EUROPEAN SPALLATION SOURCE

SUSTAINABILITY PARTNERS

E.ON LUNDS ENERGI

# Proposal for a **Sustainable Research Facility**

ESS ENERGY CONCEPT
FINAL REPORT
2013

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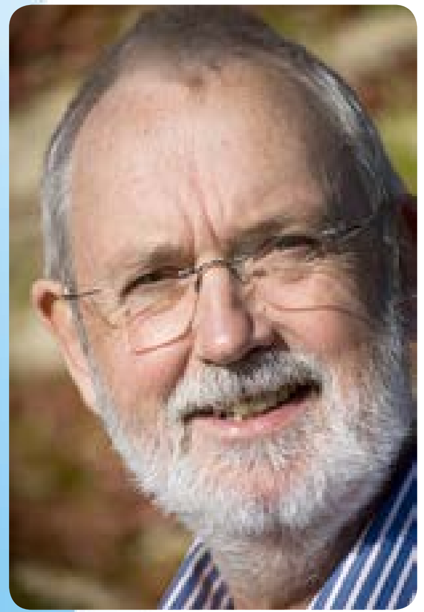
# Foreword from the CEO of ESS



**Not so long ago – but before it was settled that the European Spallation Source, ESS will be built in Lund, Sweden – two scientists, of which I had the fortune of being one, were discussing over lunch how to power such a facility in an environmentally friendly manner. On a napkin, that I still have in my drawer, we wrote down the outline to what has now been refined and will make ESS not only the world's leading research facility using neutrons, but also the first large-scale research facility that will be environmentally sustainable.**

Back then, six years ago, society had recognised the necessity of using new methods in industry to prevent global warming. Since humans have tended to use more and more electricity over time, big hopes were set on technical development and scientific breakthroughs. Facilities like ESS would, in the future, enable scientists to understand and create new materials that, in turn, would ensure future products left a smaller environmental impact than products of the day.

Less thought has been given, however, on how to power research facilities, since they will actually need large amounts of electricity. If we connect them to the electrical grid without considering the source of the power, and if we just vent their waste heat out in the air or into water, a serious paradox appears: meeting the need for new and better products with increased air pollution and $CO_2$ emissions would clearly contradict the aim of the science performed at the research facilities.

When it came to deciding where to place ESS, the preferred bid, from Lund, would give the facility an environmentally sustainable design, using available knowledge and innovative techniques to make it $CO_2$ neutral within its life expectancy. This would also have a positive impact on operational costs, giving us more science for each euro spent.

To make this possible we have partnered two energy companies, one local and one global (Lunds Energi and E.ON), who have shared their knowledge and expertise in the energy field. Engineers and scientists from ESS, E.ON and Lunds Energi have jointly made plans on how to produce renewable energy to power the facility and use the waste heat in the district heating system. Thus scientists will be able to investigate new materials that will help contribute to a better, more sustainable world, without polluting it while doing the research.

The results of the project are presented in this report.

Now that I will soon hand over the leadership of the European Spallation Source, I sincerely hope that our work will result in a breakthrough now and in the future – not only in material science, but also in the construction of sustainable large-scale research facilities. ESS will be an example of how large science facilities can and should be built and operated.

Lund, January 2013

**Colin Carlile, CEO,**
European Spallation Source ESS AB




# Foreword from the Collaboration Partners

**When we were first introduced to ESS's plans to build a sustainable research facility, we were attracted by the opportunity of making a difference. We realised that we had the necessary knowledge and experience from building sustainable cities, providing power grid and heat recycling setups to be able to develop the optimal solution.**

The energy sector faces some major challenges ahead. High on the agenda of customers, investors and politicians in Sweden and Europe are access to energy, how it is produced, the environmental impact it causes, and not least, its cost. New technologies are being introduced for the production and distribution of electricity. Small- and large-scale energy production will exist within the same system. New types of partnership are being established between various stakeholders, energy suppliers and customers. The customer's role may be changed into that of a producer of energy and vice versa. All these components exist within ESS's energy concept.

This challenge has brought two energy companies to work side by side with one mission; using all our combined knowledge and the best technology available to present a conceptual design for an innovative and optimal energy solution for ESS and the great science that will be performed there.

The collaboration with ESS has been, and will be, of importance to us on a local, regional and international level. By contributing to the establishment of ESS as a unique research laboratory, we will help create opportunities for strengthening the Öresund region. We also believe that this will enable a long-term increase in global competitiveness for Europe.

Lund and Malmö, January 2013

Sylvia Michel, CEO and MD, Lunds Energikoncernen and Anders Olsson, Deputy CEO, E.ON Nordic

E.ON is one of the world's largest energy companies with a presence in Europe, the US and Russia. E.ON Nordic is responsible for E.ON's Nordic energy market, and aims to provide energy solutions that significantly improve the energy system and develop competition locally, regionally and globally under the motto "Cleaner and Better Energy". E.ON Nordic had about one million customers, 4,000 employees, and a turnover of approximately 39 billion SEK in 2012.

Lunds Energi is owned by Lunds Energikoncernen AB, which in turn is owned by the four South Swedish municipalities Lund, Eslöv, Hörby and Lomma. The group's aim is to work together with customers and collaboration partners to create sustainable energy solutions for future generations. Operations, which are conducted across a number of Swedish municipalities, reported turnover of approximately 2.6 billion SEK in 2012. Activities include an electricity grid, sales, and production, in addition to district heating and cooling, natural gas, communications networks, lighting, contracting and services. The group has some 300,000 customers and about 400 employees.

# The ESS  Energy Proposal

**THE CONCEPT**

The concept 'Responsible, Renewable, Recyclable and Reliable' will make ESS a net sink for carbon dioxide and therefore contributes greatly to the sustainability of the facility.

**THE RESEARCH**

With this concept ESS will set a new standard for large-scale research facilities. The research at ESS will put Europe in the lead with regard to sustainable development.

**THE FUTURE**

ESS is a long-term commitment that will benefit coming generations and contribute to managing global environmental challenges. Setting a new standard is an important statement for the future.

**THE ECONOMY**

The concept 'Responsible, Renewable, Recyclable and Reliable' will significantly lower the operations cost, making it possible to produce more research for a better future.

# Progress in the Energy Area

**The range of possibilities for ESS is as broad as science itself. Research using neutrons will advance our knowledge considerably, spanning many different disciplines such as physics, chemistry, geology, biology and medicine.**

## Studying Materials

The 'Olympic' challenges for today's materials to be lighter, stronger, cheaper, and more environmentally friendly require extensive knowledge of the materials properties beginning on the atomic scales. The information is needed by material scientists and developers to be able to tailor the properties of new materials for optimum performance.

Materials are made from assemblies of atoms, which are arranged either in orderly or disorderly fashion, as in metals and liquids. They can, for example, form long intertwined chains, as in polymers, or combine in complex arrangements, as in proteins. It was not until the discovery of X-rays, and later neutrons, in the first half of the 20th century that scientists could study materials at an atomic level. Thanks to the size of neutrons, and the fact that neutrons have no electrical charge, they can interact with the atoms' nuclei, and as such help scientists measure positions, motions and magnetic properties. The 1994 Nobel Prize in Physics was awarded to Clifford G. Shull and Bertram N. Brockhouse for the utilisation of neutrons showing "where atoms are and what atoms do".

## Neutron Production and the Scientific Use

Atoms are formed by electrons moving around an atomic nucleus, which consist of a mix of neutrons and protons. The neutrons can't be used as a tool for examining materials when they are in the nucleus, so they must be extracted from it. This is efficiently done in two ways: either with a nuclear reactor, using fission, or by using an accelerator system to generate high-energy protons which hit a target, knocking out neutrons. This is called a spallation process, which, inherently, is safer as there is no risk of self-sustained or other chain reactions.

At ESS researchers will use the most powerful neutron beam to date to continue to study 'where atoms are and what atoms do'.

Thanks to the size of neutrons, and the fact that neutrons are neutral, they can interact with the atoms' nuclei, and as such help scientist measure positions, motions and magnetic properties.

**CATALYSTS.** A large proportion of everyday products is produced by, or use some form of catalytic process – e.g., synthetic fuel or well-known catalytic converters reducing the amount of carbon monoxide emissions in cars. These are reactions that occur on the atomic scale, often on metallic surfaces. Studying these microscopic processes, ideally under operating conditions, requires the ability to see where atoms are and what they do, a job ideally suited for neutrons.

**DEVELOPMENT OF SOLAR POWER.** Neutrons can examine and enable optimisation of new materials, such as thin layers of polymers used for photovoltaics. This is a part of the effort to develop cost-effective, reliable, efficient and environmentally friendly solar power.

**THE SUPERCONDUCTING PROCESS.** Superconducting materials allow transportation of electrical currents without any losses. Today it is not possible to get superconductive properties without first cooling the material significantly below room temperature.

Using neutrons we can understand the microscopic details better and eventually learn to create materials that are superconducting at room temperature which would offer enormous macroeconomic savings and potentially create entirely new technologies.

**PHOTOSYNTHESIS.** Neutrons allow the study of biofuel production processes in real time, i.e., when developing artificial photosynthesis for the purpose of extracting fuel from sunlight and carbon dioxide.

**ENHANCED FUEL CELLS.** Neutrons are ideally suited for studying chemical processes, such as using hydrogen in a fuel cell to make electricity. It is also ideal for studying hydrogen storage and lithium mobility, relevant for batteries.

