ECN
energy innovation

ANNUAL REPORT 2001

Energy research Centre of the Netherlands

Cover illustration

ECN's Internet site will have a new look in the fall of 2002. The simpler layout will make the site more user-friendly and will enable its visitors to find more rapidly information about the different priority research areas.

Contents

Preface

2001 was a turbulent year. The attacks on the World Trade Center in New York led to a worldwide reconsideration of the term 'safety'. In addition, whether worsened by the attacks or not, the economy clearly has been less prosperous than in previous years. Both elements have had an influence on ECN. Furthermore, labour unrest at NRG, a joint venture of ECN and KEMA, led to a national discussion about the safety of the nuclear research reactor. Safety is a priority issue for both directors and the Supervisory Board of ECN. Many measures have been taken to ensure that the operational safety of the reactor is beyond doubt. The results of an independent inspection have confirmed the safety of the research reactor. The declining economy also has led to extra measures to reduce costs and ensure earnings. We trust that the measures taken are sufficient to lead ECN through an economic setback.

The importance of sustainable energy has meanwhile permeated the various levels of Dutch society. The number of households that are actively choosing 'green' electricity has grown in 2001 to about 1 million. A significant reason for this is the Dutch government's promotion of green electricity. Studies made by ECN, however, have shown that much of the money earmarked for such incentives has been invested in sustainable energy projects abroad, without adding to existing renewable capacity in the Netherlands. The Government has also recognised this undesired situation. We hope that a package of measures will quickly be implemented so the money set aside for the purchase of green electricity is spent as intended.

In 2001 the Government further defined its role and position concerning energy research. Phase 1 of the Dutch Energy Research Strategy (EOS) project has led to a memorandum from the Ministry of Economic Affairs that was discussed in the Dutch House of Representatives in November 2001. In this memorandum the Government takes responsibility to reach its renewable energy targets. To accomplish this, the development of new technologies and strategies is necessary.

In this regard ECN's research is extremely important. Given the importance, the management of ECN has set their ambitions even higher. ECN's research is therefore largely focused on areas that should belong to the top priorities of international research. This ambition is also included in ECN's mission statement, which was approved by the Minister of Economic Affairs in 2001.

Meanwhile phase 2 of EOS started with the classification of energy technologies. For each energy technology a two-dimensional matrix has to be completed. The two elements are extent of its contribution to reaching Dutch energy targets, and the Netherlands' position as a 'knowledge centre' for energy technologies. The results of this classification will help the Ministry of Economic Affairs to prioritise research financing. However, the danger lies in too rigidly applying the matrix. A relatively small contribution of a specific technology may also be needed in the short term to achieve the transition into sustainable energy economy. We hope that the Ministry of Economic Affairs will keep this point in mind, because ultimately the objective is the long-term transition. The same Ministry suggested in EOS that future financing of knowledge areas should be organised by a tender system. This way of financing would then replace the present institutional financing, but is full of pitfalls. Tendering is generally an excellent way to improve competition, but there are many objections in the case of long-term research. Such research requires continuity, by which investments in knowledge and technology often returns gradually after many years. Discontinuity in financing such research leads to fragmentation, lack of consistency and loss of capital.

Prof.dr. Frans Saris, Chairman of the Executive Board, announced his departure from ECN in March 2002. He has decided to continue his working life as Dean of the Faculty of Mathematics and Physics at the University of Leiden. His departure is a great loss for ECN. With Frans as Chairman of the Executive Board much progress had been achieved in extending ECN's research activities, which are geared towards achieving a sustainable society. We are extremely grateful to him for fulfilling this important role. Peter Wilson has been appointed as the interim Chairman of the Executive Board as of April 1, 2002.

The Supervisory Board expresses its appreciation for the efforts made by the management and staff in this, in many ways, difficult year.

On behalf of the Supervisory Board,

Prof.dr. J.C. Terlouw
Chairman

Introduction

Safety

The terrorist attacks in the United States have greatly increased safety consciousness. As directors of ECN we have continued the long established policy to implement continuous safety improvement. Extra attention has been devoted, not only to increasing awareness in 2001, but also to further improve the procedures for safely operating installations. With co-operation of all the regional parties, much work has been done last year, to renew and formulate a regional contingency plan. Prevention also plays an important part and the reporting and recording of near-accidents is therefore essential. Furthermore, of all the large technological institutes in the Netherlands, ECN was the first to obtain the ISO 14001 standard certificate for safety and environment.

Consolidated result

Price increases caused operating income to increase by 6% (M€ 6.2) in 2001. Despite the reduction in the number of employees of 50 fte's, operating costs increased by 15% (M€ 12.6). Of this, M€ 6.8 was for incidental expenses built up from an overdue disability insurance premium (M€ 1.7) and a transfer of a claim of M€ 5.1 to our retirement funds company Achmea, our pension insurance company. Because of this cost increase and the poor investment results amounting to M€1.9, ECN has suffered a consolidated loss of M€ 8.0 in 2001.

Strategic intentions 2001-2004

In 2001 ECN formulated a new strategic plan. Continuing growth of the markets for energy conservation, renewable energy and clean fossil fuels is expected in the coming years. This will also benefit the interdependent markets for energy research. With this perspective, ECN is strongly continuing its earlier implemented strategy to develop new technologies in collaboration with industry. ECN's strategic intentions for the coming years are also based on the findings of PricewaterhouseCoopers, who were commissioned by the Ministry of Economic Affairs to ascertain the appropriateness of subsidy spending by ECN in the period 1997-2000; this was judged to be satisfactory. As part of the strategic plan a new, more clearly defined mission statement has been formulated.

The minister of Economic Affairs has approved the mission statement on November 16, 2001. In order to fulfil the ambitions in the mission statement, it is absolutely necessary for ECN to continue focussing its research on areas that have the most potential. A first step in this direction has been made by concentrating research on seven priority areas: policy studies, energy efficiency in industry, solar energy, renewable energy in the built environment, wind energy, biomass and clean use of fossil fuels. Each priority area has developed its own strategic plan to further develop into a policy and technology developer within the European knowledge infrastructure. Each of these research areas has a good starting position either to remain or to join internationally the top five of its kind internationally.

Students from the Olympium School (for talented youth) in Heerhugowaard visit ECN .

Mission Energy research Centre of the Netherlands

- Together with the government and industries we work to achieve (and maintain) sustainable energy resources. Through R&D we contribute to the efficient use of energy, the accelerated implementation of renewable energy and the cleaner use of fossil fuels.
- As knowledge centre our priority areas belong to the international top 5. Our work concentrates on technologies and research knowledge that will be applied within several years. This bridges the gap between R&D, universities and the application of knowledge.
- Our research takes place in an inspiring, effective and innovative surroundings, in which we focus on the care for our employees and our environment.

Energy Research Strategy

At the end of 2001 the minister of Economic Affairs submitted the Energy Research Strategy (EOS) memorandum to the Dutch Parliament. In this memorandum the minister expressed her vision of the Government's role concerning energy research. The main theme of Dutch energy policy is focused on the transition to a sustainable energy supply. Within such a context, the Government wishes to stimulate energy research and to help safeguard a sustainable energy supply. Three important trends and developments have been identified in EOS:

- liberalisation of the energy market: in countries that have opened their markets earlier, energy research in the market is more oriented towards the short-term and less on the long-term;
- internationalisation: a shift is taking place from national to European or even global research;
- a new Government role: the Government is shifting its role from field player to manager.

A new course has been announced in EOS. As industry concentrates more and more on the short term, the Government is shifting its focus on the long term. Furthermore, the Government wants to concentrate itself (financially) on a more limited number of topics. Research should become more directed towards areas that contribute the most to solving environmental problems.

ECN's directors note that the Government's principles for policy concerning energy research corresponds with those of the Strategic Intentions 2001-2004. Elaboration of the policy, described in EOS, will take place in 2002. To provide more focused research, a matrix has been set up with all the possible future energy technologies. This matrix will help to discover the contribution that each technology makes to obtain a sustainable energy economy, as well as give an indication of the position of the Netherlands as a knowledge centre for each technology internationally. In 2002 ECN will use all its knowledge and expertise available to make this exercise a success.

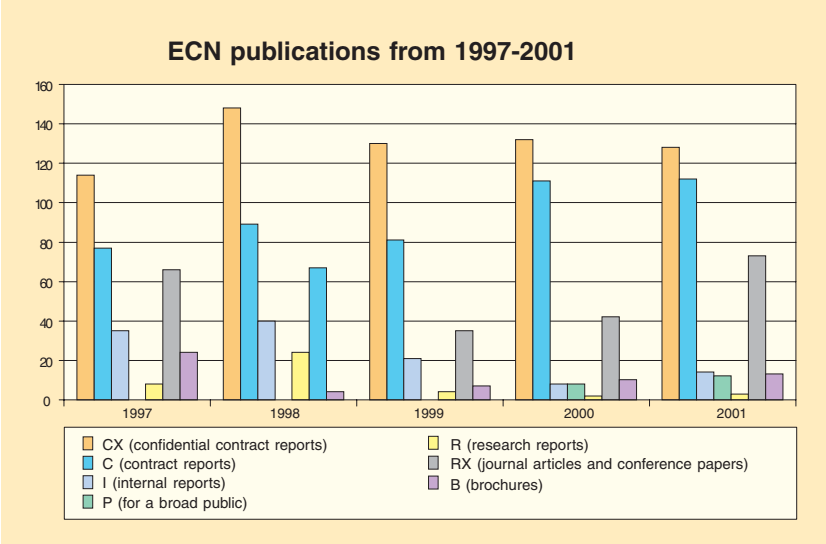


Figure 1. Overview of the number of ECN publications from the last five years (exl. NRG).

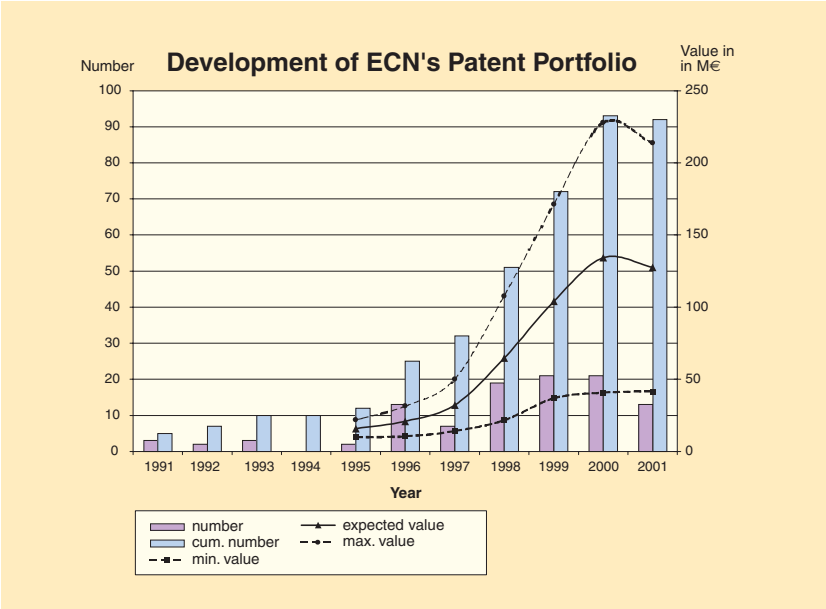


Figure 2. Development of the ECN patent portfolio 1991-2001.

Knowledge transfer

The number of activities in the area of knowledge transfer has considerably increased in 2001 in the framework of ECN's function as national knowledge centre for energy. Early 2001, ECN started publishing its own monthly newsletter and has now over 1000 external subscribers. ECN often receives questions about energy from the public or market parties. In order to improve the information, ECN has opened the Internet portal *www.energie.nl*. This portal gives access to periodical reports, such as the *Dutch Energy Report* and *Energy Market Trends in the Netherlands*. The portal also provides databases and models concerning energy in the Netherlands.

Figure 1. shows that the total number of publications has not noticeable changed. In the context of stronger international competition and the ambition to be

among the top internationally, it is important that ECN publishes frequently in prominent international journals. ECN's management will continue to actively encourage the publication of such contributions.

Patents in 2001

In addition to co-operation with Dutch and foreign universities and research institutes, ECN also intends to use its policy on patents to strengthen its position as knowledge centre. In 2001 thirteen inventions were internally registered and four patent applications were officially submitted. These four applications are described in more detail elsewhere in this report. It seems that the high tempo of inventions, as manifested in the last years, cannot be maintained. Also, a critical evaluation of the patent portfolio has led to a decision to cancel various patents. Furthermore, the estimated value of a number of patents needs to be adjusted downwards, based on better insights into the market and consultations with (potential) licensees. Figure 2. shows the development of ECN's patent portfolio.

Human Resource Management

Energy innovations form an important reason for young people to want to work at ECN. In competition with other employers, ECN will not only have to address this challenge, but must also provide research facilities, innovations and contacts with clients. In 2001 many creative researchers came to work at ECN. Employees of ECN can make themselves known as researchers, while having excellent prospects for furthering their career, because of the co-operation with universities, governments and companies. Due to the internationalisation of education and industry, ECN will also need to become a more attractive employer for foreigners.

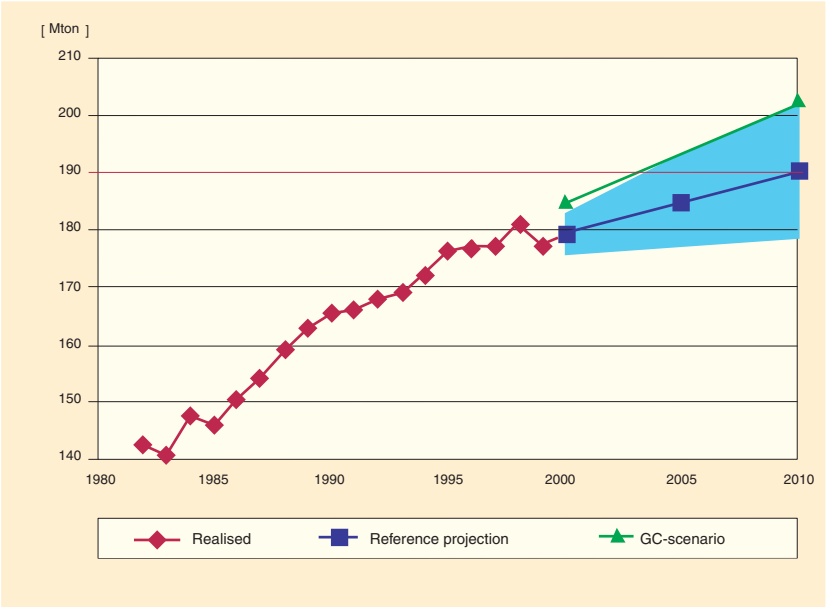
Ir. W. Schatborn, Director
Drs. P. Wilson, Chairman of the Executive Board, interim (as of 1 april 2002)

Policy Studies

The research area of Policy Studies aims to strengthen the synergy between market forces and goals of sustainability by giving independent policy advice to government authorities and various organisations, with a special focus on the integration of national, European and global policy.

In this way ECN Policy Studies plays an important supportive role for the Ministry of Economic Affairs. Examples are the reference projection for energy and greenhouse gas emissions, the establishment of an energy conservation protocol and various activities in framework contracts to support policies for renewable energy and combined heat and power (CHP). Success has also been achieved in European policy topics, particularly regarding renewable energy and the execution of Joint Implementation projects in Eastern Europe.

Figure 3. Projection of Dutch greenhouse gas emissions to 2010 (ECN/RIVM).



Reference projection for energy and CO_2

The Ministry of Housing, Spatial Planning and the Environment (VROM), and the Ministry of Economic Affairs (EZ) commissioned ECN and RIVM to make a new projection of Dutch greenhouse gas emissions up to 2010. According to this projection, the Netherlands' Kyoto target is more easily attainable than was originally believed. This is primarily because of more favourable economic circumstances that include lower expected economic growth, a less energy-intensive economic structure and an increase in imported electricity.

