ANNUAL REPORT 2000

ECN
energy innovation

Energy research
Centre of the
Netherlands

Cover illustration

ECN's image has changed over the past four years from nuclear to sustainable as is shown by the General Laboratory's façade. As part of the renovation scheme this laboratory which is one of ECN's oldest buildings was fitted with a new 'coat': an adjustable shading system consisting of solar panels producing electricity. The wings can also be adjusted to optimise the light entering each room. Photograph: BEAR Architects, Tjerk Reijenga

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Preface

The past year was the final year of the strategic plan 1997-2000, a period during which ECN became ever more dependent on its performance in the market for energy-R&D, or in other words, on research orders acquired in competition with others. Last December, the consulting firm PriceWaterhouseCooper acting on behalf of the Ministry of Economic Affairs evaluated the effectiveness of the use of ECN's Government funding and concluded that ECN has indeed chosen the right direction for its development into a market oriented organisation. ECN's clients gave a favourable judgement on the quality of the R&D, and the large number of international projects and the growing interest of foreign companies indicate that ECN has also improved its international position. In conformity with the plans the annual turnover increased from € 63.5 million in 1996 to € 86.2 in 2000.

The Supervisory Board has observed with pleasure that ECN has successfully implemented its ambitious strategy and it congratulates directors and staff for this accomplishment. We are confident that they will likewise devote their best efforts to the new, and again ambitious, strategic plan, which will take us to the end of 2004.
The Ministry of Economic Affairs has traditionally very much influenced the direction of the Dutch energy-R&D, but due to recent changes in the energy sector now finds itself in the midst of a process of reconsidering its policy. Whether or not the government still has a role to play in this field has become a matter for debate. And if the answer is yes, the next questions is: which role? The Ministry of Economic Affairs invests € 135 million each year: for which purpose and which objectives should it be used: for specific research and technology development, as in previous years? Or should this money be spent in a generic manner, for example, to fund individual companies by a system of research vouchers? The Ministry is seriously considering these questions and it has promised to issue a parliamentary document containing its new vision on energy R&D some time during 2001.
We express our hope that the national government will continue to exert its influence on the future direction of energy research. In a market which is dominated by competition on the basis of price the producers and suppliers of energy will no longer be prepared to finance the long-term R&D necessary to realise the internationally agreed targets concerning climate and energy. However, much progress was made during the previous decennia. At this moment in time the solar cell, the fuel cell, the wind turbine, the heat pump and most other technologies for a more sustainable generation and conversion of energy find themselves in a development phase which is comparable with that of the internal combustion engine a century ago. Their enormous technological potential can only be realised if the Government continues to participate in their development until the activities become self-supporting.
The quality of the technological infrastructure in the European Union will develop into one of the most important factors for competition. It will be in the national economic interest of the member states that their governments remain actively involved in the development of specific goal-oriented national R&D programmes. In view of the present high quality of the Dutch knowledge infrastructure in the field of energy, it seems a logical choice for the Netherlands in particular – with its natural gas, its energy intensive economy, its large petrochemical industry and its ambition to serve as a model country in the field of the environment – to concentrate on energy R&D. The Ministry of Economic Affairs is considering the role the Government wishes to play in the field of energy. If it assumes the role of an arbiter merely to supervise the correct compliance with the rules, then the Government will implicitly have abandoned its ambitious energy targets, bringing to an end the fruitful co-operation between government, industry and research institutes in the field of energy innovation. This would have far reaching consequences, also for ECN. But if, on the other hand, the Government seriously intends to turn the energy economy into a sustainable system, it needs to retain the authority to dictate the specifications for the ecological *performance* of the energy market, which can only be met by a continuous development of more efficient and more environmentally friendly technologies. A concerned Government should participate in these developments actively, intensely and in a concrete manner.

On behalf of the Supervisory Board,

Prof.dr. J.C. Terlouw
Chairman

The Dutch Energy Council came to Petten for a working visit on 14 December.

Introduction

In 2000 ECN needed to increase its provisions for its 'historical' radioactive waste from € 22 million to approximately € 40 million. Mainly as a result of this allocation and also due to a new agreement with COVRA and the Dutch Government about the removal of radioactive waste, ECN made a loss of € 8.3 million in 2000. The provisions for radioactive waste are earmarked to cover the expenditure for the treatment, handling and storage of radioactive waste generated by the nuclear research and also for the future dismantling of NRG's nuclear installations. This measure was based on the results of a study which showed that the costs, in particular those pertaining to the dismantling of nuclear facilities and installations, had been underestimated. This underestimation was caused by various factors, ranging from stricter safety and environmental requirements regarding the dismantling operation to higher than anticipated salary increases. The Ministry of Economic Affairs has contributed an extra € 8.6 million to these provisions. ECN's Supervisory Board has given permission to debit the remaining € 8.3 million to ECN's assets. An agreement was made with the NRG Board of Directors that the nuclear R&D programme for the next few years would be modified so that the removal of radioactive waste is given the highest priority. The directors of ECN, NRG and the Joint Research Centre of the European Union have agreed the division of roles in the removal of the historical radioactive waste and the future dismantling of the installations at Petten.

The consolidated operating result remained at € 2.6 million below last year's € 4.7 million. This decrease can be explained partly in terms of the time required to implement a large number of organisational changes, to train new staff and to refurbish and partly clear out the project accounting. Unfortunately, the many hours spent on these internal activities could not be completely compensated in the costs. In 2000 ECN's consolidated income increased again by 4% to € 88.1 million. This increase is mainly due to the increased government funding and an increase of external orders for the units active in the fields of renewable energy and policy studies. The order book for NRG (70% ECN and 30% KEMA) shrank by 1% to € 36.9 million. The consolidated result for 2000 is € -8.2 million, compared with € 3.4 million for 1999. The group equity decreased from € 27.7 million to € 9.6 million and the solvency from 24% to 17%. The number of participations increased from five to seventeen including six in research companies.

Mission Statement

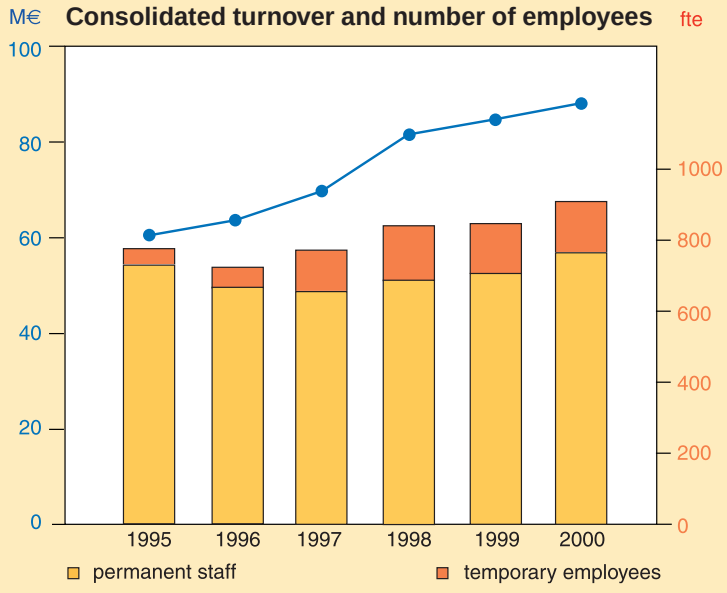
- ECN's research and development contributes to the more efficient use of energy, advances the introduction of renewable energy systems and stimulates the clean and efficient use of fossil fuels. Active pursuit of these research themes will lead to the reduction of greenhouse gas emissions. The research is targeted at finding solutions for both the shorter and the longer-term problems.

- Working in close collaboration with industry ECN's position as a developer of energy innovations enhances the synergy between free market processes and sustainability.

- As an international knowledge centre ECN builds up new knowledge in the field of energy together with the universities and transfers this knowledge to society

Evaluation 1996-1999

In 1996 the Minister of Economic Affairs changed the terms of its funding of ECN. From that time at least half of the total amount of government funding had to be used for projects in which third parties participate for at least 50%. At least a quarter was earmarked for long-term research. The necessary market orientation was formulated explicitly in the new mission statement as *Energy innovation commissioned by government and industry.* It was further elaborated in the Strategy 1997-2000 and formulated in concrete targets concerning annual turnover.



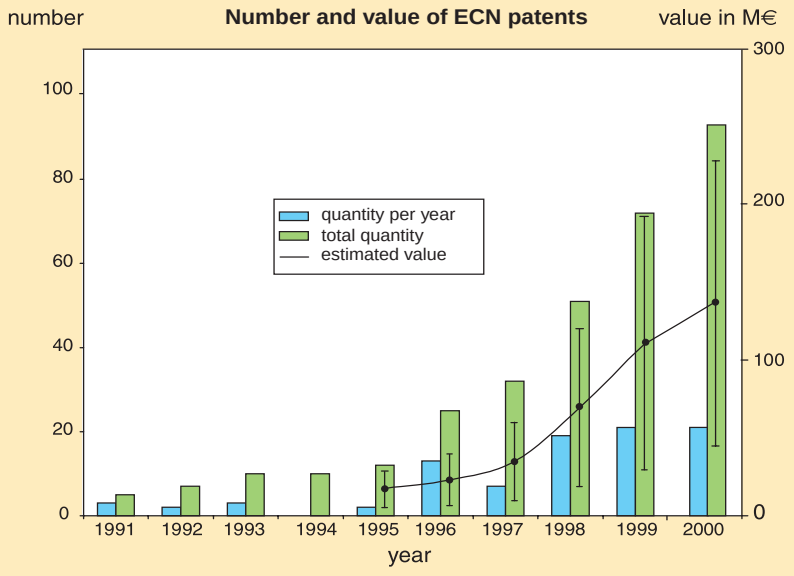
As agreed with the Ministry of Economic Affairs the utilisation of the government funding during the period covered by the previous Strategic Plan was evaluated in 2000. The consulting firm PriceWaterhouseCoopers (PWC) scrutinised the performance of ECN during the period 1996-99 and declared in its final report in December 2000 that the government funding had predominantly been used effectively and efficiently. PWC observed that the turnover had grown by 25% according to plan and that ECN had succeeded in gaining international recognition as a leading research institute in a number of fields including photovoltaic solar energy, ceramic membranes, policy studies and micro CHP (combined heat and power). In summary, PWC concluded "that ECN (with reference to its strategic plan) had made good progress". However, not every target has been reached: PWC observes that the transition to a greater market orientation has not yet been completed and that the concentration on spearheads deserves undiminished attention.

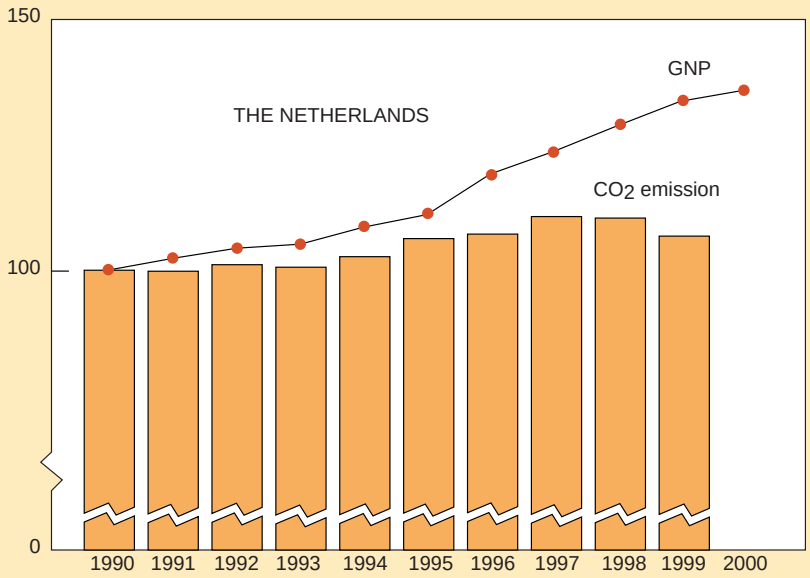
Needless to say that we, directors of ECN, are very much satisfied with the outcome of this evaluation, which underlines that our organisation has successfully changed its course, both business- and programme-wise. At the same time we are well aware that it is difficult to fathom the progress made in the many projects which ECN has carried out for a variety of clients during the past years. Without wanting to appear immodest we think that our achievements make it clear that ECN's work demonstrably increased the chances for a sustainable energy economy. The growth

Patents in 2000

short title	name inventor(s)	explanation on page
Supercapacitor	F.H. van Heuveln, G.D. Elzinga, L. Plomp	30
Stirling micro-CHP	G.J.J. Beckers, J.S. Ribberink, J.G.M. Zutt et al.	26
Algae based system	J.H. Reith et al.	23
Separator plate for PEMFC	R.K.A.M. Mallant	25
Silkscreen printing ink	M.P. de Heer, F.A. de Bruijn	20
Sealing socket	F.T. Rusting, G. de Jong, P.P.A.C. Pex, J.A.J. Peters	29
Isothermal module	P.P.A.C. Pex, Y.C. van Delft, H.M. van Veen et al.	9
Anode based electrolyte	F.P.F. van Berkel, J.P. Ouweltjes, P. Nammensma	27
SOFC anode	J.P. Ouweltjes	17
Magnetic connectors	P.J.M. Heskes	15

Twenty-one inventions were reported in the year 2000. This high level was reached for the third consecutive year. It clearly shows us that our patent policy has a favourable effect on the number of innovations. For 10 out of these 21 inventions a patent has been officially applied for. These 10 patents are listed in the table above.





Economic growth need not be accompanied by increasing CO_2 emission, as is obvious from the figure (sources: RIVM Environmental Balance 2000, and CBS). ECN will explain and analyse this new decoupling in 'Energy Report Netherlands 2000' which will be published later in 2001.

Renewable and sustainable energy innovations

• The photovoltaic (PV) solar cell is an elegant but still expensive technology to produce electricity from sunlight. ECN developed important innovative concepts in this area and among other things invented a PV-module based on crystalline silicon with a new design to allow high-volume production at reduced cost. In addition, the design yields a higher efficiency and has an attractive appearance. During the past few years ECN has become the main supplier of PV knowledge to Royal Dutch Shell.

• The 'stall flags' diagnosis method can analyse the results of blade improvements very rapidly within a few days instead of months. This results in a larger average energy output of wind turbines. These innovations are essential for the development of the very large multi megawatt turbines, which, placed offshore, must make it possible to increase rapidly the Dutch production of 'green' electricity in the next few years.

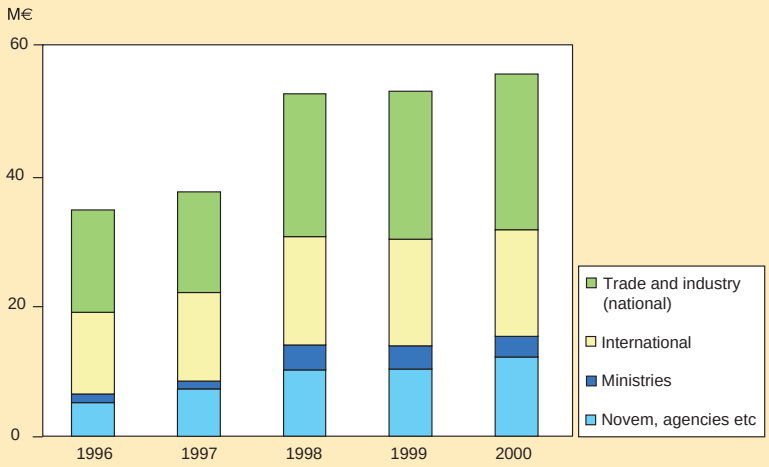
• When the gas reserves in Slochteren have been exhausted, the Netherlands will still remain a 'gas land', because of the synthetic natural gas produced from hydrogen and biomass or organic wastes. ECN invented several methods for the efficient production of 'green' gas, with which it is not only possible to generate heat and power but also to produce plastics or other synthetic materials.

• Not only greenhouse gases but also aerosols play an important part in the radiation balance of the earth. It was generally believed that sulphate is the dominant aerosol component and that the contribution of nitrate is small. However, ECN came to the unexpected conclusion that the nitrate concentrations over Europe in terms of the particulates size range relevant to the radiation balance are comparable to the sulphate concentrations. This insight was the result of a systematic screening on measurement artefacts of the many available but very diverse nitrate data in Europe, based on knowledge from another research project. Aerosols reflect a considerable part of the sunlight and the surprising outcome may have serious consequences for the future climate policy.