# How ESS Works

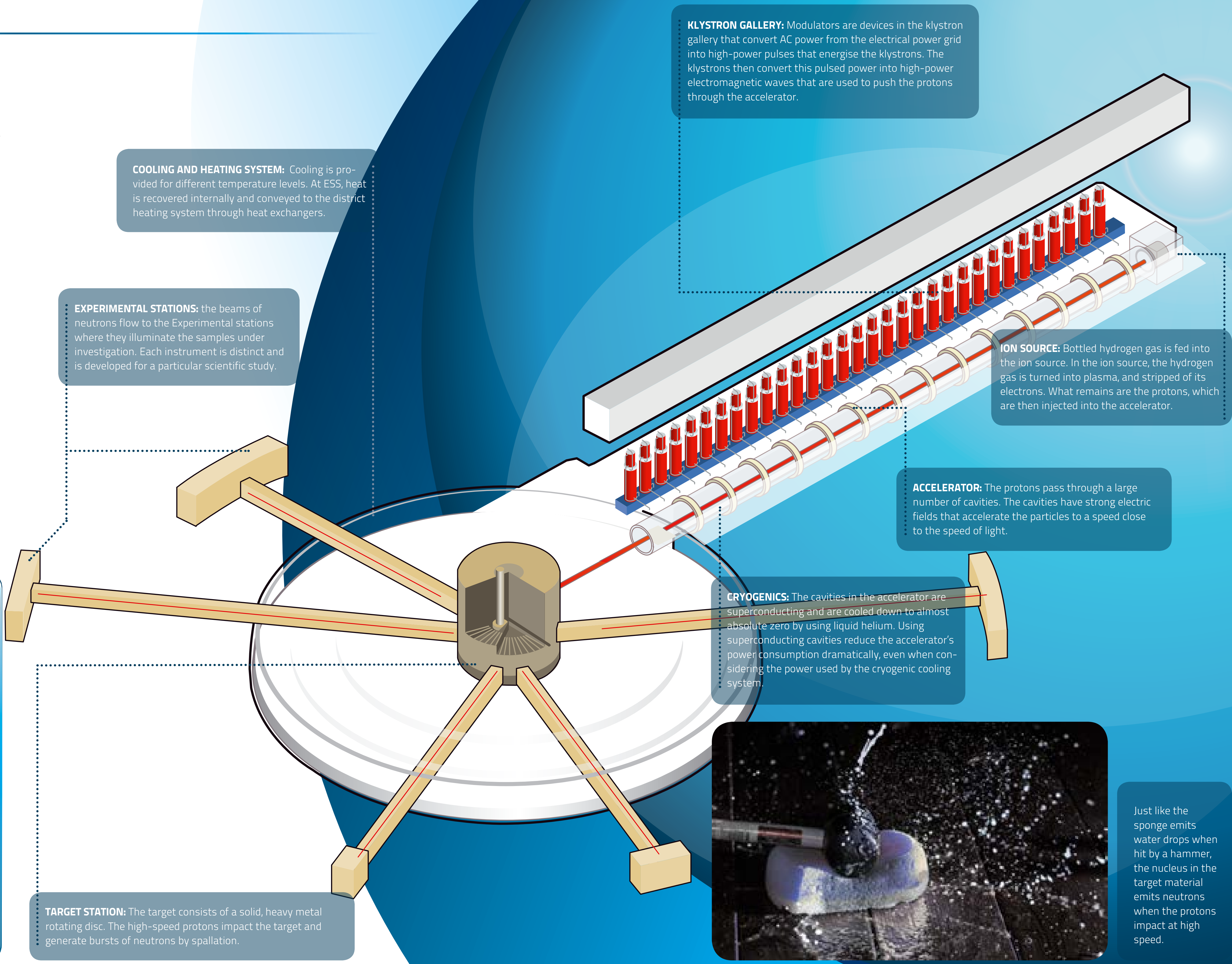
## What is spallation?

Spallation is a process in which neutrons are split off – or spalled – from an atomic nucleus by a proton moving at a speed approaching that of light. The process can be compared to bowling, with the accelerated protons represented by the bowling ball. The neutrons resemble the pins flying in all directions when hit by the 'bowling ball'. The protons are accelerated and focused by electric and magnetic fields towards the target. Each proton in the accelerator releases about 30 neutrons. The neutrons then pass down tubes to the instrument stations.

Neutron researchers have long used nuclear reactors as neutron sources and there are several similar facilities in Europe. They will continue to be used in the future for experiments requiring continuous neutron beams, but these facilities have a technological intensity limit. Also, due to age limits, a number of these sources will need to be decommissioned in coming years. Spallation-based neutron sources allow the continued development of neutron research instrumentation. Although the spallation process is energy-intense, it is not limited by the same technological barriers as nuclear reactor neutron sources, and offers the potential for a brighter beam.

### ESS IN BRIEF

- **How it works**
  We see everyday objects when they are illuminated by light. The light is reflected into our eyes and an image is formed in the brain. Neutrons function in a similar way but are able to visualise much smaller objects, such as atoms and molecules. ESS will be able to produce more neutrons than any current facility, thus enabling scientists to examine and create new materials for a better tomorrow.
- **€1.5 billion**
  ESS is a European project hosted by the Governments of Sweden and Denmark. Currently 17 Partner Countries have signed the Memorandum of Understanding on participating in the Design Update Phase, with the intention to participate in the construction and operation of ESS. The Swedish Government has pledged to cover 35% of the required capital expenditure of approx. €1.5 billion, in addition to 10% of the operating costs.
- **Inauguration in 2019**
  Construction is planned to commence early 2014. The facility is expected to be inaugurated in 2019, and to reach full specification by 2025. Some 3,000 researchers will use ESS annually.




Just like the sponge emits water drops when hit by a hammer, the nucleus in the target material emits neutrons when the protons impact at high speed.

# The **Challenge**

The purpose of the collaboration between Lunds Energi, E.ON and ESS was to enable construction of the world's first sustainable research facility, by designing energy systems fulfilling the ESS energy concept.

The energy concept for ESS consists of four steps:

- **Responsible – requires that the facility use as little energy as possible**
- **Renewable – requires that all energy must derive from renewable sources**
- **Recyclable – requires that as much waste heat as possible is recycled**
- **Reliable – requires an energy system providing stable electricity and cooling supplies, which are vital for the research**

## The Project Scope

The scope of the project, which was formally started in January 2010 and ended in December 2012, was to find the conceptual solutions for how energy could be used in the most efficient ways to fulfil the "four Rs" above. The outcome goals were savings in terms of $CO_2$ emissions and operational costs, see details in the illustrations on page 17. The project deliverable was to describe the solutions in an Energy Design report.

## The Solution

Periodical energy inventories of the facility carried out within the energy solutions collaboration show that the estimated energy consumption has been continually and significantly reduced throughout the Design Update phase. A cooling system that avoids cooling towers and instead recycles enough waste heat to supply 15,000 single-family houses is proposed.

Moreover, the study shows that almost half of the waste heat is sufficiently hot to be transferred directly to the district heating system. Heat pumps are proposed to extract the energy from the remaining lower temperature waste heat, and raise its temperature enough to also transfer it into the district heating system. In either case, heat is conveyed to the district heating system via heat exchangers. Additionally, projects have been started to create a demand for lower-temperature heat, adding an alternative to the use of heat pumps.

**THE RENEWABLE GOAL: All Energy from Renewable Sources**

The Renewable goal requires that ESS will be supplied with energy from new, dedicated renewable production at a stable and competitive cost. A feasibility study points to wind power as a possible solution. A completely new and dedicated wind power farm of 100 MW, corresponding to approximately 30-40 wind power turbines, will provide the facility's annual consumption.

**€3-4 million annually in net average revenue and savings compared to procuring electricity on the market.**

**135,000 tonnes of $CO_2$ emissions are averted.**

Read more on pages 18-19.

**THE RESPONSIBLE GOAL: Reduce Energy Consumption to Under 270 GWh per Year**

The Responsible goal requires that the facility will be even more energy efficient than the design that applied when Lund was selected as the location for ESS, which means the greatest possible energy efficiency without impacting quality or availability. Efficiency enhancement is in progress throughout the facility – all the way from the klystrons to the cafeteria.

**€4 million in annual savings**

**40,000 tonnes of $CO_2$ emissions are averted compared to the original design**

Read more on pages 14-17.

## No Greenhouse Gases

Thanks to the exclusive use of new, dedicated renewable energy sources, ESS will not cause any new greenhouse gas emissions from its energy use. The waste heat will replace heat production generated by fossil fuels, thereby reducing the emission of carbon dioxide in the region by an additional 15,000 tonnes annually. This makes ESS operations a net carbon sink, even when building materials and transportation are taken into account. Sustainable development is also a matter of saving money. Our energy solutions are estimated to provide revenue and reduce costs by approximately €8-10 million annually.

**A SUSTAINABLE RESEARCH FACILITY**

This report's focus is on sustainable energy and its costs. Other important sustainability issues are discussed in the annual sustainability report. Moreover, an environmental impact assessment has been submitted to the Swedish Environmental Court, in accordance with the Swedish Environmental Code.

**THE RELIABLE GOAL: Reliability in the Energy System**

The Reliable goal requires that the energy system for ESS must be stable to ensure the desired functioning of research activities. ESS can obtain a redundant power supply by utilising two high-voltage power transmission lines already available. Research is being carried out in close co-operation with RWTH Aachen University in Germany to ensure power quality, both for the facility and the surrounding community. The district heating and cooling networks will provide a reliable source of cooling for ESS.

Read more on pages 28-31.

