

Annual report 2003



Energy research
Centre of the
Netherlands

Cover illustration: Bridging Function

*In 2003 the government set up the Ad Hoc Committee
“Bridging Function GTI’s and TNO” to evaluate the
intermediate knowledge infrastructure on this issue.*

Contents

1. Foreword	2
2. Introduction	4
3. Research	9
3.1 Social Context.....	9
Policy Studies	9
3.2 Energy Conservation	11
Energy Efficiency in Industry	11
Renewable Energy in the Built Environment.....	13
3.3 Renewable Energy	16
Solar Energy	16
Wind Energy.....	19
Biomass.....	22
3.4 Clean and Efficient Fossil Fuels	24
Clean Fossil Fuels.....	24
Fuel Cell Technologies	27
4. Technological Services and Consultancy.....	31
5. Nuclear Technology	33
6. Annual Social and Environmental Report	37
7. Financial Report	41
8. Members of the Supervisory Board, Advisory Bodies, Management.....	51

1. Foreword

The government set up an Innovation Platform in 2003, headed by the Prime Minister, thus stressing the importance of innovation and the Netherlands' ability to innovate to achieve economic growth and competitiveness in the long term. The danger with a platform of this kind is that, with so many Ministries involved in policy-making, attention will become fragmented and there will be too much focus on detail. The biggest threat to effectiveness, however, is a national focus. Nowadays innovation takes place in an international environment, with broad networks involving large numbers of foreign partners playing a major role. Knowledge institutions such as ECN work hard to achieve a top-level international presence, and this requires a European level playing field, as there are differences within Europe in the funding and roles of the various knowledge institutions. Consequently there is also a need for a national innovation policy based on a clear vision of the role of the Netherlands within Europe. In this respect it is my view that the 'Letter on Innovation' published by the Ministry of Economic Affairs at the end of 2003 focuses too much on the Dutch situation: knowledge institutions can only survive in the long term if they are able to target the whole of Europe. The Netherlands by itself is too small, and top-level knowledge exists mainly in an international context. Communicating a vision of this kind, I am convinced, is one of the main functions of the Innovation Platform.

The Ad Hoc Committee on the "Bridging Function" of MTIs and TNO (the Wijffels Committee), set up in 2003 by the Minister of Education, Culture and Science, is also looking at the role of the Major Technological Institutions (MTIs), including ECN, in the national and international context. The Committee is reviewing how TNO and the MTIs' bridging function is working, starting with a self-evaluation by all the institutions.

ECN has made substantial efforts in this regard over the past year which have been particularly useful to the organisation itself, (a) clarifying ECN's role and position in the knowledge infrastructure and (b) producing even greater awareness internally of ECN's function in that infrastructure. In the process it was realised that the metaphor of a 'bridging function' between the universities and the private sector no longer adequately describes ECN's role. Nowadays innovation takes place in dynamic networks and alliances, in which the players have their own unique roles. In the discussions with the Committee ECN clarified its role in relation to the universities and the private sector. ECN focuses on the long-term research required to make the transition to sustainable energy management. On the goal/market axis ECN is primarily goal-oriented, and this role is expressly stated in the new mission statement.

To the realisation of the need to articulate the demand I would like to add my observation that the transition to sustainable energy management in the Netherlands is currently fragmented in short-term activities without adequate cohesion and with no view of the long-term implications. The transition idea in the Netherlands is unique in the world, but it needs to be handled carefully. It is increasingly clear that a consistent, integrated vision needs to be developed if the transition process is to continue successfully. 'The government' and 'the politicians' need to set the transition goals in consultation with other players and take on the role of transition manager. This is a major challenge for 2004.

The foreword to the 2002 Annual Report noted that the government needs tools for its innovation policy that are better geared to the way the MTIs work as pillars of the Dutch knowledge infrastructure. The costing system under the new comprehensive scheme

*Jan Terlouw is leading
the debate at the
NMNH-congress on
18 June 2003 at ECN.*



(Innovation Grants for Joint Ventures) fails to take the different funding systems of (a) TNO and the MTIs and (b) the universities into account. The Minister of Economic Affairs is aware of this problem, and an international Ministry working group is reviewing the subsidisable costs.

We also expected last year from the 'Letter on Innovation' that the concept of sustainability would serve as a guide to innovation policy. It is good to note that the Minister of Economic Affairs included this point in the Letter and that significant progress has been made in this area. The results of the ICES/KIS-3 (subsequently Investment in Knowledge Infrastructure (BSIK)) exercise are not in line with this approach, as only a very small part of the 800 million euros plus has been earmarked for sustainable energy. A lot has been said about the procedure, but it remains cause for concern that research into solar power and biomass – vital to the transition processes mentioned earlier – has been rated so poorly. It is regrettable to note that the powerful industrial consortia that were prepared to lead the alliances and help fund them are now falling apart.

Energy research policy is also in a high state of flux. A few years ago a desire to sharpen the focus of long-term research was expressed. The Energy Research Strategy (EOS) exercise was undertaken with this in mind, setting out priorities that are now being developed programmatically in consultation with organisations in the field.

Following three years of substantial losses ECN came back into profit in 2003. While the figures are no cause for jubilation, it is good to note that there has been a turnaround in an unfavourable economic climate. This does not mean that our problems are solved, but it gives us heart to work on strengthening our capacity still further in the coming years. In the long run I thus expect ECN to achieve a healthy equilibrium again. Solving the pension problem is taking a lot more time than expected: here too there is light at the end of the

tunnel, though considerable efforts are still needed to achieve agreement between all the parties. As far as that is concerned ECN is in a similar position to many other companies in the Netherlands.

Peter Wilson was succeeded by Dr Ton Hoff as Chairman of the Board on 1 March, and we also said farewell to Wouter Schatborn in 2003. We would like to thank them both for their special efforts on behalf of ECN. After serving for a year as Deputy Director, Prof. Wim Sinke indicated that he would prefer a post that involved him more directly in the research, so he is taking charge of the major integrated EU project CRYSTALCLEAR on 1 January 2004. ECN is coordinating this highly ambitious project involving sixteen European partners. Wim's decision is a piece of good fortune for CRYSTALCLEAR, but for us on the Supervisory Board it is a loss to the management. Wim will however continue to assist the Board in various capacities, e.g. with self-evaluation. Following his departure as Deputy Director we have decided to divide up the responsibilities between the two remaining Board Members.

All in all ECN's world is in a state of flux, both with regard to government policy and the changing market conditions. ECN therefore needs a flexible organisation that is able to respond to and anticipate changes. The past few years have not been easy for ECN's staff, and things will not get easier in the years to come, but our attention is now completely devoted to the work again and we are continuing to develop a robust ECN. We would like to thank the Board, management and staff for their commitment and the quality of their work, which enables us to look forward to the future of ECN with confidence.

J.C. Terlouw
Chairman, ECN Supervisory Board

2. Introduction

ECN's financial situation improved in 2003. The negative financial trend of recent years has been reversed with a small profit and we can look forward to the future with more confidence. All ECN staff have worked hard over the past year to achieve the turnaround.

A new Strategic Business Plan (SBP) was drawn up at the start of the year, setting out the strategy for the coming years. ECN has also evaluated itself for the study into the 'Bridging Function' of the MTIs and TNO by the Wijffels Committee set up by the Ministry of Education, Culture and Science. The whole organisation was involved in both exercises, resulting in a broad base of support within ECN for the choices made and the strategy adopted. As a result of this work we have a new, more clear-cut mission and a transparent underpinning for the priorities and research clusters selected.

Turnover and profit and loss

Following three years of substantial losses we came back into profit in 2003. Turnover fell to 96 million euros in 2003, compared with 100 million in 2002. The drop was caused entirely by the reduction in the 'Work in progress' item. There was a profit of 1.1 million euros in 2003, compared with a loss of 8.1 million in 2002. It is good to note that there has been a turnaround. ECN was still faced with the protracted pension problem in 2003. To achieve a modest profit ECN staff were awarded a one-off pay rise, with the result that the cost of pension contributions did not rise any further. In 2004 the Board hopes to introduce a pension scheme that will be fair to all concerned: current staff, pensioners and the company itself.

Mission

ECN's new mission is:

'ECN develops high-level knowledge and technology for the transition to sustainable energy management'.