• Distillation for dehydration and other industrial separation processes is a highly energy consuming process. A special ceramic membrane, recently introduced by ECN, separates just as effectively as distillation and it consumes almost no energy. If the whole Dutch industry would apply this technique it would save several tens of petajoules annually. Of course, the best way to avoid the emission of carbon dioxide is to avoid the consumption of energy.

• The fuel cell converts hydrogen to electricity and heat. Before it can be developed into the foremost power source for vehicles and for domestic micro CHP systems, an efficient and above all safe hydrogen technology has to be developed. The reforming of traditional fossil fuels in situ – underneath the vehicle hood and at home – is a potential winner. ECN contributed considerably to the development of a *fuel processor* which can transform both natural gas and naphtha directly into clean hydrogen.

Assignments per customer category (NRG included)



of ECN's patent portfolio, the value of which during the same period increased by more than NLG 90 million, also shows that the approximately NLG 180 million government funding which enabled ECN to develop this knowledge and know-how has not only led to an increase of the more abstract and theoretical knowledge (see Patents). The contribution of last year's innovations is detailed in the following chapters.

Qualitative growth

Simultaneously with the completion of the previous Strategic Plan, the organisation spent much effort in the development of the new strategic intentions for the period 2001-2004. This was carried out by means of an iterative process in which in principle all staff members were given the opportunity to contribute. The concomitant intensive internal communication, supported by a specially created intranet site, while asking much attention of the unit management, helped to create ambitious and broadly supported targets per priority area, which have been translated into concrete R&D-results to be reached by the end of 2004.

As directors we are convinced that ECN, with its present number of staff , has reached its optimum size. The growth ambitions formulated in the strategic plan concern quality rather than quantity. In conformity with PWC's recommendations we have tried to translate the targets into verifiable results, ranging from an increase in the number of PhD staff to a doubling of the value of the patent portfolio.
With this emphasis on quality our organisation will during the coming years try to qualify in each of its priority areas as the developer of internationally important, and for some topics leading, knowledge and technology. We are convinced that in the long run within the European Union energy innovation will be the sphere of activity of only a limited number of centres of excellence and we want ECN to form an integral part of this European R&D-infrastructure.
In view of the constant devotion and creativity of ECN's personnel this task will surely be performed satisfactorily.

In 2000 the organisational reform which was started a number of years earlier with the disconnection of ECN and NRG and the programmatic focusing on priority areas, was completed with the re-organisation of the central staff departments and service activities. An important change was the decentralisation of the marketing activities: the responsibility and authority for market development and marketing communication have been delegated explicitly to the individual business units.

In addition it was decided to concentrate a large number of financial and administrative tasks in a Shared Service Centre, which will be finalised during the course of 2001. The group Technological Services & Consultancy (TS&C) was disconnected from the business unit Energy Efficiency (EE) and formed into a separate business unit TS&C, which offers technical support, both to ECN research units and third parties.

Last but not least, for organisational reasons the group Renewable Energy in the Built Environment (DEGO) was placed with the business unit Solar Energy. This underlines the crucial role that thermal and PV solar energy play in sustainable building(s) and ensures optimum synergy between technology development and application in the built environment. DEGO now is an independent priority area, which in due time could develop into a separate business unit. These changes in the year under review combined with a flattening of the organisational structure within the units to shorten the communication paths outline ECN's organisational form for the next few years.

Prof.dr. F.W. Saris, Chairman of the Board
Ir. W. Schatborn, Director

Policy Studies

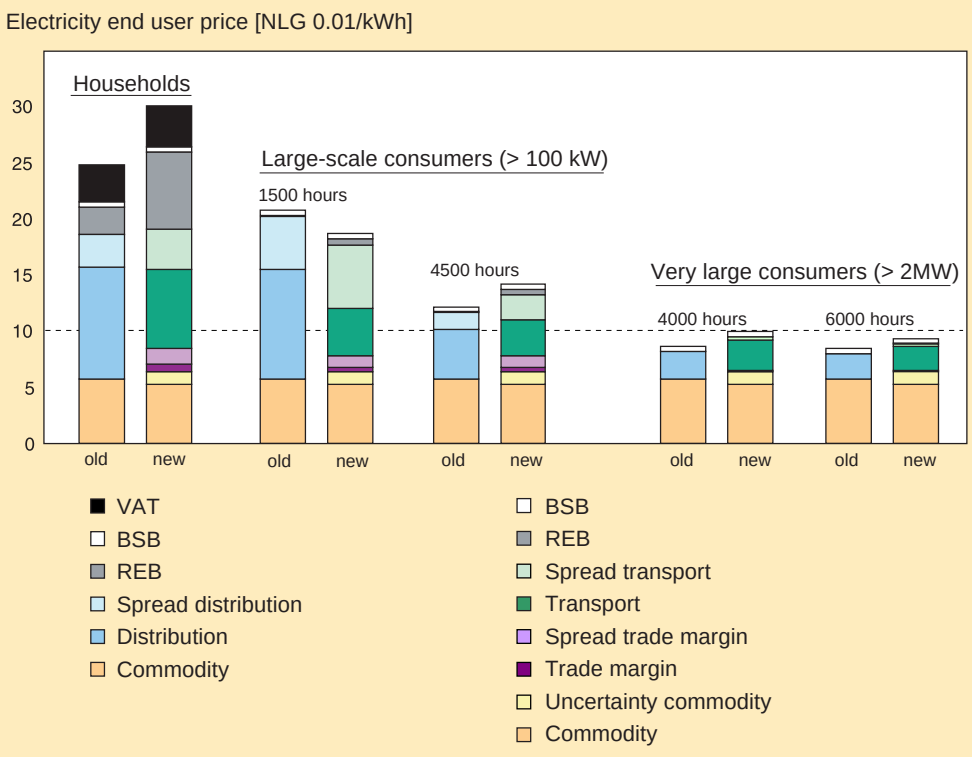
Several European countries, including the Netherlands, are currently preparing plans to introduce tradable green certificates. Energy companies are changing from utilities into market parties. Foreign energy companies are taking over Dutch companies. The energy sector is rapidly changing as a result of liberalisation, and there is much uncertainty as to how the sector will develop in the future. The Dutch government leaves the developments to the market parties and limits its role to regulation.

However, a market oriented energy economy does not necessarily only have positive results: development of renewable energy and liberalisation may have conflicting interests. In this arena of potential conflicts Policy Studies tries to identify opportunities for synergy. From this angle they give advice to government agencies.

Dutch energy policy

At the present time market parties and the government in the Netherlands experience the uncertainties which a free market entails and much effort is directed towards predicting the future shape of the energy market. Which technologies will characterise the future Dutch energy supply system? What will be the relationship between a competitive market and sustainability? In order to clarify these questions ECN Policy Studies published *Energy Market Trends 2000* (EMT), an overview based on independent, in-house research. This publication offers information about the Dutch energy sector, analyses recent developments and sketches the foreseeable future. According to the Dutch government liberalisation will lead to a reduction of the energy price. In practice, however, this does not always happen and in some cases the government is the influencing actor. In a liberal market energy suppliers compete by keeping prices low but the actual impact on the consumers is negligible because energy prices are largely determined by government taxes and levies. Also, a price increase could stimulate consumers to save more energy and to use more renewable energy. Expectations of how sustainability and free market forces can go hand in hand in the future are formulated in each analysis.

ECN Policy Studies investigated the feasibility of three future technological scenarios. A point of special interest was the future role of gaseous and liquid energy carriers, for example, natural gas, gasoline and diesel fuel. In the first scenario these products are replaced by electricity, in the second by hydrogen, while in the third they stay in use but are produced from alternative feed stocks, whereby the existing energy infrastructure remains intact. In this third case the consumer will



In 'Energy Market Trends 2000' the structure of the electricity end user prices is analysed in a non-liberalised (old) market system and in a completely liberalised (new) market system.

hardly notice any change at all. The other two scenarios, however, either with much more electricity or with hydrogen gas as the dominant energy carrier, differ strongly from the present situation and they will lead to substantial changes in the energy infrastructure. Calculations show that each of these scenarios can lead to a 50% reduction of CO_2 emissions. The authors consider that the third scenario is most likely to succeed. This is not so much because energy suppliers clearly prefer it to the other options but probably because they do not make any choice at all. In this period of liberalisation suppliers seem afraid to commit themselves to a particular scenario and limit the available options. From the environmental aspect it is not yet necessary to adopt a completely new scenario, at least not for the next 20 years. A gradual transition to the third scenario may therefore be considered most likely.

European energy policy

The liberalisation of energy markets and climate change also make their imprint on European energy policy. The European Commission has decided to give the implementation of renewable energy an important place. *Tradable green certificates* (TGC) fit quite well in this policy. In a TGC system energy producers receive a certificate for every unit of electricity produced from renewable energy sources. This certificate indicates the 'greenness' of the energy production. ECN Policy Studies looked into the various possibilities to set up a TGC system, in which by issuing green certificates two separate markets are created, the renewable energy market and the green certificate market.
A TGC system can indeed work well if sufficient care is taken to define the rules. The design of the system is the key to its success, in particular, issues such as the transfer of credits towards targets from one year to the next and the sanctions against malperformance should be clearly regulated. Implementation appears feasible on the national level but on the international level the problems are still large. The European states have different fiscal measures and other incentive systems in place, all having different effects on the TGC system.

At the request of the Norwegian Statoil company, ECN Policy Studies looked at the development of wholesale prices of electricity over the next 15 years in France, Belgium, Germany and the Netherlands. Their conclusion is that the prices will continue to differ between countries because on the one hand, the national laws and rules are not completely harmonised and on the other hand, because the infrastructural possibilities for the distribution of electricity throughout Europe are still limited. As a result of the current production overcapacity, prices will still drop somewhat in the short term. In the Netherlands and Germany prices are expected to be at a significantly lower level than in France and Belgium, because the latter two countries are opening up their markets to a lesser extent.

International climate change policy

In the Kyoto protocol in 1997 the Netherlands made a commitment to reduce the release of greenhouse gases by 6% over the next ten years. Part of this target may be realised by means of *Joint Implementation*: a mechanism by which an OECD country invests in a project aimed at reducing the emissions in, for example, an Eastern European country. This 'host country' has also its own CO_2 reduction targets.

In co-operation with *Det Norske Veritas* ECN Policy Studies drafted a clear step-by-step plan for baseline studies, validation, monitoring and verification of Joint Implementation projects including CHP, fuel substitution, landfill methane and forestry. The guidelines and manuals are primarily intended for use by project developers and validation/verification agencies.
In collaboration with Novem ECN Policy Studies started a JI *capacity building* project in Romania. With this project ECN Policy Studies assist Romania in the local implementation of the international climate policy: during the past year climate institutions were set up and procedures for decision making were developed. To transfer the relevant knowledge ECN Policy Studies provided briefing and training.

In addition to Joint Implementation yet another flexible instrument was included in the Kyoto Protocol: the *Clean Development Mechanism* (CDM). The host country, usually a developing country, has no targets of its own for the reduction of CO_2 emissions and this makes it all the more important to establish a good set of criteria about how in practice to determine the reduction of the emissions. In the CDM framework traditional energy sources for lighting (kerosene, candles) are replaced by solar cells: the Solar Home Systems. This measure achieves a relatively large CO_2 reduction, but it is not always exactly clear to which extent. ECN Policy Studies compared the emission reductions of different systems. It was concluded that an average emission reduction of 200 kg CO_2 per household per year is a reasonably accurate average estimate. This amount can serve as a standard for project developers and other stakeholders.

External partners and customers Policy Studies

EZ, VROM, BuZa, Novem, IEA, multilateral institutions, local authorities, energy companies

Energy Efficiency in Industry

In the priority research area of Energy Efficiency in Industry, ECN is working on various aspects of energy saving and improvement of the energy efficiency in industrial processes. The main research topics are: energy efficient separation technologies using inorganic membranes, cost efficient upgrading of industrial residual heat, and novel process techniques by combining (chemical) reaction with heat exchange and separation of products.

Isothermal membrane module

In the Dutch process industry nearly half the energy is used in processes to separate the product from the by-products. At present distillation is the dominant technique. For a number of years membrane technology has had the potential to take over this role but a breakthrough has not yet occurred, mainly because of materials problems. ECN is working on the development of inorganic membranes. In comparison with polymer membranes these can better withstand higher temperatures, are resistant to many organic chemicals and are also mechanically stronger.

In 2000 the emphasis was on pervaporation, i.e. the selective vaporisation of a component from a liquid mixture through a membrane. The development of the technology for dehydration of organic liquids by means of silica membranes led to a licence agreement from January 2000 with Sulzer Chemtech, a producer of distillation columns and pervaporation systems. In close co-operation with Sulzer Chemtech ECN developed a module in which membrane separation and heat exchange take place simultaneously. A patent application was filed for this isothermal module and the necessary joining technique. Further, a field test programme was conducted with a skid mounted prototype unit with a membrane surface area of 1 m^2. This mobile installation was successfully tested at 150ºC on site at an Akzo-Nobel plant.

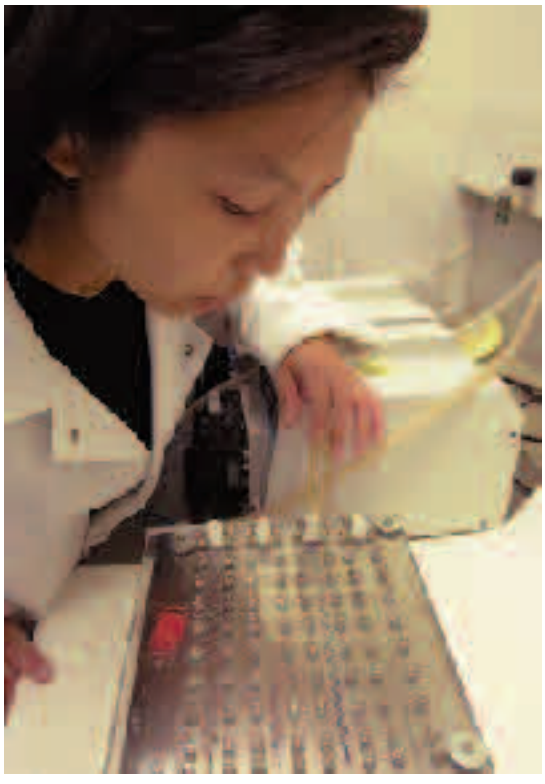
Membrane module for process intensification

In many industrial processes the various unit operations take place sequentially, resulting in a substantially lower than ideal efficiency. Pervaporation is a separation technique in which one of the components of a liquid mixture is evaporated over a membrane. The membrane cools off due to the vaporisation thus slowing down the pervaporation process. In co-operation with Sulzer Chemtech, ECN developed a module which combines the functions of liquid separation device and heat exchanger in a single piece of equipment, so that the process takes place at an optimised rate – this is called process intensification. ECN's well tested ceramic tubular membranes, with the membrane layer on the outside surface, are individually contained in a metal annular tube leaving a gap of less than 1 cm between the metal and the ceramic. By means of a heat transfer medium outside the metal tube the feed liquid for the membrane is kept at the right temperature. Using return plates with a simple but well designed system of channels, the liquid is fed through several of these annular spaces in succession, which is equivalent to having these membranes in series. A relatively small pumping capacity is needed to operate these membrane systems. It is also a relatively simple matter to modify the system of channels in the return plates so that it becomes possible to build this basic membrane module with all required combinations of series or parallel connected membranes. Inventors: (from left to right) Paul Pex, Henk van Veen and Yvonne van Delft; missing from the photograph are H.E.A. Brüschke, F. Marggraff and N. Wyn (from Sulzer Chemtech GmbH)

The silica membrane can also be used in reactor concepts in which, by combining the synthesis reaction and the dehydration in one reactor, a shift in the equilibrium can be accomplished, resulting in a higher product yield. This has been proven experimentally for the esterification of alcohols. The dehydration during the production of ureum is being studied in a EET Kiem project in co-operation with Continental Engineering. Here also a shift in the reaction equilibrium appears to be possible, albeit that under these aggressive conditions the stability of the current membrane is not sufficient. Sulzer Chemtech has meanwhile started the world-wide introduction of this new technology. Technical and economic assessments indicate that there is a market potential of several tens of thousands of square metres of surface area for these membranes. By using this technology annual energy consumption in Europe can be reduced by approximately 400 PJ.

SWEAT heat pump

Industrial residual heat is available mainly in the temperature range 50 to 200ºC. In the Europoort/Botlek area alone the annual supply of industrial residual heat already exceeds 40 PJ. Important barriers against its utilisation are the economic conditions and the mismatch, in temperature, time and location, between demand and supply. ECN is working on specific heat pumps and heat/cold storage systems. Moreover, advanced systems for the conversion of residual heat to electricity and power are presently being assessed, partly in the framework of a European project.



