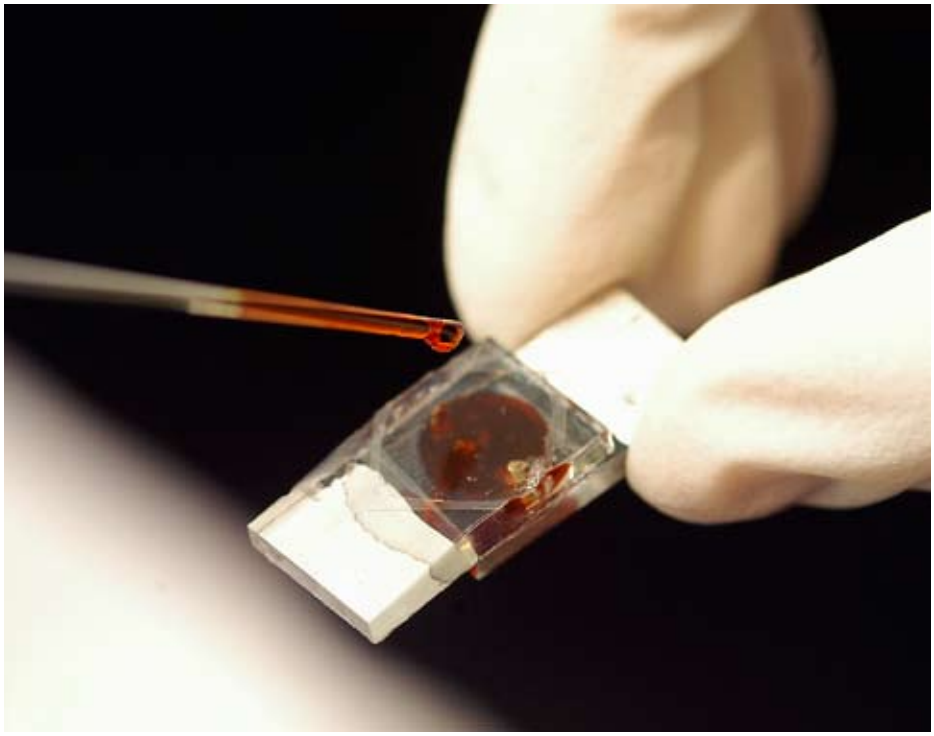
Power transmission

The total length of power lines in the Swedish electricity system is about 515 000 km, of which most is in local distribution networks, supplying electricity to homes, businesses, industry etc. over a particular area. This length of power lines is equivalent to about 13 times round the world.

Wind power

Mapping wind power resources for cost-efficient construction

How windy is Sweden? The answer is provided by plotting the country's wind assets, which has been done since 2002. The work involves modern meteorological methods, which allow for height variations and differences in vegetation, as these factors affect wind velocity. Scientists at Uppsala University have constructed a model that calculates wind speeds for a large number of weather situations throughout the year. The results can then be used to assess potential wind power energy production. The calculations divide the country into a grid network, in order to be able to provide data representative of quite local variations. The work at present provides a resolution of 1 x 1 km. In height terms, wind variations can be plotted in as small increments as 10 m, with the calculations showing how wind speeds vary with height. In this way, it is



The Grätzel solar cell is what is known as a photoelectrochemical solar cell, of which the important elements are a light-absorbing pigment and an electrolyte that can conduct current. Sunshine on the cell starts a photoelectrochemical process that generates current.

possible to calculate how much energy wind power plants of different heights could produce.

The results are used for planning purposes by county councils, local authorities, designers and power companies investigating potential plant conditions at different sites. Interim results show that conditions in the interior of the country are more favourable for wind power than had previously been thought. Large areas of the interior of the north of the country, together with the southern Swedish highlands, have been identified as such areas.