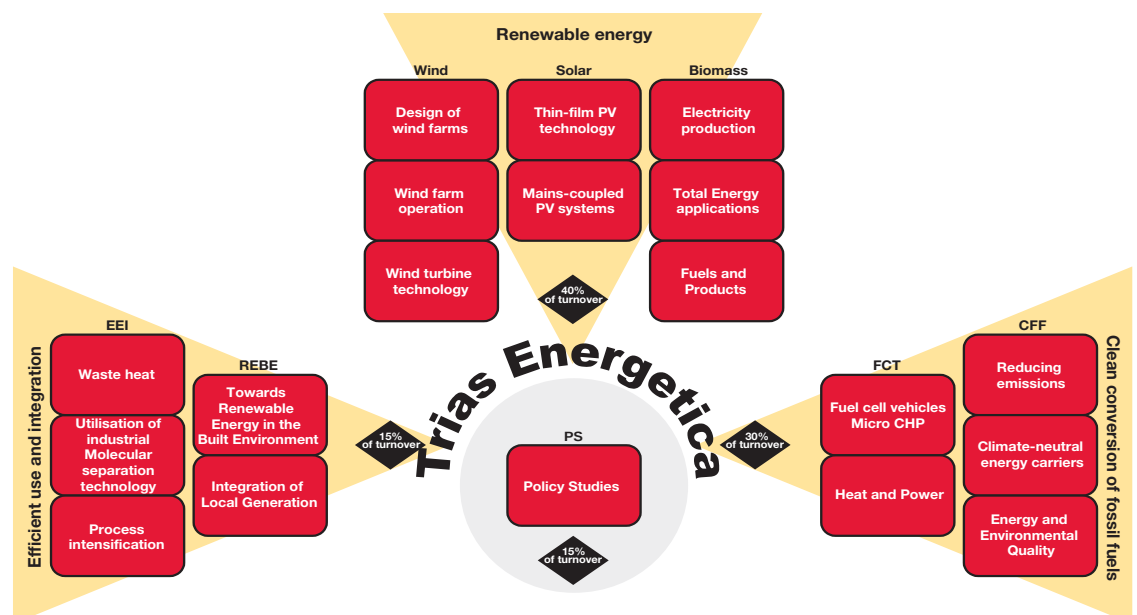
In more detail its mission is as follows:

- ECN focuses on the knowledge and information the government needs to develop and evaluate policy and achieve policy objectives in the field of energy, the environment and technological innovation.
- ECN partners industry in the development and implementation of products, processes and technologies important to the transition to sustainable energy management.
- ECN closely works together with Dutch and foreign universities and research institutes and performs a bridging function with implementation by carrying out technological research.

Research and development

ECN aims to put itself forward within its mission area as a top-level international institution, and it therefore opts to play an active, often central, role in national and international networks and consortia. This level of ambition is reflected in the restricted number of priority areas for research and associated skills. Industrial partnership is being developed in all the priority areas through the consortia and through bilateral contracts.

Figure 1:
Trias Energetica and
ECN's research areas



ECN's programmatic policy is based on the 'Energy Triad' – efficient utilisation, use of renewable energy sources and clean conversion of fossil fuels – and thus contains all the elements required for the transition to sustainable energy management. We ensure that the research programme remains targeted and is in line with the needs of government and industry by clustering the individual research projects. The research clusters are appraised on the basis of the following criteria: their potential contribution to achieving policy objectives, the added value they lend ECN in terms of its international knowledge status, the presence of a 'target group series' and funding that covers the costs. ECN has focused its research on the areas shown in *figure 1*.

2003 was a year of successful research in the above areas. The results are set out in *chapter 3*.

In addition to the clusters mentioned above, important work has been done in the area of electricity supply. The Electricity Network Users Research Programme (PREGO) is a joint research project by KEMA and ECN, commissioned by the Ministry of Economic Affairs, the aim of which is to enable the transition to free and sustainable energy management to take place quickly and in a controlled manner while maintaining a reliable electricity supply.

ECN and KEMA's nuclear facilities were brought under the Nuclear Research and consultancy Group (NRG), the Dutch knowledge centre par excellence for nuclear technology, in 1998. The essential areas in NRG's research programme are the storage of radioactive waste and reducing its lifetime, developing materials and fuel cycles for innovatory reactor systems, and natural radioactivity and radiation health. The main results of the work carried out by NRG in 2003 are set out in *chapter 5*.

The Wijffels Committee

The government set up an Ad Hoc Committee on the 'Bridging Function' of TNO and the MTIs under the chairmanship of Social and Economic Council (SER) chairman Herman Wijffels, its remit being to review the 'intermediary knowledge infrastructure'. The Committee comprises a small team of leading and experienced people. The study was commissioned when it was realised that, while the Netherlands carries out high-quality research, it is often not strong enough or fast enough to make use of the results. As part of the review all the institutions (TNO and the MTIs, including ECN) were asked to carry out a 'self-evaluation' and take a critical look at their performance. They were asked to say how they saw the future, in particular their relationship with government. Many ECN staff worked hard on the self-evaluation in the summer of 2003. In the autumn ECN discussed the report with the entire Committee. The main preliminary conclusions from the report and the discussions are as follows:

- ECN is a goal-oriented organisation focusing primarily on putting government policy and objectives into practice (the transition to sustainable energy management).
- Because of its goal-oriented nature, specific guidance from government is needed (the demand needs to be articulated).
- The long-term nature of this goal means that government funding is needed, as industry cannot and will not fund the required research by itself.
- ECN therefore sees itself having a clear relationship with government in future, albeit the nature of that relationship may change.
- Through its close association with industry ECN is also helping to build a knowledge-intensive economy and achieve sustainable economic growth: developing and implementing energy innovation is entirely in line with the desires of e.g. the Innovation Platform.
- ECN operates internationally and aspires to be one of Europe's top-level energy research organisations.

The Ad Hoc Committee will make its recommendations to the government in spring 2004. The Board of ECN looks forward to these with confidence.

Knowledge and technology transfer

ECN's new 2003 Strategic Business Plan made the organisation's 'bridging function between basic and applied research' even more explicit. It has gradually become clear, however, that the 'bridging function' metaphor falls short: in practice there are complex (often international) networks in which everyone involved plays a part. These networks include almost all the universities in the Netherlands, many Dutch and foreign companies, Dutch and foreign knowledge institutions, foreign universities etc. Various ECN staff work as part-time professors or lecturers at universities, for instance, and a number of PhD students are seconded to ECN. A constant transfer of knowledge takes place in all these networks.

Knowledge is transferred not only in specific contacts but also more generically. An important medium for recording research findings is ECN's reports: its publications totalled 259 in 2003, including 62 in peer-reviewed journals and conference papers. *Figure 2* shows the reports published over the 1998-2003 period. The fluctuations from one year to another are due mainly to the differences in the size and duration of projects, as a result of which the number of final reports varies.

Three years ago it was decided to focus on the Internet as the medium for disseminating the public knowledge developed at ECN more widely, and the web site www.ecn.nl was completely revamped. Now almost all ECN's public reports are also published in PDF format. The web site www.energie.nl has also been launched: this concentrates on providing general information on

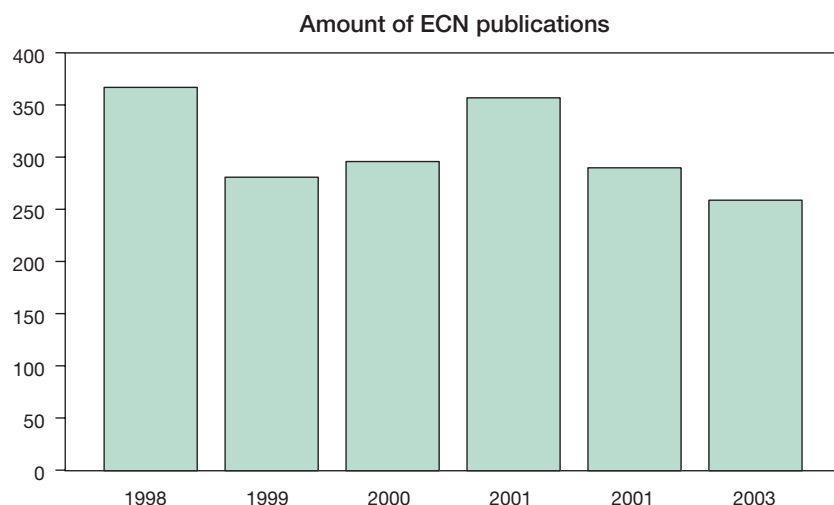


Figure 2:
Number of ECN (excl. NRG) publications per year.