Eva van Dorst researches the HEX (heat exchange) reactor combining a chemical production process with heat exchange. The chemical reaction is carried out here in the small channels of a compact heat exchanger.

Solid/vapour heat pumps, based on reversible solid-vapour reactions, offer an excellent perspective, both from the technological and economic aspects.
They can upgrade heat by a large temperature step and they are thus able to convert residual heat into valuable process steam or cooling energy. In addition it is also possible to use these systems for storing residual heat indefinitely and with a much higher energy density than in conventional heat storage systems.

An example of this type of heat pump is the SWEAT system (Salt Water Energy Accumulation and Transformation), powered with residual heat at 80ºC. Heat can be stored and released at a later point in time or used to provide a cooling medium at approximately 10ºC. By applying SWEAT as a cooler in the utility building, transport and industrial sectors, energy consumption can be cut by more than 10 PJ annually. The mechanism of the pump is based on the hydration and dehydration of sodium sulphide, which, however, is a very corrosive salt. In ECN's development work for SWEAT BV, a joint venture of NUON, Inalfa-Ares Energy Systems and ECN, the emphasis is on controlling the corrosion process in combination with maintaining a good heat transfer between the salt and the embedded wire fin tubular heat exchangers. In the past year, ECN, together with its industrial partners, worked on the selection of a good coating and a deposition method suitable for mass production. An electrochemical characterisation method was developed for a rapid quantitative determination of the defect surface area per heat exchanger unit. Together with the manufacturer Spirotech ECN worked out modifications to the production process. As a result of this effort the fraction of defect surface area could be reduced by a factor of 100,000 to a level of 0.0003 % whilst the coating still satisfies the heat transfer requirements. Long duration verification testing of the corrosion behaviour is in progress. A Matlab/Simulink model was developed to simulate the SWEAT system. On the basis of these favourable results the client gave its approval to start phase 3 of the development route, which involves the construction of a prototype.

Heat Exchange (HEX) reactor

The centre of a chemical production process is the reactor. At its periphery various separation and heat exchange steps take place, which serve to condition the reactants before they enter the reactor and to separate products from by-products. By combining the different process functions within a single device,

Student Onno Halsema assists in the research on the SWEAT heat pump commissioned by SWEAT BV, a collaboration between NUON, Inalfa-Ares Energy Systems and ECN.

process intensification can lead to substantial improvements in the production processes.

One of the developments in this field is the so-called HEX-reactor, in which the chemical reaction takes place in the channels of a compact heat exchanger. In 2000 a large number of experiments was performed on a number of mini-reactors, each simulating a single channel of a commercially available compact heat exchanger. Typically the size of the channel is 1 × 1 mm^2. The Naphtol colour reaction was used as a model system. The results show that it is possible to suppress the formation of by-products to a very large extent. Due to the short residence time and the good mixing of the components the selectivity is increased by 30%. By carrying out the process in this way it is possible to obtain a large throughput with very compact equipment.

In addition to the experimental work a number of supporting activities was undertaken. Contacts were made with Heatric (a Brtitish manufacturer of 'printed circuit' heat exchangers) and Alfa Laval (corrugated plate heat exchangers) on the subject of testing commercially available heat exchangers. Through a contract from Novem and in collaboration with Process Design Center (PDC) and Chemserveand, ECN reviewed the concrete applications and quantified the potential advantages of these systems.

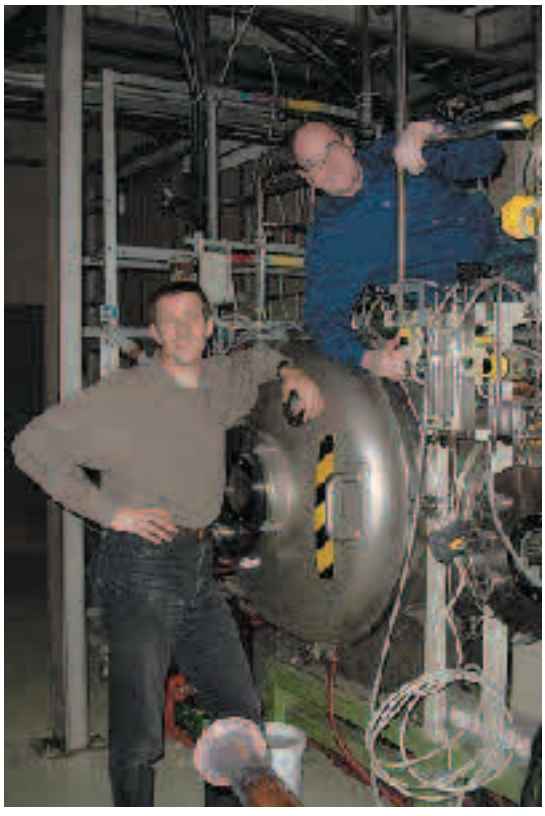
External partners and customers Energy Efficiency in Industry

Akzo Nobel, ATO-DLO, Aircofin, Alberts Alligator, Aster TAS, Bayer (D), De Beijer RTB BV, BHR Group (GB), Caldic Chemie), CERES, Chart Marston (GB), CINTEC, COGEN Projects, Continental Engineering, Corus, Cristopia (F), Cytec, Diosynth, DSM, Eco Ceramics, E.E.T, ESD (UK), ETE, Electricom, Enersearch, EPFL (CH), European Commission, Exxon Chemical Europe Inc (B), ExxonMobil ER&E (VS), Haltermann Ascot GmbH (D), Hoek Loos, Hüls Creavis (D), IRC-CNRS Lyon (F), Inalfa-Ares Energy Systems, Institut Francais du Pétrole, Jacobs Comprimo Nederland, Kemira Engineering (B), Kropman, KTH Stockholm (S), Linde AG (D), Lyondell Chemical Nederland, Ministry of Economic Affairs, NEAT(SL), NL-GUTS, Novem, NV NUON, Pall (VS), Purac Biochem, Quest International, RWTH Aachen, SCT(F), SDE, Senter, Solvay, Spirotech, Stork Screens, Sulzer Chemtech, SWEAT BV, TNO-Bouw, TNO MEP, TU Delft, TU Eindhoven, Unichema, Universities of Aken, Amsterdam, Bath, Messina, Newcastle, Salford, Sevilla (GB), Twente, Utrecht, Ulster, Wellman CJB Ltd (GB), Wientjes Emmen.

Solar Energy

At the end of the first year of the 'Solar Age' we can confidently say that the year 2000 was an excellent beginning to this new era. The world market for photovoltaic solar energy showed an unprecedented growth of 40%, several countries embarked on extensive implementation programmes and the solar energy industry continued its rapid development into a mature industrial sector. In the Netherlands many organisations, and ECN in particular, were likewise highly active in this field.
The 'PV Covenant 1996-2000', which has resulted in the commissioning of nearly 10 MWp worth of grid connected PV-solar energy systems, came to a successful conclusion. The success has given the participants the motivation to adopt the ambitious objective to realise a further 250 MWp in the period 2001-2007. ECN strongly supports this goal and is actively involved in the drafting of the actual implementation plans. A major part of ECN's R&D programme on PV is dedicated to the support of this national enterprise, which should result in the development of a self-sustained market for PV systems.

On a more local scale the progress in this field is also visible. The visitor entering the ECN site will immediately notice several unique PV-systems integrated in new and renovated buildings. Though eye-catching, they are certainly not designed as mere showcases but as objects of serious research and monitoring activities.



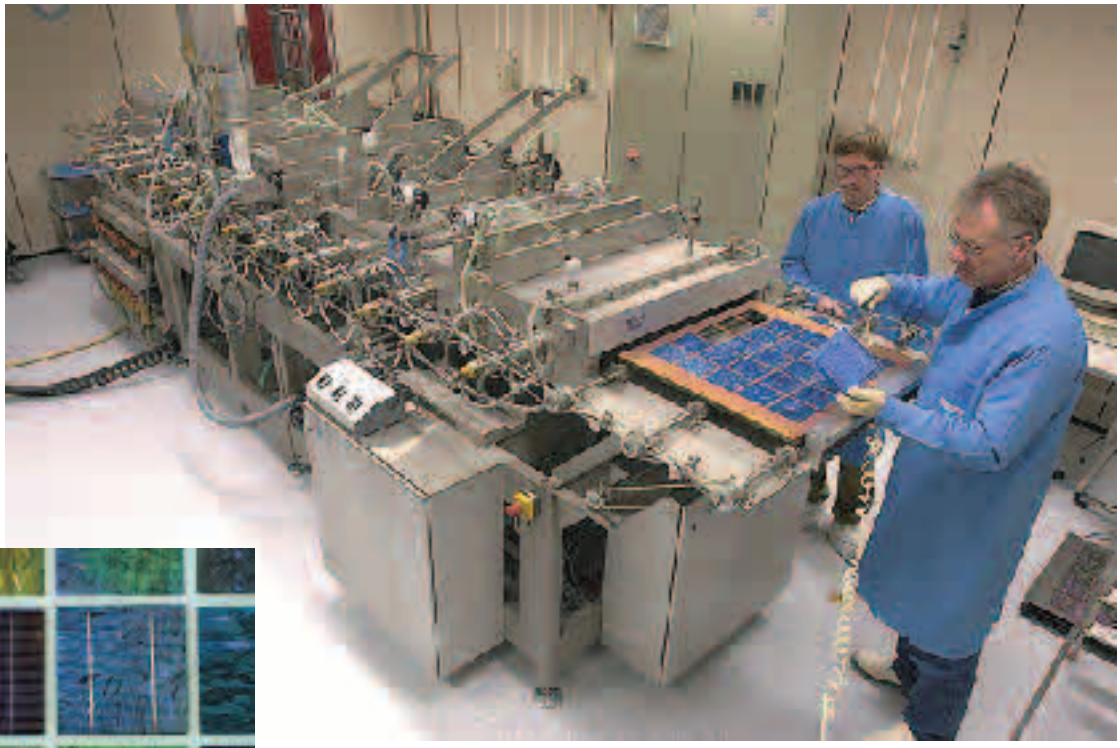
Axel Schönecker and Leon Laas (left) are putting the finishing touches to the equipment for the production of silicon wafers (RGS).

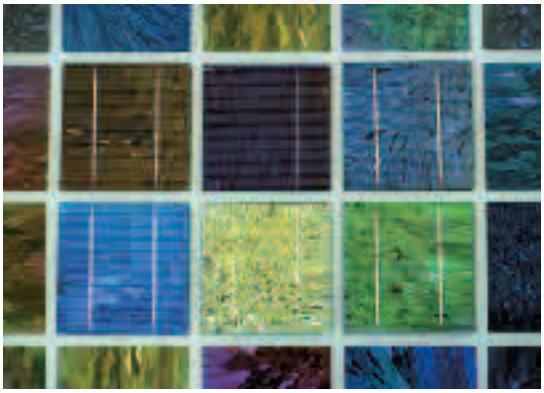
A closer look at the various buildings will reveal the new 'silicon-grey' laboratories of the business unit 'Solar Energy', the epicentre of most of ECN's R&D on PV-technology. Equally important are the new research facilities for PV system technology.

Crystalline silicon technology

Crystalline silicon is the first PV-technology to be utilised on a large scale. Hence its dominant position in the R&D programme, which is aimed at answering pertinent questions such as "Is performance in line with expectations?" and "Are we able to accomplish the predicted and necessary decrease in manufacturing costs?" In co-operation with its partners ECN Solar Energy has achieved some very good results and in general made excellent progress.
The silicon base material to a large extent determines not only the cell output, but is also an important cost component of the resulting PV modules. The availability of silicon of suitable quality at an acceptable price is an essential prerequisite for the industry. An agreement was signed with Bayer for the further development by ECN of the so-called Ribbon-Growth-on-Substrate (RGS) technology. This development will be carried out in an extensive EET-project, to which Philips and Sunergy also make important contributions. If it is successful, the RGS-technique will enable the production of silicon wafers at the unprecedented rate of 1 per second, without resorting to sawing. At the end of the year the existing RGS-equipment was transferred from Germany to Petten. The next generation equipment will be built in the period 2001–2002.

The manufacture of a good solar cell requires a fabrication process which minimises the electrical and optical losses. The remote plasma reactor for the deposition of silicon nitride layers, commissioned at the end of 1999, solves three problems simultaneously. It yields an excellent anti-refection layer, the hydrogen present in the plasma and the layer diffuses into the silicon, thereby neutralising the negative effect of crystal defects, and finally the light absorbing surface is passivated, again resulting in lower losses. Not surprisingly, there is much interest in this equipment, also outside the Netherlands. ECN made the silicon nitride process part of its baseline and so achieved an excellent cell efficiency of more than 15%. Silicon nitride can only passivate the cell surface when the phosphorus doped top layer is sensitive to this treatment, i.e. not too heavily doped and not too thick. Underneath the metal contacts, however, heavy doping is necessary. Application of the patented process (see Annual Report 1999) for selective phosphorus diffusion again raises the cell yield by a further 0.25% relative to the reference process.





Paul Wyers and Hans ter Beeke (right) at the plasma reactor applying silicon nitride layers on silicon wafers. Small differences in layer thickness give the wafers different colours, causing the same effect as oil on water.

Thin film technologies

For some time the PV community has viewed the family of dye sensitised and organic solar cells with considerable scepticism, which is understandable since scientific and technological progress has been rather modest. The year 2000 marks a change. Impressive results in the United States, Japan and Europe have convinced the insiders that these cell technologies are serious contenders for future PV systems. In this particular field the Netherlands plays an important role. ECN devotes an appreciable part of its R&D programme to the development and study of these materials.

In collaboration with Philips and the universities of Groningen and Eindhoven, ECN manufactured fully organic solar cells based on C_{60} molecules ('bucky balls') plus a polymer, giving an efficiency of 2.5% on a scale of 0.1 cm^2 and of 2.3% on 1 cm^2. This result, albeit still modest in absolute terms, is a very significant advance for this type of solar cell.

The pilot production line for dye sensitised solar cells will be fully operational at the beginning of 2001. A cell yield of 4-5% on 4 cm^2 has already been obtained on so called master plates. The next step, presently under elaboration, is the development of this process to yield much larger surface areas. Another important research item is cell stability. It was shown that the stability under conditions of UV-light can be improved by adding certain compounds to the electrolyte in the cell. The stability at elevated working temperatures was found to be strongly dependent on the quality of the encapsulation of the cell. A glass seal was developed, permitting use at temperatures as high as 85ºC. At a temperature of 45ºC and an illumination intensity of 1 sun the cells were shown to be stable (i.e. they show less than 10% decrease in efficiency) over periods of at least 3500 hours.

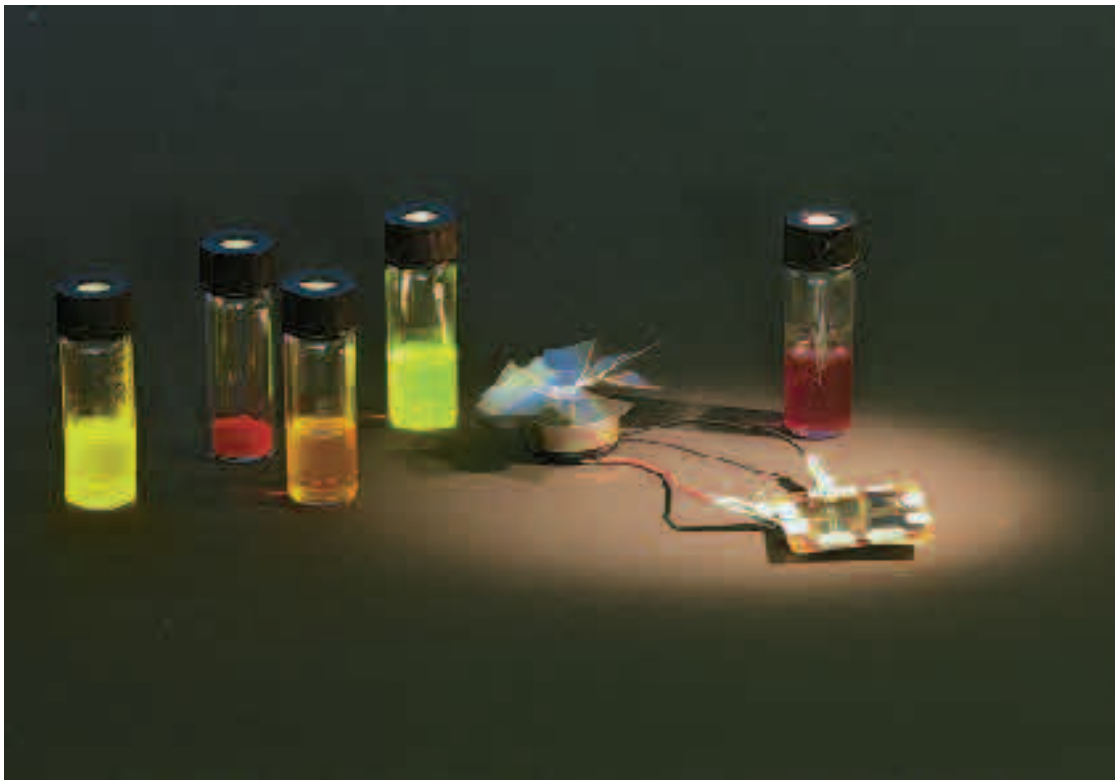
The research programme on thin film crystalline silicon was appreciably modified last year. Emphasis has shifted towards methods to deposit silicon layers at low temperatures (i.e. <600ºC). With the prototype remote plasma reactor, mentioned above, homogeneous and closed layers of microcrystalline silicon were successfully deposited onto glass substrates. This is the first step in a new programme, in collaboration with the universities of Utrecht, Delft and Eindhoven and others.