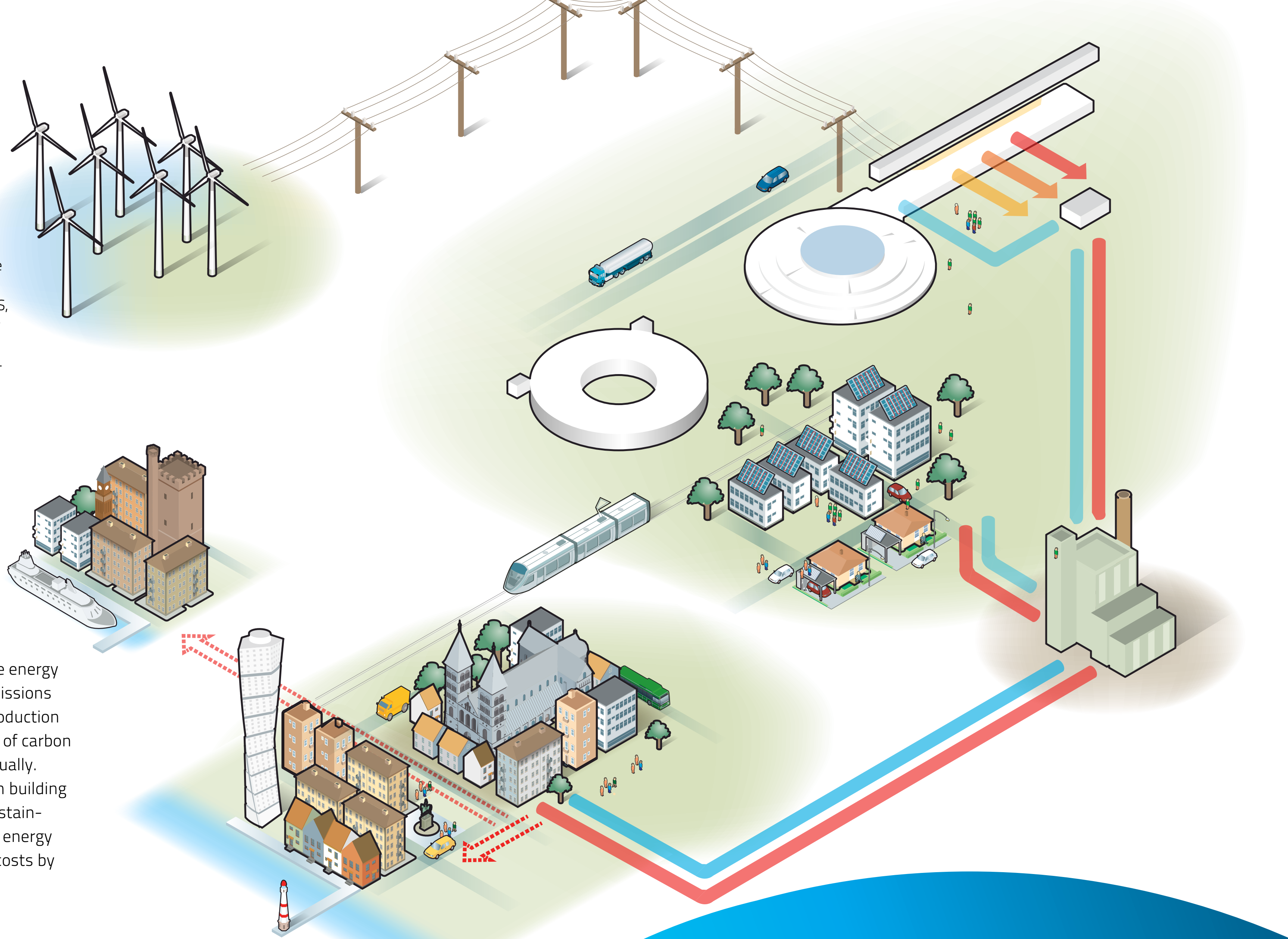
**THE RECYCLABLE GOAL: No Cooling Towers**

The Recyclable goal requires that ESS will recycle the waste heat generated in the facility and supply Lund's district heating network with a full 20% of its annual requirement. This is a unique new feature for a large-scale research facility, though increasingly common in local industry. In traditional designs, cooling towers are used to vent waste heat into the atmosphere.

**€1-2 million annually in net revenue in addition to €1 million included in "Responsible".**

**15,000 tonnes reduction in $CO_2$ emissions from the heating system.**

Read more on pages 20-27.



Our energy solutions are estimated to provide revenue and reduce costs by approximately €8-10 million annually.

# RESPONSIBLE Managing Energy Flows and Costs Offers More to Research

**For ESS to succeed in building by far the most powerful neutron source in the world, the scientists and engineers involved will have to excel in efficient design. To achieve the ambitious energy commitments, the same excellence will have to be shown in the design of the support systems.**

In the ESS Costing Report 2011, the cost of electric power for running ESS represents 14% of the overall ESS operating cost. Reducing the power consumption would therefore free significant resources that could be used for conducting research at ESS, while simultaneously leading to a smaller environmental impact.

The ESS Energy Concept has from the very beginning encompassed two specified paths towards achieving the goals Responsible, Renewable, Recyclable and Reliable. These were the establishment of an energy culture and regular energy inventories. The cyclic energy inventory encourages and maintains continual dialogue between the energy team and the accelerator, target, instrument and conventional facilities teams, thus also promoting the establishment of a strong energy culture at ESS.

## The Energy Inventory of ESS

The results of the latest Energy Inventory are shown in table on page 15.. The inventory shows that the expected consumption level is considerably below the starting point of 350 GWh, which was the initial estimate for the facility as envisioned in the Scandinavian bid to host ESS. The total electricity use is also close to the target level of 270 GWh. It is also clear from the inventory that the target is within reach and can be achieved by reduction of the power used for the cooling system.

## The Energy Inventory Method

The Energy Inventory is a measure of progress towards achieving the Responsible goal. It is also one of the main methods of achieving the goal, forming the basis of a cyclical process of assessment, design and reassessment that leads to improvement. The Energy Collaboration Team has performed six consecutive Energy Inventories, three of which have been published. The first Energy Inventory was actually based mostly on data from Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee, because, at that early stage, there was not sufficient data on the ESS design.

For each iteration of the Energy Inventory, the Energy Collaboration Team has worked closely with the engineers designing accelerator, target and instruments to improve both the understanding of the interaction of the various systems and the performance of the systems themselves.

This method aids in the identification of areas with significant energy consumption and opportunities for improvement of the energy performance. Actions for improvement of energy performance are focused on the top energy consumers of the facility, since those areas have the greatest opportunity for improvement. The repeated Energy Inventory process focuses the attention of developers on energy issues and enables efficient management of the process.

Conducting an energy inventory also facilitates cross-functional co-ordination between the different project groups (machine parts), since the performers of the energy inventory work as a hub, collecting and distributing information back and forth before compiling all the information into a report to be distributed to relevant stakeholders.

**ENERGY INVENTORY**

| Part of the facility | Annual electricity use [GWh] | Annual cooling need [GWh] |
|---|---|---|
| Accelerator | 167 | 138 |
| Target | 31 | 57 |
| Conventional facilities | 4 | -6 |
| Neutron scattering system | 32 | 32 |
| Heat pumps | 44 | 44 |
| | | |
| **Total (incl. heat pumps)** | **278** | **265** |
| **Total (excl. heat pumps)** | **234** | **221** |

## Energy Inventory and Energy Management System

ESS has adopted an Energy Management Plan, based on the most recent energy inventory, as a basis for further development towards a complete energy management system.

Systematic energy management is another tool to fulfil the Responsible goal and provides the means for the organisation to ensure achievement of the set goals. Conducted activities will continually improve the energy performance of the organisation and ensure facility wide fulfilment of the energy goals. The implementation of an energy management system is not an objective in itself. What matters are the results of the system; anchoring attention for energy in daily practice.

Energy management aims for structural attention on energy consumption issues with the objective of continually reducing the energy consumption and maintaining the achieved improvements. With the energy management system energy flows are mapped at a certain point in time, and relevant energy aspects are identified and subsequently take action. The analysis of the energy consumption must be performed regularly to keep insight up to date and to enable new measures when changes occur.

## Energy Inventory and Energy Culture

Regular energy inventories gauge progress and enable management. An energy culture in an organisation keeps energy issues in the minds of personnel, enabling ideas to be generated and empowering proposals for improvement. Together these tools lead to technical solutions arising and being implemented.

The Energy Collaboration Team has published three public interim reports; held events on-site in Lund, in the Swedish and European Parliaments; held a number of press conferences; in order to established an energy corner in the ESS exhibit and in countless meetings to achieve and maintain awareness of energy issues on a very high level. Energy inventories were published in each of the public interim reports, and more were conducted in between reports to support decision-making and focus attention.