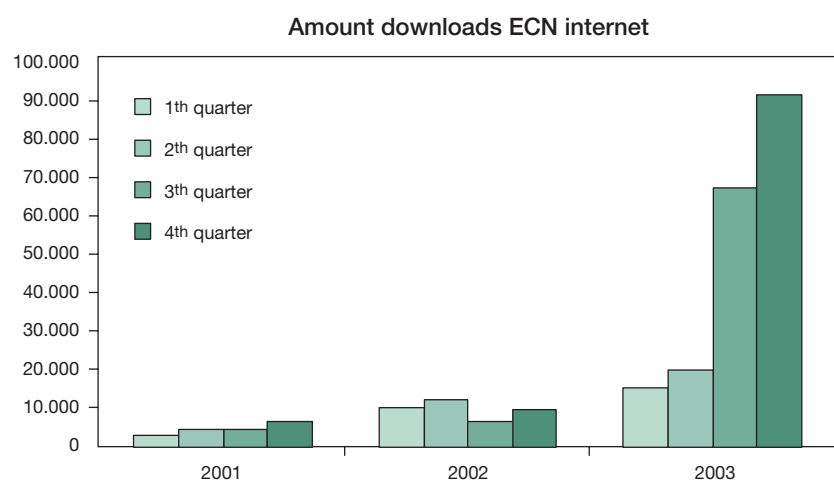


Figure 3:
Amount of downloads per quarter.

developments in Dutch energy supplies to a professional target group. Currently there are around 30,000 downloads of ECN reports per month (see figure 3): the number of reports downloaded thus far exceeds the numbers previously requested in writing.

Direct visits to the two web sites also rose in 2003: *www.ecn.nl* attracts an average of about 26,500 visitors per month (a 26% rise on 2002), who read an average of 105,000 pages, and *www.energie.nl* (launched during 2002) attracts around 13,000 visitors, who read an average of 25,000 pages. A lot of queries are also received and dealt with via the e-mail addresses *info@ecn.nl* and *corp@ecn.nl*.

Another type of knowledge transfer takes place through the monthly newsletter, which draws the attention of 1,450 outside subscribers directly to four or five topics per month. Links bring them to the web site to read about the topic. Among the subscribers are staff of almost all the Ministries, all the major energy companies, many municipalities, the SME sector, students, the press etc. Virtually all the newsletters have resulted in articles being published in the press. In addition to this active interaction with the press, ECN is frequently approached directly by the media: newspapers, magazines, radio and television devoted a good deal of attention to ECN's work in 2003, one of the highlights being the radio programme about hydrogen from ECN on Radio1, which took up a whole morning.

Patents

During the past year ten inventions were reported internally and four official patent applications made, two of which we are able to mention. The applications made are listed below.

The number of patent applications made in 2003 was less than expected. Although there will always be substantial fluctuations, a figure of four gives the Board cause for concern, and special attention will be paid to this during the coming year.

Brief title

Heat and Flux (increasing the yield from offshore wind farms)

Magnetische interconnectie PV

Name of inventor(s)

G.P. Corten,
P. Schaak

M.W. Brieko

Unit

Wind Power

Solar Power

Energy policy

The debate on achieving long term sustainable energy supplies is being conducted on the basis of the Transition Model developed by the Ministry of Economic Affairs. Transition paths were defined and developed in 2003 by a number of working groups, consisting of stakeholders in industry, government and research organisations. The four projects are biomass, new gas, sustainable production (now known as MEK II) and Sustainable Rijnmond (now R3). The suggested transition paths are now being studied and cleaned up. ECN has been closely involved in all these activities. At the beginning of 2004 an intervision group will look at the overall picture regarding the transition and how the four projects interrelate. The aim is now to input the results of the transition debate to the debate on long-term research (the Energy Research Strategy project: see *Energy research*).

The electricity industry is concentrating on (a) the effects of liberalisation and (b) decoupling production/distribution and network operation, and this has reduced its innovatory capacity substantially. It is disquieting to note that the industry is focusing mainly on commercial interests rather than technological innovation that benefits the environment.

A lot of attention in 2003 was devoted to the European Trading Scheme for CO₂ emissions to be introduced in 2005. ECN, in partnership with the National Institute of Public Health and Environmental Protection (RIVM), was commissioned by the Ministry of Housing, Spatial Planning and the Environment to ascertain what target levels should be applied for CO₂ emissions in each sector. Experts from the energy sector and industry gave their views on how emission rights could be assigned to the various parties involved in a particular production process. The findings were used when emission rights were allocated.

In order to set the production subsidy levels for renewable electricity projects (MEP subsidies), ECN Policy Studies has carried out research in collaboration with KEMA into the financial gap involved in various sustainable technologies. Following discussion with the private sector and government it reported to the Ministry of Economic Affairs, which has adopted the final report in its entirety.

The Energy Premium Scheme (EPR) was discontinued at the end of 2003, as the budget had run out. In view of the cutbacks there are currently no plans to reinstate it in 2004. The scheme was available not only for a range of economic measures in the built environment but also for local PV systems, solar water heaters and heat pumps, and its discontinuation will slow down investment in these systems.

Energy research

In 2002, as part of the Energy Research Strategy project (EOS), the Ministry of Economic Affairs asked the private sector and knowledge institutions what they thought should be priorities in energy research. They were asked to rate sixty options, chosen by the participants themselves, on the following criteria:

- Contribution to sustainable energy management (in 2010 and 2030)
- The knowledge status regarding this option in the Netherlands

The findings of this market consultation were processed in 2003 and classified under the following headings:

- Biomass
- New Gas/Clean Fossil Fuels
- Industrial Efficiency
- The Built Environment
- Generation and Networks

A medium-term research programme will be drawn up for each of these areas in 2004, for which purpose a vision of the situation in 2020-2030 will be developed. Biomass, New Gas and Industrial Efficiency are also project modules in the transitions exercise mentioned above. Programme Preparation Committees have now been set up for all these areas and they will produce programmes in summer 2004. ECN is represented on all the committees.

A continuing matter of concern is the overhaul of the funding system. The situation is still not clear, and the Order in Council that has been published shows that the particular nature of MTIs and TNO has not been taken into consideration sufficiently when setting hourly rates and funding terms for long and medium-term research. It is clear, however, that Laurens-Jan Brinkhorst, the Minister of Economic Affairs, is aware of the problems, and the Board of ECN therefore expects them to be resolved in 2004.

Innovation policy

The government decided at the end of 2003 to invest 800 million euro in strengthening the knowledge economy in the Netherlands. The money is to go to 34 approved programmes and three that are yet to be developed, all partnerships between companies and research organisations and special-interest groups (NGOs). The grants were awarded following appraisal by the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Netherlands Bureau for Economic Policy Analysis (CPB) and recommendations by the Committee of Wise Men, a government-appointed committee. The grants come under the Investment in Knowledge Infrastructure scheme (BSIK), previously known as ICES/KIS-3. The Board welcomes the fact that ECN is involved in the next three major projects under the scheme.

- Offshore Wind: this programme, launched at the instigation of ECN and Delft Technical University, is designed to provide a structural foundation for the commercial development of offshore wind power. It was requested by Stichting WE@SEA, a consortium of thirty industrial partners including Shell, Nuon and Ballast Nedam, knowledge institutions such as ECN and TNO, and special-interest groups such as Greenpeace and Stichting Noordzee. WE@SEA will receive 13 million euro per year for four years to implement the programme.
- CO₂ Collection, Transport and Storage: the aim of this programme, coordinated by the Utrecht University, is to build a powerful knowledge network combined with knowledge transfer on the transport, storage and use of CO₂. TNO, ECN and Utrecht Centre for Energy Research (UCE) are to implement the programme in partnership with companies such as Shell, Gasunie and NAM. The total cost is 29 million euro.
- Climate for Space: the aim of this programme, coordinated by Wageningen University Research Centre (WUR) and the Vrije Universiteit Amsterdam (VU), is to equip government and industry with an operational knowledge infrastructure geared to climate change and use of space. The programme has been awarded 40 million euro in grant aid.



Ton Hoff (left) and Kees van der Klein.

A disappointing aspect of the whole exercise is that the total funding awarded for sustainable energy is low in relative terms: important initiatives in the field of biomass and solar power in particular did not make it. The Board regrets that tremendous opportunities for sustainability and innovation are remaining unexploited as a result.

In conclusion

Although 2003 has been a better year in terms of both research and funding, a number of problems remain to be dealt with in 2004. This will require understanding and effort on the part of all concerned. The Board is fully confident that 2004 will be another successful year, thanks to the commitment, expertise, flexibility and perseverance of all ECN staff.

Dr. A.B.M. Hoff
Chairman of the Board

Dr. C.A.M. van der Klein
Deputy Director

3. Research

3.1 Social context

Policy studies

Sustainable energy systems must be implemented within an energy sector that has been transformed almost completely from public, national utilities to commercial, international energy companies. The programme unit Policy Studies of ECN analyses these major social and economic developments and advises public authorities at the regional, national and international level about energy- and environmental policies. The following four themes form the key areas of policy research:

- Energy use and climate change;
- Transition and innovation;
- New and Renewable energy;
- Gas- and electricity markets.