System technology

The viability of PV does not only depend on cells or modules, but also on other components making up complete systems. Now that the Netherlands and other countries are preparing for solar energy generation on a large scale, problems of normalisation, quality assurance and yield prediction must be seriously addressed. ECN devotes a substantial part of its R&D capacity in the field of solar energy systems technology to these issues.

There is a growing demand for fast and reliable predictions of the behaviour and yield of large numbers of systems. It has been found possible to obtain a rather reliable picture of the system behaviour under field conditions by applying a judicious combination of laboratory measurements, outdoor tests, and calculations. For this purpose test facilities for inverters and modules are available and insolation calculations can be made. A large range of inverters, of different types and sizes, are tested both in the laboratory and connected to a real outdoor 10 kWp PV system. Modules are likewise tested both under simulated sunlight in the laboratory and outdoors. On the basis of these data the predicted behaviour under realistic conditions of the various types of modules (see Photon International, November 2000) can be compared. As a service to the general public, or at least to the private owners of PV

Henk Kisteman loads the climate chamber for testing solar energy components under extreme conditions.

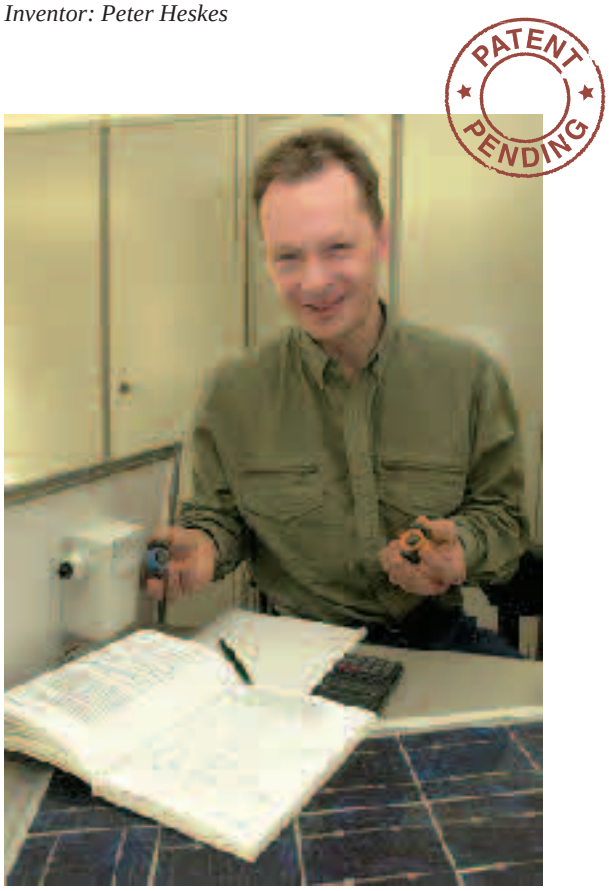


Plastic solar cells can be readily made from polymer-C_{60} solutions.

Electromagnetic connectors for solar panels

The reliability of photovoltaic systems depends strongly on the quality of the electrical connectors. These connectors ensure the supply of energy from solar cells to (the battery of) the consumers or to the electricity grid. PV systems are rightly expected to operate for many years without failure in the outside air. The solar cells in the panels are already permanently connected to each other and sealed in the factory using high-quality techniques. The electric connections between the panels are mostly made during the installation. Plugs and other clip connections and various types of anti moisture devices are used for this purpose. This method is labour-intensive and because one bad or broken connection can cause a considerable energy loss, it is very important to develop a solid and reliable connection technique. At the same time it is desirable that the panels can be easily exchanged if necessary, for example, when damaged. To fulfil these conditions, ECN plans to use electromagnetic (EM) connectors instead of electric connectors. These dust and moisture resistant EM connectors are commonly used in electric toothbrushes which are recharged without using conductive contacts. An EM connector is in fact a transformer sawn in two with both halves carefully sealed. This is already done in the factory using the same technique as for solar cells. When the two halves are joined again, energy can be transferred without a current running from one half to the other. This means that making a connection now is simply a matter of clamping together both sides of the transformer: in a suitable design this can be realised easily and very reliably. Moreover, a small play in the connection has hardly any consequences for the quality of the energy transfer.

This EM connector was invented almost a hundred years ago and its application in photovoltaic systems is also not new. However, ECN and its partners expect to be able to use this connector in new concepts for reliable and maintenance friendly systems with a better price/performance ratio.
Inventor: Peter Heskes



systems, the web site www.ecn.nl/solar/yield was set up to provide owners the necessary computational tools to calculate the yield of their systems.
PV is not limited to outdoor use. It can also be applied indoors, for instance to power consumer products. A comparison at low light intensities showed that dye sensitised cells outperform all other cell types. Their power is an almost linear function of the light intensity over a very broad range (1 to 1000 watt/m^2 (0.001 to 1 sun)).
An extensive review of world-wide experience with Solar Home Systems which was made for Novem by ECN found that systematic information from projects is not readily available making it practically impossible to improve the systems in a targeted way. This stresses the importance of projects in collaboration with local partners in Indonesia and China, to monitor Solar Home System use under practical conditions. Finally, in co-operation with Philips Lighting and Eindhoven Technical University, ECN has started to investigate the optimum design of inverters for grid connected systems. This rather fundamental work, performed by an experienced Post Doctoral Graduate, will contribute to the necessary knowledge base in the field of systems technology, which has been a somewhat neglected area of research in the Netherlands.

External partners and customers Solar Energy

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

Renewable Energy in the Built Environment

The building and construction sector, including its suppliers, has in recent years begun to devote more of its attention to energy-efficiency and renewable energy. This is partly in response to the continuously increasing demands by both government and customers on the energy performance of houses, commercial and industrial buildings and districts. The targeted incentive programmes of the government, for example in the field of photovoltaic energy and heat pumps, also stimulate this market.

Sufficient technology is already available to enable a shift towards a more sustainable energy supply in the built environment, but both government and market are fully aware that for the full utilisation of the potential both novel approaches and novel products are needed. The ultimate perspective is one in which the amount of renewable energy harvested in the built environment exceeds the energy demand in this sector. The objective of the R&D programme in the priority area of Renewable Energy in the Built Environment is precisely to contribute to this development.

Last year an important testing facility, consisting of four family houses, became available. These dwellings will be used for R&D on technology for energy-efficiency and the integration of renewable energy systems. The first testing configurations, which were built in 2000 in and around these houses, are aimed at cutting the primary energy consumption by 50% with reference to that currently required in newly built houses. The future extension and modification of the testing configurations are designed for an increased share of renewable energy, such that it will fully cover the energy demand. To this end solar energy and environmental heat will be deployed in various combinations. An important condition for the large-scale breakthrough of such concepts is that they lead to cost reduction and to improvement of comfort in summer and of indoor air quality. These aspects therefore play an important role in the measurement and testing programmes to be carried out in these houses during the next few years. To prepare for these programmes an extensive measurement infrastructure was put in place in and around these houses.

Intelligent combinations of efficient use, generation and storage of energy are being tested in a real environment in four test houses. Considerable energy saving is possible without affecting comfortable living. Ventilation air pumped up through an underground pipe is one of the features. The very constant ground temperature at approximately 10ºC provides warm ventilation air in winter and cool ventilation air in summer.

Oxidation resistant SOFC-anode

The simpler the supply system of fuel and air to a fuel cell stack, the less expensive they are to produce. The flat disc shaped ECN cells in the micro CHP system which will soon be introduced into the market by Sulzer-Hexis are fed from the centre of the disc, on one side with hydrogen, on the other side with air. These gases meet at the edge of the cell. The remaining hydrogen is burned and the heat is transported to the central heating part of the installation. If the gas flows fluctuate slightly, and in any case when the apparatus is shut down, the oxygen reaches the nickel of the anode and forms nickel oxide. The green nickel oxide is reduced again to nickel metal as soon as it gives up its oxygen to the passing hydrogen, but in the long term the quality of the anode, and the quality of bonding to the electrolyte, deteriorates. Alternating oxidation and reduction gives rapid changes in the microstructure of the anode material, which consists of a mixture of metallic nickel and gadolinium doped cerium oxide. In the long run these materials crumble despite the many recent improvements. Jan Pieter Ouweltjes has solved this problem in an extremely simple way, namely by applying one of the pure components of the powder mixture to each side of the anode. The layer of pure metallic nickel on the surface facing the gas is sufficiently elastic at an operating temperature of 950ºC to accommodate the strains due to the oxidation/reduction reaction. Pure gadolinium doped cerium oxide on the reverse side promotes a perfect and permanent bonding to the electrolyte.

Increasing the share of renewable energy in buildings relies heavily on photovoltaic systems. The R&D programme is therefore aimed at developing and testing advanced methods to integrate these systems into buildings. Last year a new method for the integration of thin film PV on metal roof panels was successfully tested. Some 250 m^2 of transparent photovoltaic cells were applied to one of ECN's new office buildings. A PV project for ECN staff yielded useful experience with the installation of photovoltaic panels on the roofs of existing houses. Installing these photovoltaic panels not only changed the energy economy but also the outward appearance of the houses of some 50 ECN staff.

The so-called PV combi panel, a solar panel which produces both electricity and heat, provides a further means to incorporate PV in buildings. It consists of a heat collector in which a photovoltaic panel has been integrated (See photograph on page 18). ECN worked on the improvement of the thermal efficiency of PV combi panels jointly with the Technical University of Eindhoven. Last year the development of a further prototype was started which is in particular aimed at exploring and developing the possibilities for large-scale fabrication. Special attention is given to the quality requirements which PV panels and thermal collectors have to meet. This is not as simple as it may appear because in a combi panel the situation may arise that the photovoltaic cells are subjected to substantially higher temperatures than in a traditional photovoltaic system. At present a number of prototypes are being tested for electrical and thermal output and for mechanical strength. In the framework of a European demonstration project panels will be placed on the new headquarters of Renewable Energy Systems, a British consulting firm in the field of renewable energy.

Not only sunlight but also ground heat is an important renewable energy source for buildings. ECN is involved in the design and evaluation of a first series of projects in which 'heat piles' are used. This is a pile with an embedded heat exchanger in the form of a plastic hose, with which heat can be extracted from the ground. The local ground temperature stays at approximately 10ºC throughout the year. Obviously this temperature is too low to heat a building. Therefore a heat pump is used to lift the temperature to the desired level. The first results of measurements show that the system performs quite well and gives an output of 140% on primary energy. The first project evaluated also showed that the

Marcel Elswijk en Herbert Zondag are mounting two specimens of a prototype of a solar panel (for electricity) and a solar collector (for heat) combination. Nearly all the energy from the sunlight can thus be utilised.

system can work for a number of years without cooling the ground.
A more extensive research programme was prepared to investigate whether the performance of this sort of system is still favourable under different soil conditions and with a higher number of heat exchangers per unit surface area. Not only vertical but also horizontal ground heat exchangers can extract heat from the ground. The extraction of cold from the ground for cooling purposes in summer is also possible because, as previously remarked, the ground temperature stays at around the 10ºC level throughout the whole year.
For the test houses on the ECN site a design was made and a prototype was built for two different systems. One is a water-filled hose, embedded in the soil at a depth of several metres and connected to a cooling system for the ceiling. The other is a tube in the ground – likewise at a depth of several metres – by which ventilation air is cooled in summer and preheated in winter (See photograph on page 16).
The efficient use of energy is an important condition for success in concepts in which renewable energy will have to cover a large part of the energy demand in a building. In this context ECN has been working on two techniques for limiting heat losses, i.e. insulation of the shell of the building and heat recovery from ventilation air. For one of the test houses a so-called hybrid ventilation system was developed, which, depending on the season and user requirements, can function in various ways, that is, in winter as a fully balanced ventilation system with heat recovery, in spring and autumn as a natural ventilation system, in summer as a system for cooling with outside air. The specially developed control systems form part of an integrated system for the control of ventilation, cooling, lighting and heating. Last year this particular ‘domotica house’ was furnished as a demonstration house to show the building sector how intelligent systems can create energy-efficient comfortable living conditions.

In the year under review the prototype of a comfort management system was completed, which provides the dynamic optimisation of comfort, taking into account personal preferences and the current energy prices. Simulations have indicated a 10-20% potential reduction of energy consumption. The development was started of a more advanced comfort management system coupled through the Internet. In 2001 a field test of this system will be carried out in a new office building.

As in previous years ECN was involved in many projects concerning the built environment in which novel and advanced technology could be applied and by which knowledge could be transferred. ECN contributed to an energy vision for the post-war housing in Amsterdam and Haarlem, in which a potential for energy saving of up to 50% was identified. A ‘zero-energy’ concept which lends itself to a wider range of applications was developed for a school in the town of Castricum.
A new phenomenon in 2000 was the growing concern over the high energy consumption in the ICT-sector. An investigation by ECN at a number of newly established ICT firms revealed that energy management, utilisation of waste heat and cooling with outside air made it possible to accomplish a reduction of energy consumption of the order of 40%. More efficient software architecture may further increase this percentage.

External partners and customers REBE

Construction companies, suppliers, project developers, TNO, Novem, EET, European Commission, local governments, consultants, universities

Wind Energy

As shown in the figure, the world-wide expansion of wind energy in 2000 was most encouraging. In the Netherlands, however, the rate of expansion remains rather low, despite much government pressure on local authorities. The public opposition to wind turbines on land seems to grow rather than to diminish. Offshore turbines are beginning to be regarded as a way out of this deadlock. On the other hand, the Netherlands has developed successfully as a supplier of knowledge and advanced technology. The local production of wind turbines is also increasing. Traditionally, ECN's main clients have been the manufacturers of turbines and turbine blades. But during the last few years the demand for R&D-services has changed in character. Accordingly, in its R&D on wind energy ECN has allotted more space to: a) characterisation of wind as the source of power and the main source of mechanical loads on the turbines, b) knowledge transfer and training, and c) the operational aspects of large wind power plants. But at the same time the demand for design support and for research in the field of offshore turbine concepts has also increased. Last year ECN therefore decided to concentrate its R&D programme on the design aspects of wind energy, and to reduce its activities in the field of the certification of wind turbines, which had for many years formed a substantial part of the programme, within the framework of the CIWI-foundation. Work concerning the formal certification of turbines was considerably reduced in scope, but the co-operation with certifying agencies was intensified so that clients do not suffer from this change of direction. The Netherlands owes much of its strong knowledge position in the field of wind energy to the collaboration between ECN and the Technical University of Delft. This collaboration was further intensified in 2000. The combination ECN/TUD is presently one the of the world's four main research institutes in this field.

The characterisation of wind as a source of power

Wind is a unsteady energy source. The quantity of electricity generated increases with the increase of the accuracy of the prediction of wind strength. ECN has been developing energy prediction techniques, in co-operation with foreign research groups. First results obtained with existing predictors, adapted to Dutch conditions, show that they are insufficiently useful due to the very specific demands of the Dutch electricity sector on the predictability of the energy yield. In the field of resource assessment, ECN, together with Dutch and foreign partners, is developing a programme for the measurement of wind and wave in the North Sea. A preliminary design was made for a measuring station and the feasibility study concerning its realisation and utilisation is currently in progress.