## Recyclable is the Key to Responsible

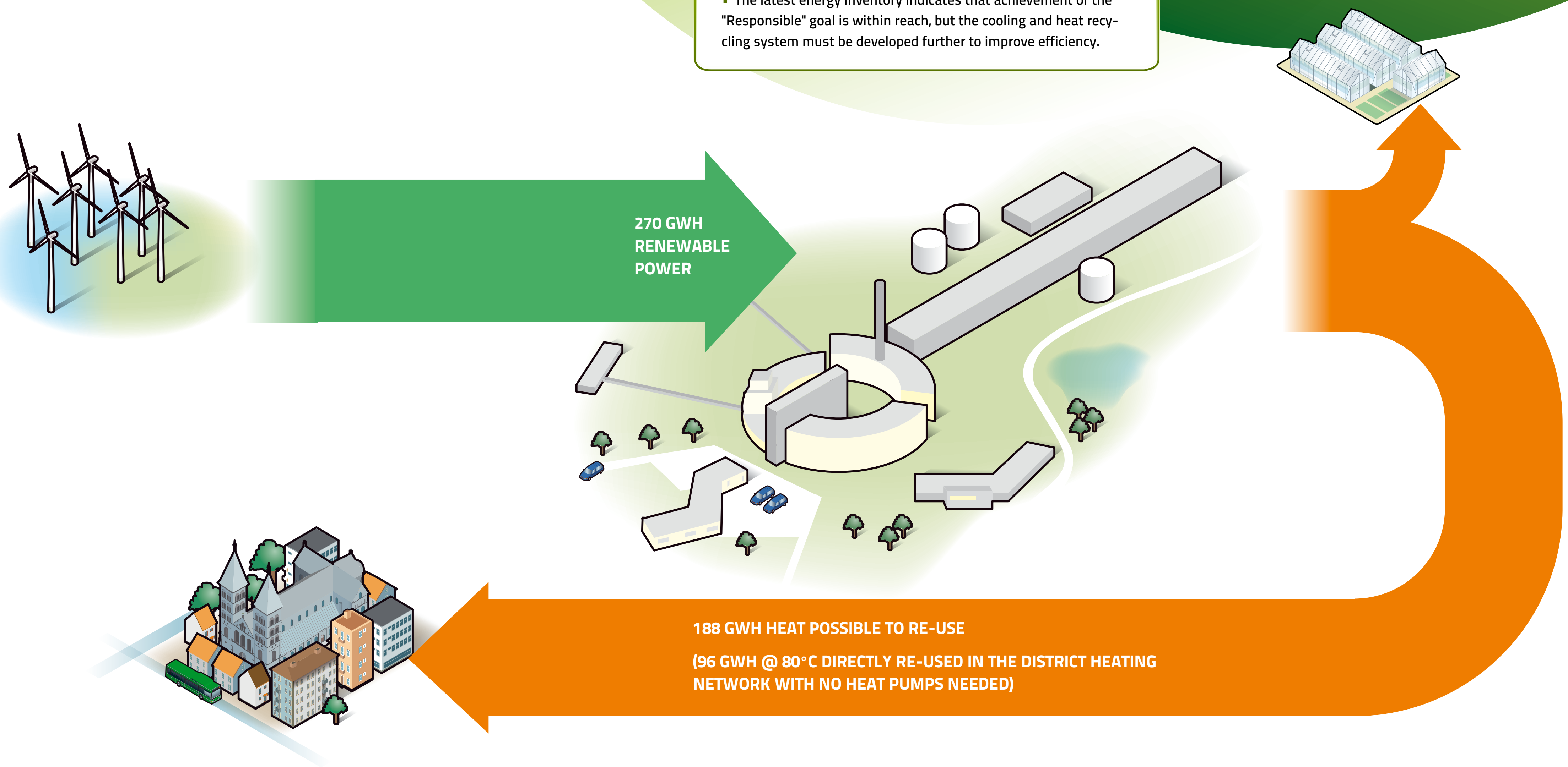
High-temperature cooling is a new idea proposed by the Energy Collaboration Team that is critical to the success of the ESS Energy Concept. The key point is to cool equipment, wherever possible, at a temperature level that is sufficient to supply heat to the district heating system without adding additional energy. High-temperature cooling is both Responsible and Recyclable, as cooling at lower temperatures requires additional energy use to get rid of the heat.

Approximately 30% of the total cooling need of ESS can be achieved with high-temperature cooling. The rest must be upgraded by means of heat pumps, if it is to be recycled to the district heating system. The energy that needs to be supplied to a heat pump in order to raise the waste heat temperature is substantial. It is therefore beneficial to find other uses of the low grade heat that can make use of heat at the lower temperature. One such application is heating for local buildings. All ESS buildings will therefore be designed for the use of low-grade heat.

High-temperature cooling is a new idea proposed by the Energy Collaboration Team that is critical to the success of the ESS Energy Concept.

**ENERGY EFFECIENCY IN BRIEF**

- The Responsible target entails that ESS has pledged to reduce energy consumption to less than 270 GWh annually. This will be implemented without jeopardising the availability or intensity of neutrons for experiments.
- Key tools to enable efficiency innovation are an energy culture, regular energy inventories, and systematic energy management.
- The latest energy inventory indicates that achievement of the "Responsible" goal is within reach, but the cooling and heat recycling system must be developed further to improve efficiency.




**ESS SCANDINAVIA DESIGN 2008 WAS THE STARTING POINT FOR THE COLLABORATION.** The original design for ESS in 2002 called for a much larger facility, less efficient, with conventional power and cooling solutions. This facility would have used an estimated 610 GWh per year, most of which would become waste heat. The winning Scandinavian design from 2008 was for a leaner facility, using more superconducting technology, renewable energy sources and heat recycling. This design was estimated to consume 350 GWh per year.

The current energy inventory indicates energy consumption around the goal of 270 GWh per year, still with renewable energy input and heat recycling.

# **RENEWABLE** Using Wind Power To Produce Neutrons

**The Renewable goal requires that ESS is to be supplied via new renewable energy sources. The amount of energy required for ESS corresponds to the annual output of 30-40 wind turbines. This is about as much as a mid-size paper mill or a small Swedish municipality consumes annually.**

When ESS is fully commissioned, electricity consumption in Lund will rise by 20-30%. The extra load on the Nordic power system would require a power contribution from what is referred to as marginal production.

Currently, electric power in the Nordic system derives largely from renewable and climate-friendly energy sources, but marginal production is still to a substantial degree fossil-fuelled, i.e. carbon dioxide-emitting oil or coal. This means that each new marginally produced GWh increases carbon dioxide emissions by about 500 tonnes. A facility of the size of ESS would then raise carbon dioxide emissions by a full 135,000 tonnes annually.

Fossil-fuelled marginal production will be replaced in the future, but at ESS we are already focusing on renewable electric power. The power options that will make ESS a sustainable research facility include wind power, solar power and biothermal power, of which wind power currently seems the most feasible choice for the primary supply.

## Wind Power Technology is Developing

The average new wind turbine currently has a rated output of 2.5 MW. Depending on its location, annual output will be about 2,600 MWh for each installed megawatt. The technology is developing steadily and when ESS is commissioned in 2019, it is likely that the average output will be closer to 3 MW, or possibly higher. This will reduce the required number of wind turbines. Even with this improved efficiency, the investment is expected to amount to about €150 million for an installation of roughly 100 MW.

## Gains for the Climate and Economy Stability Alike

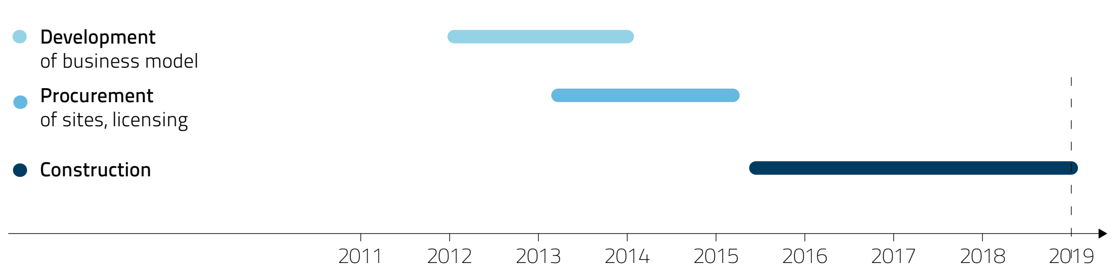
A new, renewable, and dedicated power production for ESS will secure a competitive, stable and more predictable electricity cost, which is vital for research operations. For ESS, a dedicated renewable production facility represents a crucial hedge against variations in power prices. Other major research facilities in Europe have been hit by falling research budgets when the operating budget was used increasingly to cover rising power costs.

A dedicated renewable power production will create average savings of €3-4 million annually during 20, years compared to buying electricity on the market during the same period. The calculation is based on an electricity and green certificate price development above inflation of 1% and an inflation of 2%. Hence, a dedicated wind power production facility is a crucial hedge against electricity price variations.

## Demonstrating and Developing the Latest Technology

Although wind power is seen as the primary option for electricity production, there are several other renewable energy sources which could be used. Combined heat and power production using bioenergy or solar photovoltaic cells integrated in the buildings are two examples. Since the research results at ESS are expected to make news in the energy sector it is also interesting to visualise new solutions in this field. At the ESS site it will be possible to demonstrate and develop leading edge energy technology.

### TIME SCHEDULE






### RENEWABLE ENERGY IN BRIEF

- When ESS is commissioned, electric power consumption in Lund will rise by 20-30%. Normally this would be supplied by greater use of marginal production, for which fossil-fuelled plants continue to represent a large share. A facility of ESS's size would then generate 135,000 tonnes of carbon dioxide annually.
- The Renewable goal requires that ESS is fully supplied via new renewable energy sources. A number of options have been considered, among which wind power is currently viewed as the best solution. By building a wind power farm that meets the facility's requirement – currently estimated at between 30 to 40 wind power turbines – ESS would compensate its energy consumption with renewable energy. In this event, the facility would not produce any carbon dioxide emissions.
- The construction of a new wind power farm requires an investment of about €150 million for an installation of roughly 100 MW. In the longer term, however, this is an economic gain for the facility, since this will secure a competitive, stable and more predictable electricity price, which is vital for research operations.