In the new projections the necessary reduction is 40 Mton CO_2 equivalent. The original policy target amounted to a reduction of 50 Mton CO_2, half of which was to be attained abroad. This target is within reach because the thus-far enacted policy is expected to lead to a reduction of 14 Mton CO_2. However, this requires that a part of the planned extra policy, in particular the 'coal covenant' and 'kilometre pricing', be implemented. The Netherlands will also obtain 11% of its electricity from renewable sources in 2010, so it will amply fulfil the target of the European Renewable Energy Directive of 9% in 2010.

Protocol monitoring energy conservation and analysis of savings trends 1990-2010

Energy-saving figures depend to a great extent on the definitions and measuring methods used. To deal unambiguously with monitoring and analysis of detailed energy-saving figures in the Netherlands, a protocol was eventually set up between ECN, CPB, Novem, RIVM and CBS to monitor energy conservation. This protocol includes the detailed rules used by these institutes to discern effects of volume, structure and savings in the different sectors.

Based on this protocol a survey was made of energy-saving trends and policy effectiveness from 1990 to 2000. Energy consumption in the Netherlands increases annually by 1.5%. This percentage is comprised of a volume-effect of plus 3.4%, a structural effect of minus 0.9% and a savings effect of minus 1.2%. The service and transport sectors are particularly characterised by a relatively high growth in energy consumption and a relatively low rate of energy saving. The effectiveness of policy expenditures for energy saving is about 300 MJ/guilder or approximately 23 €/ton CO_2. Effectiveness for the service sector is lower by a factor of two while for CHP it is higher by a factor of two.

Cost sharing for renewable energy targets in Europe

Agreements on renewable energy targets in Europe raise questions about the role the market can play in lowering the total costs to achieve these targets and how this will affect the distribution of costs between countries. ECN Policy Studies was commissioned by the European Union (EU) to look at the bottlenecks and opportunities for international trade in renewable energy together with the realisation of renewable energy targets. A model was thus developed to be able to make quantitative statements about costs and prices in this market. Using marginal cost curves for renewable energy potential per country allows conclusions to be made about both the costs of specific objectives per country and the expected international market prices (REBUS model). International trade can reduce total costs by at least 15%. For individual countries these savings can be as much as 40%. In order to allow this

ECN Policy Studies provides general knowledge transfer of results and experiences through publications such as Energy Market Trends in the Netherlands, Dutch Energy Report and Reference Projection for Greenhouse Gas Emissions in the Netherlands.

market to function well, a large number of conditions must indeed be satisfied. Harmonisation of national green certificate trading systems is, moreover, a prerequisite.

Information services

ECN Policy Studies focuses strongly on distributing the results of the many projects carried out with government financing. Periodic publications, such as the *Dutch Energy Report* and *Energy Market Trends in the Netherlands*, have until now played an important role in this. To an increasing extent in the coming years the new Internet site *www.energie.nl* will also play a significant role. In addition to presentations at many conferences in and outside the Netherlands, Policy Studies also started to organise its own conferences to disseminate results and opinions about current policy issues. In November 2001, a symposium was organised on the interdependence of national and European energy policy, which attracted a lot of attention.

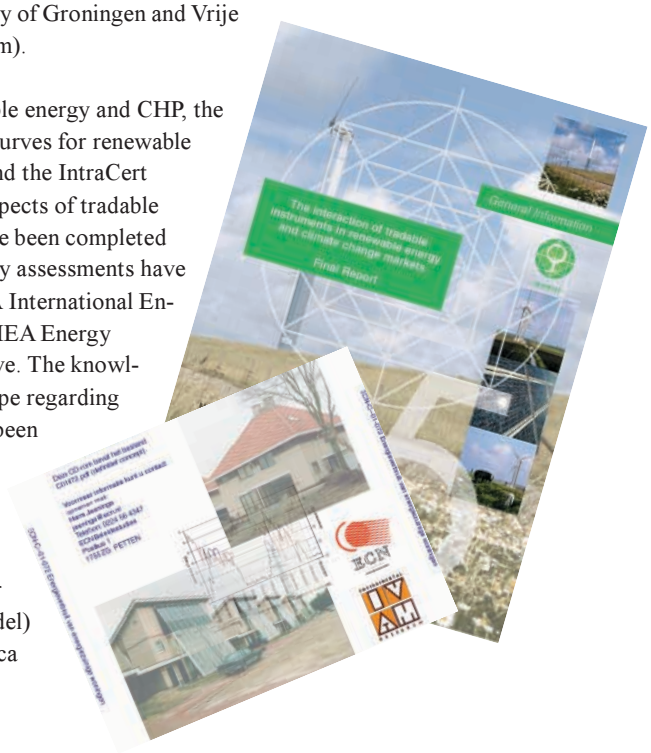
External partners and customers Policy Studies

In addition to the Ministries and the European Union as its largest customers, Policy Studies has carried out many smaller assignments at the national level for a broad range of organisations. To name a few, there have been studies done for AER, Ecooperation, Greenpeace and Novem. Internationally, projects have been completed with JI partners in Eastern Europe and developing countries, with customers including both national – notably Senter – as well as international financiers.

Co-operation

Closer co-operation has developed between ECN and RIVM in the areas of policy evaluation and international climate policy. The reference projection that forms the basis of the Dutch Energy Report and the Climate Policy Evaluation Framework has been jointly formulated, and work is being done together on a joint-use national energy model (PIE). Co-operation with the IPCC Technical Support Unit of IPCC Working Group III, which is currently based at RIVM, increased especially for the production of the IPCC Third Assessment Report. There is also university collaboration in fields of climate-related research such as technology and behaviour (University of Twente and Eindhoven University of Technology) and flexible instruments (University of Groningen and Vrije Universiteit Amsterdam).

In the area of renewable energy and CHP, the REBUS model (cost curves for renewable energy per country) and the IntraCert project (integration aspects of tradable green certificates) have been completed for the EU. Technology assessments have been made for the IEA International Energy Outlook and the IEA Energy Technology Perspective. The knowledge acquired in Europe regarding green certificates has been transferred to and applied in China on behalf of the World Bank. The first initiative leading to transfer of the MARKAL (model) to CSIR in South Africa has been made.



Energy Efficiency in Industry

Saving energy and increasing energy efficiency in industry is one of the cornerstones of the Dutch Government's policy to fulfil the Kyoto agreements. New technology and system innovations are essential and must lead to drastic improvements. ECN research in the priority area of Energy Efficiency in Industry (EEI) is oriented towards innovative separation technologies based on inorganic membranes, upgrading and utilisation of industrial waste heat, and process intensification by combination of (chemical) reaction, heat exchange and product separation.

Separation technology

Almost half of the energy consumption of the Dutch process industry is used for separation of products. Especially separation by distillation is extremely energy intensive. In many cases these energy intensive unit operations can be replaced by membrane techniques such as pervaporation and gas separation. It is expected that such techniques could save 30 PJ/year in the Netherlands.

Pervaporation

In 2001 ECN further developed its pervaporation technology, the selective vaporisation (and thus separation) of components from a liquid mixture through a ceramic membrane, for industrial application. Sulzer Chemtech opened a new production facility in Germany for these membranes based on ECN technology. Membrane production is set up using two robots that apply the membrane layers and weld the assembly joints to the membrane tubes. The first installation will be placed in Italy by the end of 2002 with a membrane surface area of 40 m^2. ECN's research has been primarily aimed at optimising the performance of this specific membrane under industrial conditions with regard to separation efficiency in dehydration applications and long-term flux stability. Tests still need to be done to show whether the optimised membrane fulfils all the requirements.

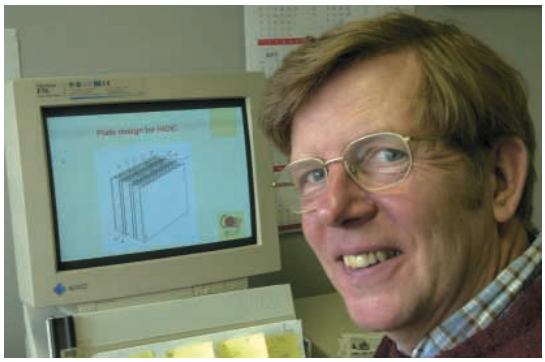
Based on this technology a follow-up project has been set up in which membranes are developed for (m)ethanol separation. The first results are promising. It appears that the state of the art membranes have a good performance in various applications with respect to flux (quantity) and selectivity (purity). Also the results in terms of energy savings are very positive. For example, with these membranes applied methanol removal from a THF flow produces a 50% energy savings compared to the standard distillation process

Compact heat exchanger makes distillation more efficient

In the petrochemical industry approximately 40% of all energy is used for distillation, a common separation method for liquids. Conventional distillation has a low efficiency. The liquids are brought to the boil in the lower part of the distillation column, where upon the vapours are cooled and then condensed in the upper part of the column. The heat thus released often cannot be used. Many proposals have been made to improve this, but up to now very little has actually been done in practice.

In an existing patent, a Japanese consortium describes a distillation column in the form of a heat exchanger. Heat is exchanged between the upper and lower parts of the distillation column. The two halves of the column are connected by a compressor, which ensures that the upper part of the column reaches a higher pressure and temperature. Once this happens the released heat from the condensing vapours can be used to bring the fluids in the bottom of the column to the boil. Although energy is needed to create a pressure difference, the 'heat-integrated distillation' saves net energy compared to traditional distillation.

Jim Hugill (see photo) has developed a variation on the Japanese patent. He wants to replace the heat exchanger consisting of tubes within a shell pipes by an exchanger with plates. This makes the heat exchanger more compact, which better satisfies the current wishes of industry to make smaller production facilities while maintaining the same rate of production. The plate concept also provides more flexibility to arrive at an optimal geometry. This makes the compact heat exchanger a better option for integration than the standard models. Hugill hopes that his invention clears the way for integrating alternative heat exchangers that make distillation more efficient.



(3.4 PJ/year globally). In addition to further membrane development, research is also being done with Sulzer Chemtech and TU Delft on applications for the end users (Lyondell, Cytec, Akzo Nobel, Quest, Purac and Unichema).

Gas separation

To separate hydrogen, composite membranes of palladium and silver appear very suited. The membranes are initially intended for application in fuel cell vehicles. A special method has been developed to guarantee a homogeneous membrane assembly. This is necessary to prevent a reduction in stability owing to hydrogen embrittlement. The knowledge and equipment to accomplish this method has been put at the disposal of the University of Utrecht, in the NWO-JapanTech project, which also involves the Twente, Eindhoven and Delft universities of technology. In a project partly financed by Novem research was done to determine which industrial applications of this type of membrane have potential. A survey has been made of approximately 20 (petro)chemical processes. Application in steam cracking and hydrocracking was further elaborated with detailed process calculations. For the time being, the results for these applications in terms of energy saving potential are disappointing. This has to do, in particular, with the fact that with this type of membrane the hydrogen becomes available at relatively low pressure and that it has to be used again elsewhere in the process at higher pressure. Raising the pressure requires expensive and energy-intensive hydrogen compressors, so the earlier obtained benefit is completely nullified.

Waste heat technology

In the Europort and Botlek areas approximately 40 PJ of waste heat is generated annually and cooled to ambient by air or cooling water. ECN is developing techniques to exploit this surplus energy. By doing this the Netherlands can save at least 15 PJ/year over a period of ten years. ECN is primarily concerned with the development of specific heat pumps that can convert waste heat into process steam or cooling duty.

Thermo-acoustic heat pump

ECN is developing a thermo-acoustic heat pump within the framework of an EET project. This pump converts heat into acoustic energy, which is then used to pump heat to a higher temperature level. A temperature difference of approximately 100ºC was measured in an initial, unloaded set-up. At the moment research is being done to determine how efficiently power can be extracted. Furthermore, preparations have been made for the construction of a waste-heat-driven and a burner-driven test set-up of 1 kW. For the waste heat

Hassan Tijani checks the construction of the thermo-acoustic heat pump.

set-up, a multistage generator unit has been made, which better amplifies the acoustic wave. For the burner-driven version, a radiation burner appeared the best option to supply power.

With the help of Computational Fluid Dynamics (CFD), calculations were made for four different geometries of the resonator. A careful evaluation revealed a good agreement between the calculations and experimental results. The lowest energy losses are attained when the geometry of the resonator resembles the shape of a dog bone

SWEAT heat pump

Solid/vapour heat pumps can achieve a large lift in temperature, and thus convert residual heat into valuable process steam or cooling duty. The Salt Water Energy Accumulation and Transformation (SWEAT) system is an example of such a heat pump that is being developed by ECN. In 2001 a solution had to be found to remedy corrosion of the system's wire-fin heat exchangers caused by the presence of very corrosive salt. Together with a coating supplier and a heat-exchanger manufacturer has been developed a coating recipe in combination with a deposition technique that satisfies all the technical requirements and is at the same time very cost-effective. This clears the way for the construction of the system prototype.

HEX reactor

A production process can be radically improved by combining different sub-processes. An example of this is the Heat Exchange (HEX) reactor, in which a chemical reaction is initiated in the channels of a heat exchanger. Through a contract from Novem and in collaboration with Process Design Centre and Chemserve, ECN investigated two chemical processes for a short-term demonstration project: emulsion polymerisation and toluene oxidation. The first process appears too complex for application in the short-term, however, it could save the Netherlands 0.25 PJ per year. The second process still needs to be evaluated. A broad survey of applications provides a list of the 61 processes that were inventoried, of which oxidation processes form an important group. These processes are highly exothermic and are also known for their selectivity problems. Further screening has furnished six processes that will be investigated in 2002.

Test installation with 1 m^2 ceramic membrane surface used by the (chemical) industry to study the dehydration of process flows by means of pervaporation.

External partners and customers Energy Efficiency in Industry

Akzo Nobel, Caldic Chemie, Corus, Cytec, Diosynth, DSM, DuPont, Lyondell, Novem, Nuon, Senter, Shell, Stork, VNCI, etc.

Solar Energy

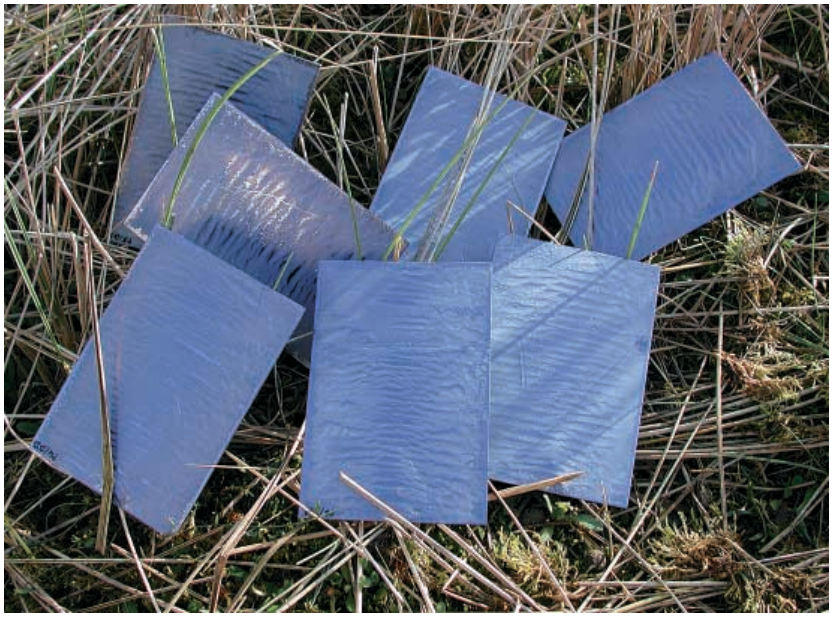
The year 2001 marks a clear change in Dutch policy concerning photovoltaic solar energy (PV). This holds for implementation as well as research and development. It was decided to terminate the preparations of a new covenant for the period 2001-2007, and the National Research Programme Solar Energy (NOZ-PV) was replaced by the broader Renewable Energy in the Netherlands (DEN) programme. Since the ECN research programme, partly on the advice of the External Review Committee and Programme Advisory Committee, aimed at supporting the carrying out of the PV-Covenant, this change in policy has important consequences for the priority area Solar Energy. These, however, will only become fully visible in 2002.