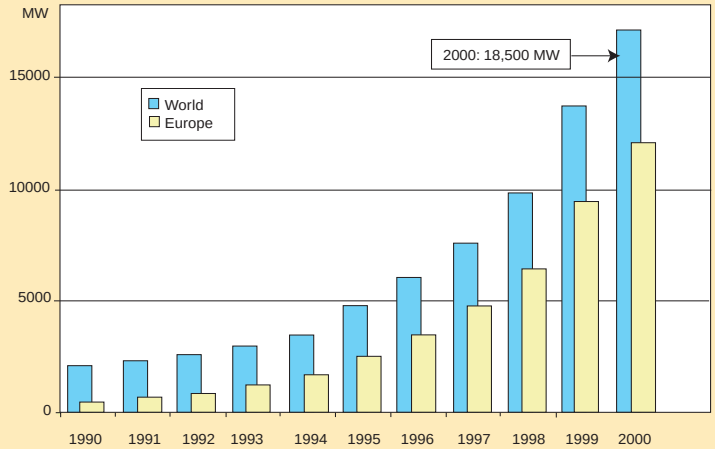
Rotor R&D

Aeroelastic stability is a highly complex phenomenon but also an extremely important factor in the design of the rotor. By efficient modelling of non-stationary aerodynamics and lead/lag vibrations, ECN contributes to the development of a reliable design method (under the national project STABTOOL led by TU Delft). This work has already yielded much improved knowledge and insight in the methodology of designing for stability of large, stall controlled turbine blades. The results calculated with ECN's models were verified against the observed phenomena of a turbine rotor failure resulting from aeroelastic instabilities.

The complex conditions under which the air flow around an aerodynamic profile separates can give rise to two separate and distinct power levels in the wind velocity/ power level curve in stall controlled wind turbines. In practice this leads to losses in yield. ECN obtained a better insight in this phenomenon as a result of a number of projects in which the fast visualisation technique with stall flags, described in the 1999 Annual Report, was applied. Interestingly enough, it was found that, in addition to the deposition of insects on the leading edge of the blade, the topography of the terrain could also be identified as a possible cause.

The availability of low noise turbines forms an essential prerequisite for the implementation of wind energy. ECN made an important contribution to the knowledge of wind turbine noise through acoustic measurements in the Dutch/German wind tunnel on a scale model of a wind turbine. Although ECN was initially only responsible for the aerodynamic design of the model wind turbine, it later contributed valuable suggestions about how to silence a turbine.

Installed wind energy capacity



Source: BTM Consult Denmark

Concepts and Designs

In the past, every European country active in the field of wind energy developed its own wind turbine design program. Those used most frequently, including ECN's PHATAS, are presently being validated by means of measurements on three real wind turbines (Lagerwey 750 kW, Tacke 500 kW and Nordtank 500kW). The first results show rather substantial differences between calculated and measured stresses on the blades, the tower and the shaft (from 10 to 40%). Since the uncertainty in the measured data is also rather large, owing to the stochastic nature of the wind, this type of validation is increasingly carried out in wind tunnels. The development of offshore turbines occupies an important place in the total package of design related research. In the framework of the DOWEC (Dutch Offshore Wind Energy Converter) project, four concepts for the 3 MW and 5 MW prototypes, to be realised at a later date, were pre-selected. For the 3 MW turbine both the concept and the preliminary design were fixed. ECN made the aerodynamic design of the rotor blades, optimised for the lowest cost per kWh. This design includes a very slim rotorblade which leads to a significant reduction of the extreme loads. The prototype of the 3 MW turbine will be finished by April 2002.

Operational Technique and Systems

This part of the programme includes work in the field of reliability, availability and maintainability of wind turbines system design. In collaboration with Baas & Roost Maintenance Consult ECN is developing a 'maintenance manager', an automated system for collecting, analysing and providing feed back on wind turbine failures. Using operational data as an input the design and the maintenance procedures for both wind-turbines and wind parks can be substantially improved. A demonstration version, fully equipped for registration and analysis of failures and disturbances, was set up for the firm 'Lagerwey the Windmaster'.
Effective control of wind turbines is of the utmost importance from at least three aspects:
optimising the energy yield, minimising the loads during operation and avoiding electrical and mechanical instabilities. The third point is of particular importance for offshore turbines where fluctuations in wind velocity, wind direction and wave loads occur simultaneously.

Projects

In their assessment of the complexity and risk of investing in wind energy projects, real estate developers and bankers increasingly rely on ECN's knowledge. ECN itself also actively contributes to the implementation of projects. A recent example is the 20 MW Costa Rica project. This is a project, jointly developed by ICE (the electrical utility of Costa Rica), ESSENT, a turbine manufacturer and ECN. ECN is responsible for the wind measurements, site characterisation, the grid connection, design calculations, assessment of environ-

Electrodes for the polymer fuel cell

There is little doubt that the fuel cell will play a central role in the energy supply system in the 21st century. However, it is difficult to estimate how quickly the fuel cell will evolve into a commercial system. Michiel de Heer (right) and Frank de Bruijn have brought inexpensive mass production a step closer by developing a screen printing technique for applying the electrodes (both anode and cathode) to a polymer fuel cell.
An electrode consists mainly of a noble metal catalyst (for example platinum) absorbed onto active carbon. To make screen printing possible this carbon must be converted into a stable dispersion, with a viscosity resembling that of molasses. This was accomplished by a suspension, based on a rather syrupy, not too volatile organic solvent. Due to its low vapour pressure at ambient temperature this liquid poses no health hazard and it does not dry during printing. Its viscosity makes the preparation of a dispersion relatively simple. The liquid also contains a small amount of dissolved polymer membrane material. This addition stabilises the suspension and improves the adhesion of the electrode to the membrane.

The technical design of wind turbines for large-scale offshore wind farms differs from the design of 'land-based' turbines. Wave loads and much higher wind velocities have to be considered. PHATAS-IV developed by Koert Lindenburg (left) can calculate the stresses and moments at design critical places in the blades, shafts and tower. The ECN programs SWIFT and ROWS developed by Danny Winkelaar (right) are used here as wind and wave generators. Controller modules developed by Tim van Engelen (mid) are included in PHATAS for realistic load assessment.

mental effects and 'human resource' and 'institutional' building. The first on site wind measurements were performed in 2000. Together with Ecofys ECN has developed a service package under the name of WEC SEA for the preparation of offshore projects. The services also include the determination of the wind potential.

In the rapidly developing wind energy sector very efficient knowledge transfer and training have become crucial factors for industry. ECN contributes by organising an annual International Course on Wind Energy Implementation. In April 2000 some 18 participants from 13 countries participated in this 2-week course at Petten, which was given for the ninth consecutive year. There has always been much interest for this course, especially from countries which have a large wind energy potential but as yet insufficient knowledge for its implementation.

Experimental facilities

As wind energy projects grow in scope, and wind turbines increase in size and power, so their technical challenges and economic risks increase dramatically. One way to keep the risk under control is systematically to reduce the uncertainties in all steps of the development chain, including the design process. Experimental verification of calculated results is therefore essential. The scope of ECN's experimental research programme has for some years been lagging behind the need for field data, so more emphasis was placed on experimental work in 2000. The main activities were:

1. The setting up of a new test site for very large wind turbines in the Wieringermeer district. The preparations have advanced smoothly so that the first wind turbines will be erected near the end of 2001.
2. The realisation, jointly with Delft Technical University, of an improved and enlarged laboratory for fatigue testing of very large wind turbine blades. In 2000 a design was made and a business plan drafted.
3. The development of a method to measure wind velocities at high elevations without the use of measuring towers. With this method, called SODAR ('SOund Doppler Acoustic Radar'), substantial cost reductions are expected especially in the area of offshore wind resource assessment and verification. In the past year the results of measurements with ECN's SODAR were compared with those obtained from the 212 metre high measuring tower at Cabauw, owned by the Dutch Royal Meteorological Institute (KNMI).
4. Maintaining quality regimes for measurements, i.e. EN45001 certification by the 'Raad van de Accreditatie (Sterlab)', and maintaining the MEASNET-authorisation for noise and yield measurements. The round robin tests for wind velocity/wind power measurements, carried out last year, were concluded successfully by ECN.

External partners and customers Wind Energy

Aerpac, Ballast-Nedam, BuZa, Essent, European Commission, ISET, KNMI, Lagerwey, LM, NEG-Micon, NLR, Novem, NREL, NUON, van Oord ACZ, Polymarin, Stork, TNO, TU Delft

Biomass

With the commissioning of the biomass combustor at Cuijk and the biomass gasifier at the river Amer the total installed biomass based power generation capacity in the Netherlands reached the 114 MW level. Biomass is currently the largest contributor of renewable energy in the Netherlands with a potential annual yield of over 7 PJ (excluding the 30 PJ generated annually from domestic wastes).
Further concerted effort is required in the following areas to reach the official Dutch targets on renewable energy: a) to increase the contribution of biomass as a replacement of coal and natural gas in large power plants, b) to make available the technology for decentralised combined heat and power generation, and c) to develop the technology for making gaseous and liquid fuels from biomass, in addition to heat and power production. In the past year ECN made sizeable contributions to all three fields.

Central Units

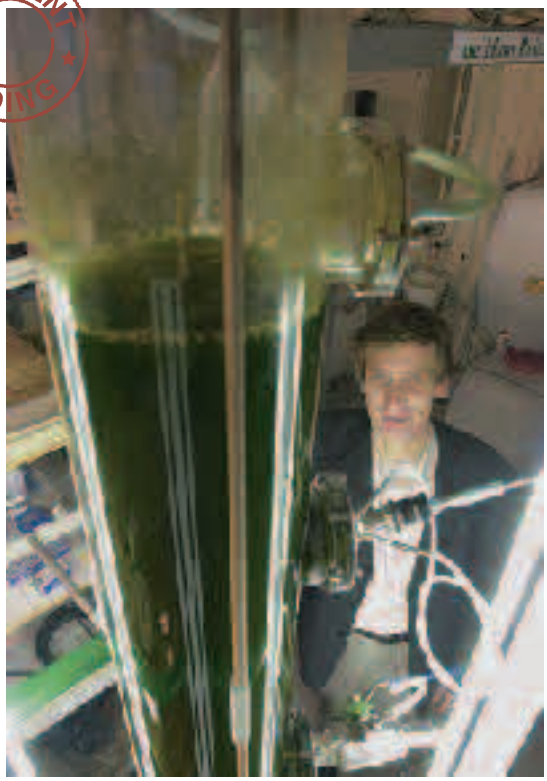
Co-firing of biomass in coal fired power stations (i.e. feeding a mixture of biomass and coal) is a relatively simple and inexpensive way to introduce biomass as a CO_2-neutral energy source in the Dutch energy supply system. It is expected that for co-firing biomass up to approximately 10% (based on energy) will require only very modest investments. At present biomass is already used as an additional fuel in 5 out of a total of 8 coal fired power stations and plans exist to extend this practice to the remaining 3 power stations.
Despite this progress it is clear that the electricity producers need to increase the amount of biomass in their installations to 20% or more, both in order to comply with their agreements with the Dutch government and to reach the official long-term targets. During the past year ECN conducted several studies into bottlenecks which could arise if biomass use was increased by this amount. ECN was also involved in several of the mentioned initiatives regarding co-combustion.
The feasibility of direct and indirect co-firing of 20–40% biomass in coal- and gas-fired power plants was studied both from the financial and economic aspects and also the environmental effects. The main conclusions were:

- Approximately 7.5–8.0 Mton (dry matter) of biomass is required to meet the final target for the use of biomass in the energy supply system in the year 2020. Approximately 3.6 Mton of this amount is used for direct and indirect co-firing. To obtain these quantities both import and domestic production of biomass is necessary.
- The optimum technology for the use of biomass in coal-fired power stations depends on the type of biomass. From the financial and economic aspects direct co-firing is preferred. Relatively clean biofuels which are hard to chop or grind are preferably either co-burned directly, after a separate milling/drying/crushing process, or indirectly by means of a front-end gasifier with limited gas cleaning. The most attractive scheme for polluted biomass is gasification in a front-end gasifier with extensive gas clean up, or possibly direct co-combustion after mixing with clean biomass.
- Important potential bottlenecks are: a) milling and feeding of the biomass b) a high proportion of unburned carbon in the bottom ash and fly ash, c) high tempera-

A transition from coal gasification to biomass gasification would start a new phase in the life of the Demkolec 'Buggenum' demonstration plant. The plant could thus contribute considerably to the renewable energy target in the Netherlands and also convert manure and waste into biofuels in the provinces of North-Brabant and Limburg.

Algae based system for water purification

For their growth algae use sunlight and simple nutrients, predominantly CO_2, soluble nitrogen compounds and phosphates, in other words, substances we prefer not to release into the environment. Algae can take up CO_2 from discharged gases which are passed through the algae growing system. Algae are also effective removers of nitrogen compounds and phosphates from sewage, for example, from the effluent of a biological water purification plant. After separation of the algae the purified water can be re-used for industrial processes. A number of high-quality products can be manufactured from the algae, for example, multiple unsaturated fatty acids, dyes and bio-active compounds, which can be used in food, pharmaceuticals and cosmetics. The remainder of the biomass (approx. 80%) can be used in "green" electricity and heat.The manufacture of high-quality products requires controllable and selective growing of specific species of algae. This is impossible to accomplish in the conventional open growing systems. In a closed photo-bioreactor the growing conditions can be accurately controlled, but these systems are expensive and not yet suitable for large scale application. The solution to this problem was found in a closed bioreactor system of limited size, connected to an open growing system of a novel type, which is optimised for the production of industrial water.
Inventors: Hans Reith (photographed), Luuc Mur (UvA), Cees Hack (Suiker Unie) and Ronald Kalwij (Cosun)



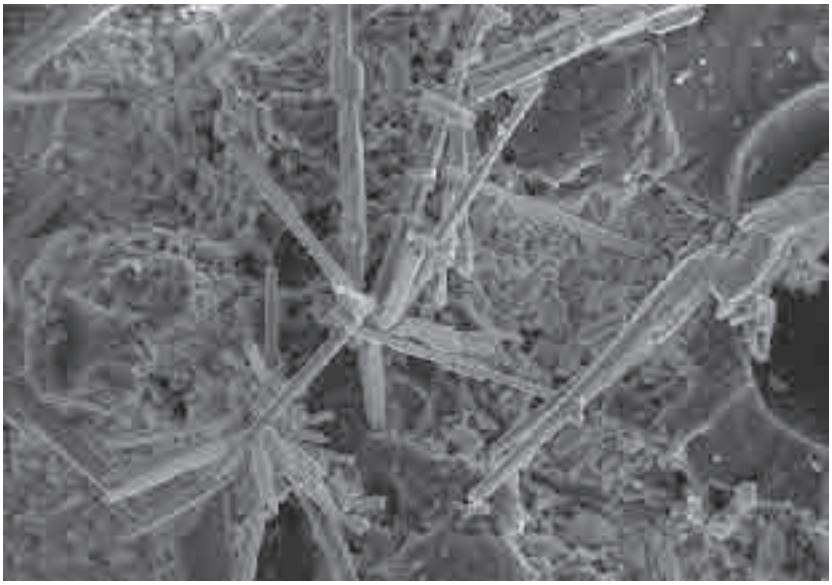
ture corrosion and increased risk of slagging and fouling in the boiler, d) negative effects on the performance of the conventional gas clean up and e) inferior quality and diminished sales potential of the produced solid residues (for example, bottom and fly ash and gypsum from the flue gas desulphurisation process).

Assessing and removing these potential bottlenecks formed a central issue in a number of ECN research projects. Attention was paid to the influence of the co-combustion of biomass on the quality of pulverised coal fly ash and on the quality and possibilities for utilisation of ashes from separate biomass gasification or burning processes. In a broad co-operative European effort experiments were performed to determine the mechanism of slagging and fouling during co-combustion for a range of biomass types, including various types of wood, chicken manure and straw. The research was not limited to analysing samples from industrial power installations but included tests in ECN's experimental facilities, in which the conditions of real pulverised coal combustors can be accurately reproduced.

The understanding thus gained proved to be useful for answering specific industrial questions including the determination of the combustion characteristics of specific types of biomass. In addition, a cost-benefit analysis was carried out concerning the utilisation of biomass in the Demkolec coal gasification plant at Buggenum, in comparison with other renewable energy options. ECN's extensive expertise on all aspects of ashes is used in support of the operation of the BioEnergy power station at Cuijk, owned by Essent.