# RECYCLABLE
## Energy can be Recycled

**In other large-scale research facilities, the waste heat is released into the atmosphere. By contrast, ESS is planning to recycle this heat and provide the district heating network in Lund with 20% of its total annual requirement.**

### Where Does the Heat Come From?

Much of the power supplied to ESS is consumed in the process of accelerating protons to a speed close to the speed of light. Unfortunately, the energy efficiency in the acceleration process is low, resulting in the production of a large amount of waste heat. In order to improve the accelerator energy efficiency, a large share of the accelerator is designed using cryogenic superconducting technology.

Even though the overall result is an increase in the energy efficiency, it also results in the creation of more waste heat in the cryogenic system. In total, waste heat comes from three primary sources - the klystrons and modulators in the klystron gallery, the cryogenic system, and the target station. These three components produce over 80% of the total waste heat at ESS.

### How Do We Recover It?

Much like the cooling system for a car engine, the cooling system at ESS circulates fluid (in our case water) through the hot equipment to keep it cool. The circulating water picks up the heat, and safely carries it away from the equipment. However, unlike an engine cooling system which expels this heat to the environment through a radiator, the ESS cooling system will recycle the heat to other users.

In order to optimise heat recovery efficiency, the cooling system is calculated to operate at three temperature levels: 20 °C, 40 °C and 80 °C. The high-temperature waste heat can be transferred directly to a district heating network. Some of the ESS systems generate heat at lower temperatures than can be used directly by the district heating network. The cooling water temperature from these other systems can be raised by the means of heat pumps, which is the most efficient method of utilising all the waste heat. The total amount of waste heat available would then be approximately 200 GWh annually, corresponding to some 20% of the annual district heating requirement in Lund. Alternative heat pump technologies, such as absorption heat pumps, may be of interest in order to further reduce the power consumption. The following illustration shows the flow of heat from ESS to a district heating system.

### Where Can We Use It?

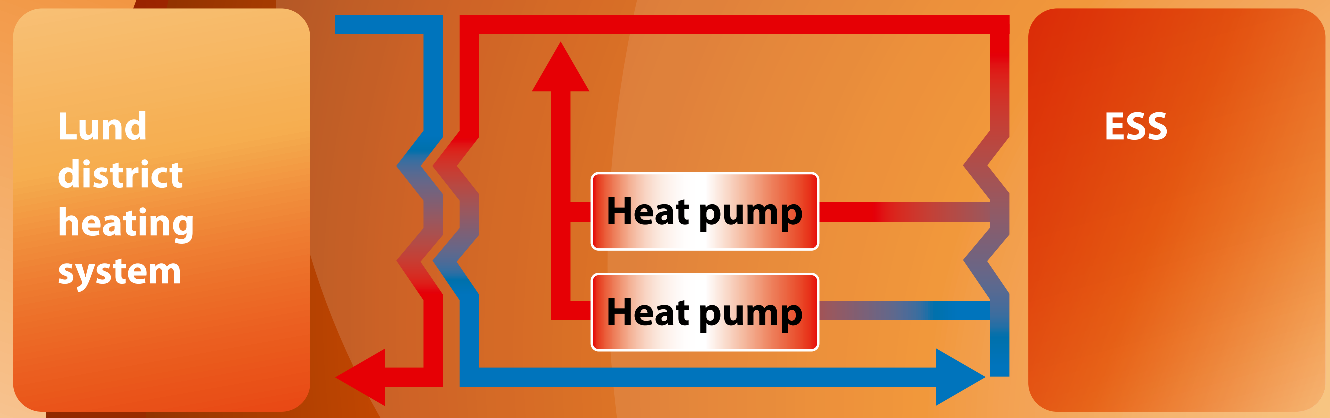
The primary customer for ESS waste heat will be the Lund district heating system. Some of the low temperature heat will also be recycled to heat the facility's buildings.

However, as discussed on pages 26-27, ESS is investigating potential uses for the heat such as local greenhouses, fish farms, or biogas production. It is also possible to use the energy from the waste heat to power cooling systems for the facility and comfort cooling for offices, a process which requires a minor power input.

It could also be used during winter for snow and ice removal at parking spaces, bicycle lanes and squares at the ESS site as well as in the new Lund city district Brunnshög adjacent to the ESS site. This process can make use of low-grade heat and avoid both the safety hazards of icy roads and paths and the environmental impact of the use of salt and machines.

The district heating system in Lund covers almost the entire city and heats the homes of more than 80% of the people living in the city. Offices and work places for thousands of people, as well as the neighbouring cities of Eslöv and Lomma, are heated by the same district heating system. With ESS contributions, the production of district heating may periodically exceed the requirement during warmer months. This excess heat may be stored and made available when the requirement arises. Currently, a ground heat storage facility on the ESS site is not deemed attractive. However, storage may be possible in the aquifers that are already used for district heating production in Lund. During maintenance periods and brief periods when the facility is not fully operational, waste heat production will obviously be lower. Effectively managing the supply and demand of ESS waste heat will require co-ordination between ESS and the district heating system. Annual output of waste heat is shown in the table below.

In addition, ESS may benefit from plans to expand the district heating market by linking up Lund's district heating network with other large networks in Western Skåne. The current district heating networks available are in Malmö or Landskrona – Helsingborg.




THE FLOW OF HEAT FROM ESS TO A DISTRICT HEATING SYSTEM.

**HEAT IN BRIEF**

- A research facility of the size and capacity of ESS requires large quantities of electrical power but also generates large amounts of heat. In all other large research facilities worldwide, this waste heat is either released into the air using cooling towers, or released into a local body of water.
- The Recyclable goal means that ESS aims at replacing wasteful cooling towers by recycling the waste heat, primarily for the district heating network. This effort makes the facility unique in the accelerator world.
- An excess of waste heat can arise in Lund municipality during certain times of the year, meaning that the local district heating network cannot accept all the waste heat. A review is in progress of the potential to expand the district heating market by linking up networks, or the potential to use seasonal storage. The district heating networks in question are in Malmö or Landskrona – Helsingborg.
- Waste heat from ESS offers benefits for the climate and economy alike. For ESS, the sale of waste heat represents net revenue and savings of some €2.5 million annually, which could be invested in research and innovation. Moreover, global carbon dioxide emissions will be reduced by 15,000 tonnes per year when waste heat from ESS replaces other heat production that generates higher carbon dioxide emissions.

## How Much Will It Cost?

The investment for recovery of ESS waste heat is estimated at approximately €10.5 million, including some lesser expense for dividing the cooling system into three temperature levels. This should be compared to the €5 cost for meeting basic cooling needs (conventional cooling towers and chillers). The income from selling the waste heat will cover the investment of the heat recovery system within the first few years of operation. The economy and technology for recycling heat at the lower temperature levels is being studied more closely in the current design effort.

## What are the Benefits?

Waste heat from ESS has both climatical and economical benefits. Waste heat from ESS represents an economic value related to the heat production that ESS replaces. An estimate based on an average of waste heat prices in Sweden represents gross revenue of €4 million annually. Since the waste heat from ESS replaces other production with higher carbon dioxide emissions, total carbon dioxide emissions will decrease. The reduction in carbon dioxide emissions will be about 15,000 tonnes annually, corresponding to emissions from 8,000 cars.