It is clear that PV will also be able to develop itself without a covenant or national research programme, albeit in a less focused and co-ordinated manner. It is therefore necessary to organise the PV sector differently, so that implementation bottlenecks can be identified and solved in time. Only then can the Netherlands continue to play a significant role in this global growth sector. ECN will do its utmost to motivate PV parties to maintain their enthusiasm and commitment (also financial) and to limit disinvestments. Furthermore, for as far as possible within the boundary conditions of available financing, efforts will be made to strive towards further internationalisation, especially within Europe, where ECN already has a good or leading position in different fields of research.

The general aim of ECN Solar Energy is to enable and promote large-scale application of photovoltaic solar energy in the Netherlands and abroad. This should mostly be achieved by increasing the utilitarian value of PV, lowering the costs for generating electricity, optimising and assuring quality, and by improving the sustainability of PV components and systems as a whole. The research of ECN Solar Energy is currently organised in three programmes: Advanced Crystalline Silicon PV Technology, Thin Film PV Technology, and PV Systems.

Crystalline silicon technology

The application of modules based on crystalline silicon technology will continue to take place on a large scale in the next 20 years. This ECN programme remains fully dedicated towards improving system performance and lowering the cost of electricity generation. The agreement signed with Bayer to further develop the Ribbon-Growth-on-Substrate (RGS) technology was already reported in last year's Annual Report. This technology will enable silicon wafers to be produced at high speed (1 wafer/sec) and low cost (no losses or costs related to sawing). At the beginning of 2001



The first wafers produced with the Ribbon-Growth-on-Substrate (RGS) technology achieved 8.6% efficiency.

Bayer's installations were brought from Ürdingen (Germany) to ECN. The first wafers were already made in the spring and by now some 40 runs have been carried out. The first results are extremely encouraging. Cells made with ECN's baseline process on RGS wafers have achieved up to 8.6% efficiency. In collaboration with Philips, the design of a bench-scale machine has been completed, and ECN is now seeking a partner who will build this machine.

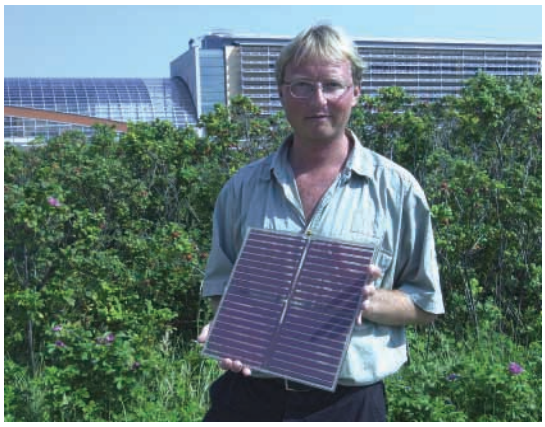
The European Ace Designs project was finished in 2001. In collaboration with different partners (University of Konstanz, Fraunhofer-ISE, IMEC, BP Solar, Eurosolare), ECN developed cells that have all electrical contacts placed on the back. This project may rightly be called a great success. With this type of cell, all partners attained efficiencies of 16 to 17%. BP Solar will take the 'metallisation-wrap-around' technology into production. ECN has applied a conductive epoxy specifically for the interconnection of 'back-contact' solar cells. The stability of the conductive paste appears excellent. Tests in a climate chamber (2600 hours at 85°C and 85% relative humidity, 55 temperature cycles of -40°C to +80°C) show that the connections do not degrade under such conditions.

In 2001 a prototype of the Contact-Resistance Scan apparatus (CoReScan) was made. This device helps determine the distribution of contact resistance and potentials over the surface of solar cells. Such a detection method has helped achieve significant results in finding the causes of inhomogeneities in the contact resistances formed during the manufacturing process. It has thus been ascertained that the temperature difference over the width of the conveyor belt in the

furnace, which is used to sinter the metal contacts, is considerably greater than originally thought (40°C instead of 3°C). The CoReScan was introduced in 2001 at the 17th European Photovoltaic Solar Energy Conference and Exhibition in Munich. Great interest was shown there, and since then Sunlab has responded to dozens of invitations for tenders.

Thin film PV technology

Cells using sensitised oxides (including dye-sensitised cells) and organic (polymer) solar cells form an important part of ECN Solar Energy's research programme in the area of thin-film PV technology. The first generation of dye-sensitised solar cells has meanwhile developed to such a level that work is being done on scaling-up the surface area and the laboratory manufacture of larger numbers. The objective is to raise the efficiency of dye-sensitised cells within a few years to 10% (not as a record, but as a regular result), while in the longer term at least 15% should be attainable. Polymer solar cells are not nearly that far developed, but by combining research efforts in the Dutch Polymer Institute, of which ECN also is a member, important themes such as efficiency and stability will be dealt with very actively. Obviously, both types of cells are developed because they offer the prospect of being able to compete in the long term with other PV technologies in terms of price/performance ratio or other aspects.



Martin Späth with a prototype of a 30×30 cm² dye-sensitised solar module containing 4 integrated cells and fabricated at ECN.

In 2001 ECN achieved a significant result related to the cell efficiency of a solid-state dye-sensitised cell, made with simple techniques. This entails use of the well-known ruthenium (Ru) dye as a sensitiser, but replacement of the liquid electrolyte by a solid-state hole conductor, in this case CuSCN. An efficiency of 2% has been achieved for this Ru-dye/TiO_2/CuSCN cell.

In collaboration with the German institute INAP (Institut für Angewandte Photovoltaik), the university-affiliated Freiburger Materialforschungszentrum, plus the Swiss company Solaronix, ECN has developed a dye-sensitised solar cell of 2.5 cm² with an efficiency of 8.2%. This is the highest efficiency reached with this type of solar cell of more than 1 cm². In the laboratory the researchers have optimised a manufacturing method in terms of reproducibility, stability and ease of production at a larger scale. The lifetime of dye-sensitised solar cells is still considerably shorter than that of silicon cells, but significant improvements have been made on this point in the last year, particularly owing to increased insight into degradation mechanisms. The present dye-sensitised solar cells are expected to be able to operate for at least five years. The objective of ECN research is to ensure that they last for at least 10 years.

The second part of this programme concerns inorganic thin-film solar cells, with silicon films as an important representative. In a national consortium (Mission-N), microcrystalline silicon is being developed that, in combination with the already widely applied amorphous silicon, should make it possible to reach a stable module efficiency considerably over 10%. It is crucial for a cost-effective production of this microcrystalline material to increase the deposition rate to at least 1 nm/s. It has been shown in the past year that this is possible with remote microwave plasma deposition (MW-PECVD). Figures 4a and 4b show a cross-section of the microcrystalline material deposited with MW-PECVD and a related X-ray diffraction spectrum, which gives information about the crystal orientations in the film. Further research will need to show whether this material is also suited for application in thin-film silicon solar cells.

PV systems

The total system for conversion of light into usable (electric) power ultimately determines the relevant price and performance. Research in the area of PV systems, however, has a serious image problem. Despite the considerable amount of solar energy that is lost owing to failure of inverters, faulty installation and less than optimal system design, it is increasingly difficult to find financing for this part of the research. PV system technology may appear fairly trivial and typically a responsibility of market parties. Although some system-related problems will undoubtedly solve themselves, the question is whether one can afford to wait for this to happen. In addition, the so-called balance-of-system (the whole system including installation, except the modules) comprises about 50% of the total costs. In Germany, for example, these are reasons to elevate system technology to a spearhead position. System technology therefore also still plays an essential role in ECN Solar Energy's research.

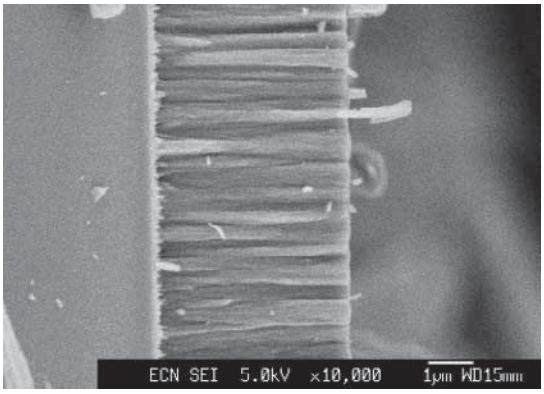


Figure 4a. Cross-section of a microcrystalline silicon film.

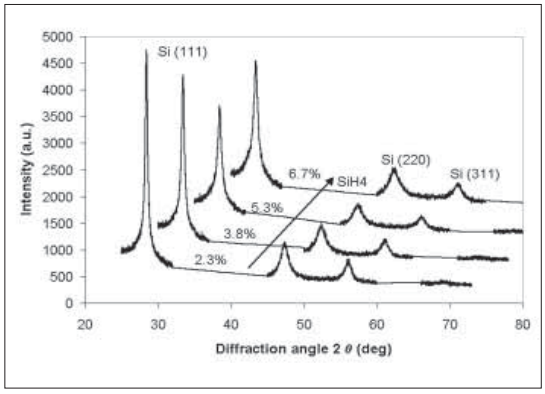


Figure 4b. X-ray diffraction spectrum of a microcrystalline silicon film.

When a PV system does not function optimally, the cause can sometimes be found in the separate modules. A panel that provides no electric power appears about 2°C warmer than a panel that partly converts the solar energy into electricity, as is intended. Thermography with the help of an infrared camera can make small temperature differences visible. This technique was tested by ECN for this purpose in 2001 and proved very successful as an instrument to quickly locate defects in the PV modules or the installation. In particular, panels that are not easily reached, situated on high roofs or in unusual locations, thus become simple to test. The technique has meanwhile been applied to analyse the PV system on the noise barrier of the A9 motorway south of Amsterdam, for a few building-integrated systems at ECN in Petten, and at a new housing project with a large number of similar systems.

Evaluation and monitoring of experiences with existing systems in developing countries is an important instrument to improve systems for this specific use. A programme has been started for technical monitoring of solar lanterns and solar home systems in Botswana, China and Indonesia. Consequently, it was possible to distinguish the different losses in the system. Shading by trees around the houses and dust on the modules appeared to play an important role here. In addition, important lessons have been learned about the use of the systems and, thereby, the optimal design of systems.

For these Tibetan semi-nomads in Qinghai, China, one solar panel provides sufficient electricity for lighting and the use of a radio. In this way two million households by now have a reliable alternative when no grid connection is possible. ECN monitors the use and operation of small solar energy systems in several developing countries. This helps provide better information on the use of components, and further fine-tuning of the battery.

External partners and customers Solar Energy

EET, various energy companies, the European Commission, Novem, government agencies in the Netherlands and abroad, PV companies (national, international), World Bank, and others.

Renewable Energy in the Built Environment

The Dutch Government's energy and climate policy objectives can only be achieved if buildings are designed to use energy more efficiently and, thus, make more use of renewable energy sources such as sunlight and ambient heat. ECN's Renewable Energy in the Built Environment (DEGO) Group develops the technology needed to substantially increase the share of renewable energy in buildings, and attention is also placed on measures in the area of energy efficiency. An integrated approach is applied, by which various innovative techniques are incorporated in the design of a new building, a renovation plan or a whole district. DEGO also develops components and subsystems. Research is carried out in co-operation with the building sector and its suppliers, as well as university departments.

Extensive measuring system monitors the test house.

In past years the building sector has become increasingly busy with issues of energy efficiency and renewable energy. This is partly in response to the continuously growing demands by both government and customers for increasingly higher energy performance in houses, commercial and public buildings, and districts. The Government's targeted incentive programmes, for example, in the field of photovoltaic solar energy (PV) and heat pumps, also stimulate this market. The increased interest in energy conservation and renewable energy has resulted in more research assignments for DEGO.

The degree of ambition of the DEGO programme manifests itself in its long-term objective of working towards 'energy neutrality'. Energy neutral means that the annual energy demand can be produced with locally obtained renewable energy sources. This development was started in new building projects, because innovative energy concepts for this sub-sector are the first to be developed and applied. This technological development has an influence on other sub-sectors: new commercial and public buildings such as offices, shops, hospitals, schools, and swimming pools, but existing houses can also benefit from this.

Integrated concepts

Energy-neutral houses

In 2001 a series of experiments with renewable energy systems, which are energy-efficient, maintain comfortable living conditions and are integrated into building design, were carried out in the four test houses at ECN (Petten). The experiments are aimed at achieving an energy performance coefficient (EPC) of 0.5, which is half the energy use compared to current requirements. The results of this are used to compile a series of measures that can lead to this greatly improved energy performance, and also satisfy the conditions for large-scale application. The most important pre-conditions are acceptable costs, a good indoor climate, even in the summer, and an improved environmental performance over the whole life cycle of the building. The energy performance level thus achieved is a step up towards energy neutrality. Lowering PV costs and improving PV integration into buildings in particular, could make it possible to construct energy-neutral houses on a large scale. Energy-neutrality is already being applied on a modest scale. An example is the 'zero-emission' house in 'De Edele Steen', a residential area in Anna Paulowna, for which ECN designed the energy blueprint in 2001. The heating demand in this house is greatly reduced and a combination of renewable energy technologies is used to satisfy the remaining energy demand. These include PV-generated electricity, solar collectors built into the façade that provide heat, and a heat pump that makes use of heat in the ground.

Residential areas and business parks

For the development or renovation of a residential area, there are very good possibilities to limit energy consumption and make maximum use of renewable energy without incurring large additional costs. Two examples of areas where ECN designed and incorporated an 'energy vision' are the Noordstrook in the Schalkwijk in Haarlem and the Nieuw Den Helder Centrum. From these and similar studies it appears that a reduction in the use of fossil fuels of an order of magnitude of 50% is in many cases achievable.

In 2001 research was also conducted on the energy management of existing or future business parks. Furthermore, attention was also paid to the necessity for a new energy infrastructure and the way in which this can be exploited. An example of this would be Boekelermeer, the future business park in Alkmaar. Wind turbines will be placed here, and the companies will be connected to receive waste heat from the provincial household refuse treatment plant. More stringent energy-performance requirements apply to all the companies located here. This will make Boekelermeer

Water meter as an alarm signal

In the near future the periodic use of water, gas and electricity will be monitored by electronic meters. These modern meters, which are already being used in a number of Dutch cities, emit an electronic signal (or pulse) for each unit used. A computer chip in the meter records the times when the resident is using water, which establishes the regularity in the resident's living pattern. An accident or illness causes a deviation in the pattern, so the emergency services are automatically alerted. Elderly people who want to continue living on their own are the ones who would benefit most from this development, because they would not need to operate any switches or wear a portable transmitter.

Of all the houses in the Netherlands 97% are equipped with a water meter, which will increasingly be outfitted as a 'pulsing' meter in the coming years. Jan Römer has applied a patent for his idea of linking an alarm installation to an electronic water meter. This construction is a simple version of ECN's 'life-alert monitoring' project. By combining the usage pattern determined from the water meter with occupancy detection via infrared sensors, the behaviour of residents can be reliably recorded without having to use cameras. If a resident becomes unable to call for help because of an accident or illness, an alarm signal will be triggered automatically.

A water meter as part of the alarm system.