Solar cells

White and red pigments in solar cells

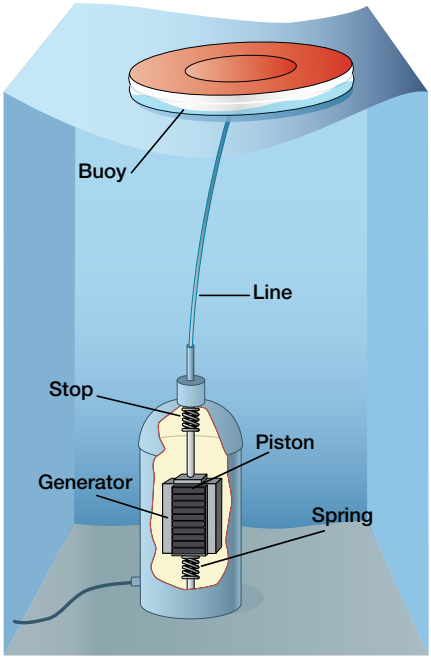
Electricity can be produced from solar cells based mainly on titanium dioxide, which is a pigment that is also used in white paint. These cells, which are known as Grätzel solar cells, have the benefit of potentially being able to be produced on plastic film in a machine somewhat similar to a mini-format paper machine. Production costs would therefore be low in comparison with those of traditional solar cells based on silicon. There are as yet no commercial Grätzel cells on the market, although several demonstration installations have been erected in Japan, Australia and China. The Royal Institute of Technology is carrying out a research project investigating new pigments and electrolytes in order to achieve higher efficiency and improved durability. Grätzel solar cells have so far reached an efficiency of 7 %, and this project is among world leaders in this sphere. In addition to the basic research being carried out by the Royal Institute of Technology, the manufacturing process is also being developed by IVF Industrial Research and Development AB in Mölndal, with the aim of developing cost-efficient solar cell technology for large-scale electricity production.

Wave power

Wave power costs can be reduced

Sweden's first pilot-scale wave power park has been launched off Lysekil. The prototype has been developed at Uppsala University, and consists of a completely new type of generator to extract energy from the slow up-and-down movement of the waves. A generator is placed on the sea bed, with one end of its moving element connected by a line to a buoy on the surface, and the other end secured to a spring, which is in turn itself secured to the base of the unit. The moving part of the generator is in the

FIGURE 15: *A wave power buoy*



The buoy follows the movement of the waves and pulls the line connected to the generator. The rotor in the generator is pulled up and down by the buoy, thus generating electricity.

form of a piston, carrying permanent magnets, which is pulled up and down in the stator by the buoy, thus inducing a voltage in the windings in the stator. This moving piston corresponds to the rotor of an ordinary generator, except that here it does not rotate but is pulled up and down by the movement of the buoy on the surface. The prototype has a number of advantages: the generator is protected from severe weather as it is on the sea bed, while the mechanical elements are simple and can withstand high loads.

The pilot project consists of ten generators which will be installed between 2005 and 2009, with the project continuing until 2014. The generators can be connected together in groups, 20-100 m below the surface. Power electronics convert the varying frequency AC from the generators to DC which is connected to a shore station by standard cables. An inverter then creates 50 Hz AC for connection to the electricity transmission or distribution system. In order to investigate the effects on the local environment, the project is being expanded with up to 30 mock buoys in order to be able more clearly to identify and investigate environmental effects. The technology should be able to extract energy from relatively small wave heights, as are encountered in, for example, Kattegat. Generators with a capacity of about 10 kW are suitable for use in Swedish waters, while units with capacities of about 100 kW or more could be installed in waters off Norway or Scotland, where wave heights are greater. As the whole technology is based on modules, further modules can be added if the energy demand increases.

Silicon carbide

Silicon carbide improves the efficiency of electricity transmission

Silicon carbide is a semiconductor material that withstands high voltages and currents, and which can also operate at high frequencies. It can be used in transistors, replacing the silicon that is normally used. With funding support from the Swedish Energy Agency, Norstel in Norrköping has developed a manufacturing process for silicon carbide. Transistors made of the material open the way to produce compact, temperature-insensitive motor control systems that need less cooling. Such control systems can play an important part in the development of electric hybrid vehicles. The new transistors are being developed by the TranSic company, which is a spin-off of an earlier research project financed by the Swedish Energy Agency. However, there are more applications: at present, the transistors are being tested and developed in close conjunction with pilot customers in real applications such as electric trucks, motor control of robots and welding power units.