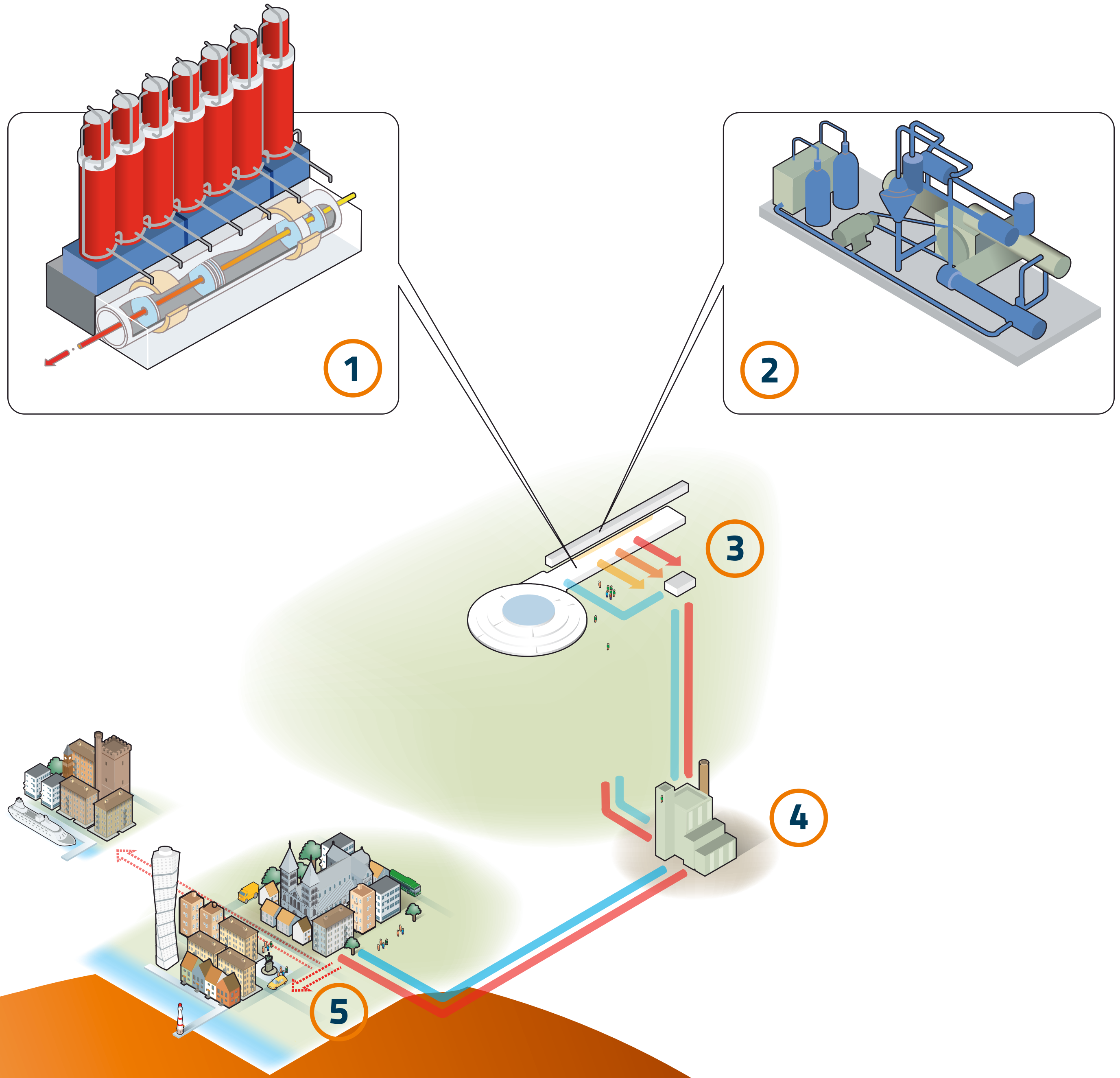
**COOLING REQUIREMENTS – ESTIMATED FIGURES**

| Unit | Temp 20°C (MW) | Temp 40°C (MW) | Temp 80°C (MW) |
|---|---|---|---|
| Ion source incl. normal conducting section of the linear accelerator | 0.5 | 0,1 | 0.5 |
| Linear accelerator incl. klystron gallery | 3.7 | 2.3 | 7.9 |
| Cryogenic system for linear accelerator | 0.3 | 2.0 | 2.0 |
| Cryogenic system for target station | 0.1 | 1.0 | 1.0 |
| Cryogenic system for instruments | 0.0 | 0.2 | 0.2 |
| Target station | 4.3 | 1.7 | 1.5 |
| Instruments | 1.6 | 0.0 | 0.0 |
| Miscellaneous | 1.0 | 0.0 | 1.0 |
| **Total** | **11.5** | **7.3** | **14.1** |
| **Heat pumps to raise temperature** | **5.4** | **1.8** | **0.0** |

# Energy Recycling at ESS

### Energy Recycling at ESS

The illustration below shows where waste heat arises in ESS (1 & 2) and how it may be used (3 & 4).




Waste heat from ESS represents an economic value of €4 million annually. The reduction in $CO_2$ corresponds to emissions from 8,000 cars.

**1 LINEAR ACCELERATOR INCLUDING THE KLYSTRON GALLERY**

The linear accelerator consumes the majority of the energy supplied to ESS. Most of this energy is funnelled into the klystron gallery. Like all electrical devices, klystrons and modulators are not 100% efficient and about two thirds of the supplied energy is converted into waste heat.

**2 CRYOGENIC SYSTEM**

The cryogenic system is the second major waste heat producer at the ESS facility. The cavities in the accelerator are superconducting and, thus, must be cooled down to almost absolute zero. This cooling, which is performed by the cryogenic system, requires considerable energy, while concurrently producing a substantial quantity of waste heat.

**3 TARGET STATION**

A substantial quantity of heat is also generated when the proton beam from the accelerator impinges on the target and spalls off neutrons. This excess heat amounts to approximately 25% of ESS's total waste heat production.

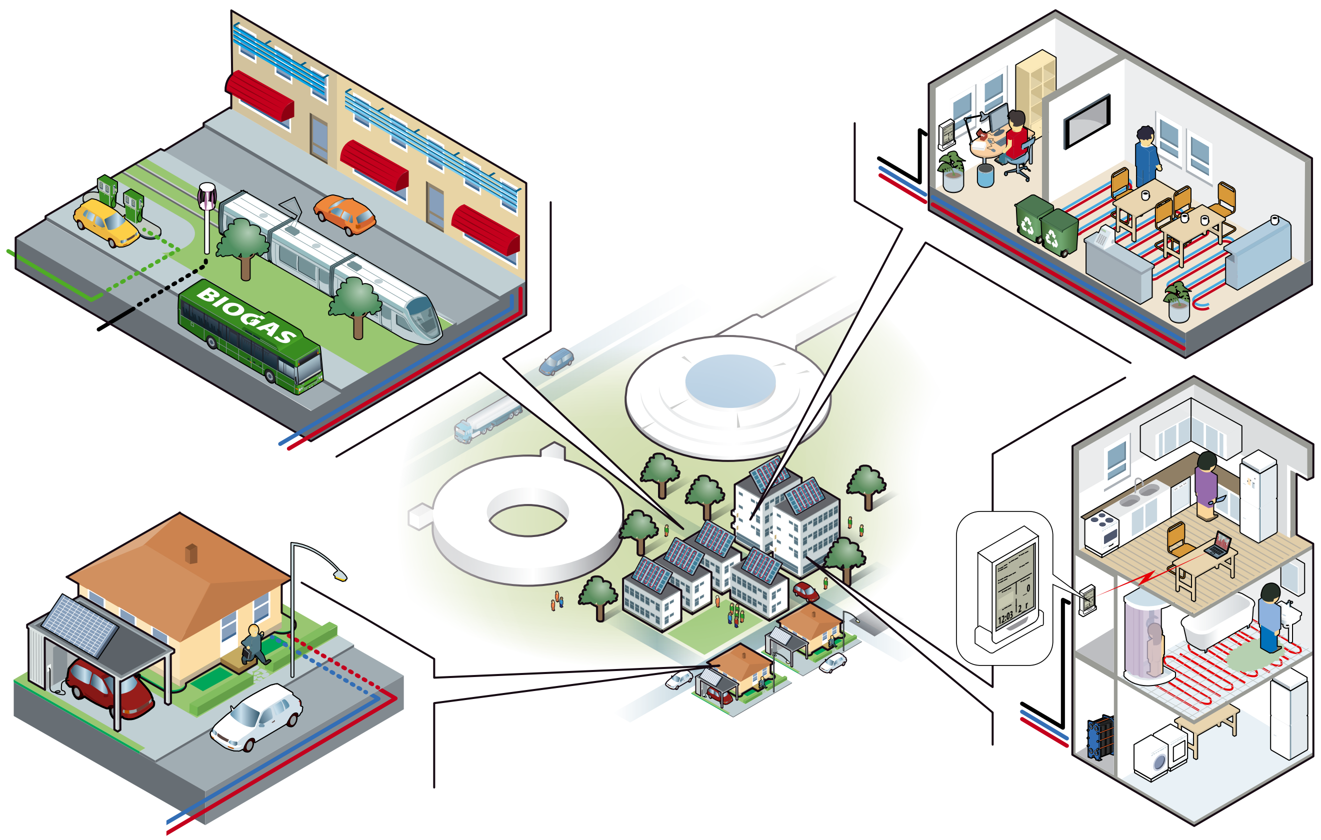
**4 CENTRAL ENERGY UNIT**

The central energy unit links up all the facility's cooling and heat systems. By means of various heat exchangers and heat pumps, the waste heat is then conveyed to the district heating network.

**5 CONNECTING UP TO THE DISTRICT HEATING NETWORK**

To avoid waste heat from ESS leading to a periodic excess in Lund's district heating network, there is a possibility to create a larger district heating network by linking up the district heating network in Lund with the networks in Malmö and Landskrona – Helsingborg.

**DISTRICT HEATING** is an intelligent and environmentally friendly alternative that can efficiently utilise industrial waste heat for the purpose of heating homes, schools and other premises, as well as providing hot tap water. More than half of all heating in Sweden and Denmark derives from district heating.



# Recycling 2.0
# Taking Recycling One Step Further

**ESS's commitment to sustainability reflects all aspects of energy management within the facility. In this section, we will take a look at a number of new innovative solutions that could permit us to make use of the low temperature heated water. This would mean taking our commitment one step further by using sustainable, economic and innovative solutions that add value to the climate and society, and generate valuable knowhow that can be shared with others.**

## A world of possibilities

We are investigating the potential of new ways of recycling low heat water (below 50°C) since ESS will generate about 92 GWh annually. In this area, ESS holds a unique possibility to set a new standard on how to recycle energy. This is due to several favourable conditions that stimulate the development of recycling technology and systems by allowing other parties to utilise the energy excess.

- **ESS is a solid, long-term project with steady annual output of excess energy over the facility's lifetime. This offers an excellent possibility for other parties to operate using this excess.**
- **In cases that demand financial support for different energy recycling research and development projects, ESS is an excellent partner due to its international structure.**
- **The location with proximity to the district heating system of Lund municipality offers necessary redundancy for the usage of excess energy.**
- **ESS's location also enables agricultural use of recycled heat such as greenhouse heating.**

## Recycling of energy and system change

In Europe today, over 50% of the produced primary energy ends up as unused waste heat. This represents a value of €500 billion annually. Recycling of energy is becoming more attractive but there are still many obstacles to overcome. Source to be added by Indebetou.