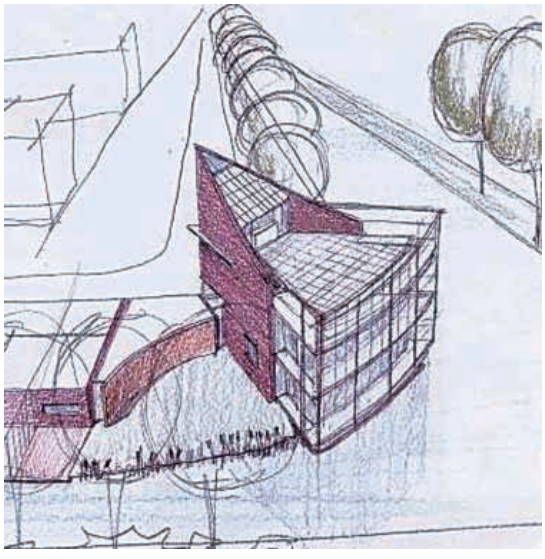
Jan Römer shows the occupancy detector that combines with the water meter in the alarm system.

Currently, calling out for help at the time of an accident depends largely on actions that the resident must do themselves, such as wear portable transmitters, pull cords or press switches. This does not always work in practice, because elderly people can forget to turn on their transmitters, etc. In addition, there can always be situations where the victim is unable to reach the alarm switch. The water meter as an alarm signal to call for help makes it unnecessary for the victim to do so. Moreover, this invention reduces accident-response time.

one of the most sustainable business parks in the Netherlands.

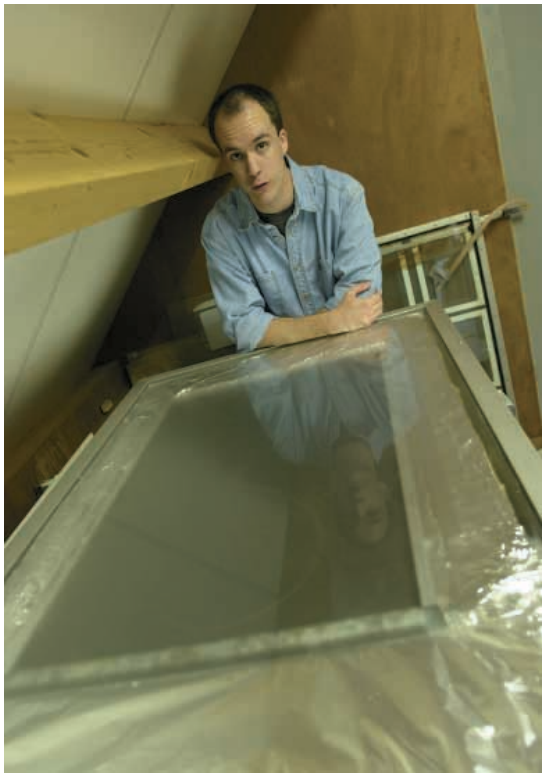
ICT companies

In co-operation with the environmental agency of the city of Amsterdam, ECN looked at how energy consumption in the ICT sector could be reduced. It appears that starting telecom companies and Internet businesses can save twenty to thirty percent of their energy use without incurring extra costs. Efficient cooling is of particular help for this. The overall findings have led to energy saving guidelines for ICT companies, which can be used by the companies themselves, and also by municipal officials. By granting environmental permits, municipalities can stimulate companies to think about energy-efficient design.



Artist impression of the zero-emission house that is planned for construction in 'De Edele Steen', a new residential area in Anna Paulowna.

Marco Bakker explains the prototype 2-channel PVT panel that is now being tested in the Ecobuild test houses at ECN.



Components

Warmth and coolness from the earth

At the beginning of 2001 the measuring programme in the Ecobuild test houses was started at the ECN site. Different ways to use ground warmth and coolness are tested here. This has already produced some interesting results. The ground-derived cooling systems appear to work well. In particular, the system with 'earth tubes' linked to the ceiling for cooling seems suitable for further development to a marketable, large-scale system, which can provide very efficient 'sustainable' cooling in buildings. Heat can be withdrawn from the ground with the use of a vertical ground heat exchanger, and cost savings can be achieved by integrating this into a construction pile. Monitoring projects, in co-operation with TNO, have in the meantime given insight into the performance of these systems. In combination with cooling via the same piles, this becomes an especially cost effective way to save a lot of energy.

Compact heat storage

At the beginning of 2001 a water bag was installed in the crawl space of one of ECN's test houses. Solar collectors heat this water bag up to about 70°C. The heat stored in the water bag is then used to heat tap water, but can also be used for space heating. It has been calculated that the heat capacity of the water bag can be increased by filling it with material that goes through a phase transition so extra heat is stored (Phase Change Material or PCM). Compact heat storage is not only important to increase the share of solar energy used in buildings, but also for the application of heat pumps and micro-cogeneration.

PV Thermal

The development of good quality PV Thermal (PVT) panels has been successful. In co-operation with Shell Solar and ZEN, two trial series of PVT laminates have been manufactured as preparation for a larger, first series of zero-emission houses for a European project in 2002. DEGO is still carrying out experiments to determine the maximum temperatures that can be reached in the panels without affecting their functioning. A prototype two-channel PVT panel has been designed and constructed, which has provided important information, particularly about the mechanical design aspects of such panels. The measurements in the spring of 2002 should show whether the predicted energy yield was attained.

Domotics

Much experience is being gained in the 'domotics' house at ECN with the use of advanced automatic control systems that can contribute to energy efficiency in houses. In particular, the ability to regulate the amount of ventilation based on human occupancy and indoor air quality, and using extra ventilation for home cooling can lead to substantial energy savings. Market interest in this sort of control system is great, especially in the elderly housing sector where combinations with other 'intelligent' features such as life-alerting and security systems are possible. At the end of 2001 DEGO was awarded the 'Sprongprijs' from the NIDO (Netherlands National Initiative for Sustainable Development) for the further development of these systems.

External partners and customers Renewable Energy in the Built Environment

Aedes, BAM Wilma, Brouwer Architecten, De Vries Kozijnen, EC, Ecofys, Econosto, EET, Eneco, City councils of Amsterdam, Haarlem, Groningen, Alkmaar, Heembeton, J.E. StorkAir, Kropman, Limburg Kozijnen, NHP project development, NIDO, Novem, Province of North Holland, Nuon, Rabobank, Senter, Shell Solar, Studio E Architects (UK), TNO-Bouw, TNO-MEP, TUD, TUE, Unidek, Woningstichting Den Helder, Wooncompagnie Schagen, ZEN.

Wind Energy

Installed wind capacity has been growing world wide by about 30% per year during the last 5 years. At the end of 2001 there was 24,930 MW installed wind capacity in the world, of which 17,810 MW in Europe and 520 MW in the Netherlands. At the time of this report the Netherlands is ranked 8th in the world in terms of installed capacity, and it added approximately 50 MW in 2001.

The mission of ECN Wind Energy is to contribute to the achievement of both national and international targets concerning the placement of wind energy systems by conducting research. The focus of this research is on reducing the costs of wind energy, increasing output and the value of wind-generated electricity, as well as gaining public support, while removing uncertainties in the entire development chain of wind turbines.

Wind and Waves

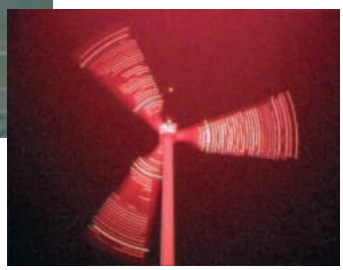
The ENGINE project 'Renewable Energy Forecasting System', which is intended to forecast available wind energy up to 48 hours ahead of time, has produced a working prototype of the forecasting system. Unlike the models that are being developed elsewhere in the world, the supply of both wind and solar energy is considered. Currently, this forecasting system is the only one that gives predictions of wind capacity in the Netherlands on a 15 minutes basis.

Resource assessments have been made for projects in areas with complex terrain, such as in Sri Lanka, Costa Rica and Spain. Based on the measured data, accurate long-term wind regimes have been determined on the sites of planned wind farms. In this way, average energy output of and loads on the wind turbines are calculated.

Wind farm in Costa Rica where ECN conducted resource assessment an micro-siting.

Aerodynamics and aero-elasticity

Research in this area is directed towards the improvement of computational models (development and validation) to be implemented in design software, as well as the development of diagnostic techniques that can be used to increase the energy output of large turbines. In terms of model development and validation, the main project, with the support from the EU and Novem, is MEXICO (Model Experiments in Controlled Conditions), which employs wind tunnel measurements to test fundamental aerodynamic models, such as tilt.



Aerial photographs of a wind turbine near ECN where stall flag experiments are conducted. Right: Light traces of stall flags during a measurement of the BONUS 300 kW turbine.

STABTOOL (a Novem project), in particular, has taken the prediction of aeroelastic stability of large rotor blades a step further. As far as application concerns, the design (together with Polymarin) of the DeWind D80 blade (2 MW turbine) can be mentioned, as well as the design calculation for the Smart Tower concept. An important milestone has been reached concerning the 'stall flag' diagnostic technique, which lead to the PhD – thesis by G.P. Corten from ECN [Flow Separation on Wind Turbine Blades, University of Utrecht, 2001]. This technique has made the stall of wind turbines visible during operation, so that optimisation of the power curve is possible, for example, by the application of vortex generators. This can be done in a substantially shorter amount of time than currently available techniques allow.

Concepts and Design

In the framework of the 'Dutch Offshore Wind Energy Converter' (DOWEC) project, a 6 MW offshore turbine is being developed (rotor diameter 129 m). The intended breakthroughs in this project are the large upscaling step – via a 3 MW intermediate phase – and the transition to offshore conditions. But instead of one, there are two demonstration wind turbines being built and tested in the intermediate phase. The first turbine – about 3 MW – fulfils the role of the original test turbine, while the second is a pre-commercial version.

The cross understanding gained here has greatly improved the rate of progress. Meanwhile, a reference design from the conceptual study has been selected and dimensioned based on the structural loads.

Together with ECN Policy Studies, a model-programme has been developed to map the costs for offshore wind energy at the Netherlands Continental Shelf. In 2001 this 'Offshore Wind Energy Cost and Potential' (OWECOP) programme was improved and further elaborated. Extension of this programme mostly has to do with modelling of the offshore transport and installation of wind turbines and of wind resources. The model-programme now consists of more than 100 parameters, varying from type of turbine to wind farm layout and economic life span. A relatively comprehensive estimate of the cost of offshore wind energy can now be made with the programme. In addition, a probabilistic version of the programme is also available.

Operational Technique and Systems

Future large wind farms, consisting of a large number of turbines, will have to be managed as a power station. If accessibility to the installation is good, it can have a high availability because rapid corrective intervention can take place when problems arise. At sea, where accessibility is much more limited than on land, inadequate O&M procedures can lead to great loss of availability and energy output, despite high reliability.

Efficient management of an offshore wind farm requires the development of a specific maintenance strategies. Knowledge is therefore needed with respect to turbine failure, the deployment of ships and other means of access to the turbines, and the weather conditions (wind, waves, fog, lightning) at the wind-farm site. To develop an optimal maintenance concept based on this knowledge, use should be made of a 'probabilistic cost-model', a cost-model that takes into account the uncertainty of the data. Such a probabilistic cost-model was developed and used in the ENGINE project 'Management of Large-scale Offshore Wind Farms' to set up a maintenance strategy for the Near Shore Wind Farm (NSW). The cost-model can also be used to analyse the damage caused by lightning, a phenomenon, that people think will have an enormous influence on the financial return of an offshore wind farm.

To gain insight into turbine failure, ECN, together with Baas en Roost Maintenance Consult, has over several years developed the 'Maintenance Manager'. In the 'Large-scale Implementation Maintenance Manager' project, the demo version of the Maintenance Manager (MM) was ultimately developed into a version that could be used to manage the daily maintenance of large-scale offshore wind farms. The MM for this project was implemented by the service department of 'Lagerwey the Windmaster'.

The probabilistic cost-model developed by ECN for the maintenance strategy of the Near Shore Wind Farm has helped take a step towards a more efficient management of large offshore wind farms. Source: Ballast Nedam.

Research has also been done to improve the operational and managerial aspects of an offshore wind farm. This has led to an approach that is different from the currently used on shore practices. Modifications have been proposed to improve the diagnostics, the treatment of failures and alarms, to reduce the structural loads and to adjust the rated power for better performance of the entire wind farm.

Measurements

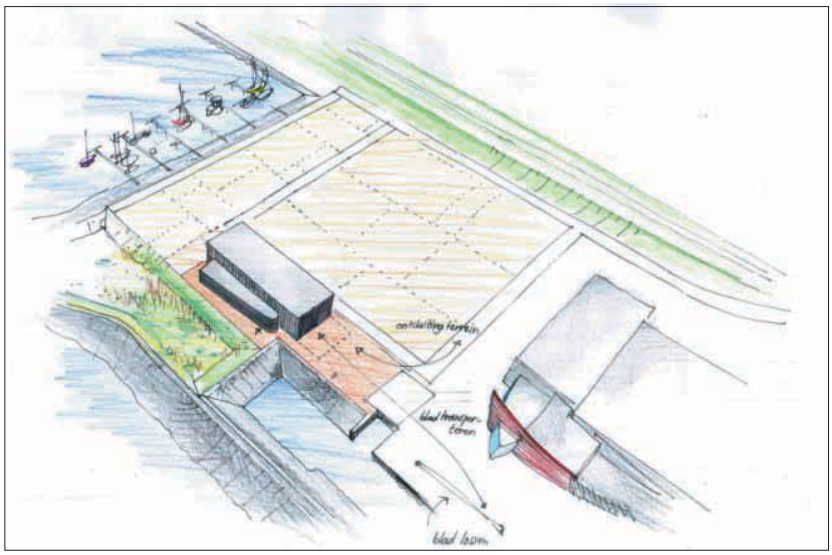
Along with the very rapid growth of wind capacity in Europe, there is also an increasing demand for meteorological (and hydrological) measurements to determine local wind energy potential and external design conditions. ECN Wind Energy has made a design of the total measuring system for the Near Shore Wind farm (NSW) near Egmond aan Zee. This measuring system is a part of the Measuring and Evaluation Programme (MEP). All three different consortia that submitted tenders for the NSW, included a measuring system based on ECN Wind Energy's design.

Special projects

A test wind farm is being set up at Wieringermeer for research on very large wind turbines and on wind farms. Together with 19 neighbouring farmers, ECN established the 'ECN Windturbine Testpark Wieringermeer' (WTW) limited partnership. As managing partner of WTW, ECN acts under the name of another company, 'ECN Wind Energy Facilities'. This company will manage the testing area. In 2001 the environmental permit was obtained to allow construction of the 50 kV connection to the Westwoud sub-station. The testing area has four foundations where prototype turbines up to 5 MW can be tested, as well as a wind farm with 5 turbines of about 1.5 to 2 MW for research on wind farms.

Two kinds of activities will be carried out at the testing area. Wind turbine manufacturers can make an agreement with WTW for the erection and testing of large prototypes, and ECN will use the testing area as an important experimental facility for its research.

Together with TU Delft, ECN is designing a new laboratory to conduct material research and fatigue tests on large wind turbine blades. The new laboratory, which will be realized with financial support from the ICES-KIS programme of the Dutch government and the provincial government of North Holland, is planned to be built in the municipality of Wieringermeer. The business plan for the Knowledge Centre Windturbine Materials and Constructions (WMC) and the preliminary design of the building became available in 2001.



The testing facility of the Knowledge Centre Wind turbine Materials and Constructions.

External partners and customers Wind Energy

Baas en Roost, CORUS, CRES (Greece), Ecofys, Ecotécnia (Spain), ESSENT, KEMA, KNMI, Lagerwey the Windmaster, MARIN TUDk (Denmark), NASA (USA), Netherlands Air and Space Lab, NEG-Micon Nederland, Novem, NREL (USA), NRG, NS-Railinfrabeheer, NUON, Risø National Laboratorium (Denmark), Siemens Nederland, Stentec, TNO-MEP, TU Delft, University of Oldenburg (Germany), University of Wageningen, Wind Constructors International.