Decentral Units

In 1996 ECN, in co-operation with Stork, Afvalzorg and Novem, started with the development of a circulating fluidised bed gasifier. Initially this installation was built with the objective to acquire hands-on experience with the gasification process and with the behaviour of the different types of biomass and biomass waste in a gasification plant.
Within a relatively short period of time the gasifier was developed into a reliable installation. With a view to future commercial application the installation was furnished with a gas clean up plant, developed by HoSt,



The use of meat and bone meal (MBM) as feed for cattle is no longer permitted. A considerable residual stream of MBM will be left, not only at the present time as a result of the destruction of BSE and FMD risk material but also in the future. This biomass can be utilised for energy generation. Rian Visser has found that the high concentrations of alkaline metals and chlorine cause operational problems in the combustion installation and affects the composition of ashes and thus the potential utilisation of the ashes.

The SEM photograph shows sample material from a clogged pipe in the cooling route of a fluid bed installation. Formation of elongated potassium and sodium sulphate crystals is thought to be the cause of the capture of much ash material and thus the cause of the clogging.

which decreases the emission of pollutants to a level well below the Dutch emission standards. The next step will be to add a back end gas engine. The final goal is to develop the technology for relatively small biomass power plants, i.e. with a capacity between 1 and 3 MWe.
It is to be expected that in 2001 at least three of these installations will be built. HoSt was commissioned to build a 2.5 MWth fluidised bed gasifier for Romania. A 7.5 MWth fluidised bed gasifier for the gasification of waste wood will be built at Hengelo (The Netherlands). The various gas purification steps were tested at ECN. Finally, a gasification plant for the processing of chicken manure of a size suitable for one farm will be built. It will produce approximately 200 kW of electricity and 400 kW of heat, the latter to be used for heating the stables and drying the manure.

Polygeneration

Besides heat and power, the mid and long term technology development and implementation is aimed at the production of gaseous and liquid fuels and products with a high added value (for example, fine chemicals) from biomass and waste. ECN is active in five lines of technology development:

- Integrated gasification/Fischer-Tropsch synthesis/CHP-process for making 'green' diesel fuel, plus electricity and heat from biomass and wastes. In 2000 an SDE-project (Royal Dutch Shell, University of Utrecht, ECN) was completed, in which the feasibility of the process, seen from an environmental and a financial/economic point of view was analysed, with a positive outcome. It led to the definition of a follow-up R&D-project in the SDE framework, and possibly in the GAVE framework, and at the realisation of a laboratory-scale Fischer-Tropsch Research reactor (FITOR) to be used for experimental research.

- Integrated Fermentation/CHP-process (GF/WK-process) for the production of bioethanol, electricity and/or heat from (ligno)cellulose rich organic wastes, which are relatively cheap and in abundant supply. Here too the feasibility of the process was analysed from the environmental and financial/economic aspects resulting in the definition of a follow-up RD&D project in the E.E.T Kiem framework and possibly in the GAVE programme. This project was defined together with Nedalco, Shell, ATO, and Delft University.

- Hydrogasification of biomass for the production of 'green' natural gas (SNG). The main activities in 2000 concerned an E.E.T. Kiem-project (in collaboration with Gasunie and the University of Twente). Industrial parties, for example Methanor and General Electric, were contacted for the realisation of a demonstration plant in the framework of the GAVE programme.

- Innovative technology for the sustainable co-production of natural fine chemicals and energy from micro algae. In 2000, in the framework of a multi-annual E.E.T. project in which twelve predominantly industrial parties participate, a 60 litre reactor for growing micro algae was put into use at ECN.

- An advanced gasification concept for the production of a tar free conditioned synthesis gas for the production of a broad range of secondary energy carriers and other products. In the year 2000 a closer analysis of a number of concepts developed at ECN in previous years (CASST, STAR) was made and followed by a comparison with concepts developed by others. In 2001 this activity will result in the strategic selection of an ECN technology for further development.

External partners and customers Biomass

ATO, BTG, Cosun, Demkolec, Essent, Hoek Loos, IFRF, KEMA, Senter, EnergieNed, Gibros, IFRF, IMAG-DLO, Gasunie, HoST, Kachelbouw Doetinchem, Nedalco, Novem, SDE, NVA, Shell SIOP, Siemens/KWU, Stork E&C, Suiker Unie, TNO-MEP, VROM and universities

Clean Use of Fossil Fuels

ECN's R&D programme on the clean use of fossil fuels addresses four areas (project clusters): micro cogeneration for domestic use, zero emission power systems for vehicles, CO_2-free use of fossil fuels and the environmental impact of the use of fossil fuels.

Micro-cogeneration systems

The projects in this cluster are set up to support and promote the demonstration and market introduction of cost-effective micro-cogeneration systems for domestic applications, both in existing and in new buildings. In 2000 ECN worked on three different systems for micro-CHP: Stirling technology, the solid oxide fuel cell (SOFC) and the solid polymer fuel cell (PEMFC). The objective for all three systems is to perform the first field tests within 2-3 years. Utilisation of these systems could lead to considerable energy savings, of the order of 150 PJ over a 20-year period, in combination with a sizeable reduction of the CO_2 emission, of the order of 5-10 Mton over the same period. If the purchase price of these systems does not exceed the price of the best commercial high efficiency central heating systems currently available by more than € 1400, then the economic prospects will be favourable.
The most important developments of the past year were the demonstrations of critical Stirling and SOFC micro-cogeneration system components and the development of a fuel converter and a fuel cell stack for PEMFC. Enatec B.V, a joint venture of ECN, Eneco and ATAG, demonstrated the good performance of a 1 kWe Stirling engine which met nearly all its specifications. Some ten field tests are planned with these micro-cogeneration systems for 2001.
In collaboration with Gasunie and Shell Hydrogen, ECN conducted a field test on a 1 kWe SOFC micro-cogeneration system, for which Sulzer Hexis AG in Switzerland had developed the system technology and ECN the fuel cell technology. The ceramic fuel cell components used in these field tests were manufactured by InDEC B.V. using ECN technology. As a next step in 2001, two prototypes manufactured by Sulzer Hexis will undergo a field test in the Netherlands.
In collaboration with Shell Hydrogen, ECN developed a fuel processor, which works under variable conditions to convert natural gas to a hydrogen-rich gas mixture of a preset composition. In the framework of a joint development programme with Gasunie, Nedstack B.V. and Nefit-Buderus in the field of stack technology a start was made with the optimisation of the cell stacking. This work is complementary to ECN's own stack

Fuel cell system becomes less expensive

Every individual cell in a fuel cell stack must be sufficiently and uniformly fed, on one side with air and on the other side with hydrogen. The meandering channels in the separator plates between the individual cells make this possible. However, this makes the separator plate rather bulky, its thickness approaching 4 – 5 mm, while the thickness of the cells themselves is not more than 0.5 mm. Thus the separator plates make up the bulk of a fuel cell stack. The weight of the stack as well as a substantial part of the fabrication costs are determined by the materials used in the design of the separator plate. A very important aspect of the design is how the gas passes the inner sealing between cell and separator plate. For this particular part of the fuel cell process ECN has developed an elegant improvement, which not only increases the reliability of the stack but also simplifies the fabrication process of the separator plate, thus making it cheaper. The patent applied for offers the perspective of enabling the use of thinner and lighter separator plates. In addition, it may be possible to circumvent one of the basic patents granted to the market leader in the field of stacks design. These developments all contribute to making the use of fuel cells less expensive.
Inventor: Ronald Mallant

development programme for the PEMFC. The objective for 2001is to assemble and demonstrate a micro CHP system on the basis of a PEMFC, when the various components, for example, fuel processor and fuel cell stack, become available.

Zero emission vehicles

There is a rapidly growing world-wide interest in fuel cell vehicles. In Europe, Japan and California the first prototypes of zero emission passenger cars have made their appearance on the roads and their final break-through seems to be mainly a matter of sufficiently large price reductions. The target for the price of the electrochemical engine is of the order of € 100 to 150 per kilowatt electrical power. Fuel cell power for special purposes, for example, for buses or lorries in urban traffic, may even be economically feasible at a substantially higher cost.
Important progress made in this field in 2000 includes the development of a novel fuel cell stack concept for temperatures above 100ºC, research and development of processes and in-vehicle reactors for the conversion of logistic fuels into H_2, the development of control systems and the development of a Supercapacitor. This last development has already attracted industrial interest.

CO_2-free use of fossil fuels

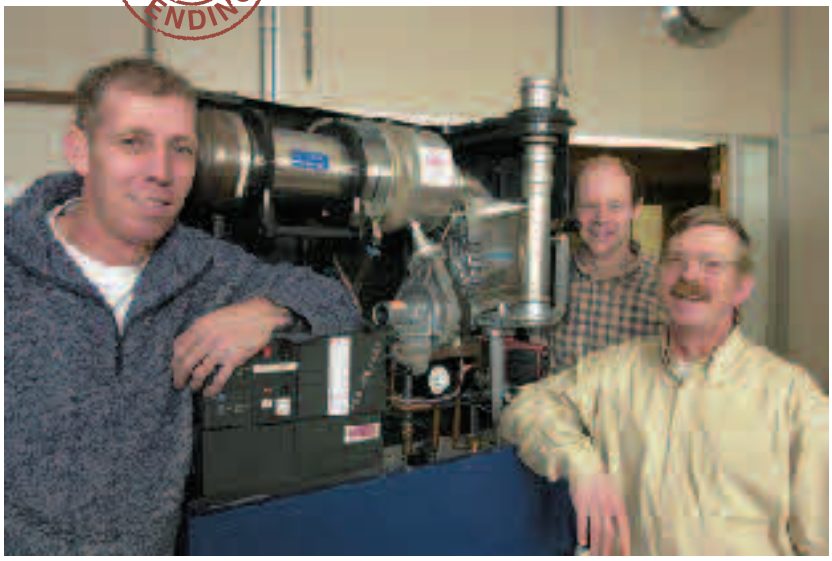
The use of fossil fuels will ultimately only be permitted on condition that CO_2 is no longer released into the atmosphere. An energy supply infrastructure based on the conversion of natural gas to hydrogen, with CO_2 sequestration, can only be regarded as 'clean use of fossil fuels' if the hydrogen from the fossil energy carrier is subsequently converted into heat and power by means of fuel cell systems so avoiding the release of particulates and NO_x into the environment.
In 2000 the results of a study on the potential of CO_2 storage in coal deposits and the simultaneous extraction of methane were presented. The working principle is that the CO_2 displaces the methane in the coal layers, which can then be extracted and used for energy supply purposes. Estimates of the capacity showed that in this way approximately 0.6 Gton of CO_2 can be fixed and 3.9 EJ of natural gas can be obtained, so that during a period of 25 years approximately 5% of the national Dutch energy demand can be satisfied in a CO_2-neutral manner. From the perspectives of the Kyoto agreements for 2010 and of the national policy concerning sustainable energy, this is quite a substantial contribution.

Environmental quality and reduction of emissions

ECN's main research activities in the area of environmental quality and emission reduction concern the influence of aerosols on the climatic impact of greenhouse gases, the problem of ultra fine particulates in the urban environment, the reduction of the release of nitrous oxide (laughing gas) in the nitric acid industry and of NO_x in combustion processes.
The results of the aerosol research show that the cooling

More efficient CHP

The development of technologies for central heating boilers which produce both electricity and hot water is being pursued in a number of places around the world. The development company ENATEC, in which the firms Eneco, Atag and ECN participate, decided to concentrate on the incorporation of the Stirling Engine to produce the electrical power. A new improved design which may be patentable features a rather unusual flow circuit for the return water and a vibrationless suspension for the Stirling engine. The advantage of the new suspension system is clear. The new cold water circuit improves the systems' output by 1%. If this seems a rather modest improvement, in practice it is much more significant. With a yield of 97.5% the efficiency of this type of system is already extremely high and an increase of 1% implies that losses are almost halved.
The electricity producing central heating boiler will incorporate a burner plate made of ceramic foam (patent granted 1990). This burner plate was produced by ECN's R&D and gives a 25% higher yield compared to a conventional burner. The market introduction of the new boiler is planned for mid 2003.
Inventors: Ger Beckers, Hajo Ribberink, Sjaak Zutt (from right to left) and ATAG co-workers Jos Luttikholt and Kees Baijens



Solid Oxide Fuel Cell less expensive

The SOFC normally has an operating temperature of approximately 900ºC. The containment of these cells – and the central heating boiler itself where the cells form part of a micro CHP-system – have to withstand this rather high temperature. The system would be significantly less expensive if the operating temperature was 100 – 200ºC lower. The limiting factor is the Ohmic resistance of the electrolyte. This implies that the electrolyte, which is usually a 150 micrometer thick layer has to be made thinner. This can be accomplished in a simple and inexpensive way by screen printing the electrolyte onto one of the electrodes, specifically the anode. The electrolyte has to remain gas tight. In practice it has been found feasible to obtain layers of approximately 7 micrometer. An electrolyte layer as thin as this lowers the operating temperature of the SOFC to around 700ºC, making it possible to use a substantially cheaper type of steel for the containment. Jan Pieter Ouweltjes, Pieter Nammensma and Frans van Berkel (from left to right) have realised

a further cost reduction: a fabrication technique by which the zirconium oxide electrolyte is screen printed onto a solid tape cast layer of anode material and both green products, thus joined, are fired together. Unfortunately the cathode, which in turn is screen printed on the reverse side of the electrolyte, cannot be heat treated in the same step since its heat treatment temperature is a few hundred centigrades lower than that of the combined anode and electrolyte. Further research is needed before a patent can be applied for.

Cathode 50 µm

Electrolyte 7 µm

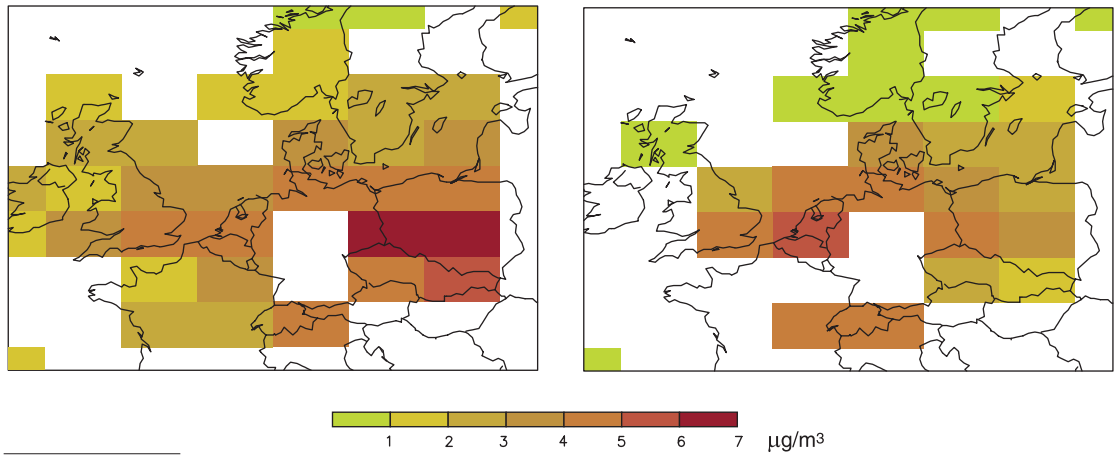
Anode 700 µm

due to aerosols is considerable in the world's industrialised areas. Ignoring this effect leads to a serious underestimation in the prediction of the regional temperature increase caused by greenhouse gases. The following procedure was adopted: all measured data concerning nitrate aerosols in Europe were screened, checked qualitatively, corrected if necessary and transformed into a concentration distribution map for Europe. This map forms the basis for the assessment of the influence of aerosols on the radiation balance. It is evident that the yearly average of nitrate concentrations over approximately 40% of the surface area of Europe is of the same order of magnitude as that of the sulphate concentrations. It is assumed that the cooling effect of nitrate aerosol is as large as that of sulphate. However, all calculations to date have erroneously ignored the contribution of nitrate to the aerosol cooling. It is therefore to be expected that if the countermeasures against acidification, excessive manuring and ultra fine particulates prove effective and lead to lower concentrations of nitrate aerosol, its cooling effect will also be diminished, resulting in a larger temperature increase than has been predicted so far.

This effect of aerosols adds a regional dimension to the climate problem, because the temperature increase can vary strongly between different regions depending on the local aerosol concentrations, particularly in the world's industrialised zones. The influence of this effect can only be estimated. New models which fully and quantitatively account for the role of aerosols are indispensable to the proper mapping of this alarming problem.