ESS has a viable solution to recycle its excess energy by converting it into district heating. In addition, new possibilities are emerging. One option is to use the excess energy in the production of food, fodder and bio-fuel. Together with the Swedish University of Agricultural Sciences, SLU (Faculty of Landscape Planning, Horticulture and Agricultural Science at Alnarp), ESS is investigating how SLU can be of help in finding solutions and applications for the recycling of excess energy.

The result can be described as a "hybrid cooling chain" where the surplus energy at sequential stations is extracted and lowers the temperature gradually.

The effect of the proposed production chain is not only outstanding efficiency, in comparison to having each application stand alone with its own energy and production system, it also consists of a closed system with minimal environmental effects. The hybrid system enables recycling of other waste products in the process, such as nutrients. A hybrid cooling chain would enable other technical inventions and allow ESS to contribute to and stimulate the development of multiple research disciplines supporting food, fodder and biofuel production. Some examples are:

- **The next generation of greenhouse technology**
- **Growing in the open air by means of tunnel greenhouses and land cover**
- **Integrated, high-intensity land-based fish farms**
- **Next-generation mushroom farms**
- **Algae cultivation as a resource for biofuels**
- **Microbial fermentation for the production of bio-protein**
- **Nano technology in agricultural systems**

## Other possibilities

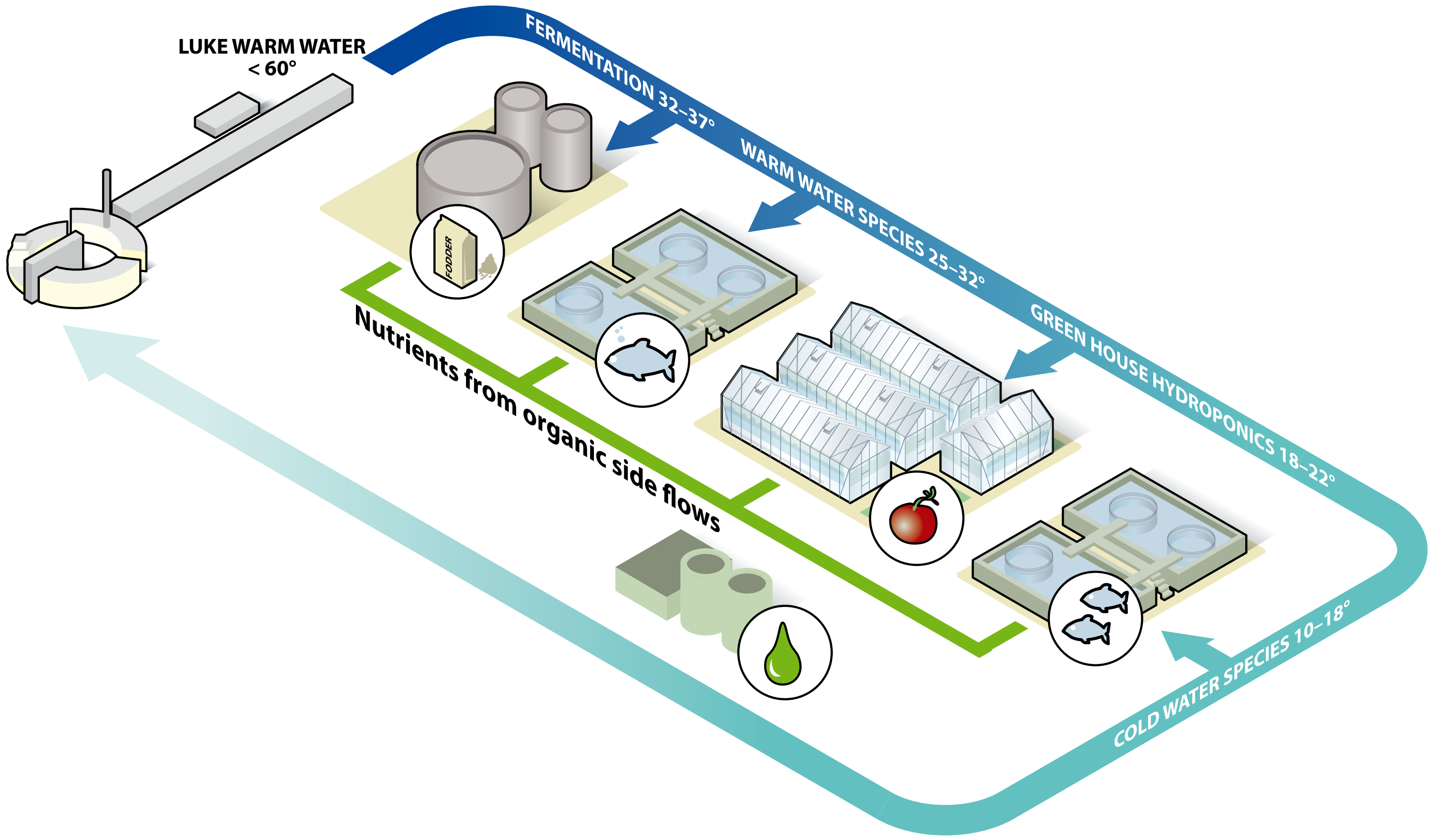
Another option is utilising excess energy in water treatment. The developing area Brunnshög located west of ESS, will require water treatment. Lund municipality has therefore approached ESS with a first draft suggesting how to utilise ESS's low gradient (below 50°C) waste heat partly in the purification process but also to produce biogas from the waste derived from Brunnshög's population.

Since the sewage system at Brunnshög will be completely new it can be tailored to the district's needs by accessing excess energy from ESS. This would allow an anaerobic (free of oxygen) treatment of the effluent by raising the temperature above 30 °C.

Filtration of nitrogen and phosphorous can be done by algae farming binding the substances into the algae. The algae in turn can be harvested and digested into biogas and bio fertilisers.

## Challenges

There are many challenges that need to be investigated before realising these projects. Many financial and legal issues need to be solved, and they may be not be among ESS's first priorities. But ESS has seen it as part of its responsible behaviour to investigate these options. It would certainly connect ESS with its environment in an unexpected, although natural, way and contribute to a social and economic sustainability that goes beyond the walls of the facility.




**SOURCE:** Swedish University of Agricultural Sciences, SLU (Faculty of Landscape Planning, Horticulture and Agricultural Science at Alnarp).

# RELIABLE Secure Supply will Keep ESS Available for Research

**Electric power connections are a significant feature of ESS's energy solution, and present a number of challenges. What is required is a supply of power that offers the appropriate quality and does not disturb the grid, the accelerator, or the research activities.**

For the power supply to ESS, the challenge is to supply electricity of the appropriate quality, with a high level of supply security, to the research facility without disturbing its sensitive equipment and operations. The ESS energy system must be reliable, because a power cut could lead to several weeks of valuable research being lost. Conversely, the ESS facility can also give rise to disturbances in the grid, which may affect other high demand facilities or electricity generation plants. Consequently, it is important to take the necessary measures to avoid problems that may arise in the electric power interplay between ESS and the grid, and also within ESS.

## Research to Minimise Operational Problems

RWTH Aachen University in Germany has specialist expertise in the modelling of complex power systems. Under the supervision of a number of world-leading academics, a simulation model in which the adjacent 130 kV grid and ESS are integrated is being developed and verified. Several scenarios are being investigated to buffer the power flow to ESS. The simulation infrastructure used makes it possible to evaluate different disturbances in real time and study how any impact on the grid and ESS can be avoided. The simulation work performed so far shows that controlling the 14 Hz power excursions caused by the linear accelerator are critical to the successful operation of ESS.

Effective control of the power fluctuations requires the development of a constant power capacitor charger and new control algorithms for the klystron modulator. This task will be the subject of further development work with industrial and academic partners. The intention is to let the klystron modulator manufacturers obtain the design from ESS and integrate it with their products.

## Back-up for Disruptions

Protracted disruptions in power supply result from faults in one or several sections of the power grid. In the event of disruption, the power supply to the ESS facility will be maintained throughout crucial sections. This will be achieved by using a back-up system. Serious damage to the facility can be avoided and the loss of valuable research time will be minimised.

The back-up system could be standard diesel generators. However, large fuel cell based back-up systems are emerging as a viable technology. Fuel cells are much cleaner than diesel units. The energy is stored in hydrogen, eliminating the risk of pollution from leaks, and the only emission is distilled water.

### ELECTRIC POWER GRID IN BRIEF

- A new receiving station will be built and suspended cables that currently cross the site will be laid underground
- The ESS facility is highly sensitive to interference from the power grid. A power outage could lead to the loss of several weeks of valuable research work. Conversely, the ESS facility can also give rise to disturbances along the power grid, which may affect other users or power production facilities.
- ESS – in co-operation with E.ON Nordic and Lunds Energi – has commenced collaboration with RWTH Aachen University, in Germany to simulate complex disturbances in real time.
- To reduce the power variations caused by the accelerator to a safe value, novel control algorithms are being developed by RWTH Aachen University. These will be implemented during the design of the klystron modulators.

# Connecting ESS to the Grid

The high-voltage regional grid runs adjacent to the ESS site and is owned by E.ON. The power lines run between Malmö and Helsingborg. West of Lund, there are an additional two regional lines that may be used as an auxiliary supply to ESS via existing cables, which are owned by Lunds Energi. The key issue is to ensure that the grid is sufficiently robust and offers a high short circuit power (the maximum power that can be drawn from the grid). ESS requires 1,500 Mega Volt Ampere (MVA). In normal grid operation, the available short circuit power currently amounts to 2,600 MVA and, in the event of faults within the grid, to a minimal 850 MVA. By means of relatively simple rebuilding, the minimal short circuit power can be increased to 1,900 MVA.