Biomass

In a sustainable society an important role will be assigned to biomass for delivering energy and as a substitute raw material for fuel. The ECN Biomass Group contributes to the use of biomass and waste as part of a sustainable energy supply by research, development and demonstrations as well as giving advice to relevant stake holders. Its activities are oriented towards meeting the Netherlands' target regarding the use of biomass and waste.

Biomass is the energy source of the future.

Decentralised conversion

Decentralised conversion of biomass and waste, which generates electricity and heat, has a number of advantages compared to centralised combustion: energy savings owing to lower transport costs, lower transport emissions and lower investments in the electricity distribution grid. For integrated biomass gasification up to about 30 MW_{th} ECN has, in close co-operation with HoSt (a turn-key supplier), developed a 0.5 MW_{th} circulating fluidised bed (CFB) 'BIVKIN' gasifier with a gas cleaning system 'GASREIP'. The fuel gas produced, which contains less than 1 mg of dust per m_n^3 and is free of heavy tar, has been successfully tested during 85 hours in an 85-kW_e gas engine. Based on this experience, HoSt is building an upscaled version of this gasifier with limited gas cleaning in Romania that uses sunflower husks as fuel and one in Friesland operating on chicken manure as fuel. ENECO intends to realise a small-scale biomass gasification plant that consists of an ECN-type CFB gasifier, a wet scrubber and a gasifier/generator.

Roadside grass: fuel, not waste.

A laboratory gasifier has been used to test biomass-generated fuel gas in a SOFC fuel cell. The gas cleaning occurs in two steps: at the ppm level and then at the ppb level. This 'Proof Of Principle' test was successful. Tests at a larger scale are being prepared.

The two-staged gasifier 'TREPKA' has been used successfully to recover bromine from plastic waste that contains brominated flame-retardants. Use of this installation has also shown that metals can also be recovered, in addition to recovering energy from electronic scrap and shredded auto remains.

The 350 kW_{th} fluidised bed combustor 'NARGUS' has shown that burning coated (waste) material produces a valuable rest material. Knowledge about decentralised waste and biomass combustion will be used in 2002 for a study on the 'Sustainable City', with the purpose targets that the input of drinking water and energy and the output of residues are minimised at the district/city level.

At the end of 2001 ECN together with Shell demonstrated the production of 'green diesel' from biomass for the first time ever. In the summer of 2001, in the framework of a joint SDE project, Shell installed a small test set-up at ECN (Petten).

Green diesel

This set-up is connected to one of ECN's biomass gasifiers, which converts wood (willow) into biosyngas. This gas contains mainly carbon monoxide and hydrogen, which is converted in the Shell test set-up into a long hydracarbons, a sort of wax paraffin with the Fischer Tropsch process. This can subsequently be cracked to diesel that is suitable for direct use in the existing car and truck motors. In December 2001 a long duration test was performed, in which the reactor produced the first 'green' fuels from cleaned biosyngas during a period of 150 hours.

The principle of the Fischer-Tropsch synthesis is actually fairly old. It was applied on a large scale in Germany during the Second World War to produce petrol and later in South Africa during the oil boycott. The integration of a biomass gasifier and a Fischer-Tropsch reactor, however, is new. This is considered to be an important development since it is a mean to produce a commodity fuel out of a renewable CO_2 resource.

An additional environmental benefit of 'green' diesel is that, unlike fossil diesel, it contains practically no sulphur or volatile organic compounds. For this reason, and the fact that the fuels contain only linear chain molecules, combustion is cleaner than conventional fuel.

Meat and bone meal

Since BSE and the foot-and-mouth crisis in Europe there has been about 300 million kilos of meat and bone meal stored in the Netherlands. Because of European regulations this may not, at least not for the time being, be incorporated into fodder. In 2001 the Dutch Minister of Agriculture asked power plants and the cement industry to burn meat and bone meal. Co-firing of meat and bone meal in coal-fired power plants seemed the most practical solution in the short term to dispose of the stored meal. In this way combustion heat can be used to generate electricity.

Meat and bone meal is well suited to be co-fired with coal in coal-fired power stations. It can also be used as fuel in special incineration plants. However, meat and bone meal contains volatile and mineral elements that can have a negative influence on the combustion process. Work at ECN showed also that high concentrations of alkaline metals and chlorine could cause operational problems in the entire operation, starting from the boiler to the smokestack and ash collection system. As part of an ongoing EU project, materials from a commercial installation have been examined, such as material from a clogged flue gas channel. It was ascertained under electron microscope that the deposits arose from the formation of elongated potassium and sodium sulphate crystals that prevented fly ash from flowing freely, and thus led to total clogging. Also in the coming years ECN will also do research to optimise the use of meat and bone meal as fuel, and avoid problems such as deposition and corrosion.

Algae for water and air purification, as a valuable ingredient and to generate 'green' electricity

In the framework of an EET project, an experimental photo-bioreactor was introduced in the spring of 2001 by which, in co-operation with R&D institutes and companies, the possibilities of algae cultivation are being investigated. The reactor is situated on the roof of an office building at ECN (in Petten). Algae grow in aquatic environments, and with the aid of sunlight convert simple inorganic substances (N, P, CO_2) into useful products. They can also treat exhaust gases and wastewater biologically. Algae productivity is, per unit of area, two to five times higher than traditional agricultural crops or energy crops. Furthermore, algae can remove nitrogen compounds and phosphates from wastewater and remove CO_2 and No_x from exhaust gases. Other valuable ingredients can be obtained from the algae mass for foods, cosmetics, etc., and the remainder of the biomass can be used as a biofuel for renewable energy production.

'Green diesel' from biomass and waste produced via the Fischer-Tropsch synthesis.

In an earlier project at Suiker Unie in Dinteloord, a 30-liter bioreactor is operating and succesful cleans flue gases and wastewater. As part of an EET project, ECN has recently placed an experimental 60-liter outdoor bio-reactor in which algae grow under realistic conditions. A selected type of algae that produces high-quality fatty acids was successfully grown during nine months in 2001. The system works trouble-free and is used for an extensive measuring programme.

The aim of the EET project is to optimise the productivity and development of a model to show the effect of the intermittent supply of sunlight and other climatological variables on algae production. ECN is developing bioreactor technology for designers to determine the ideal conditions for algae cultivation: maximum productivity of algae and a high quality product. A system evaluation will take place in 2002, and the EET project will be finished by the end of 2002. Based on the results and industrial interest the algae programme will be continued in the form of a pilot phase.

External partners and customers Biomass

Aarding, ABC, ATO, BTG, CIEMAT, Demkolec, Ecofys, EGKS, Eneco, Essent, Gastec, Gasunie, GDA, HoSt, Kaltschmitt, KEMA, Nedalco, Novem, NPCC, Nuon, Rabobank, SDE, Shell, TNO, TU Delft, TU Eindhoven, Universities of Twente and Wageningen, Volkswagen, Volund, VTT.

Clean Fossil Fuels

ECN Clean Fossil Fuels dedicates itself to research on the use of fossil fuels with the highest possible energy efficiency and the lowest possible environmental impact. It gathers knowledge and develops technology for government and industry. Its activities are divided among four areas or clusters: micro-cogeneration, fuel cell vehicles, 'climate-neutral' energy carriers, and energy and environmental quality.

Micro-cogeneration

A micro-cogeneration (CHP) system can help a household to become self-sufficient in terms of energy by generating its own heat and power. The savings potential of such a system varies from 10% with Stirling engines to 20% with fuel cells. These technologies can help an average household to emit 15 to 25% less CO_2. In addition, a CHP installation ensures less No_x emissions, and in the case of fuel cell micro-CHP there are no emissions at all. It is important, however, that the total efficiency of the system is high enough: less than 95% efficiency could mean to use a more cost-effective alternative by separating electricity generation (from the grid) and heating (with a condensing boiler). The Government can support micro-CHP via mechanisms as EPA, EPN and REB to give additional stimulus to its market introduction. For the Netherlands, the initiative of Cogen and ECN has established the 'Locogen' platform. This platform wants to play an active role in the removal of market barriers created by regulations.

The SAM as a test model for a fuel cell drive system.

Field tests

In 2001 ENATEC (a consortium of Eneco, ATAG and ECN) commissioned the construction of ten Stirling engines, which ATAG incorporated into ten CHP systems. In February 2002 a field test of these systems was started, which will provide useful data on savings in practice.

Work on CHP systems that use SOFC type fuel cells has led to a substantial cost reduction of 23%. Sulzer will build the experimental SOFC cells into a system, which will be field-tested at ECN in 2002.

A third CHP system uses PEMFC type fuel cells. This system requires a reliable, compact and inexpensive desulphurisation unit. In 2001 the first step to achieve this was taken: a sulphur absorbent was found that has a much greater absorption capacity compared to the otherwise frequently used active coal.

ECN has developed a new stack design that was validated in a 2 kW PEMFC stack that performs very well. Meanwhile, the Danish company IRD has successfully applied this ECN design.

Catalysis work from past years on selective CO_2 removal has meanwhile produced results: Shell has integrated the Selox reactor, developed by ECN, into its natural-gas-fired fuel processor (the MIP). These MIPs are meanwhile tested long-term at ECN.

Fuel cell vehicles

ECN Clean Fossil Fuels main priority is the development, field test and market introduction of clean vehicles which are based on fuel cells. This can be an important step towards reducing the emissions of NO_x particulates, hydrocarbons and noise. In 2001 the effects of fuel cell vehicles on the emission of greenhouse gases and particulates were described in a survey of scientific publications. This survey showed that buses and lorries that are equipped with fuel cells can reduce their emissions dramatically. To test ECN's fuel cell technology in practice, ECN purchased the 'SAM', a small and simple electric vehicle that will be equipped with a fuel cell drive system in 2002.

Green Vespa

The European FRESCO project started in 2001. This project is a collaboration with Piaggio, the Italian scooter manufacturer, to design an emission-free scooter. ECN Clean Fossil Fuels is responsible for developing the electric energy supply that will consist of a fuel cell stack and a supercapacitor. Fuel cells,

with oxygen, convert hydrogen into electricity and water. Part of this electrical energy goes directly to the electric motor and part of it is stored in a supercapacitor. The stored energy serves as extra power for acceleration. Since the fall of 2001 ECN has been working with Umicore on a supercapacitor with a power density that can also store a lot of energy. ECN has developed new materials (EMX-1) for the electrodes. These materials enable the production of thicker electrodes, which are beneficial for capacity. Additional to technical benefits, EMX-1 is environmentally sound, different from the material (nickel) that it can replace.

Watergas-shift reactor

In 2001 Shell commissioned the development of an advanced watergas-shift reactor. This is part of a petrol-based fuel processor for mobile applications. The thermal mass of the shift section was reduced. By using an alternative reactor concept, the dynamics of the conversion with conventional catalytic convertors was improved by a factor four, while the start-up time was halved. In the second half of 2001 ECN also did research on alternative watergas-shift catalytic converters. Apparently, existing catalytic converters are not suitable for road use. They are not active enough and, furthermore, are too sensitive to humidity and oxygen. Research on new watergas-shift catalytic converters forms a good supplement to the already developed technology for syngas production by Shell and the technology for CO removal developed by ECN.

Climate-neutral energy carriers

Hydrogen

In 2001 a number of development chain studies were done on the benefits of using hydrogen as an energy carrier. These studies show that adding hydrogen to the natural gas network provides few benefits, unless the CO_2 formed in the production of hydrogen is captured and stored. Decentralised hydrogen production and distribution via a local infrastructure could, thanks to efficiency improvement, lower CO_2 emissions. One condition is, that hydrogen production can take place with a sufficiently high efficiency (80 to 85%). The hydrogen must also be converted in the right way to heat and electricity with the use of, for example, PEMFC systems in the right output categories. The necessity for a flexible and efficient reformer technology is confirmed by the specific studies on hydrogen for residential areas and for buses in Amsterdam.

CO_2 capture and storage

Technologies for the capture of CO_2 are available but still too expensive. Moreover, these technologies waste a lot of energy. ECN is developing membranes and SOFC technology to make the capture of CO_2 process-integrated, less expensive and more efficient. Re-use of the captured CO_2 and conversion into valuable products will considerably increase public support. The possibilities for re-use, however, are very limited. Chemical production from CO_2 is not an attractive route because this would require extra use of fossil fuels. An attractive alternative would be the assimilation of CO_2 into alkaline residues (mineralisation), so the end product can be re-used in an environmentally responsible manner. A new project to address this, commissioned by Shell, has been started, where research is being done on the residues, the application possibilities and the market values. The initial results correspond with Shell's process conditions.

Piaggio's deluxe model X9 scooter; this version still has a 4-cylinder combustion engine. Piaggio and Selin Sistemi from Italy, CEA from France and ECN are working together in the European 'FRESCO' project to give the X9 an emission-free drive system. ECN is developing the fuel cell and supercapacitor. The first prototype scooter is scheduled for testing by Piaggio in 2004.

Energy and environmental quality

Particulate matter and aerosol characterisation

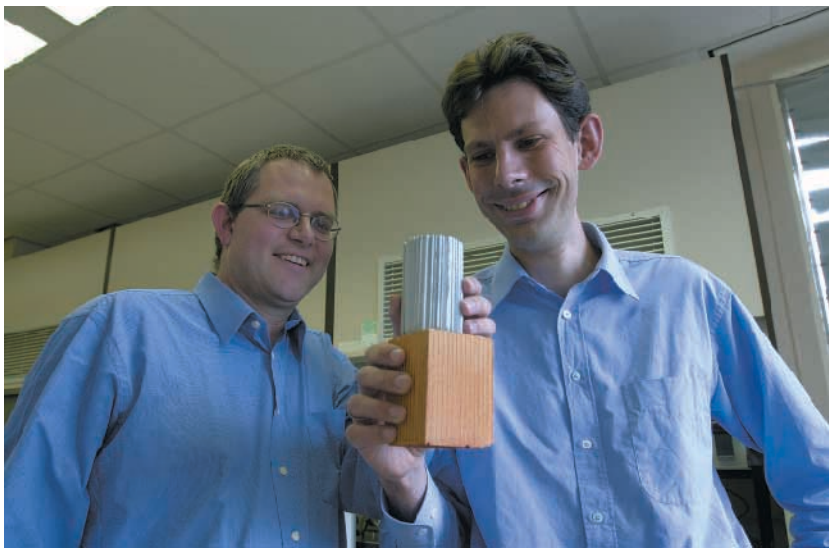
In 2001 substantial progress was achieved with the characterisation of aerosols and particulate matter. The equipment that has been developed enables continuous determination of the chemical composition of particulates as a function of size. Such equipment does not exist anywhere else in the world, although there is a great demand for it. The first measurements at 200 metres above ground at the Cabauw tower showed

Dual catalytic converter reduces nitrogen oxide emissions

Nitrous oxide (N_2O) is a potential greenhouse gas: over a period of a hundred years it can hold 310 times as much heat in the atmosphere as CO_2. One of the largest sources of N_2O in the Netherlands is the nitric acid industry. Most of the seven nitric acid factories do not yet have the necessary equipment to remove harmful nitrogen oxides (NO_x) from their flue gases. Removal of both NO_x and N_2O in a reactor would be a cost-effective method for industry to implement the two environmental measures.

Jan Pels and Ruud van den Brink (see photo) have developed a method to remove nitrogen oxides including N_2O from a gas flow. This is done using selective catalytic reduction in a reactor. By placing two catalytic converters one behind the other, the nitrogen oxides, with the addition of hydrocarbons, can be converted into nitrogen, water and carbon dioxide. The method works as well with propane as with hydrocarbon, but researchers are attempting to develop the method with less expensive methane (natural gas).