Energy use and climate change

The fact that energy use can change the climate has become a prominent item on the political agenda. According to the Kyoto protocol The Netherlands has to reduce its greenhouse gas emissions by 6% in the present decade. ECN Policy Studies advises the central government about the options and consequences of this target for developments in the energy sector. How energy use will develop in specific sectors and how effective energy policy is in reducing energy use and related environmental emissions, are key questions. In addition attention is paid to how other policy instruments could be implemented to reach the reduction target.

An important policy issue during 2003 was emission trading which will be implemented in 2005. Commissioned by VROM ECN has determined in co-operation with RIVM which target values are reasonable for CO₂-emissions in specific sectors. Experts from the energy and industrial sectors have been consulted on how emission rights could be assigned to the main emitting processes. The results of this study are being used to assign national emission rights.

For the Ministry of Economic Affairs a study was made to determine which mix of policy instruments would be appropriate to reduce future CO₂-emissions. It appears that the allocation of emission rights must have an effective limiting influence on emissions to induce cross-border trading of emission rights and to profit in an optimal way of cheaper reduction potentials abroad. This makes a proper allocation important in order to avoid higher national costs that would result without such trade. In an international context the unit also studied the interaction between emission trading and other policy instruments. It appears that many existing policy instruments can be combined with emission trading,

but their application reduces the overall cost reducing impacts of emission trading. Yet there are good reasons to maintain or add additional instruments for other purposes such as stimulating specific innovations or strengthening the synergy between emission reduction and other policy targets.

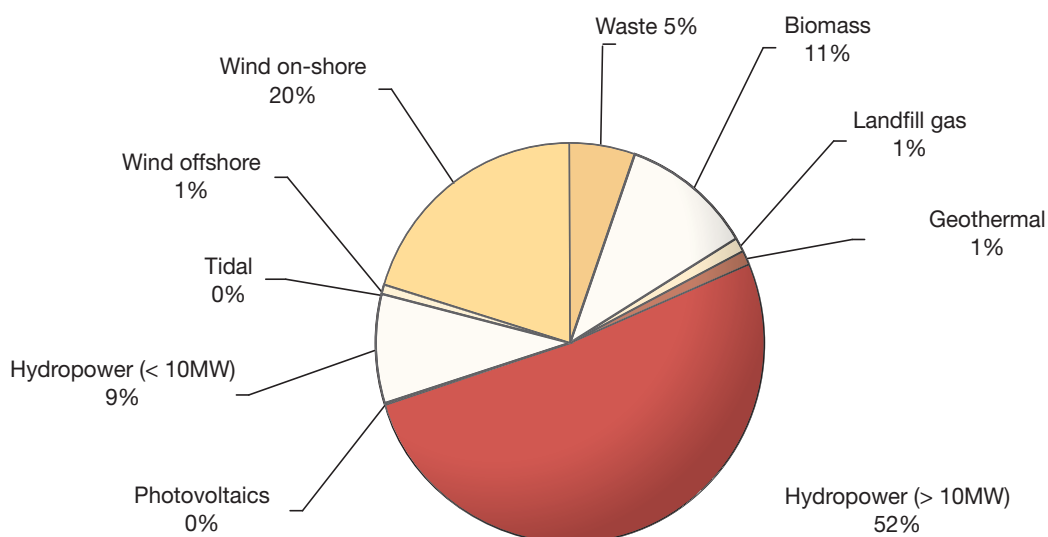
The future development of energy use and CO₂-emissions in the Rijnmond area has been explored for the period 2002-2020. It was concluded that the use of both electricity and heat could grow by roughly 50%. This is primarily the result of planned new activities on the second Maasvlakte. The study also looked at available opportunities for limiting CO₂-emissions in the region. On the international level ECN Policy executes a number of tasks for Working Group III of the Intergovernmental Panel on Climate Change (IPCC) commissioned by the IPCC support unit stationed at RIVM. Specifically, ECN is in charge of the co-ordination of a Special Report on CO₂-sequestration and storage.

Transition and innovation

New technologies are often relatively expensive. The average costs of new equipment will however fall through the scale and learning impacts of increasing market demand and growing production capacity. These impacts can be described by a so-called learning curve, a curve in which the going level of cost per unit is plotted against the cumulatively installed production capacity for a certain type of new technology over a number of years. In a European co-operative project ECN Policy Studies has determined the learning curve for photovoltaic (PV) systems. It turned out that the cost of PV have fallen by 20% for each doubling of capacity. In the 1990's costs even fell by 30% for each doubling of capacity. Continuing investments in both research and implementation are required to bring average costs down to competitive levels. By choosing the right mix of R&D and market implementation total government support can be optimised. Learning curves for more than a hundred types of technologies have been defined and implemented in the integral energy technology model MARKAL.

For the Ministry of Economic Affairs an analysis was made to determine the steps to be taken to in promoting the use of biomass in 2030. This transition study was made in co-operation with ECN Biomass and a number of other institutes. The results showed a potential of up to 30% of total energy use by conversion of biomass in electricity, heat and fuels such as green gas and green diesel.

Expected use of renewable technologies in Europe in 2010



In the framework of the European Admire-Rebus project scenarios were constructed for the employment of renewable energy in EU member states. It appears that large-scale hydro remains the major source in 2010. Additional capacity mainly concerns biomass and on-shore wind.

New and renewable energy

Electricity from renewable resources such as biomass, solar energy and wind is presently more expensive than electricity from fossil fuels. Therefore it was decided a few years ago to exempt renewable ("green") electricity from a regulatory energy tax (REB or ecotax), while suppliers received a fixed payment for delivering green electricity. Notwithstanding this strong stimulation domestic renewable electricity was insufficiently promoted. It turned out that these measures resulted mainly in promoting large amounts of renewable electricity imports from existing capacity elsewhere. It was therefore decided to replace the existing policy with a new instrument called the Law on Environmental Quality in Electricity Production (MEP), which went into force by July 2003. The new law rewarded domestic producers of renewable electricity, not suppliers of green electricity regardless of its source. The new law is intended to promote domestic investments in renewable sources rather than domestic consumption.

To determine the level of MEP-payments for different types of renewable electricity ECN Policy Studies in co-operation with KEMA made an analysis of the non-profitable part of production costs per technology. After consulting market representatives an advice was prepared for the Ministry of Economic Affairs, which was consequently implemented without changes.

Internationally ECN Policy Studies has played an important role as project leader of the Admire-Rebus project. In this project a number of scenarios has been developed to arrive at a harmonised European market for renewable electricity. One of the conclusions is that present policies are insufficient to reach the stated goals of the EU. In addition it is shown that a higher speed of harmonisation in the European market will decrease overall costs for the European Union to reach these goals.

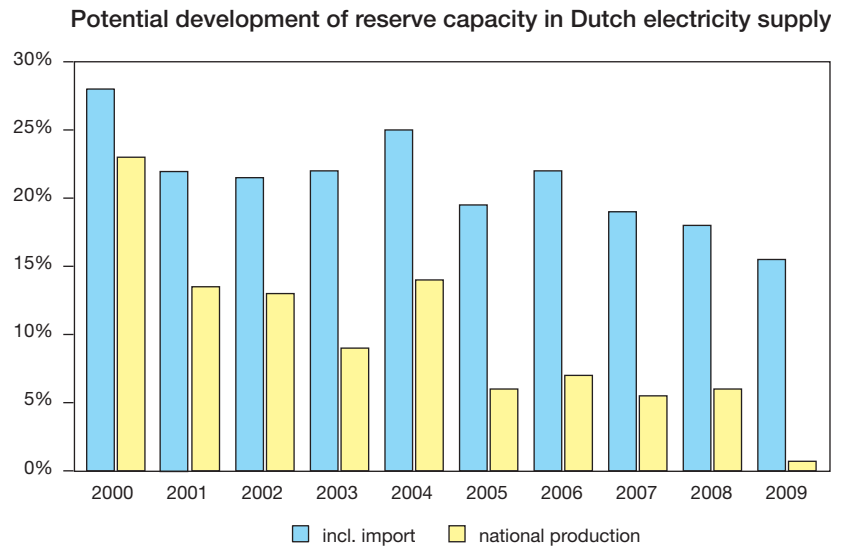
In the framework of the EU project 'Clear Views on Clean Fuels' (VIEWLS) ECN Policy Studies has provided an overview of all possible routes for the production of gaseous and liquid transportation fuels. Another achievement concerns the design of a computer model for analysis of the technological and economic features of these different routes. This model offers the European Commission more information about the potential role that biofuels will play in the transport sector in the near future. The EU has set indicative targets in this respect in order to reduce the environmental impacts of road transportation and to diminish the dependence on oil imports.