International cooperation essential

In proportion to its GDP, Sweden invests more in research and development than does any other EU country. However, Sweden is a small country, and the Swedish inputs are small in an international perspective. Developing and introducing new energy systems to the market requires a high degree of specialisation and cooperation between specialisms in many countries. For a small and R&D-orientated country such as Sweden, international cooperation and monitoring of the business climate is therefore a large and essential part both of energy research policy and of energy policy. The fora that are utilised are primarily EU and IEA-based, although other types of bilateral or multilateral cooperation such as the Nordic Energy Research Programme are not overlooked.

More effective research through IEA cooperation

As far as Sweden is concerned, by far and away the largest international cooperative forum is that reached through the International Energy Agency (IEA), which facilitates coordination of both national and international efforts.

The Swedish Energy Agency participates in the work of the IEA through representing and furthering Sweden's interests. Within the IEA there are about 40 technology-orientated cooperation groups, known as Implementing Agreements (IA). Sweden is one of the countries that participates in the largest number of IAs, amounting today to about 25. Work is carried out mainly in the form of limited-time projects, known as annexes or tasks, within each Implementing Agreement.

→ More information at
www.iea-sverige.org
www.iea.org

EU membership increases the scope for international cooperation

Increasingly, research in Europe is carried out in the form of distribution of the work between countries. It is therefore important that Sweden's research environments should possess the skills and characters that make them interesting for international purchasers. In some areas, it is more cost-effective to work with other countries, or to purchase the results from them, than to establish Sweden's own research.

New EU directives concerned with the energy sector can affect research and development activities to greater or lesser extents. Another international area that can affect research is that of standardisation: although this is mainly of interest for industry, various elements of research may also be involved.

Within the EU Sixth Framework Programme, research into sustainable energy systems has a budget of about EUR 810 million. A new Seventh Framework Programme is at present starting up, and a European Research Area (ERA) that can compete with the USA and Japan is being established. In addition to the Swedish Energy Agency being involved in the objectives and selection of coming pro-

grammes, it is also partly financing most of the research projects that are in turn receiving their basic financing from the Sixth Framework Programme. One particular project that has received substantial funding from the Programme is the Värnamo plant for investigation and development of the production of synthetic gas by gasification of biomass; a gas which can be used for the production of motor fuels.

Research funding bodies work together and publish common calls for funding applications

Networks known as ERA-NET have been set up within the Sixth Framework Programme. The objective of this is that research funding bodies within the European research area should be able to work together more closely and coordinate research and development work that would otherwise be carried out at the national level. It is the intention that, within each network, the countries involved should inform each other of their respective programmes and activities, and

identify opportunities and obstacles for increasing coordination of research and development work. The countries should also decide on common activities and develop a strategy for carrying them out, as well as investing in projects that involve several countries. The Swedish Energy Agency is a member of four ERA-NETs: bioenergy, hydrogen, solar cells and innovative energy research. The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning is a member of the Buildings ERA-NET, which also handles energy research issues. Work within the various ERA-NETs affects the Swedish Energy Agency's priorities of future research work, as the objective of the networks is to identify common priorities and coordinate national activities. In addition, common calls for research projects have been published in 2006.

EU technology platforms for world-leading research

The Seventh Framework Programme has introduced a new concept for the EU: that of technol-