In 2000 the National Programme 'Particulates and Urban Environmental Quality' was launched. This may be regarded as an important breakthrough. ECN has undertaken the co-ordination of the programme. Many parties in the Netherlands, including ECN, had been urging the Government for some considerable time to initiate this programme because of strong suspicions that the main environmental and health effects related to urban transport are determined by the emissions from combustion engines. Indications have been found in the literature that in particular the smallest particles with their toxic compounds, such as heavy metals and

Sulphate **Nitrate**



Aerosol charts

It was generally believed that sulphate is the dominant aerosol component and that the contribution of nitrate is low. But the first systematic construction of nitrate concentration maps over Europe shows that the nitrate concentrations are comparable to those of sulphate – higher in Western Europe and about half as high in Eastern Europe. This surprising outcome will have consequences for the global climate models and also for the future climate policy, because aerosols reflect a considerable amount of sunlight.
Martijn Schaap and Harry ten Brink have been the first researchers to screen systematically the existing and available European nitrate data on measurement artefacts, on the basis of knowledge from other research, and to process them into reliable figures. The above charts show the annual averages.

polycyclic aromates, are detrimental to health. European regulations on permissible levels of particulate emissions are in preparation, but their relevance and practicability will have to be better underpinned. It is partly with this objective in view that the programme was set up. ECN's contributions are mainly in the field of the characterisation, with regard to size distribution and chemical composition, of particulates by means of its home developed advanced sampling equipment (Steam Jet Aerosol Collector, SJAC + impactor) and its facilities for microchemical analysis. In the autumn of 2000 measurements started on the 200 metre high meteorological observation tower of the Royal Dutch Meteorological Institute KNMI at Cabauw. The concentration and chemical composition of particulates in two particle size classes are being determined at two altitudes. It is to be expected that on the basis of these results a distinction can be made between domestic and foreign contribution to the amount of particulates in the Netherlands. The same measuring equipment will be deployed in Rotterdam to determine the level of particulates exposure to the people in the inner city. By the end of 2001 the measurement programme should have progressed sufficiently to allow preliminary conclusions to be drawn on suitable indicators of the effects and the possibilities for reducing the release of particulates.

The high-effective catalyst, developed by ECN for the removal of nitrous oxide formed during the production of nitric acid is an efficient instrument to realise a large part of the goverments' targets for reduction of green house gas emissions. Unfortunately, it is a rather expensive option, as has become clear from a market assessment. Modification of the production process, which is fairly easy to incorporate in a new plant, yields the same emission reduction at much lower cost per tonne CO_2 equivalent. This same technology can accomplish more than 50% removal of NO_x in small-scale energy generation processes. At present there is still no better alternative for this problem. Together with several industrial parties ECN is looking into the possibility of conducting a field test and investigating the feasibility of NO_x removal by means of methane.

External partners and customers Clean Fossil

Afvalzorg, ATAG, Ciment d'Obourg, Corus, Den Oudsten Bussen, DSM, Econosto, ENATEC, ENECO, EnergieNed, EZ, Gasunie, IRD Denmark, FZ Jülich, KEMA, Mechatronics, Nedstack, Novem, Rijkswaterstaat, Senter, Shell Hydrogen, Stork, Sulzer, Volkswagen, VROM, TNO, universities

Technology Services & Consultancy

Technology Services & Consultancy (TS&C) is positioned at the interface of science and technology. Whereas until recently TS&C worked almost exclusively for ECN's own business units, nowadays it has developed into a professional partner for external clients as well. TS&C is involved in most of ECN's projects. It handles the engineering and construction of prototypes, installations, data acquisition and control systems, and process instrumentation and it develops software applications. TS&C also works for industrial partners on a variety of projects. Some illustrative examples are given below.

Micro-Plasma Spray

TS&C developed a Micro-Plasma Spray System (MPS), based on an idea and a prototype of the Paton Welding Institute at Kiev, Ukraine. This system can deposit extremely thin and narrow strips of material, both conventional materials and special materials, for example, aluminium oxide with its high melting point (2030ºC). MPS is not only a spray and repair technique but also an alternative welding method. The first results are quite promising, and the development of applications will continue in 2001.

Pelletizer

'Sand blasting' with particles of solid CO_2 has a number of advantages over blasting with sand or metal particles. The pelletizer which is an instrument that produces the grains of solid CO_2 was developed by TS&C for Cryojet BV. The first pilot series of pelletizers, made in the reporting year, performed extremely well. ECN worked on the realisation of a number of industrial applications in conjunction with Cryojet.

Gas tight metal ceramic bond

The use of ceramics is becoming increasingly attractive in industrial processes due to their excellent performance in high temperature and high pressure applications. One of the major problems in the use of ceramics is the joining of ceramic and metallic components. A particular problem which has been solved by ECN is the end sealing of ceramic membrane tubes, which often have imperfect cylindrical geometry.
A metal sleeve is passed partly over the end of the ceramic tube and the space between is filled with graphite. The graphite is retained by a metal ring.
A metal cap is then placed within the metal sleeve and bears against the metal ring through a set of spring washers. By axially loading the system the graphite is compressed and deforms plastically to make a seal between the metal sleeve and the irregular shape of the ceramic tube. The metal cap and the metal sleeve are welded whilst the axial load is maintained, so ensuring a gas tight seal. It is a simple and very inexpensive technique. At high temperatures and pressures the graphite layer remains sufficiently elastic to compensate for the difference in thermal expansion coefficient between the metal sleeve and the ceramic tube.
Inventors: Frans Rusting, Gerard de Jong, Paul Pex and Jack Peters

A superior supercapacitor

As their name indicates, supercapacitors are capacitors giving above-normal performance. Their capacity is several orders of magnitude higher than that of a normal capacitor and they can store and release as much as 5 watt electrical power per gram of material. Thus, a supercapacitor can be used for peak shaving, which is sometimes very desirable, for example, in electric vehicles. The crucial factor determining the price of the supercapacitor is the electrode material. Thus, throughout the world research is focused on trying to find a suitable material to replace expensive noble metals. ECN has succeeded. by developing at Petten two inexpensive materials to replace expensive noble materials, both having outstanding electrical properties. In contrast with existing electrode materials, these novel materials do not pose health risks and are not environmentally harmful. In addition, they are simple to produce. The materials were named EMX and EMZ by their inventors. There is an intermediate material, EMY, with electrode material Y, which needs further research before a patent can be applied for. Inventors: Bert Plomp, Fred van Heuveln and Gerard Elzinga (from left to right)

E-commerce

For another external client TS&C developed an ‘e-commerce’-system which operates in an MS Outlook environment. Outlook and MS Exchange Server are used for the listing of objects for sale. Potentially interested parties can specify their demands and wishes. This information is exported to a database that is accessible through a website. Vendors can easily introduce changes to the database, on line or off line.

Drilling platform for hire

In May 2000, Offshore Facilities Brokerage Software BV (OFBS) was founded, with ECN owning 33% of the shares, the other shareholders being TNO Beheer BV and Sterker Consultants. The software, developed by ECN, for matching supply and demand for used offshore oil and gas facilities, has been brought into this new firm. This software will be given in licence to The Web Platform Brokers, who will use it to offer commercial brokerage services. The offshore industry has shown a growing interest in the re-use of gas and oil platforms. ECN has contributed to the establishment of the market in used platforms through topical seminars organised jointly with the Institute of Petroleum.

Wave energy

TS&C is involved in a promising project in the field of hydropower. The project is being carried out by Archimedes Wave Swing (AWS) BV, in which ECN has a minority share. Its objective is the development of the Archimedes Wave Swing, which, below the water surface, extracts energy from the undulatory motion of the ocean. The construction of a half-scale pilot model (nevertheless about as large as a three-storied house) is almost finished and will be installed off the Portuguese coast near the end of 2001.

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 Research

At the beginning of 2000, the Nuclear Research and consultancy Group (NRG) – the joint venture in which ECN and KEMA have combined their nuclear expertise since 1998 – took over the Centre for Radiological Protection and Dosimetry (TNO-CSD). TNO-CSD's activities fitted well with NRG's own activities in the fields of personal dosimetry, radiation protection and radioactivity measurements. TNO-CSD's tasks also included the management and execution of the National Doses Registration and Information System. The take-over has further reinforced NRG's position in the nuclear field.

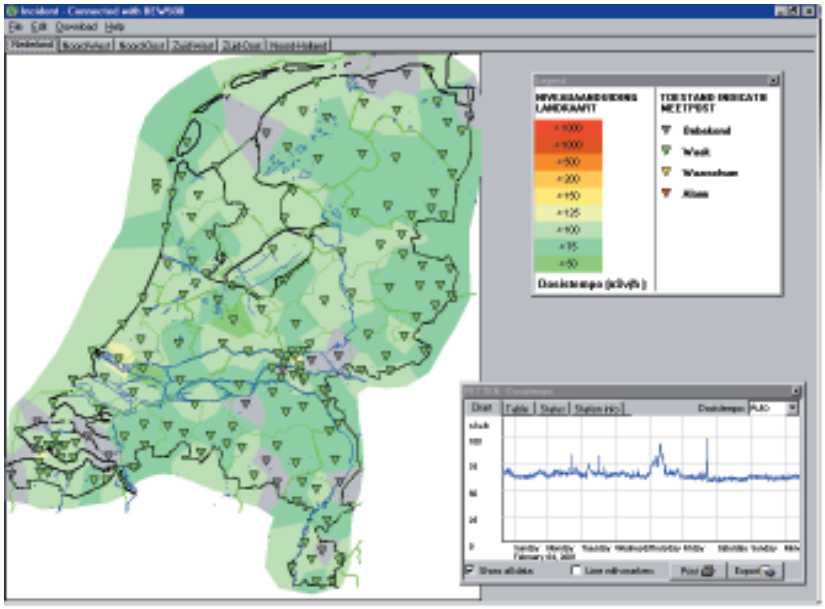
Medical radioisotope production at the HFR secured

In 2000 two important milestones were reached on the HFR's fuel cycle. The delivery of fresh fuel to the HFR as well as the transport of spent fuel from the HFR were secured, guaranteeing the production of medical radioisotopes for the coming years. The European Commission's decision to convert the reactor core so that low instead of high-enriched uranium can be used as a fuel was welcomed by the United States. The US encourages these conversions as part of the non-proliferation policy and is now willing to supply fresh fuel and take back spent fuel. The supply of fresh fuel started at the end of 2000.The return of spent fuel to the US will take place in 2001. Because the preparations for the transport to the US will take some time, it has been necessary to transport part of the spent fuel for storage at the Centrale Organisatie Voor Radioactief Afval, COVRA, in Zeeland. This roused the interest of several parties, including the media, but the four transports were carried out without incidents.

New nuclear fuel reduces radioactive waste

Since the beginning of the peaceful use of nuclear energy it has been known that thorium, in addition to uranium, could be a useful energy source. In the period from 1950 to 1970, the thorium cycle was extensively investigated. Thorium is an interesting fuel because the world's thorium reserves are sufficient for many millennia of energy production. However, the interest in the thorium cycle faded, because there was no shortage of uranium. Recently, the thorium cycle has again been given attention from quite another perspective, namely the reduction of radioactive waste resulting from the use of nuclear energy.

In the autumn four transports of spent HFR fuel to COVRA in Zeeland took place without incident.



A National Radiation Monitoring Network user's PC screen

As part of the European Union Fourth Framework Programme the thorium cycle was re-assessed by a number of European institutes. This work was co-ordinated by NRG . The report published at the beginning of 2000 demonstrates that the thorium cycle has many advantages with respect to radioactive waste. The radiotoxicity of thorium is a factor 10 to 100 lower in all stages of the cycle compared to that of uranium. On the basis of the recommendations from the report the Fifth Framework Programme has started a follow-up study, again co-ordinated by NRG . The research will take four years.

Radiation Monitoring Network modernised

NRG is responsible for the maintenance and management of the National Radiation Monitoring Network (NMR), owned by the Ministries of the Environment and Interior. Users of this network are the fire brigade officials and the local authorities. NRG has developed a desktop application for this monitoring network enabling the users to obtain data from the system on their PCs. Several distant users can simultaneously read out the real-time radiation levels in the Netherlands. By the end of 2000 the Second Generation NMR project was concluded successfully with a quality test using software to simulate the alarm mode in half the number of measuring stations. Two primary functions of the monitoring network were tested, namely the speed of the alarm from the monitoring posts and the speed of the transfer of the related data. The speed increased by a factor of two. This new network provides the Netherlands with one of the world's most advanced radiation-monitoring systems.

Depleted titanium for nuclear medicine

Titanium is frequently used for the manufacture of medical implants. Titanium is also used as a container material for radioactive substances which can be inserted in the human body, for example, for internal irradiation of a tumour. Many of these radioactive substances are manufactured in the HFR at Petten. Because of the radiation levels and thus the need for shielding, the insertion of a radioactive material into a titanium container is a laborious process. It would be much easier to insert the non-radioactive material in the container first and then to activate it by irradiation in the HFR. However, as a result of the irradiation, the titanium also becomes radioactive, which is undesirable. Together with Urenco, NRG has investigated the feasibility of producing and using titanium that contains no or hardly any titanium isotopes which become activated (depleted titanium). Urenco has expertise in the depletion and enrichment of stable isotopes. NRG specialises in irradiation for medical purposes and analysis of materials. Initial results of the irradiation and measurements of the activation suggest that the use of depleted titanium for nuclear medicine is technically feasible.

New construction material for fusion reactors

Nuclear fusion is one of the potential energy sources for the future. One of the bottlenecks in the development of a fusion reactor is the availability of a suitable construction material. The fusion installation's first wall or blanket will be constantly subjected to a bombardment of high-energy neutrons. The kinetic energy of these neutrons is converted into heat absorbed by the blanket, and partly into radiation damage to the blanket material. Each atom in this blanket is knocked out of its lattice position many times during the blanket's life, which causes a large impact on the mechanical properties of the blanket material. In addition, neutron capture leads to activation of the material. Research including the use of the HFR showed that steel alloyed with 9% chromium might be a suitable construction material. It becomes less activated than the common nickelferous stainless steels. This new type of 9% Cr-steel, Eurofer 97, is currently being manufactured under the EU's long-term fusion programme. NRG participates in a large-scale research programme into the mechanical and physical qualification of this material. Reuse of this material seems possible because of its low activation. The most important research aspect is the impact of the neutron irradiation on the material properties. NRG irradiates test samples and determines their fracture toughness (ductile-to-brittle transition).

Scan facilities at Schiphol Airport to assist customs

On 2 October 2000, the Minister of Finance officially put two scan facilities into operation at Schiphol Airport. In 1996 it had been decided to install a more effective system for checking the growing flow of airfreight.
The new scan facilities enable the inspection of cargo packed on pallets and in 10 and 20ft containers by using gamma rays. In each scan facility a vertical 6 MV and a horizontal 9 MV linear accelerator is used to produce a side and a bottom view of the cargo content. The system is designed to scan twenty units per hour. From the start, NRG was involved in the radiological aspects of the scan facilities. NRG's activities included an assessment of the wall thickness in the initial building plan in connection with the necessary shielding, the preparation for obtaining a licence and the testing and evaluation of the equipment with special attention to the radiation levels, alarm signals and safety systems. In the first few weeks of the new facilities' operation a total of 60 kg of cocaine was intercepted, demonstrating the effectiveness of the system.

Sludge with natural radioactivity

Solids with highly variable concentrations of natural radionuclides are extracted during the production of oil and gas. When these concentrations exceed the limits as laid down in the Dutch Nuclear Power Law, the sludge is regarded as radioactive waste. However, there are no facilities available for the long-term storage of these large amounts of sludge. NRG has experience in the extraction of lead-210 from sludge. In collaboration with an industrial partner NRG has performed a feasibility study on the construction and operation of a sludge treatment facility capable of extracting the radioactive elements from the many types of radioactive sludge, so that the remaining small amount of radioactive waste is suitable for storage at COVRA. The study has demonstrated the technical feasibility. The practical realisation depends on economic factors and on the new regulation in this field.