Gas and electricity markets

The past year was characterised by severe electricity supply problems. In the US, Italy, Denmark and Sweden major supply disruptions took place, which appeared to be related to large-scale electricity transfers across national borders. In the Netherlands exceptional warm and dry weather conditions occurred in August. Electricity demand increased sharply because of air conditioning and cooling while at the same time power production was constrained because of limitations on cooling water discharges. The resulting threats of supply shortages functioned as an early warning sign for actions to limit demand or expand supply. The ministry of Economic Affairs requested ECN Policy Studies to explore the availability of reserve capacity abroad and the feasibility of temporary demand reductions. Partially on the basis of this information the ministry formulated a new vision on supply security in the electricity market.

Not only electricity but also natural gas may run into problems of supply security although of a different nature. In this area of research ECN Policy Studies completed the ENGAGED project, an international co-operative study that explored the potential problems

and consequences of supply disruptions of natural gas on the European level. The study was implemented for the European Commission. ECN also co-coordinated the SUSTELNET project (Sustainable Electricity Networks), in which a roadmap was developed for European regulatory actions favoring better integration of decentral and renewable electricity generation in the present centrally oriented network. Finally, a number of issues regarding the impacts of liberalisation in gas and electricity markets were analysed using respectively the GASTALE and COMPETES market models. These issues concerned for example the importance of foreign market policies on the functioning of domestic markets, the effects of emission trading and the consequences of strategic behavior of major producers and traders.



During the August heat wave electricity supply shortages were imminent. This also led to increased attention for supply security issues in the medium term. An ECN report concludes that energy companies may invest too late in new power plants to prevent such shortages.

3.2 Energy saving

The increasing demand for energy can be countered by a more efficient use of energy. It appears that there is still much to be gained in this area. Accordingly, ECN conducts research into ways of saving energy within industry and the built environment.

The unit Energy Efficiency in Industry (EEI) aims by development of knowledge and technology to contribute to innovative solutions to reduce the use of energy and materials in this sector. The unit Renewable Energy in the Built Environment (DEGO) concerns itself with energy saving in buildings.

Energy Efficiency in Industry

Industry, with a share of 42% (including feedstock), is responsible for the lion's share of the national energy consumption. Especially the process industry uses a lot of energy. ECN Energy Efficiency in Industry develops new energy-saving technologies and system-innovations for this sector. This occurs in three areas, namely industrial waste heat, molecular separation technology and process intensification.

Industrial Waste Heat

Energy is used in industry mainly to heat up process streams so that they can be used at the correct tempera-

ture. Subsequently the streams are cooled down again. This heat is ultimately released to the environment via cooling water, cooling towers, and air coolers. Much energy can be saved by using this waste heat. Although in the last few years the amount of waste heat has been drastically reduced, especially at high temperatures, by process integration and optimisation, there is still much potential for energy savings. In the Dutch chemical and refinery sectors there is estimated to be at least 100 PJ per year available in the temperature range between 50°C and 200°C. (1 PJ per year is sufficient to meet the energy requirements of 10,000 households.) Heat



*Robert de Boer
inspects a prototype of
the SWEAT system.*

pumps can convert this waste heat to process steam or cooling, which can be used on site. ECN Energy Efficiency in Industry is developing two types of heat pump for this purpose.

One of these heat pumps is the so-called SWEAT (Salt Water Energy Accumulation and Transformation) system. This heat pump is intended to provide cooling, but is also suitable for energy storage. A prototype for cooling has been tested under a range of process conditions for nine months. The system performance was stable during this test, and there were no indications of corrosion or rust formation. Following this test, SWEAT is entering the phase of specific product development and market introduction. A consortium of ECN with the energy company Nuon and the consultants De Beijer shall start the marketing under the name SWEAT BV. Further development is foreseen for a system that on the basis of similar principles can convert waste heat from Combined Heat and Power installations into cooling for industry or utility buildings.

Another heat pump is the chemical heat transformer (CHT). This is also a solid-vapour system, but now for the production of process steam. In the last year various materials were investigated for application in the heat exchanger of the CHT. From experiments with a test-unit it appears that these materials are stable enough to guarantee a lifetime of at least ten years. In addition, various implementations have been evaluated for their practicability. The feasibility of the desired temperature lift and efficiency has been demonstrated in a preliminary design. Further development involves scale-up to a unit with a power of 1 to 5 kW. This shall be designed and tested in 2004.

Parallel to the CHT, the thermoacoustic heat pump (TA-HP) is being developed with the same objective. This apparatus converts sound into heat. This works as follows: sound waves cause a variable pressure amplitude in the working gas. This effect can be so strong that the sound waves cause a temperature difference in a regenerator. The thermoacoustic heat pump makes use of this principle. Last year it was demonstrated that the regenerator material could withstand the variable load. In addition, in a newly developed heat exchanger the heat transfer was improved by a factor four. Also the required low start temperature of the system has been achieved by use of a three-stage motor, a result that is unique in the world. The scale-up to a larger test-unit of 1 to 5 kW will take place in 2004. In the meantime research has been started into a burner-driven TA-HP for distillation, which according to an extensive market study can save 9 PJ per year in the Netherlands.

Molecular Separation Technology

Separation processes are responsible for a large part of industrial energy use. The petrochemical and chemical industry in the Netherlands is estimated to use 474 PJ per year, of which about 190 PJ per year is used in separation processes. A much-used technique is distillation, in which liquids are boiled and then condensed again. These kinds of thermal separation techniques are very energy-intensive and have a low energy-efficiency. Much energy can be saved by performing separations with membranes instead of thermal techniques. Systems based on inorganic membranes have the greatest potential.

The advantage of membranes is exemplified by the separation of an azeotropic mixture, a mixture that cannot be separated by normal distillation. In industry such separations are currently achieved by complex distillations, which are very energy-intensive. An energy-efficient alternative for this is a process in which only one of the components in the mixture is evaporated through an (inorganic) membrane. This process, which is called pervaporation or vapour permeation, offers a large potential for energy saving. From a study, in which the fifty largest distillation processes were examined, it appeared that the Netherlands could save at least 7 PJ per year. For Europe this is about 40 PJ per year, and worldwide about 200 PJ per year.

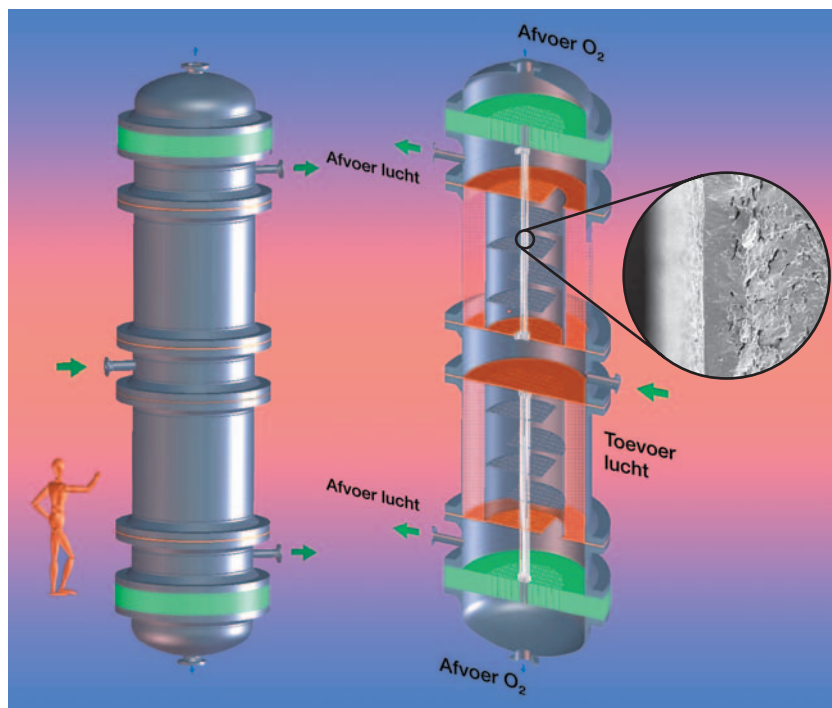
ECN has been involved with development of membranes for a number of years. The ECN technology is based on a manufacturing method for tubular ceramic membranes with intermediate layers and a microporous silica-based top layer. In addition, ECN has techniques to join and seal such membranes, as well as expertise in the module concept by means of which a number of membranes can be built into one system. This system has already been successfully tested by various Dutch companies. It appears however that fouling of the membranes when used with industrial process mixtures and

the long-term stability of the membranes are subjects that require further attention.