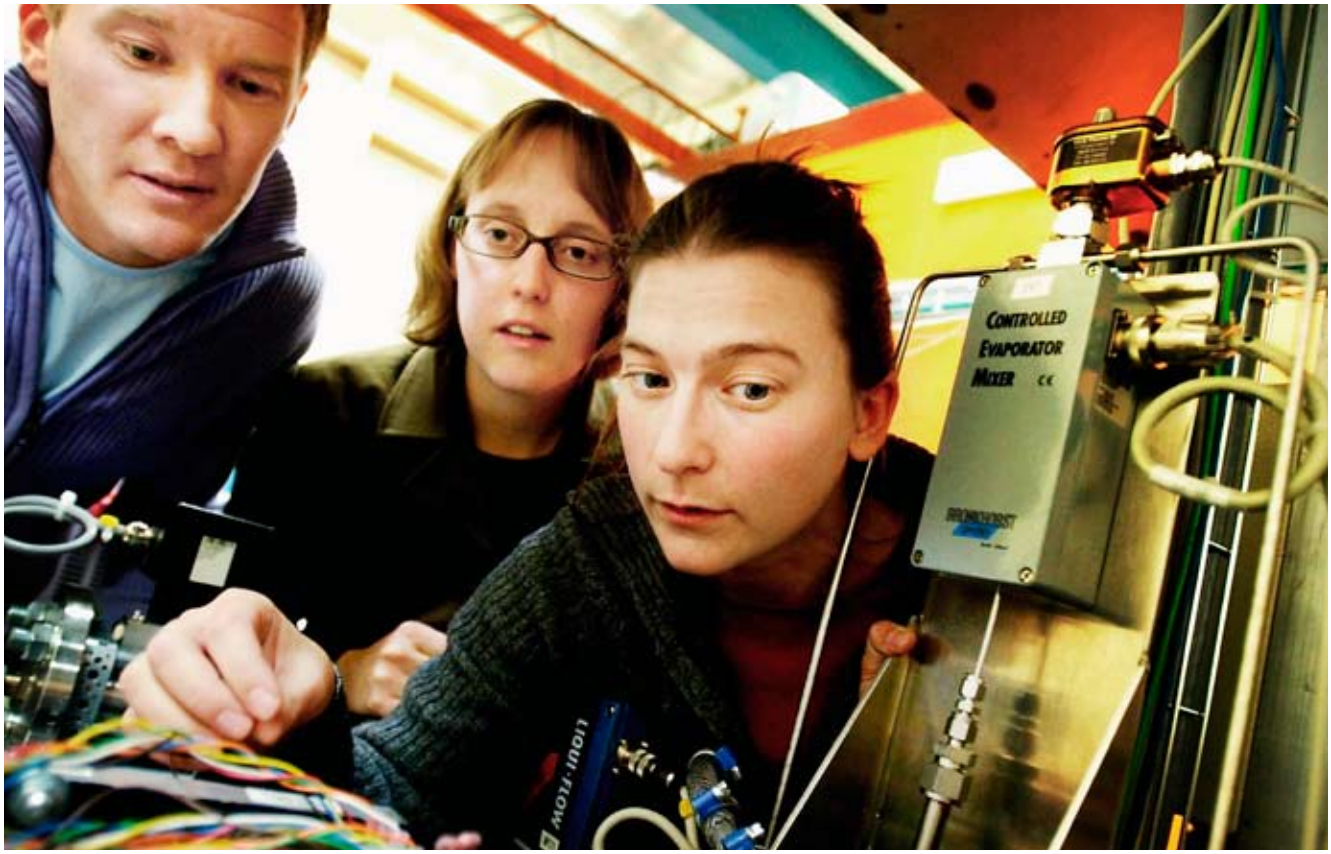
IEA

The five main IEA committees are:

- Committee on Energy Research and Technology (CERT)
- Standing Group on Emergency Questions (SEQ)
- Standing Group on Long-Term Cooperation (SLT)
- Standing Group on the Oil Market (SOM)
- Committee in Non-Member Countries (CNMC)

Most energy research work is dealt with by the Committee on Energy Research and Technology. Swedish work with the various Implementing Agreements is carried out within the following working parties:

- Working Party on Fossil Fuels
- Working Party on Renewable Energy Technologies
- Working Party on Energy End Use Technologies
- Fusion Power Co-ordinating Committee.



ogy platforms. The purpose of these platforms is to bring together representatives of companies, research institutes, public authorities and consumers. Working within specific and carefully delineated technical development areas, they are then intended to develop common European visions of technical development and identify possible ways forward, known as road maps. The underlying starting point is that Europe should become a world leader in each technology area, and develop a strategy for doing so.