Facility for the inspection of airfreight pallets

‘De Republiek der Kerngeleerden’ describes the history of RCN/ECN in the period 1962–1984. The author is Professor Kees Andriesse of the University of Utrecht. The book was launched at Petten on 6 July 2000, when ECN celebrated its 45th birthday. The main figures in the book appear on the cover in a cartoon inspired by Rembrandt’s Anatomic Lesson.
ISBN 9075541058, BetaText, Bergen

‘De Republiek der Kerngeleerden’ is a sequel to ‘Een kernreactor bouwen’ published in 1995 and deals with the history of RCN in the period 1945-1962.
ISBN 9075541015, BetaText, Bergen, author J.A. Goedkoop

In ‘De Vliegende Geest’ ECN researcher Jan Willem Erisman compiled all existing knowledge about ammonia from agriculture and its impact on nature. The book starts with the Ammonians who may have been the first people to use natural ammonium salts in ancient times and concludes with the Dutch manure surplus problem caused by the considerable mismatch between import and export of nitrogen compounds. ‘De Vliegende Geest’ contains more than 100 figures, photographs and tables.
Jan Willen Erisman is head of the Air Research and Technology Group of ECN Business Unit Clean Use of Fossil Fuels.
ISBN 9075441066, BetaText, Bergen

‘Vacuum is niet niks’ is an anthology of essays and columns by Frans W. Saris and published in De Gids, NRC Handelsblad, de Volkskrant, Technisch Weekblad and Het Financiële Dagblad. ECN director Frans Saris who is also one of the De Gids’ editors describes a number of scientific phenomena and techniques – the behaviour of atoms and molecules – and also the behaviour of the researchers and developers in the technical and scientific world.
ISBN 9029069155, J.M. Meulenhoff, Amsterdam

Consolidated Financial Statements 2000

Consolidated Financial Statements 2000

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

Assets

	2000	1999
Fixed assets		
Tangible fixed assets	33,627	28,728
Intangible fixed assets	821	-
Financial fixed assets		
• Participations in knowledge-based companies	54	18
• Other participations	690	611
• Deferred loan	227	-
• Securities	39,075	33,583
• Other receivables	1,942	1,803
	76,436	64,743
Current assets		
Work in progress	15,395	9,325
Receivables and prepaid expenses	20,715	17,105
Securities	-	6,220
Liquid assets	-	19,138
	36,110	51,788
Total	112,546	116,531

Liabilities

	2000	1999
Group equity		
Equity	18,709	26,955
Third party share	896	747
	19,605	27,702
Provisions	4,452	21,407
Provisions early retirement	10,396	11,842
Provisions redundancy	39,756	21,929
Provisions radioactive waste	2,066	3,294
Other provisions	56,670	58,472
	983	953
Long-term liabilities		
	35,288	29,404
Short-term liabilities		
	112,546	116,531
Total		

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

	2000	1999
Operating income		
Financing and other income		
• Basic, ENGINE, and Collaboration financing from the Dutch government	29,782	28,527
• Third party revenues	48,401	46,507
• Increase/decrease work in progress	6,070	5,426
	84,253	80,460
Capitalized production for own organisation	1,958	2,144
Income from licences	723	947
Other operating income	1,189	1,183
	88,123	84,734
Operating expenses		
Wages and salaries	53,412	47,343
Depreciation	5,902	5,041
Other operating expenses	27,473	29,494
	86,787	81,878
Operating result	1,336	2,856
Result financial income and expenses	1,313	1,867
Result before extraordinary income	2,649	4,723
Extraordinary income and expenses	-/- 10,745	-/- 1,134
Result before share of third parties	-/- 8,096	3,589
Third party share in the result	-/- 150	-/- 148
Consolidated result	-/- 8,246	3,441

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

	2000	1999
Balance at 1 january liquid Assets	19.138	25.400
Cash flow from operating activities		
Operating result	1,336	2,856
Depreciation	5,902	5,039
Increase/decrease provisions		
Exclusive of interest addition and grant		
Dpt. Economic Affairs	-/- 23,413	-/- 1,765
Increase/decrease extraordinary income	8,622	-
	-/- 7,553	6,130
Change in working capital	1,456	-/- 12,342
Increase/decrease extraordinary expenses	-	-/- 1,134
	-/- 6,097	-/- 7,346
Result financial income and expenses	3,557	1,867
	-/-2,540	-/- 5,479
Cash flow from investing activities		
Increase/decrease financial fixed assets	-/- 5,632	4,524
Increase/decrease intangible fixed assets	-/- 1,026	
Investments tangible fixed assets	-/- 10,597	-/- 6,138
Contribution third parties tangible fixed assets	-	-
Disposals tangible fixed assets	1	35
Increase/decrease participations	-/- 342	-/- 157
	-/- 17,596	-/- 1,736
Cash flow from financing activities		
Increase/decrease of long term liabilities	30	953
Balance at 31 December liquid assets	-/- 968	19,138

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, municipality Zijpe. 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 scheduled depreciation. The site was obtained in ground rent 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 period is 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 subsidiary NRG is valued at the net equity value. The net equity value is calculated on the basis of similar principles which are used by ECN. The other participations are shown at acquisition price less provisions.

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

The valuation principle and presentation of shares has been altered as per year end 2000 with respect to 1999. As per 31 December 2000 the provisions exceed the amount of shares as a result of the adding to the provision of nuclear waste. Therefore shares are valued at market value and are presented as financial fixed assets.

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

The provision for early retirement (referred to as FUT), reorganization and nuclear waste are calculated on the basis of net present value. The redemption of the FUT by the Department of Economic Affairs is calculated on the basis of accepted actuarial principles.

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 which should be allocated to the year under review.

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

Fixed assets

Tangible fixed assets		Movements in 2000		
	Book value at 31-12-2000	Additions	Disposals	Book value at 31-12-1999
Industrial buildings/Site facilities				
Purchase price	30,676	4,303	-	26,373
Depreciation	20,561	957	-	19,604
Book value	10,115	3,346	-	6,769
Industrial installations/fixtures				
Purchase price	38,956	2,514	-	36,442
Depreciation	28,771	1,792	-	26,979
Book value	10,185	722	-	9,463
Instruments, machinery, etc.				
Purchase price	37,626	3,870	1	33,757
Depreciation	30,433	2,948	-	27,485
Book value	7,193	922	1	6,272
Fixed assets in progress				
Purchase price	6,133	-/- 90	-	6,223
Total				
Purchase price	113,392	10,597	1	102,796
Depreciation	79,765	5,697	-	74,068
Book value	33,627	4,900	1	28,728

Intangible fixed assets		Movements in 2000		
	Book value at 31-12-2000	Additions	Disposals	Book value at 31-12-1999
Goodwill				
Purchase price	1,026	1,026	-	-
Depreciation	205	205	-	-
Book value	821	821	-	-

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

Financial fixed assets

Participations

	2000	1999
• BCN BV	-	1
• ENATEC BV	8	8
• NEDSTACK Holding BV	3	3
• SWEAT BV	7	6
• INDEC BV	18	-
• MAN SOLAR BV	18	-
Total	54	18

Other participations

	2000	1999
• DNC Nuclear Technology BV	18	12
• COVRA NV	-	-
• RTC Noord-Holland Noord BV	227	227
• TIFAN BV	227	227
• ECN-INTERNATIONAL BV	18	18
• SOLAR INTERNATIONAL BOTSWANA (PTY LTD)	45	45
• AWS BV	71	71
• ENERSEARCH AB	11	11
• OFBS BV	10	-
• COGEN Projects BV	45	-
• AXCEL RIBBON DEVELOPMENT BV	18	-
Total	690	611

Deferred loan

The deferred loan has been procured to Econcern with the intention to convert this loan into shares.

Securities

The movement of the securities is as follows		
Balance at January 1, 2000 financial fixed assets		33,583
Balance at January 1, 2000 current assets		6,220
		39,803
• Minus: sell	1,337	
• Plus: sell	609	
		-/- 728
Balance at December 31, 2000		39,075

The presentation of the securities has been altered as per year end 2000. As the provisions exceed the amount of shares due to the suppletion to the provision nuclear waste, presentation as financial fixed assets is necessary. The securities are at free disposal of ECN.

Deposits

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

Securities

The bond portfolio has a face value of € 34,723. The market value as per year end 2000 is € 29,784.

Shares

The share portfolio has a book value, equal the market value of € 6,593.
The purchase price as per closing balance amounts € 6,657.

Other receivables

Deferred loan

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

Licences

Other receivables include a licence for microfiltration membranes.

Current assets

Receivable and prepaid expenses

The receivables are included for the nominal amounts net of a deduction for the necessary provisions. The receivables expire within 1 year and can be specified as follows.

	2000	1999
Trade receivables	18,555	11,176
Other receivables and prepaid expenses	2,160	5,929
Total	20,715	17,105

Liquid assets

As per December 31 1999 liquid assets are presented as short-term liabilities. The liquid assets include an amount of € 5,055, being the balance of the redemption of the FUT by the department of Economic Affairs and the insured amount deposited in the pension fund. The other liquid assets are at free disposal.

Provisions

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

Provisions voor 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, 2000		21,407
• Minus: withdrawal	1,655	
• Minus: deposit pension fund	15,422	
• Plus: interest addition	122	
		-/- 16,955
Balance at December 31, 2000		4,452

Provision for redundancy

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

Balance at January 1, 2000		11,842
• Minus: withdrawal	2,047	
• Plus: addition	60	
• Plus: interest addition	541	-/- 1,446
Balance at December 31 , 2000		10,396

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, 2000		21,929
• Minus: withdrawal	2,823	
• Plus: suppletion to actual liabilities after investigations	19,578	
• Plus: interest addition	1,072	
		17,827
Balance at December 31, 2000		39,756

In 2000 it appeared that the valuation dating from 1994/1995 was no longer current. On the bases of the results of the investigation the provision has been suppleted with € 19,578 in order to meet the liabilities. The department of Economic Affairs granted € 8,622 in order to compensate ECN. With regard to the current level of the provision, uncertainties remain as per December 31, 2000. There is a dispute between ECN and GCO concerning the responsibilities of 500 stored barrels and other radioactive parts. The investigation to determine the exact content is still going on. The calculation of the costs of disposed and

decommisioning of radioactive waste is based upon the current state of technology. In 2001 ECN will have to pay their share in the future operating losses of COVRA, as part of the transfer of stocks to the Government. The share has been accounted for as extraordinary loss.

Other provisions

Other provisions include the provision for functional reduncancy due to age (FLO), disability insurance (AOV), provisions for flexible retirement (SFN) and periodic maintenance.

	FLO	AOV	Maintenance	SFN	Total
Balance at January 1, 2000	1,877	913	504	-	3,294
• Minus: withdrawal	466	913	753	-	2,132
• Plus: addition	340	-	272	190	802
• Plus: interest addition	91	-	-	11	102
Balance at December 31, 2000	1,842	-	23	201	2,066

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 AOV (disability insurance)

ECN subdued the legal disability requirements (PEMBA) with an insurer with retrospect from January 1, 1998. The provision built up before 1999 has been deposited at insurance premium.

Provision for periodic maintenance

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

Long-term liabilities

ECN procured a long-term deferred loan of € 2,178, which results in a total procured loan to subsidiary NRG of € 3,161. The deferred character is based upon requirements for solvency as per joint venture agreement ECN-NRG.

Short-term liabilities

	2000	1999
Deferred income from third parties	4,619	2,452
Trade liabilities	13,954	13,025
Wage taxes and social insurance premiums	2,046	1,915
Other social charges and personnel costs	4,721	4,394
Value added tax	160	246
Miscellaneous liabilities and accrued expenses	8,820	7,372
Liquid liabilities	968	-
Total	35,288	29,404

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

Operating income

	2000	1999
Basic and ENGINE financing	14,972	14,396
Collaborating financing	14,810	14,131
	29,782	28,527
Third party revenues	48,401	46,507
Increase/decrease work in progress	6,070	5,426
Other income	1,189	1,183
Total third party revenues and other income	55,660	53,116

Breakdown into market segments:

	2000	1999
Domestic trade and industry sector	20,998	18,112
Domestic energy sector	3,032	4,753
European Commission	7,795	12,596
Foreign trade and industry sector	8,666	3,807
Governmental departments	3,104	3,614
Novem	12,065	10,234
Total	55,660	53,116

Capitalized production for own organization

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

Operating expenses

Personnel costs

	2000	1999
Salaries of permanent employees	34,080	31,091
Cost of temporary employees	7,449	6,941
Social security	4,409	3,909
Pension charges	4,102	1,874
Other personnel costs	3,372	3,528
Total	53,412	47,343

The average number of employees (in FTEs) was:

	2000	1999
• Permanent contract of service	764.7	706.5
• Temporary contract of service (including PhD candidates)	144.4	140.5
Total	909.1	847.0

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

Depreciation

	2000	1999
Industrial buildings, installations, fixtures and site facilities	2,750	2,590
Instruments and other inventory	2,947	2,449
Subtotal depreciation	205	-
Write off disposals	5,902	5,039
	2	2
Total	5,904	5,041

Financial income and expenses

	2000	1999
Interest income	3,678	3,075
Interest expenses	3,481	2,450
	197	625
Other financial income and expenses	1,116	1,242
Total	1,313	1,867

Interest income include € 230 of capitalised construction interest.The interest paid includes the interest added to the provisions for an amount of € 2,244 (€ 2,259 in 1999).

The other financial income and expenses consist of realized profits on securities and received dividends.

Financial income and expenses

Extraordinary income:	2000	1999
• Grant Department of Economic Affairs regarding radioactive waste	8,622	-
Extraordinary expenses:		
• Addition to provision FUT	1,134	1,134
• Suppletion to provision radioactive waste	16,926	-
• Share operating losses COVRA	1,307	-
Total extraordinary expenses	19,367	1,134
Total extraordinary income and expenses	-/- 10,745	-/- 1,134

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

	2000	1999
Operating income		
Financing and other income		
• Basic, ENGINE and Collaboration	21,527	20,427
• Third party revenues	21,110	20,780
• Increase/decrease in work progress	6,089	3,718
• Income from subsidiary NRG	7,741	7,323
	56,467	52,248
Capitalized production for own organization	1,496	1,626
Income from licenses	723	948
Other operating income	1,189	1,182
	59,875	56,004
Operating expenses		
Wages and salaries	35,939	31,974
Depreciation	4,935	4,463
Other operation expenses	17,881	17,192
Expenses from subsidiary NRG	884	851
	59,639	54,480
Operating result	236	1.524
Result financial income and expenses	1,045	1,865
Result before extraordinary income	1,281	3,389
Extraordinary income and expenses	-/- 10,745	-/- 1,134
Company only result	-/- 9,464	2,255
Result group company	1,218	1,186
Result	-/- 8,246	3,441

Company only balance sheet at December 31 *(in € x 1000)*

Assets

	2000	1999
Fixed assets		
Tangible fixed assets:	32,243	27,383
Financial fixed assets		
• Participation in knowledge-based companies	54	18
• Participation in subsidiary NRG	2,876	2,501
• Other participations	672	599
• Deferred loan subsidiary NRG	2,178	2,178
• Deferred loan	227	-
• Securities	39,075	33,583
• Other receivables	1,942	1,803
	79,267	68.065
Current Assets		
Work in progress	13,928	7,839
Receivables subsidiary NRG	2,635	601
Receivables and prepaid expenses	12,448	10,100
Securities	-	6,220
Liquid assets	-	10,166
	29,011	34,926
Total	108,278	102,991

Liabilities

	2000	1999
Equity	18,709	26,955
Provisions		
Provisions early retirement	4,452	21,406
Provisions redundancy	10,336	11,842
Provisions radioactive waste	39,249	21,634
Other provisions	1,431	3,062
	55,468	57,944
Short-term liabilities	34,101	18,092
Total	108,278	102,991

Notes to the company only financial 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
In conformance with the joint venture agreement ECN-KEMA, the outstanding account of subsidiary NRG has been converted into a long term deferred loan of € 2,178.

Directors and Supervisory Board
The remuneration of directors amounts € 309.
The remuneration of the members of the Supervisory board is € 48.

Participation in group company
The movements in the participating share are as follows:

Balance at January 1, 2000	2,501
• Minus: Licence Fee 1999	843
• Result subsidiary NRG	1,218
Balance at December 31, 2000	2,876

Equity at December 31

	2000	Changes in 2000	1999
• 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	1,102	-/- 8,246	9,348
Total	18,709	-/- 8,246	26,955

Petten, April 25, 2001

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

Prof.dr. F.W. Saris
Managing Director

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 2000. 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 management of the Foundation, 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 position of the foundation as at December 31, 2000 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 included in Part 9, Book 2 of The Netherlands Civil Code.

Arthur Andersen

Amsterdam, The Netherlands
25 April 2001

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In 2000 the first stage of the modular 'building 42' was completed. The energy concept of this new ECN building is largely based on experience and insights gained from the Renewable Energy office building which was completed in 1993.
Combined functions of electricity generation and daylight regulation, natural ventilation, summer night cooling and, of course, excellent insulation are important features of the concept. Clearly visible are the 356 solar modules in the 'atrium' roof in which the individual cells are mounted at a distance so that 30% of the incoming light passes through. This is sufficient to enable work without artificial light and it also prevents the need for forced ventilation. Just like the RE building at the time, the new building is a sound candidate to win the 'Most Energy-Efficient Building in the Netherlands 2001 Award'.

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