This method makes use of two catalytic converters, materials that make the conversion possible without becoming run down. The first catalytic converter converts NO_x using propane, but leaves sufficient propane for the second catalytic converter that reduces the N_2O. This invention can be applied across a broad temperature range, so the gas flow does not have to be heated in the meantime. This makes the new method simpler and less expensive in the long term.



Research by TNO shows that diesel engines, especially lorry traffic and ships, produce both N_2O and NO_x: approximately 50% of total NO_x emissions come from the transport sector. The method is therefore not only interesting because it improves the cleaning of gas discharged from industry, but also for tackling NO_x in the transport sector.

that heavy metals occur especially in the fine fraction (smaller than 2.5 micrometers). These heavy metals probably originate from large-scale transborder transport. On the other hand, sodium, chloride, calcium, potassium and iron are found primarily from local sources. Furthermore, a study has also been done on soot emissions in the Netherlands to assess the health risks of aerosols. This study indicates that almost all soot in West Europe comes from diesel traffic, and thus appears able to quantify the largest sources.

Nitrate concentration map of Europe

New measurements and thorough evaluations of existing measurements in Europe, in combination with model results, have enabled ECN to show that nitrate aerosols is as important as sulphate aerosols in most of Europe for its influence on radiation balance leading to a cooling effect. Nitrate has, up to now, remained outside the climate discussions, while sulphate has unjustly received nearly all the attention.

NitroGenius

This simulation programme has been developed at the request of the Ministry of VROM, by ECN together with Alterra to provide insight into the complex Dutch nitrogen problem. Four players take on the roles of a politician, a farmer, an industrialist and a consumer. Besides looking after their own interests, such as seeking to maximise profit, the players are expected to work as a team to attempt to solve all aspects of the nitrogen problem. The game was introduced with great success at the Second International Nitrogen Confer-

ence, which took place in October 2001 in the US. Meanwhile, sessions have been held at RIVM and VROM that have provided further insights into the nitrogen problem. Two new methods have been developed to be able accurately and quickly to determine N_2O and CH_4 emissions from sources such as refuse sites and meadowlands. The 'fast box' method determines spatial variability and the plume-detection method determines total emissions. These methods work more efficiently and on a larger scale than conventional methods.

Gas permeable membrane simplifies nitrogen analysis

The determination of nitrogen in solid and fluid medium is often done according to Kjeldahl's method. The nitrogen present is converted into ammonium and after steam distillation is determined by titrimetric analysis. This method has already been used for a hundred years to determine nitrogen in food and in the environment, and was also used repeatedly to determine protein in food and feed. However, there are disadvantages of labour intensive and time-consuming steps such as steam distillation and titration, making the method difficult to automate. Other objections to the laboratory method include high costs and a great deal of waste.

Piet Konijn (see photo) has come up with a determination of nitrogen that overcomes the disadvantages of Kjeldahl's method. This invention makes use of gas diffusion as an alternative to steam distillation, and the titration step is replaced by a conductivity measurement. These processes are rapidly executed and not labour intensive, which makes automation easier. In Konijn's method the nitrogen is converted into ammonia and then, via a gas membrane, ends up in a stream of water. The conductivity is then measured, which forms an indicator for the amount of nitrogen.

According to Konijn, his method can measure nitrogen in both inorganic and organic substances. There is, however, a preference for organic substances that are in meat, blood plasma, milk, eggs, feed, etc. The method can also be used for routine protein determination. By automating this method, a large series of samples can be measured. The measured values can be stored in a data logger, after which the researcher can analyse the data with a computer.

External partners and customers Clean Fossil Fuels

Afvalzorg, ATAG, BP-Amoco, CEA, CNRS, Corus, DSM, Engelhard, EU, EZ, Fiat, Gasunie, Grontmij, Institut für Angewandte Chemie, IRD, KEMA, NAM, Novem, Nuon, Piaggio & C Spa, Renault, Risø, RIVM, Saab, Shell, Siemens, Stork, TNO, TU Eindhoven, TU Twente, Umicore, Vaillant, Volvo, VROM, Wageningen University.

Technological Services and Consultancy

ECN's strategy for the period 2001-2004 is concentrated on R&D of the seven priority areas. Each of these groups should operate on European top level. To achieve this ambitious objective, it is necessary that all of the priority research groups be able to completely focus on their areas of expertise. The technological support is provided by Technological Services and Consultancy (TS&C).

TS&C is involved with most of the large projects that are carried out within ECN. TS&C is responsible for the engineering and realisation of prototypes, installations, data acquisition and control systems, and process instrumentation and it develops software applications.

Collaboration between ECN TS&C and Shell TIS

In October 2001 the Technology and Innovation Support (TIS) department of Shell International Chemicals and TS&C signed a co-operative agreement (in Amsterdam). This officially establishes how the combined use of their expertise.

The goal of the collaboration is to make effective use of and update existing knowledge. This also garanties availability of up-to-date instruments, by which test installations are designed, manufactured and put into operation. TIS and TS&C are working together in twenty areas, including machining, machine construction and assembly, joining techniques, surface technology, project management, measurement and control, engineering, calibration, anneal, process design, thermal spraying and inspection.

The Archimedes Wave Swing: energy from ocean waves

ECN is part of the AWS BV consortium that has developed and tested the Archimedes Wave Swing (AWS). A pilot model of the AWS, which although half-scale still measures 35 meters high on a 50×28 meter pontoon, was made and shipped to Portugal in 2001. The installation is scheduled for testing in mid-2002.

ECN TS&C has assisted the AWS project in different sub-areas such as:

- testing diverse systems such as generator cooling units, water dampers, pumps and valves for air and water management, and the operating and emergency systems;
- describing and creating numerical models and software for control and data acquisition systems during operational conditions;
- preparing transport from the Viana do Castelo shipyard (Portugal) to the location where the AWS will be submerged, and preparing the sinking operation with the help of numerical models;
- creating numerical models together with Alkyon Hydraulic Consultancy & Research to calculate the stability of the AWS base during storm conditions;
- organising, preparing and scheduling to dump sand around the pontoon of the Pilot Plant with the help of a pump dredger.

Signing of the co-operative agreement by Ir. W. Schatborn, director of ECN (l) and Ir. G.A.M. Hermans, general manager of Shell's TIS.

Knowledge-building, intelligent design and analysis techniques

ECN Solar Energy and ECN Wind Energy have enlisted the help of TS&C to participate in the ENGINE project 'Renewable Energy Forecasting Systems'. Further knowledge is being built up within the subproject 'intelligent software', in co-operation with The Dutch Foundation for Neural Networks (SNN).

TS&C has also, together with ECN DEGO, been contracted to develop a CHP forecasting system (CHP units) for a large Dutch electric utility. In the last quarter of 2001 a feasibility study was completed that led to a working prototype. The prototype consists of a combination of neural networks and linear models. The tools developed as part of this project have played a key role in the data analysis and the realisation of the final prototype.

To achieve efficient and user-friendly functions, the development of a shell around the Matlab©Neural Network Toolbox was begun at the end of 1999. This shell offers the direct possibility, thus without prior programming, to train neural models with the use of data. In 2001 this shell was further developed and, moreover, used with success for the 'Solar and Wind Energy Forecasting system' and the 'CHP Forecasting system'.

Photocatalysis

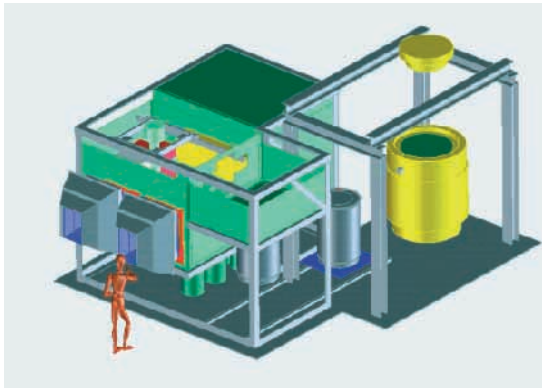
In 2001 TS&C took over the project Photocatalysis from ECN Energy Efficiency in Industry. TS&C is in charge of the overall project management and is orienting its research towards the development of the electrocatalyst. The ultimate aim is to achieve an efficiency of more than 10% for the conversion of CO_2 with water, under the influence of sunlight, into various chemicals and hydrogen.

TS&C has devoted a considerable effort to this project by developing a porous titanium (Ti) tape, which is needed as a carrier for the photocatalytic titanium dioxide. This is important because the best results of the PEC-reactor are achieved with coated Ti-foil, namely 16.5 mA at 25°C. Meanwhile, a patent request has been initiated for the innovative production method of the porous titanium tape. This request is also being made because of an important spin-off for biomedical applications.

An electrocatalyst that is capable of converting CO_2 into desirable products has been developed. Design and construction of the reactor are advancing according to schedule. Although scientific progress has indeed been made, the efficiency of the photocatalyst in sunlight still lags far behind the set targets. This is probably because of losses at the water/photocatalyst interface that are too great, or as a consequence of the recombination of hydrogen and electrons in the electrolyte.

Transport and storage of high-level radioactive waste

TS&C has been contracted by COVRA to make fuel canisters to store high-level waste (HLW). These canisters were assessed prior to use and five canisters were subjected to drop test. This test involved COVRA and government agencies. TS&C was involved with the design of the HLW processing unit to separate, pack and prepare HLW that will be transferred to COVRA in 2003.



HLSW processing unit to separate, pack and prepare HLSW (High Level Solid Waste) for transport.

External partners and customers Technological Services and Consultancy

Akzo Nobel, AVV, AZN, BIHCA Precision BV, Bayer AG, Bernard Forster, Burncare BV, CERN, Cordis Europa NV, Covra, CryoJet BV, CTT Assets BV, DeltaNautic, Dinex A/S, Dinfa, DLG Groningen, DynaVision BV, EcoCeramics, Essence Consultants, Fokker Space, Fuji Photo Film, Gasmodul BV, GCO, GDA Amsterdam, Hunter Douglas, HyCoTec Services BV, HydroRing BV, IDC IJmond BV, Ministeries EZ, OCenW en V&W, NCAM, NMA Alkmaar, Novem, Philips Enabling Technology, PMP, Profiltra, Provincie Noord-Holland, QEC, Shell International Chemicals, Shell Solar, Sonera, Spacelabs Medical BV, Steinbruck & Drucks, Stork FDO, Stork Product Engineering, Syntens, Technobis BV, Teamwork Technology, Thermimport, Tocardo BV, Verhoef Muziekinstrumenten, Wientjes.

Nuclear Technology

2001 was a challenging as well as a successful year for the Nuclear Research and consultancy Group (NRG), the joint venture in which ECN and KEMA have combined their nuclear expertise since 1998. NRG succeeded in acquiring a new site licence under the Dutch Nuclear Power Act for all its facilities. The international position in the European Research Area led to more than 60 contracts in the Fifth Framework Programme. All the activities are performed to ISO 9001 quality standards.

Staff investigate materials for recycling nuclear waste.

2001 was also a year of innovations. Many new products, techniques and computer programs were developed and tested, several of which are highlighted in the annual report of NRG. Working at the cutting edge of nuclear medicine development, NRG prepared a number of new radioisotopes in the High Flux Reactor. 'Medical Valley' Petten plays a key role in the diagnosis and treatment of patients throughout Europe and elsewhere in the world. This use of nuclear technologies for medical purposes is also important for the perception of nuclear technologies in society.

In line with the mission of NRG much attention is given to communication with the public. NRG participated in several TV documentaries on nuclear research and technology. The website www.nrg-nl.com plays an increasingly important role in meeting the growing demand for information about nuclear technologies. The number of website visitors has risen sharply: 35,000 hits in 1999; 150,000 in 2000 and 250,000 in 2001. After the events in New York on 11 September the monthly opening of the High Flux Reactor to the public was discontinued. NRG has the intention to resume these much-appreciated open days as soon as conditions allow.

In 2001 one of the reports published by NRG was entitled 'The Role of Nuclear Energy in Establishing Sustainable Energy Paths'. This independent study discusses the major facts and arguments about nuclear energy and its potential role in establishing sustainable energy paths. The report assesses to what extent energy supply portfolios including nuclear energy are more or less sustainable than those excluding nuclear technology. With this study NRG contributes to the open discussion on the role of nuclear energy in the coming decades, in the Netherlands as well as in other countries. The report is published on the NRG website.

NRG's fields of activity can be catagorised as follows:

- research and development in the field of nuclear energy, radiation protection and nuclear medicine;
- consultancy services worldwide;
- production of radioisotopes; NRG is the largest producer of 'medical isotopes' in Europe.

Research and development make up about one third of NRG's annual turnover and are embedded in international programmes. Important topics are innovative reactor designs, such as the high temperature gas-cooled reactor, advanced fuel cycles, nuclear waste reduction and nuclear medicine.

Consultancy is complementary to the research and development activities. The demand for analyses and measurements in the field of radiation and environment has grown, not only in the nuclear energy sector but also in non-nuclear sectors such as the oil and gas industries. Decontamination of equipment and facilities is of importance in all industrial sectors for a safe working environment, as is the protection of staff working with radioactive materials.

NRG also uses nuclear know-how and facilities for other industrial sectors and services. The expertise and codes for thermohydraulics and structural and fluid mechanics are also used to support customers in the non-nuclear industry.

NRG tests new materials and reactor fuels in the High Flux Reactor and in the adjacent Hot Cell Facilities for customers all over the world. The operation and exploitation of the HFR – which is owned by the European Union – are an essential part of NRG's activities. The decision to convert the reactor from high to low enriched uranium in the coming years has guaranteed the continuity of the fuel supply for the future. The testing of low enriched fuel elements in the HFR has been successful. Spent fuel from the reactor has recently been transported to the USA.

Mission Statement
NRG provides expertise and services in support of the safe, ecologically sound and efficient use of nuclear technologies in energy production, radiation protection and nuclear medicine. NRG also applies spin-off technologies for the non-nuclear market.

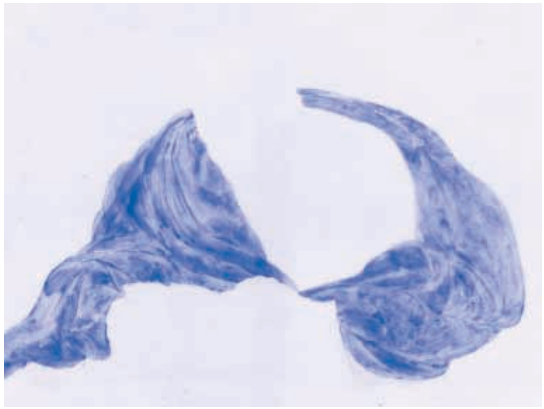
Between the end of 2001 and the publication of this report, HFR operations were suspended for a month because questions were raised about the safety culture and a weld defect in the reactor vessel. A safety review by the International Atomic Energy Agency was carried out as well as an analysis of the weld defect. Implementation of the resulting recommendations is well under way and the HFR has been allowed to resume its normal operation schedule.

Finally, a growing proportion of the annual turnover is generated from the production of radioisotopes for medical use. 'Medical Valley' Petten is a concentration of knowledge, expertise and facilities. Isotopes for diagnostics, therapeutics and palliatives are being developed and produced. Petten holds a leading position in the development of Boron Neutron Capture Therapy, an innovative treatment of tumours.

Good relations are maintained with universities and other scientific institutions, because a continuous exchange of new knowledge is essential for NRG. In 2001 two members of the staff obtained PhD degrees.

In its third year of operation NRG has successfully met the strategic challenges defined at its foundation, thanks to the effort and motivation of the highly experienced staff. NRG intends to improve further and expand its expertise in the coming years in order to provide more and better services for its customers.

'Lucas the Evangelist' by Hendrick ter Brugghen.



Computer reconstruction of the original colours from Lucas' cloak, made with the help of autoradiography of irradiated arsenic.