A completely different challenge is the manufacture of non-porous membranes for the separation of air into oxygen and nitrogen. This separation is currently still done by the energy-intensive and relatively expensive distillation of liquid air. Although the development of this so-called oxygen-membrane is still in a preliminary stage, in the last year it was already shown that a membrane with the correct thickness for a sufficient yield of oxygen could be the basis for an economically viable process. Just as for oxygen, it can also be very advantageous to separate hydrogen from process mixtures by use of membranes. A prototype palladium-based membrane has been delivered to several large industrial companies, all of which have reacted enthusiastically to the membrane performance. Especially when this membrane can be used to shift equilibrium reactions, the advantages can be enormous. (This can also be called process intensification, see below). The membrane can also be used in the technology for CO₂ capture, something that ECN Clean Fossil Fuels are currently investigating in the cluster 'Climate-neutral energy-carriers'.

Process Intensification

In order to continue to improve the energy-efficiency of the process industry it will be necessary to develop and apply new technologies. These technologies must change industrial processes in a more fundamental and radical manner. This can be done, among other ways, by process intensification, in which very compact process designs incorporate two or more conventional unit operations in one hybrid unit. A typical example is the membrane reactor, in which not only chemical reaction but also separation of the mixture occurs. Last year a membrane reactor with a palladium membrane was constructed, in which benzene can be converted



into phenol via a single partial-oxidation step. Another example is the manufacture of emulsions with membranes, which leads to an energy saving of 90% and to emulsions of very high quality. In 2004 it is planned to define more closely the research into process intensification.

Conceptual design of a membrane for the production of oxygen.

Renewable Energy in the Built Environment

Almost a third of total power consumption in the Netherlands is due to the use of energy in buildings such as offices and homes. As in industry, there are good ways of reducing the energy demand here, not only in newly built but in existing buildings as well. The built environment is also ideally suited to the use of sustainable energy on both a small and large scale. In this way the industry can contribute to achieving the government's targets in these areas. The government has set a target of obtaining 10% of the energy supply from sustainable energy in 2020. Households and the service sector need to make their use of energy 2.1% and 1.6% more efficient per annum respectively. ECN, under its Renewable Energy in the Built Environment programme



The rotatable test facility with four test-units.



Vacuum collectors. (DEGO), is developing concepts and technologies for homes and office buildings so as to achieve a transition to sustainable energy management in the built environment that meets the above targets.

For the market that ECN works for, it is important to make clear how energy-efficient components and energy concepts pay for themselves. Apart from the financial aspects, it is important to show that the new technologies and concepts remove some of the load on the environment while not affecting comfort or the indoor climate. It is also desirable to show that the technological advances and new concepts could have positive effects in these areas because major government incentives are in danger of being lost. The government is encouraging the implementation of energy-saving and sustainable energy technologies in building by means of e.g. the Energy Performance Standard (EPN) and Energy Performance Coefficient (EPC) and subsidies such as the Energy Premium Scheme (EPR) and Energy Performance Recommendations (EPA). These measures have come under fire recently, however. The government intends to abolish the Energy Premium Scheme entirely and the reduction of the Energy Performance Standard, which is an incentive to

Front and rear of a PVT panel.



technological innovation in building, has been slowed down unexpectedly.

Integrated concepts

The Ecobuild project, in which research is being conducted into the energy performance of building concepts in three Ecobuild dwellings on the ECN site, has entered its second phase, for which the outer skin has been modified in a number of ways. The house has been taped up using professional materials with the aim of substantially reducing infiltration (i.e. improving draught proofing). A new technique for measuring infiltration has also been developed, providing a clearer picture of the effects of wind direction and wind speed on energy losses due to infiltration.

Last year a test facility that can float to allow rotation around its axis was built on the ECN site in collaboration with De Vries Kozijnen and Delft Technical University. The aim is to test 'active' facades whose properties can be adapted to the season in different positions. It stands on half a metre of expanded polystyrene in a concrete bowl, which is filled with water a few times each season: the house then floats and can be turned by hand.

The rotatable test facility is also suitable for carrying out research into other exterior wall concepts, and we are actively seeking industrial involvement. The four other trial homes, the terraced houses on the ECN site, are also being examined to see how they can be used for fresh research. The aim of the experiments is to reduce energy consumption and use more sustainable energy such as the heat from the sun. We are also looking at building practices.

Solar power

Solar power is an important sustainable energy source for buildings. To take full advantage, it is essential to use as much as possible of the surface area of the building. PV panels can convert sunlight into electricity using photovoltaic cells. The demand for heat can also be met using a solar collector that takes heat from the sun to provide hot running water and water for space heating. Both systems, however, require a large proportion of the roof surface. Combining the two of them into a single device that converts sunlight into both heat and electricity at the same time saves space and supplies more sustainable energy than the two technologies separately. ECN is therefore developing PVT panels, also known as combined PV thermal panels.

Besides making more effective use of the roof surface, combined panels also have an aesthetic advantage, as it is not necessary to have different types of panel on the same roof. ECN is developing (a) a non-covered PVT panel for the production of heat at a temperature below 70°C: this heat can be used, via a heat pump, to provide space heating and hot running water; and (b) a covered PVT collector which is able to produce heat at a higher



Unit for outdoor IV-measurements (left) and the control electronics (right).

Between the measurements the panels can be hold on mmp status.

temperature. Both systems, based on a network of copper pipes beneath the photovoltaic cells, are now ready for demonstration. In parallel to this ECN is developing a much cheaper system using plastic channels which is suitable for mass production. In the European context ECN was last year appointed coordinator of a project to pool knowledge of PVT technology.

Heat storage

Sustainable energy involving new technologies such as micro CHP and heat pumps can be used more efficiently by storing heat. The amount of heat stored must be enough to compensate for the changing amounts of heat available in the various seasons, so the storage space in the home is critical to the success of the system.

The challenge is to develop storage technologies that are at the same time compact and cheap. In the case of systems using heat pumps in particular it makes sense to look at the cooling possibilities as well. ECN, as part of its Sustainable Energy in the Built Environment programme, is contributing to the development of 'phase transforming' materials capable of storing and releasing heat. The same programme is looking into the storage of heat at higher temperature (over 100°C) released from vacuum solar collectors. By storing this high-temperature heat in special materials the volume can be halved vis-à-vis storage in water. Cast iron appears to be a suitable material for this purpose, and a test system has been built to examine this. The first trials are to take place in 2004.

Vacuum collectors

In the long term, heat storage in 'thermochemical' materials is the most promising technology, as these use only a tenth of the volume compared with storage in water. To develop this application ECN, under its Renewable Energy in the Built Environment programme, has begun a feasibility study to look at the viability of various materials for thermochemical storage. A small number of pairs of materials have been identified as being suitable for high-capacity heat storage. This research project is to continue in 2004.

Domotics

Control and communication are essential if different technologies are to work together optimally, so as part of its Renewable Energy in the Built Environment programme ECN is examining the feasibility of using modern communications technology to control and regulate energy use and comfort in buildings. The aim is to link up this technology, known as 'domotics', with Internet protocols as far as possible. To this end software has been developed and a domotics system has been built over the past year, and these are now being trialled in the utility sector. They are expected to produce a 15% reduction in energy consumption. The wishes and feelings of occupants and the financial repercussions are being taken into account, and we have been looking at the possibilities of using domotics in house-building. One of the conclusions is that a domotics system with added energy functions could repay a large part of the cost of the system's electricity consumption or even yield savings. Savings of 5-10% on gas consumption can be achieved by using domotics with energy functions. This research is to continue in the coming years.

Building integration of PV

The various technologies being developed for buildings ultimately need to fit in with the building optimally, both physically and in energy terms. One example is how solar panels are attached to roofs and exterior walls and electrically connected. The PV Wire Free concept, already mentioned in 2002, shows that solar panels without electricity cables are much faster and cheaper to install. The connector that conducts the electricity to the load-bearing structure has been substantially improved during the past year.

An outdoor test system has been built to measure the IV characteristics of modules, enabling outdoor measurements to be carried out on a routine, continuous basis. It permits flash measurements to be made under standard conditions (1,000 W/m², perpendicular incident light and AM1.5 spectrum) and the annual yield and any degradation to be ascertained.

Outdoor test system

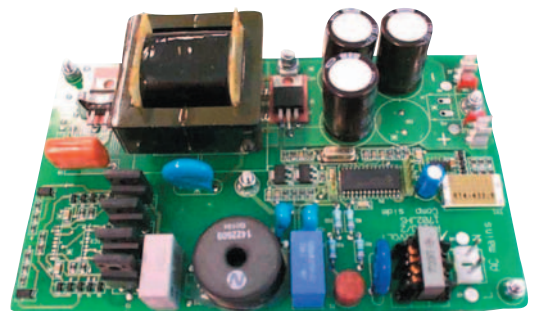
Research into how the cost of PV technology has changed over the last decade shows that it is falling as expected (Progress Ratio 0.8). This means that the sharp fall in cost expected in various scenarios is still taking place. Price monitoring and analysis are now also widely regarded as important. As modules account for 70% of the price of a system, the focus has to be mainly on lower cost. As regards inverters and building integration we need to look in particular at quality, reliability and ease of installation.