The Nordic Energy Research Programme is strategically structured with common targets

All the Nordic countries have national energy policy targets for increasing their use of renewable energy sources and improving the efficiency of production, distribution and use of energy. The countries started a common research programme in 1985. At first, this was manifested in the form of grants to scientists to enable them to work with another Nordic university. Nowadays, the research programme is strategically concentrated on a number of projects within priority areas. Overall strategy and detailed application plans are determined for four-year periods at a time. For the current period, of 2007 to 2010, this envisages continued work within the fields of integration of energy markets, renewable energy, more efficient use of energy, the hydrogen society and climate changes due to activities associated with the energy sector. Since 1999, the Nordic Energy Research Organisation forms an institution of its own within the Nordic Council of Ministers, with headquarters in Oslo.

→ More information at
www.nordicenergy.net

More information

ENERGY RESEARCH ON THE WEB

On its web site, http://www.swedishenergyagency.se/, the Swedish Energy Agency has a section called Energy research. It contains basic information on the various research fields in English. Information on news, calls for research applications can be found in the Swedish language versions of the site. There is also information on, and links to, the various research programmes.

Forskning.se is a web site that provides information on research and research findings in Sweden. It includes general information on Swedish research, news, links to all research funding sources, detailed information for journalists and presentations of various research results. **www.forskning.se**

ENERGY RESEARCH NEWSLETTER (IN SWEDISH)

Would you like an e-mail subscription to the latest news on energy research? The Swedish Energy Agency publishes a newsletter (at present, only in Swedish) aimed specifically at those interested in energy research. It contains news and information on current calls for proposals, events and conferences. Subscribe to it via the Agency's web site under 'Nyheter>Nyhetsbrev'.

BROCHURES

You can find reports, studies and other written material on our web site. Much of this material can be downloaded or linked from the respective thematic areas and research programmes. Some can be ordered from the Agency's publications service.

→ LINKS

Some research financing organisations with web sites in English:
The Swedish Energy Agency **www.swedishenergyagency.se**
Vetenskapsrådet (The Swedish Research Council) **www.vr.se**
Vinnova (The Swedish Governmental Agency for Innovation Systems) **www.vinnova.se**
FORMAS (The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning) **www.formas.se**
Mistra (The Foundation for Strategic Environmental Research) **www.mistra.org**
The national popular science magazine: Forskning och Framsteg **www.fof.se**

→ INTERNATIONAL LINKS

Nordic energy research **www.nordicenergy.net**
IEA **www.iea-sverige.org or www.iea.org**

→ OTHER PUBLIC AUTHORITIES CONCERNED WITH ENERGY-RELATED MATTERS

Swedish Road Administration **www.vagverket.se**
Swedish Environmental Protection Agency **www.naturvardsverket.se**
The National Board of Housing, Building and Planning **www.boverket.se**
The Swedish Consumer Agency **www.konsumentverket.se**
Central Services Office for the Government **www.regeringen.se**

An efficient and environmentally friendly energy supply system

The Swedish Energy Agency aims at achieving a safe, reliable, environmentally friendly and efficient energy system in Sweden and internationally. The Agency works to improve the effectiveness of energy markets, with a greater element of renewable energy. It also exercises surveillance of the electricity distribution companies and is responsible for the country's strategic energy preparedness for crisis situations.

An important part of the Agency's work is the financing of research, development and demonstration activities in the energy sector. It supports a large number of research and development programmes in conjunction with universities, institutes of technology and industry.

Swedish Energy Research 2006 provides a brief, easily accessible overview of the Swedish energy research programme. The aims of the programme are to create knowledge and skills, as needed in order to commercialise the results and contribute to development of the energy system. Much of the work is carried out through about 40 research programmes in six thematic areas: energy system analysis, the building as an energy system, the transport sector, energy-intensive industries, fuel-based energy systems and the power system.

Swedish Energy Research 2006 describes the overall direction of research, with examples of current research and results to date within various thematic areas.

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