Annual Social and Environmental Report

More information is available in a more detailed version (in Dutch) of the ECN Annual Social and Environmental Report, which can be obtained from Quality, Safety and Environment (KVM).

Annual Social Report

RI&E Modernisation

In 2000 the risk assessment and evaluation (RI&E) was completely renewed. The examining authority (AMG safety, health and welfare service) requested extra attention to be given to temporary employees and contractors. As a result, the 'Safety and Environmental Regulations for Third Parties' were completely renewed in 2001. In 2002 there will be another renewal and expansion of trainings upon employee arrival.

Investment in means

In 2001 the investment package resulting from the 1997/1998 inventories was fully completed. It concerned, among other, storage capacity for chemicals and gas cylinders, and the construction of a new depot for chemical waste.

Investment in people

Much attention was devoted in 2001 to the training and education of staff (see the table below). Most trainings in the framework of KVM were given in connection with the ISO 14001 (standard for environmental care systems) certification of the management system (MS).

Education plan 2001

Main subject	Number trainings ongoing	Number trainings completed
Verbal communication	18	3
Written communication	8	5
Language skills	50	5
Personal effectiveness	39	26
Management & Organisation	54	49
Personnel & Education	6	0
Quality, Occupational Health & Safety and Environment	60	388
Internal Operational organisation	38	15
Marketing & Sales	18	5
Financial Operational Administration	23	1
Computer use & Safety and Environment	133	50
Technique & Maintenance	148	31
Sector & Branche specification	43	147
Basic Training	284	15
Unassigned	2	1
Total	924	741

Source: part of registration in SAP HR.

Near-accident reports

The quality of the reports was good and many measures were taken. For example, five reports concerned traffic at ECN. In 2001, footpaths were created and exits were provided with speed bumps. In 2002 a RI&E concerning traffic will be carried out, which will form the basis for a long-range traffic plan.

Year	Total number of reports	Concerning Safety & Health	Concerning environment	Remarks
1998	27	26	7	ECN + NRG
1999	43	41	16	ECN
2000	35	34	11	ECN
2001	35	32	7	ECN

(Absentee-)accidents

(absentee-accidents of ECN employees, excluding accidents suffered by contractors).

Year	Fte + interns as of 31-12-01	Number of accidents	Number of absentee-accidents	IF Index	Comments
1997	924.6	3	1	0.68	ECN + NRG
1998	950.6	3	1	0.66	ECN + NRG
1999	719.7	2	2	1.74	ECN
2000	746.5	6	1	0.84	ECN
2001	668.3	4	2	1.87	ECN
Average (arithmetic) value				1.16	Target value: < 0.8 for period 2002-2005
IF Index = number of absentee-accidents x 1.000.000 / hours worked (numbers of hours worked = number of fte x 1600)					

Conclusion: The IF index lies well above the target value of 0.8.

Current efforts will be continued in the period 2002-2005. Furthermore, more detailed investigations will be launched in case of serious (near) accidents, with the expectation that the entire safety of the organisation can thereby be improved.

Health-related absence from work (ECN, excl. NRG)

Year	Average sick leave frequency	Average sick leave duration	Percentage employees with sick leave		Percentage employees with perfect attendance
			Incl. maternity leave	Excl. maternity leave	
1999	1.31	8.24	2.87	2.58	34.97
2000	1.30	9.25	3.40	3.11	39.26
2001	1.32	11.27	3.39	3.14	37.48

Annual Environmental Report

Environmentally relevant, external developments

In 2000 five environmental permits were requested. The objective was, in addition to renewal of the permits, to separate the existing ECN institute into two institutes, ECN and NRG. In 2001 this separation was achieved by the granting of five particular permits. The separation is a result of the establishment of NRG in 1998.

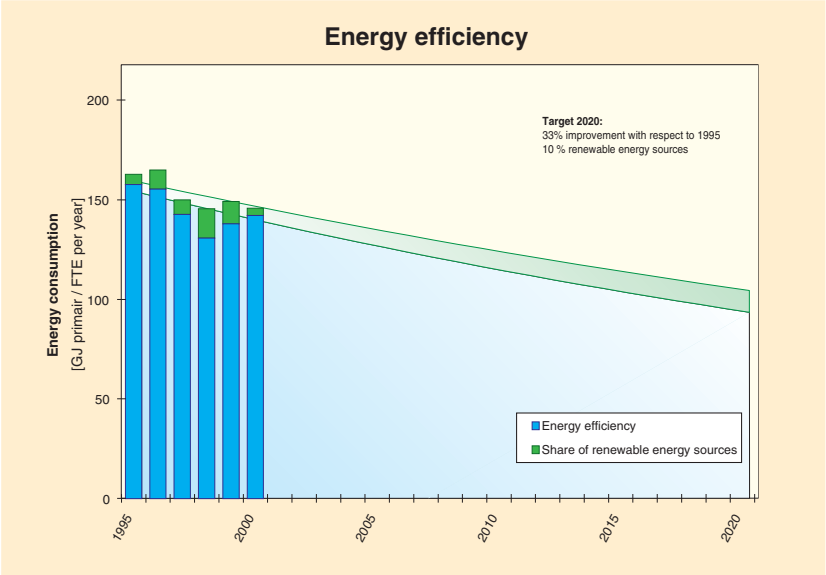
Environmental permits

Since mid-2001 ECN has three new and/or renewed permits, namely:

- a new permit on main principles required by the Environmental Management Act;
- a new permit on main principles required by the Surface Water Pollution Act;
- a revised permit required by the Nuclear Energy Act.

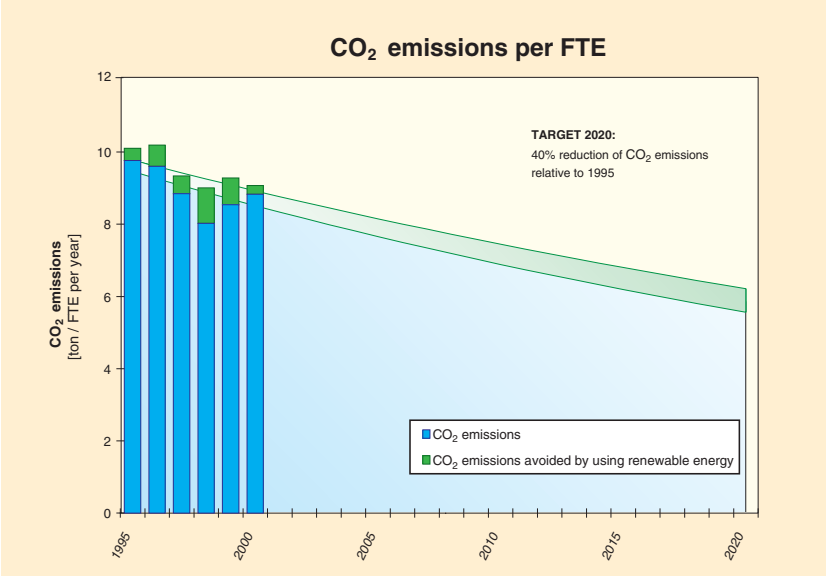
Figure 5.
Energy efficiency vs. energy consumption 1995-2020.

ECN is extremely pleased with the granting of these permits because, on the one hand, this will do greater justice to environmental interests and, on the other hand, the permits will provide ECN the necessary flexibility for R&D.



Explanation of figures 5 and 6: ECN's performance level now nearly keeps pace with its targets, after a number of years in which ECN had easily met their targets. In the years 2002-2005 investments will be made in wind energy and energy conservation for buildings. A bio-CHP is planned at ECN that could also provide a great contribution towards meeting its targets. By taking these measures ECN can maintain its performance standard and possibly even improve on it.

Figure 6.
CO_2 emissions per FTE.



Internal environmental concern

A thorough environmental management system fits within the new permits on main principles:

- in June 2001 ECN's management system was registered and certified by Lloyd's according to the ISO 14001 standard for environmental management systems (in addition to the already existing ISO 9001 certificate for quality);
- in the fall of 2001 a plan was made for Quality, Safety and the Environment for 2002-2005, which was approved by the competent authorities.

Climate change

ECN's long-term target (Third Energy Memorandum) is: a 40% reduction of CO_2 in 2020 relative to 1995 by implementing 10% renewable energy sources (green) and 33% improved energy efficiency (blue).

Other aspects

The Annual Environmental Report was established this year according to the structure in Appendix II of the Environmental Reporting Decree. The report includes all aspects and types of emissions (climate change, acidification, dispersion to air and surface water, eutrophication, waste disposal, desiccation, soil protection and sanitation, noise and odour pollution, external safety, business and environment, environmentally-relevant external developments, environmental permits).

What went wrong in 2001?

The triennial measurement of NO_x emissions from the gas engine of a compressor for a pneumatic system indicated that the emission was about five times higher than the limit (140 g/GJ). It was therefore decided, after discussion with the supplier and the manufacturer, to set up the gas engine at another working point in 2002, and to provide it with a 'lambda sensor' and a catalytic converter so the NO_x requirement should be amply met (this will be a test).

An inspection by the District Water Control Board showed that the emission from an oil-water separator and silver emission from the reprographic department were too high. Measures have been taken to avoid recurrence of these emissions.

Financial Report 2001

Financial Report 2001

Consolidated balance sheet at December 21 *(in € x 1000)*

Assets

	2001	2000
Fixed assets		
Tangible fixed assets	34,545	33,627
Intangible fixed assets	616	821
Financial fixed assets:		
• Participations in knowledge-based companies	295	54
• Other participations	858	690
• Subordinated loan	18	227
• Securities	35,126	39,075
• Other receivables	1,449	1.942
	72,907	76,436
Current assets		
Work in progress	13,822	15,395
Receivables and prepaid expenses	26,988	20,715
Cash and Bank balances	4,049	-
	44,859	36,110
Total	117,766	112,546

Liabilities

	2001	2000
Group equity		
Equity	10,702	18,709
Third party share	1,073	896
	11,775	19,605
Provisions		
Provisions early retirement	3,425	4,452
Provisions redundancy	8,833	10,396
Provisions radioactive waste	41,913	39,756
Other provisions	2,355	2,066
	56,526	56,670
Long-term liabilities	-	983
Short-term liabilities	49,465	35,288
Total	117,766	112,546

Consolidated statement of income *(in € x 1000)*

	2001	2000
Operating income		
Financing and other income		
• Basic, ENGINE and Collaboration financing from the Dutch government	30,951	29,782
• Third party revenues	61,133	48,401
• Increase/decrease work in progress	-/- 1,573	6,070
	90,511	84,253
Capitalised production for own organisation	1,639	1,958
Income from licences	228	723
Other operating incom	1,167	1,189
	93,545	88,123
Operating expenses		
Wages and salaries	61,643	53,412
Depreciation	6,476	5,902
Other operating expenses	31,301	27,473
	99,420	86,787
Operating result	-/- 5,875	1,336
Result financial income and expenses	-/- 1,955	1,313
Result before extraordinary income	-/- 7,830	2,649
Extraordinary income and expenses	-	-/- 10,745
Result before share of third parties	-/- 7,830	-/- 8,096
Third party share in the result	-/- 177	-/- 150
Consolidated result	-/- 8,007	-/- 8,246

Consolidated cash flow statement *(in € x 1000)*

	2001	2000
Cash and Bank balance at January 1	-/- 968	19.138
Cash flow from operating activities		
Operating result	-/- 5,875	1,336
Depreciation	6,476	5,902
Increase/decrease provisions exclusive of interest compensation and contribution Min. Economic Affairs	144	-/- 23,413
Increase/decrease extraordinary expenses	-	8,622
	745	-/- 7,553
Change in working capital	9,477	1,456
Increase/decrease extraordinary expenses	-	-
	10,222	-/- 6,097
Result financial income and expenses	-/- 1,955	3,557
	8,267	-/- 2,540
Cash flow from investment activities		
Increase/decrease financial fixed assets excluding participations	4,651	-/- 5,632
Increase participations	-/- 409	-/- 342
Increase/decrease intangible fixed assets	205	-/- 1,026
Investments tangible fixed assets	-/- 7,653	-/- 10,597
Contribution third parties tangible fixed assets	-	-
Disposals tangible fixed assets	939	1
	-/- 2,267	-/- 17,596
Cash flow from financing activities		
Increase/decrease of long-term liabilities	-/- 983	30
Cash and Bank balance at December 31	4,049	-/- 968

Notes to the consolidated financial statements

General
ECN is statutory established in Petten, in the municipality of Zijpe. For the foundations' aim refer to the mission statement as described in the annual report.

Principles of Consolidation
The consolidated financial statements, in which all important mutual assets, liabilities, income and expenses have been eliminated, include the financial statements of ECN, the subsidiaries NRG v.o.f. and NRG Personeel v.o.f., all established in Petten, Zijpe municipality. ECN owns 70% and KEMA owns 30% of both subsidiaries.

Principles of valuation of assets and liabilities
The tangible fixed assets are valued at purchase price or manufacturing price less depreciation. The site was obtained on long lease in 1957 from the Dutch Forestry Commission. The term of the lease was extended in 1996 from 2007 to 2032.

Fixed assets are depreciated straight line, and the depreciation periods are as follows:

· Industrial buildings	20 years
· Temporary buildings and site facilities	10 years
· Industrial installations and fixtures	10 years
· Instruments, machinery, etc.	5 years
· Goodwill	5 years
· Computer hardware and software	3 years
· Licenses	economic lifecycle

Participations in knowledge-based companies are defined as inputted expertise by ECN, which is a critical success factor for the establishment or continuation of this company. ECN is able to exercise significant control regarding the business conduct and financial conduct of NRG. Therefore, the subsidiary NRG is valued at the net equity value. The net equity value is calculated on the basis of similar principles that are applied by ECN. The other participations are shown at acquisition price less provisions if necessary.

The shares are valued at purchase value or lower market value.

The bonds are valued at purchase price, with any premiums or discounts on the purchase of bonds being debited or credited to the result, divided over the maturity period.

Work in progress is valued at the costs incurred, net of a provision for expenses to be expected.

The provisions for early retirement (referred to as FUT), reorganization and nuclear waste are calculated on the basis of net present value.

The other assets and liabilities are included for the nominal amounts; a deduction has been made on the receivables for the provisions deemed necessary.

Principles for determination of the result
All items in the consolidated statement of income are included for the amounts that should be allocated to the year under review.

Notes to the consolidated balance sheet *(in € x 1000)*

Fixed assets

Tangible fixed assets		Movements in 2001		
	Book value at 31-12-2001	Additions	Disposals	Book value at 31-12-2000
Industrial buildings/Site facilities				
Purchase price	34,735	4,206	147	30,676
Depreciation	21,837	1,294	17	20,560
Book value	12,898	2,912	130	10,116
Industrial installations/fixtures				
Purchase price	40,026	1,431	361	38,956
Depreciation	30,624	1,889	36	28,771
Book value	9,402	-/- 458	325	10,185
Instruments, machinery, etc.				
Purchase price	39,912	2,717	431	37,626
Depreciation	33,099	3,088	422	30,433
Book value	6,813	-/- 371	9	7,193
Fixed assets in progress				
Purchase pridce	5,432	-/- 701	-	6,133
Total				
Purchase price	120,105	7,653	939	113,391
Depreciation	85,560	6,271	475	79,764
Book value	34,545	1,382	464	33,627

Intangible fixed assets		Movements in 2001		
	Book value at 31-12-2001	Additions	Disposals	Book value at 31-12-2000
Goodwill				
Purchase price	1,026	-	-	1,026
Depreciation	410	205	-	205
Book value	616	-/- 205	-	821

The goodwill refers to the acquisition of TNO-CSD by subsidiary NRG.