In collaboration with the manufacturers we have investigated how to make connection to the mains supply via inverters cheaper and more reliable. As a result we came up with an inverter that has far fewer components and consequently lasts twice as long and costs half as much as a conventional model. We also found that some inverters are over-sensitive to sudden voltage drops in the mains supply. ECN, as part of its Renewable Energy in the Built Environment programme, has responded with a method of predicting harmonic interaction between the inverter and the supply.

Integrating distributed energy resources

Information and communication technology will come to play a major role as a tool for monitoring, managing and controlling electricity infrastructures in which distributed energy resources and sustainable energy are important elements. Control of supply and demand, cost-effectiveness and reliability are important factors here. We assume that supply and demand will be coordinated by means of a bottom-up automatic electronic

market mechanism, i.e. starting at home/building level, then at LT level, MT level and HT level and lastly the international supply network. Flexible supply, demand, spinning reserves and where appropriate storage will be available at all levels. In this context the knowledge of electricity storage systems is being developed. As the whole of the electricity market is in a state of flux, new players are coming onto the market, the relationships between these players are changing and they can/must supply different products. An understanding of the resulting new business models is vital if we are to make the correct decisions on what part ICT should play in this area and ascertain what opportunities there will be. These developments are important input to the distributed energy resources cluster that is to be set up. With this in mind ECN has begun developing a computer program to simulate this net management concept and support the testing of hardware components for it (to be carried out in particular by ENECO).



The PV2GO inverter without cover.

3.3 Renewable Energies

Solar Energy

The rapid growth of production of PV systems in the past years, especially in Germany, has led to a growing demand for R&D in this field. ECN is increasingly asked to assist German solar cell manufacturers in the development of their technology. We now have already several research projects paid by the German PV industry. The 100.000-roof Programme in Germany has recently come to an end, but the law concerning the compensation for solar electricity delivered to the grid has been renewed. The uncertainty preceding the renewal of this feed-in law has resulted in a rather hesitant approach of potential investors in solar energy. This illustrates how dependent the market for grid connected PV still is on political decisions. In the Netherlands, the uncertainty about the EPR-subsidy for PV systems

will probably have a (hopefully temporary) negative influence on the growth of the installed PV power. The world-wide developments in nanotechnology and in polymer electronics are giving an enormous boost to the research on dye-sensitised and polymer solar cells. Our expectation is that these “organic” solar cells will be able to profit from the developments in the micro-electronics industry, in an analogous way as silicon solar cells have benefited from the semiconductor industry in the past decades. These developments will also lead to an increase in the number of competitors active in R&D on these types of solar cells. Some industries have already expressed their interest in dye-sensitised solar cells to ECN, a.o. Konarka (US), STI (AU), GE (US) and several Japanese companies.

ECN has focused its PV research on two developments: (multi)crystalline silicon and thin films. Grid-connected systems based on multi-crystalline silicon modules could in 5 years time be 50% cheaper than the currently available systems (3Wp in 2008). In the long term, systems based on thin-film solar cells may become cheaper than silicon-based systems.

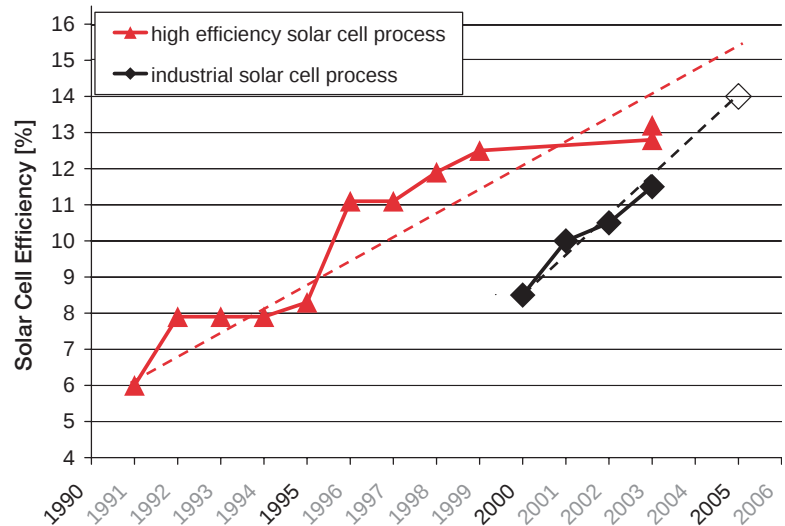
Grid-connected PV systems based on multicrystalline silicon

ECN has made an important contribution to the strong progress made in the development of a new process for solar grade silicon. The solar cell efficiency obtained with this silicon feedstock approaches 90% of that achieved with conventional feedstock. Furthermore, we have obtained a better understanding of the possibilities to improve the material quality in solar cell processing. We have shown how iron-impurities in the silicon can be made electrically “invisible”, leading to an effectively purer material, with which a higher cell efficiency can be achieved.

To reduce the amount of silicon consumed per unit of installed solar power, the substrates (silicon wafers) can be directly cast into the appropriate thickness, instead of being sawn from a crystallised ingot. The so-called Ribbon-Growth-on-Substrate (RGS) process is currently tested at ECN on a laboratory-scale. In order to achieve high cell efficiencies, the amount of impurities and the number of crystal defects in the substrate should be low. During the past year, important improvements have been obtained regarding these issues. On a limited number of wafers the concentrations of oxygen and carbon have been sufficiently reduced to allow 14% efficient cells to be made from RGS material. In other substrates the number of crystal defects was strongly reduced. These improvements have not yet been achieved integrated into a single wafer, however.

In the past year, ECN has achieved a new record cell efficiency. On a cell with an area of $12.5 \times 12.5 \text{ cm}^2$ (with a common single-layer anti-reflective coating) an efficiency of 16.3% was obtained. This is 0.5% (absolute) higher than the record efficiency obtained in 2002 on a $10 \times 10 \text{ cm}^2$ cell. With this cell performance, we are now at the same level as our main competitors, but with a very simple process, and we achieve much higher efficiencies than in the PV industry. For the first time at ECN we also succeeded in making good cells on monocrystalline wafers with a maximum efficiency of 16.8%, whereas one year ago we could not exceed the 15% level.

A module has been made in which the interconnection of the cells and the encapsulation were completed in a single process step. This process concerns the so-called Pin-Up Module, which contains 36 cells of $15 \times 15 \text{ cm}^2$ of a thickness of (only) $280 \mu\text{m}$ ($50 \mu\text{m}$ less than conventional silicon solar cells). The interconnection