Power connections to ESS from the regional 130 kV grid will be via a new receiving station that will connect to the grid. The present day overhead lines, which cross the area, will be replaced with underground cables. This will provide space for planned housing, offices and operations. The new receiving station's transformers and switchgear will supply ESS, the Brunnshög district, and other users with electric power. The station will be approximately 100 x 200 metres in size and will be designed to match the character of the area around ESS.

## Alternatives to Counteract Interference

At the ESS facility, pumps and compressors constitute core parts of the equipment. Start-up current from, for example, motors can lead to rapid changes in voltage or voltage dips that spread throughout the power grid. A 20 MW motor is expected to cause a rapid voltage change of just 2% at 130 kV level, which, in view of the applicable standard, can be allowed to occur three times per minute without resulting in disruptive voltage changes.

The ESS facility's modulators and klystrons can also give rise to interference, which can be expected to emerge at the 14 Hz frequency. The short power pulses (2-5 milliseconds) from the modulators, can propagate throughout the power grid, where they can generate mechanical oscillations in the axle systems of turbine generators in power plants connected to the 130 kV net, eventually causing the shafts to break. The 14 Hz power variations can also be a source of variations in voltage causing annoying flickering of lights. The eye is especially sensitive around the operating frequency of ESS. Therefore, the IEC standards permit only 0.3% voltage variation at the 14 Hz frequency. This limits the permissible power variation from the klystron modulators to approximately 4% of nominal power.

Higher resilience – or immunity level – to various forms of electromagnetic interference results in a sharp reduction in the number of operational disturbances. The transformers in the electrical system are designed to decouple odd harmonics and single-phase short-circuit currents between the power grid and ESS. Nevertheless, all harmonics will cause additional energy losses, typically in cables and transformers, where the heat is not recoverable and in worse case also can damage sensitive equipment.

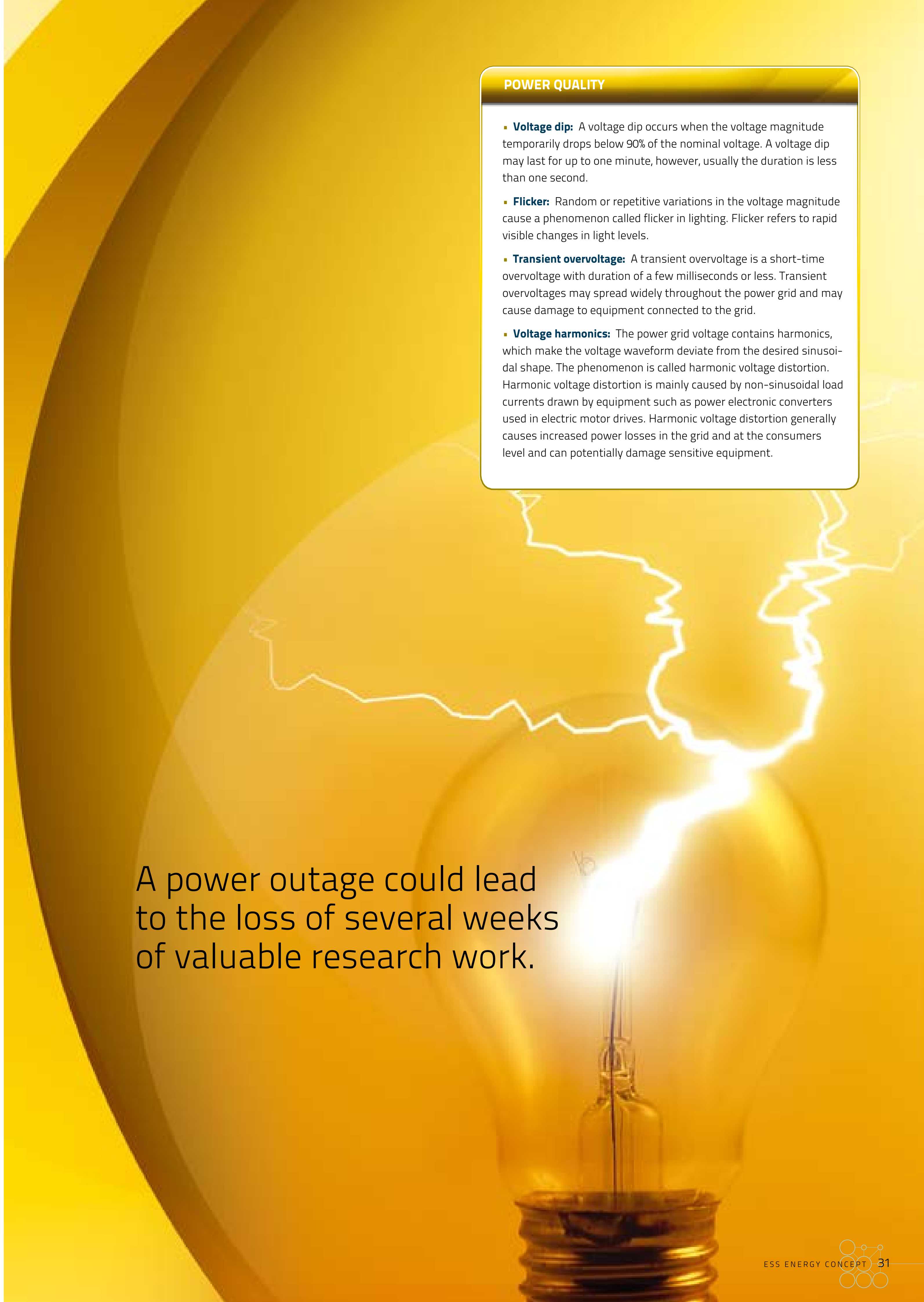
The most effective solution to minimising electromagnetic interference is to handle the problem at the source. Following current harmonised EU directives for all equipment will go a long way in increasing the overall robustness of the plant. Some systems will require specialised solutions. The earthing system in the klystron gallery and the accelerator tunnel draws heavily on the experience from similar facilities. To reduce the power variations caused by the accelerator to a safe value, novel control algorithms are being developed by RWTH Aachen University. These will be implemented during the design of the klystron modulators.

In the case that it is not possible to meet power quality requirements, filters and static compensators will be deployed at the receiving station.

## Surrounding Disturbances will be Minimised

In normal operation, the magnetic field generated from the high voltage cables is not considered to be a problem for ESS. The field produced by the cables is very small and the cables are routed a long distance from the accelerator. The planned tramway from the city centre to Brunnshög must be designed so that its ground cable system does not affect ESS operations. Experience shows that tramways can have an adverse impact on sensitive equipment such as accelerators, which was confirmed at CERN in Switzerland.

Vibration-dampening measures will be used to counteract vibration disturbances from transformers and back-up power units. This means that the electrical equipment will provide fewer disturbances than the traffic on the E22, the motorway running alongside the ESS site.



**POWER QUALITY**

- **Voltage dip:** A voltage dip occurs when the voltage magnitude temporarily drops below 90% of the nominal voltage. A voltage dip may last for up to one minute, however, usually the duration is less than one second.
- **Flicker:** Random or repetitive variations in the voltage magnitude cause a phenomenon called flicker in lighting. Flicker refers to rapid visible changes in light levels.
- **Transient overvoltage:** A transient overvoltage is a short-time overvoltage with duration of a few milliseconds or less. Transient overvoltages may spread widely throughout the power grid and may cause damage to equipment connected to the grid.
- **Voltage harmonics:** The power grid voltage contains harmonics, which make the voltage waveform deviate from the desired sinusoidal shape. The phenomenon is called harmonic voltage distortion. Harmonic voltage distortion is mainly caused by non-sinusoidal load currents drawn by equipment such as power electronic converters used in electric motor drives. Harmonic voltage distortion generally causes increased power losses in the grid and at the consumers level and can potentially damage sensitive equipment.

A power outage could lead to the loss of several weeks of valuable research work.

## A COMMITMENT TO SUSTAINABILITY

On 28th May 2009, the decision was made to establish the European Spallation Source, ESS, in Lund. The winning bid of Sweden and Denmark was committed to applying an Energy Management Strategy with the vision of a sustainable research facility "in order to minimise costs, lower the environmental impact and factor out the variability in energy costs". In contrast to other research facilities and other ESS design proposals, ESS Scandinavia had established an energy concept.

The concept Responsible, Renewable, Recyclable and Reliable will make ESS operations a net sink for carbon dioxide and therefore contribute greatly to the sustainability of the facility. Add to this the research the facility will enable, which will also contribute to sustainable development in a way that is not possible today.

Knowing the large amounts of energy that the facility will need, ESS Scandinavia had previously initiated collaboration with various energy companies. One was Lunds Energi, whose district heating network provided the inspiration to consider how heat energy could be recycled. Consequently, Lunds Energi became a key business partner in the effort to attain ESS's energy goals.

In addition, the energy company E.ON, who had previously conducted a successful and inspiring sustainability project in the Western Harbour district of nearby Malmö, became associated with the work. With its Sustainable City concept, E.ON could help ESS with the key linkage between the energy concept, the conceptual design of the facility, and the immediate surroundings.

Thus, a three-part collaboration was formed with ESS, Lunds Energi and E.ON in the ESS Energy Collaboration Team. The energy companies rapidly mobilised resources to the project, and all worked intensively together on developing the energy concept to which ESS Scandinavia had committed. This report presents the results of the collaboration up to the end of 2012.

**This ESS Energy Report is produced by ESS, E.ON and Lunds Energi.**

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