Financial fixed assets

Participations

	2001	2000
• BCN BV	-	-
• ENATEC BV	245	8
• NEDSTACK Holding BV	3	3
• SWEAT BV	7	7
• INDEC BV	18	18
• MAN SOLAR BV	18	18
• ASTER INTELLECTUAL PROPERTIES BV	4	-
Total	295	54

Other participations

	2001	2000
• DNC Nuclear Technology BV	18	18
• COVRA NV	-	-
• RTC Noord-Holland Noord BV	227	227
• TIFAN BV	227	227
• ECN-INTERNATIONAL BV	18	18
• SOLAR INTERNATIONAL BOTSWANA	-	45
• AWS BV	71	71
• ENERSEARCH AB	11	11
• OFBS BV	-	10
• COGEN Projects BV	-	45
• RGS BV	18	18
• SUNLAB BV	18	-
• ECN WIND ENERGY FACILITIES BV	18	-
• ECONCERN	227	-
• HYDRORING	-	-
• R3T	5	-
Total	858	690

Subordinated loan

As per February 14, 2001 the subordinated loan to Econcern has been converted into 3000 share. A subordinated loan of € 18 has been issued to R3T BV.

Securities

The movement of the securities is as follows:

Balance at January 1, 2001 financial fixed assets		39,075
• Sold	-/- 3,001	
• Exchange losses	-/- 948	
		-/- 3,949
Balance at January 1, 2001		35,126

The bonds for the amount € 27.512 are partly pledged. The other securities are at the free disposal of ECN.

Securities

The bond portfolio has a face value of € 31,773.
The market value as per year end 2001 is € 27,517.

Shares

The share portfolio has a book value, equal the market value of € 5,345. The purchase price as per closing balance amounts to € 6,415.

Deposits

The long-term deposit has a face value of € 2,269.

Other receivables

Subordinated loan

The other receivables include a loan to Ultra-Centrifuge Nederland NV (UCN) that represents a fee for transferred knowledge on the ultracentrifuge process.

Licences

Other receivables include a licence for microfiltration membranes.

Balance at January 1, 2001		92
• Depreciation	-/- 27	
		-/- 27
Balance at December 31, 2001		65

Current assets

Trade debtors and other receivables

Provisions for doubtful accounts are deducted from the accounts receivable. The receivables expire within 1 year and can be specified as follows:

	2001	2000
- Trade debtors	19,591	10,470
- Receivables	6,816	8,085
	26,407	18,555
Other receivables and prepaid expenses	581	2,160
Balance at December 31	26,988	20,715

Cash and Bank balances

Cash and Bank balances

The bank balance deposited with Achmea is added to retirement funds managed by Achmea.

Provisions

The remaining term of the provisions has a long-term character in general.

Provisions for early retirement (FUT)

This provision is intended for the costs of the FUT scheme.
The movement of this provision is as follows

Balance at January 1, 2001		4,452
• Minus: funds needed	1,219	
• Plus: interest	192	
		-/- 1,027
Balance at December 31, 2001		3,425

Provisions for redundancy

This provision is intended for costs resulting from staff reductions due to reorganizations. The movement of this provision is as follows:

Balance at January 1, 2001		10,396
• Minus: amounts paid	2,030	
• Plus: interest	467	
		-/- 1,563
Balance at December 31, 2001		8,833

Provision for radioactive waste

This provision is intended for the costs of the future storage or treatment of radioactive waste.
The movement of this provision is as follows

Balance at January 1, 2001		39,756
• Minus: funds used	1,376	
• Plus: provided during year	1,560	
• Plus: interest	1,973	
		2,157
Balance at December 31, 2001		41,913

Per date of balance there are still uncertainties regarding the amount of the provision. There is a dispute between ECN and GCO concerning the responsibilities of 500 stored barrels and other radioactive parts. The calculation of the costs of disposal and storage of radioactive waste is based upon the current state of technology. The intended transfer of stocks COVRA to the Government has not yet occurred.

Other provisions

Other provisions include the provision for functional redundancy due to age (FLO) and provisions for periodic maintenance and flexible retirement (SFN).

	FLO	Main-tenance	SFN	Total
Balance at January 1, 2001	1,842	23	201	2,066
• Minus: withdrawal	392	322	-	714
• Plus: provided	324	408	166	898
• Plus: interest	91	-	14	105
Balance at December 31, 2001	1,865	109	381	2,355

Provision for FLO scheme

Employees working in shifts may make use of the FLO scheme (functional redundancy due to age) as from 57.5 years.

Provision for periodic maintenance

The provision for periodic maintenance functions as an exchange equalization fund.

Provision for SFN scheme

Former KEMA employees of NRG may make use of the SFN scheme for flexible retirement.

Long-term liabilities

The long-term deferred loan of € 983 KEMA procured to NRG has been paid off.

Short-term liabilities

	2001	2000
1. Deferred income from third parties	20,831	4,619
2. Trade liabilities	11,931	13,954
3. Wage taxes and social insurance premiums	1,320	2,046
4. Other social charges and personnel costs	4,804	4,721
5. Value added tax	255	160
6. Miscellaneous liabilities and accrued expenses	10,324	8,820
7. Liquid liabilities	-	968
Balance at December 31	49,465	35,288

Notes to the consolidated statement of income *(in € x 1000)*

Operating income

Financing and other income

	2001	2000
Basic- and ENGINE-financing	15,304	14,972
Co-operation financing	15,647	14,810
	30,951	29,782
Breakdown into market segments		
Third party revenues	61,133	48,401
Increase/decrease work in progress	-/- 1,573	6,070
Other income	1,167	1,189
Total third party revenues and other income	60,727	55,660

Breakdown into market segments:

	2001	2000
Domestic trade and industry sector	23,432	20,998
Domestic energy sector	2,568	3,032
European Commission	7,949	7,795
Foreign trade and industry sector	10,237	8,666
Governmental departments	5,244	3,104
NOVEM	11,297	12,065
Total	60,727	55,660

Capitalised production for own organisation

The capitalised production for own organisation concerns the own operating expenses due to work carried out by own staff and work carried out with own operating assets that can be allocated to investments or provisions.

Operating expenses

Personnel costs

	2001	2000
Salaries of permanent employees	36,588	34,080
Cost of temporary employees	6,020	7,449
Social securities	7,056	4,409
Pension charges	7,294	4,102
Other personnel costs	4,685	3,372
Totaal	61,643	53,412

The average number of employees (in fte's) was:

	2001	2000
• Permanent contract of service	783,8	764,7
• Temporary contract of services (including PhD candidates)	111,3	144,4
Total	895,1	909,1

These numbers are exclusive of personnel on loan and agency workers.

Depreciation

	2001	2000
Industrial buildings, installations, fixtures and site facilities	3,183	2,750
Instruments and other inventory	3,088	2,947
Goodwill	205	205
Subtotal depreciation	6,476	5,902
Write off disposals	-	2
Total	6,476	5,904

Financial income and expenses

	2001	2000
Interest income	2,438	3,678
Interest expenses	3,387	3,481
	-/- 949	197
Other financial income and expenses	-/- 1,006	1,116
Total	-/- 1,955	1,313

Interest income includes € 111 of capitalised construction interest and € 883 leased molybdenum income. The interest paid includes the interest added to the provisions amounting to € 2,737 (€ 2,244 in 2000) and the interest on the current account for the amount of € 609.

The other financial income and expenses consist primarily of depreciation on securities for the amount of € 713.

Statutary balance sheet at December 31, *(in € x 1000)*

Assets

	2001	2000
Fixed assets		
Tangible fixed assets:	33,520	32,243
Financial fixed assets		
• Participation in knowledge-based companies	295	54
• Participating in subsidiary NRG	3,315	2,876
• Other participations	840	672
• Deferred loan subsidiary NRG	-	2,178
• Deferred loan	18	227
• Securities	35,126	39,075
• Other receivables	1,449	1,942
	74,563	79,267
Current assets		
Work in progress	10,715	13,928
Receivables subsidiary NRG	7.,449	2,635
Receivables and prepaid expenses	22,181	12,448
	40,345	29,011
Total	114,908	108,278

Liabilities

	2001	2000
Equity	10,702	18,709
Provisions		
Provisions early retirement	3,425	4,452
Provisions redundancy	8,833	10,336
Provisions radioactive waste	40,163	39,249
Other provisions	1,307	1,431
	53,728	55,468
Short-term liabilities	50,478	34,101
Total	114,908	108,278

Statutary statement of income *(in € x 1000)*

	2001	2000
Operating income		
Financing and other income		
• Basic, ENGINE and Collaboration	22,540	21,527
• Third party revenues	33,558	21,110
• Increase/decrease in work progress	-/- 3,885	6,089
• Income from subsidiary NRG	8,278	7,741
	60,491	56,467
Capitalised production for own organisation	1,419	1,496
Income from licenses	228	723
Other operating income	1,167	1,189
	63,305	59,875
Operating expenses		
Wages and salaries	42,811	35,939
Depreciation	5,592	4,935
Other operating expenses	20,579	17,881
Expenses from subsidiary NRG	1,234	884
	70,216	59,639
Operating result	-/- 6,911	236
Result financial income and expenses	-/- 2,402	1,045
Result before extraordinary income	-/-9,313	1,281
Extraordinary income and expenses	-	-/- 10,745
Company only result	-/- 9,313	-/- 9,464
Result group company	1,306	1,218
Net result	-/- 8,007	-/- 8,246

Notes to the statutary statements *(in € x 1000)*

Principles of valuation
The principles stated in the notes to the consolidated financial statements apply also to the company only financial statements.

Receivables from subsidiary NRG
The long-term deferred loan (€ 2,178) to NRG, to improve their solvency, has been paid off.

Directors and Supervisory Board
The remuneration of directors amounts to € 309.
The remuneration of the members of the supervisory board is € 54.

Participation in Group Company
The movements in the participating share are as follows:

Balance at January 1, 2001	2,876
• Minus: licence fee 2000	867
• Result subsidiary 2001	1,306
Balance at December 31, 2001	3,315

Equity at December 31

	2001	Changes in 2001	2000
• Foundation capital	45	-	45
• Capital consisting of investment contributions received up to 1984 mainly from the Kingdom of the Netherlands, net of write-off for depreciation	17,562	-	17,562
• Result financial years from 1983	-/- 6,905	-/- 8,007	1,102
Balance at December 31	10,702	-/- 8,007	18,709

Petten, June 28, 2002

Prof.dr. J.C. Terlouw
Chairman of the Supervisory Board

Drs. P. Wilson
Chairman of the Board of Directors a.i.

Ir. W. Schatborn
Managing Director

Other information

Auditor's report

Introduction
We have audited the financial statements of the Stichting Energieonderzoek Centrum Nederland, Petten, the Netherlands, for the year 2001. These financial statements are the responsibility of the foundations' management. Our responsibility is to express an opinion on these financial statements based on our audit.

Scope
We conducted our audit in accordance with auditing standards generally accepted in The Netherlands. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by the foundation's management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

Opinion
In our opinion, the financial statements give a true and fair view of the financial positions of the foundation as at December 31, 2001 and of the result for the year then ended in accordance with accounting principles generally accepted in The Netherlands and comply with the financial reporting requirements.

Amsterdam, June 24, 2002

Deloitte & Touche

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List of abbreviations

AER	General Energy Council
AMG	Arbo Management Group
ATO	Association Technology Transfer
AWS	Archimedes Wave Swing
BIO-WKK	Bio-energy Combined Heat and Power
BIVKIN	Biomass Gasification Characterisation Installation
BSE	Bovine Spongiform Encephalopathy
BTG	Biomass Technology Group
CBS	Statistics Netherlands
CFB	Circulating Fluidised Bed Gasifier
CFD	Computational Fluid Dynamics
CH_4	Methane
CHE	Compact Heat Exchangers
CHP	Combined Heat and Power
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
CO_2	Carbon dioxide
CoReScan	Contact-Resistance Scan
COVRA	Central Organisation for Radioactive Waste
CPB	Netherlands Bureau for Economic Policy Analysis
CRES	Center for Renewable Energy Sources
CSIR	Council for Scientific and Industrial Research
DEGO	Renewable Energy in the Built Environment
DEN	Renewable Energy Netherlands
DOWEC	Dutch Offshore Wind Energy Converter
DSM	Dutch State Mines
EBC	External Review Committee
EC	European Commission
EEI	Energy Efficiency in Industry
EET	Ecology, Economy and Technology
EGKS	European Coal and Steel Community
ENGINE	ENergy Generation In a Natural Environment
EOS	Energy Research Strategy
EPA	Energy Performance Advice
EPC	Energy Performance Coefficient
EPN	Energy Performance Norm
EU	European Union
EZ	Ministry of Economic Affairs
EZS	Economic Affairs Subsidy
FRESCO	Fuel-cell Reduced Emission SCOoter
GDA	City Waste Processing Department
GJ	Giga joule
HAVA	High Level Solid Waste
HEX	Heat Exchange
HIDiC	Heat-Integrated Distillation Column
HLW	High Level Waste
HR	High efficiency
ICES-KIS	Interdepartemental Commission on Economic and Structural Change - Knowledge Infrastructure
ICT	Information and Communication Technology
IEA	International Energy Agency
IF	Accident Frequency Index
IMEC	Interuniversity MicroElectronics Center
INAP	INstitut für Angewandte Photovoltaik
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
JI	Joint Implementation
KNMI	Royal Netherlands Meteorological Institute
KVM	Quality, Safety and Environment
kW	kilowatt
MARKAL	Energy/emission Model
MEP	Measure and Evaluation Programme
MEXICO	Model EXperiments In COntrolled conditions
MIP	Natural gas heated fuel processor
MJ	Million joules
MKZ	Foot and Mouth disease
MM	Maintenance Manager
NRG	Nuclear Research and consultancy Group
MS	Management System
Mton	Million tonnes
MW	Megawatt
MW-PECVD	Remote micro-wave plasma deposition
N	Nitrogen
N_2O	Nitrous oxide
NAM	Dutch Petroleum Company
NARGUS	Fluidized Bed Combustion Installation
NASA	National Aeronautics and Space Administration
NIDO	Netherlands National Initiative for sustainable Development
Novem	Netherlands Agency for Energy and the Environment
NOZ	National research programme Solar Energy
NPCC	Northeast China Power Combustion Research Centre

NREL	National Renewable Energy Laboratory
NRG	Nuclear Research and consultancy Group
NSW	Near Shore Wind farm
NWO	Netherlands Organisation for Scientific Research
O&M	Operations & Maintenance
OWECOP	Offshore Wind Energy COst and Potential
P	Phosphate
PAR	Programme Advice Council
PCM	Phase Change Material
PEC	Phoenix Electric Corporation
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PIE	National Energy Model
PJ	Petajoule (10^{15} joule)
PV	PhotoVoltaic
PVT	Photo Voltaic Thermal
R&D	Research and Development
REB	Regulating Energy Tax
REBUS	Renewable Energy BUrden Sharing
RGS	Ribbon Growth on Substrate
RI&E	Risk Inventory and Evaluation
RIVM	National Institute of Public Health and the Environment
Ru	Ruthenium
SDE	Sustainable Energy Joint Venture
SNN	Dutch Foundation for Neural Networks
SOFC	Solid Oxide Fuel Cell
STABTOOL	Stability Analysis Tool
SWEAT	Salt Water Energy Accumulation and Transformation
THF	Third Harmonic Filter
TiO_2	Titanium dioxide
TIS	Technology and Innovation Support
TNO	Dutch Organisation for Applied Scientific Research
TREPKA	Two-staged Gasifier
TS&C	Technological Services & Consultancy
TU	University of Technology
TUD	Delft University of Technology
TUE	Eindhoven University of Technology
VNCI	Association of the Dutch Chemical Industry
VROM	Ministry of Housing, Spatial Planning and the Environment
WKK	Combined Heat and Power
WMC	Knowledge Centre Windturbine Materials and Construction
WTW	Wind turbine Test farm Wieringermeer

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