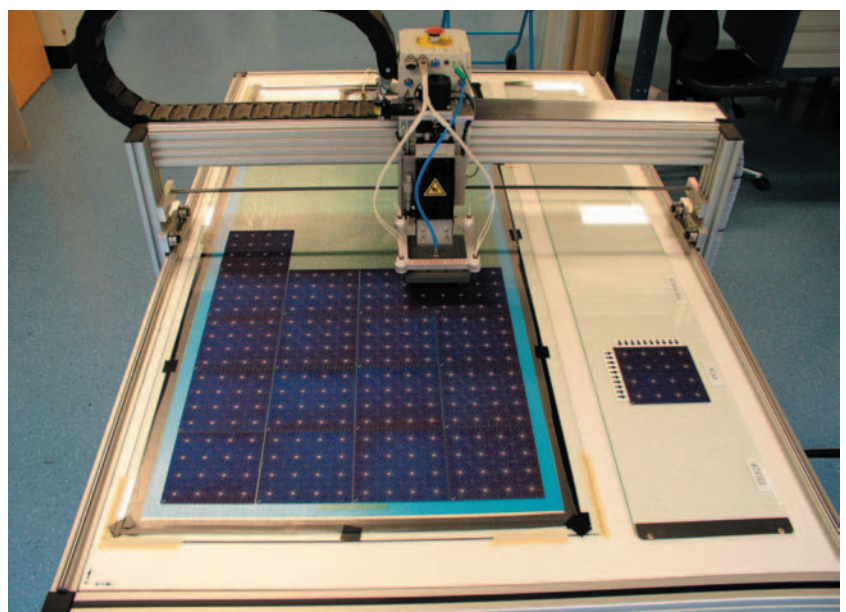


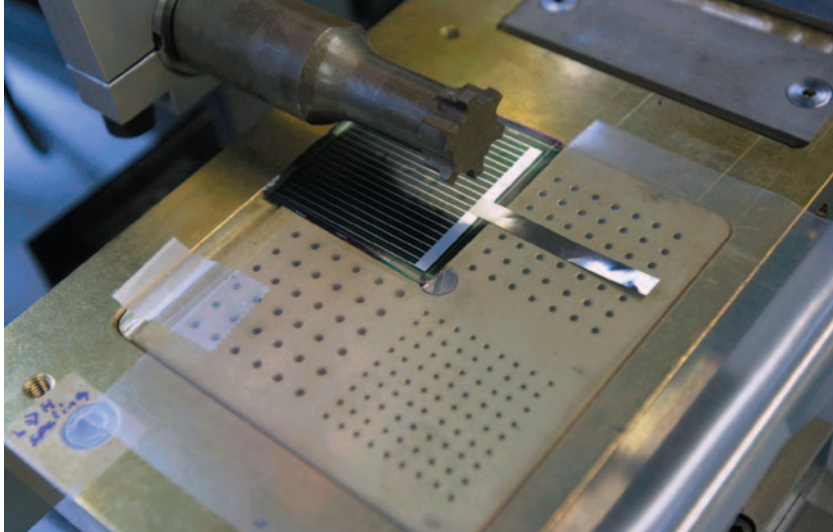
is applied at the rear of the cells, using a patterned foil and a conductive adhesive. The curing of the adhesive is performed concurrently with the encapsulation/lamination. Under standard measuring conditions, the power of this module is 116 Wp, which corresponds to an encapsulated cell efficiency of 14.3%. The encapsulated cell efficiency of the best of the two strings of 18 cells is 14.7%.

The integration of PV systems in buildings and the connection to the electricity grid have been addressed in a previous chapter.

The solar cell efficiency obtained with RGS material since the early development of the process by Bayer. ECN is producing this material since 2000. Since then an absolute increase in the efficiency of 3% has been realised.

Electrical interconnections are applied at the rear of the cells, using a patterned foil and a conductive adhesive during the fabrication of the Pin Up Module.





Ultra sonic welding device for electrical connection of very fragile thin film foils such as copper-indium-sulfur (CIS). This process is done at room temperature without the use of chemicals.

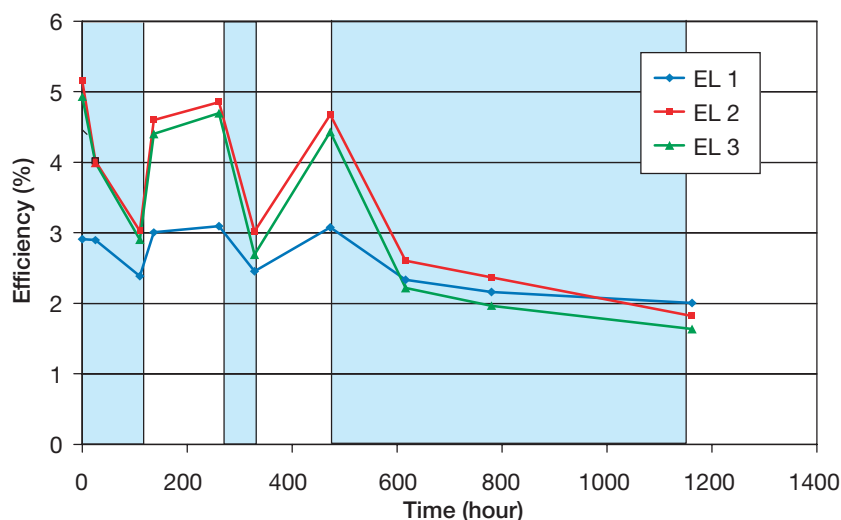
Thin-film solar cells

The development of thin-film solar cells is focused on the medium to long term. ECN concentrates its research efforts on two technologies for the medium term (thin film silicon and sensitised oxide solar cells) and one for the long term (polymer solar cells). These technologies are developed in close collaboration with fellow research institutes in the Netherlands and other European countries and with the Dutch Polymer Institute.

For the manufacturing of thin-film microcrystalline silicon solar cells a new deposition technique is under development, based on microwave-plasma CVD (chemical vapor deposition). Important electrical and physical parameters of the silicon material have already satisfied the strict requirements for high-quality solar cells. The possibility for continuous deposition on moving substrates, the achieved high deposition rate and the good homogeneity of the deposited layer make this CVD-process an attractive candidate for application in industry.

Figure 3.3.1: Efficiency decrease of DSC in the dark at 85°C followed by recovery under illumination at 1 sun, 45°C. Three different electrolyte compositions were tested (EC1-3). No further illumination after 473 h.

There is a lot of interest in flexible, lightweight solar cells that can be manufactured in a roll-to-roll process. In a NEO project (Novem) ECN is investigating how such mechanically fragile and temperature-sensitive flexible cells can be series-connected without inflicting any damage. It has been demonstrated that small magnets can be used to electrically connect conductive solar foils (substrate of e.g. silver, aluminum or copper foil) without causing any thermal, mechanical or chemical stress. The contact resistances are very low over a large



temperature range of -198°C to $+200^{\circ}\text{C}$. ECN has applied for a patent on this invention.

We observed a decrease in the efficiency of dye sensitised solar cells (DSC) after exposure to high temperature (85°C) in the dark. However, when the cells are subsequently exposed to light at a lower temperature (45°C), the cells recover and almost reach their original level of performance (see fig. 3.3.1). The reason for this remarkable behavior is still unknown. In general, dye cell stability at very high temperature depends on the electrolyte composition, as can be seen in Figure 3.3.1. In addition, other factors such as materials purity and the type of dye will also influence cell stability. The experiments will be continued, and will include the testing of a very promising new, hydrophobic dye developed by our Swiss research partner EPFL.

The most realistic stability tests for solar cells are of course outdoor tests. ECN Solar Energy has the required infrastructure to perform such tests. An important prerequisite is that the so-called extrinsic stability of the dye cell is good (depends on the quality of the seal of the cells). The durability of the cells with respect to water and UV radiation of cells sealed with Bynel (a polymer) has fortunately improved tremendously in the last year; samples can be submerged in water for months without any delamination. Due to the improved sealing of the cells, it is now possible to perform truly meaningful outdoor tests.

An important milestone has been achieved with regard to the stability of organic solar cells made from a polymer and a fullerene (relatively large spherical carbon molecules): a decrease in cell efficiency of only 20% after 1000 hours of continuous illumination with 1 Sun at 70°C (!) in an inert atmosphere. This result indicates that polymer solar cells have a much better photochemical stability than assumed thus far, as long as the cells are well sealed to prevent ingress of a.o. water vapor and oxygen. Also the very impressive cell efficiency recently announced by Siemens ($\sim 5\%$, an increase with 1.5-2% absolute within one year) shows that 2003 has been an excellent year for organic solar cells. There is still a long way to go, but the progress achieved is impressive and the perspective is excellent.

Wind power is a clean form of energy, with no emissions of CO₂ or other harmful substances, which could make a substantial contribution to a sustainable energy supply. It also has enormous potential and could supply a significant part of our electricity needs, especially from offshore sites and wind farms in remote areas, making it one of the best options for replacing fossil fuels. The wind power sector has now developed into an industry in its own right: according to the American Wind Energy Association (AWEA) and the European Wind Energy Association (EWEA) total wind power capacity in the world rose by 8,133 MW in 2003 to 39,300 MW. The new wind farms in 2003 represented an investment of around 6.6 billion euros, a rise of about 1 billion on 2002. The growth rate is particularly spectacular in Europe at 35% per annum, the highest in the world.

Research is one of the foundations upon which capacity can continue to grow, and ECN has been doing research in this field since 1976. Two large experimental facilities were completed in 2003. A test farm for wind turbines and a test lab for wind turbine blades and materials were set up in collaboration with Delft University of Technology. ECN's wind power research was divided into three clusters in 2003. The first cluster is concerned with the design of wind farms, in partnership with developers and others. The second cluster deals with the operation and maintenance of wind farms, involving owners and operators. The third cluster covers wind turbine technology in the broad sense, in partnership with e.g. manufacturers of wind turbines and its components.

A major event in 2003 was the creation of the European Academy for Wind Energy (EAWE), a partnership for long-term research and education in the wind power sector. On 17 October 2003 ECN signed an agreement with its partners in the Academy, these being the research institutes of ISET in Germany, Risø in Denmark and CRES in Greece and a number of universities in those countries. The Dutch network partners are ECN and Delft University of Technology. With this project the institutes aim to raise long-term research and education in the field of wind power to a higher level. The EAWE network is to be expanded in 2004 with the addition of institutes and universities in other European countries.

Test farm

A NEG-Micon wind turbine was installed on the ECN wind turbine test farm at Wieringermeer (EWTW) at the beginning of 2003. With 2.75 MW of power and a rotor diameter of 92 metres this is the largest wind turbine in the Netherlands to date. It has been developed and tested as part of the Economy, Ecology, Techno-

logy programme's DOWEC project to develop a large offshore turbine. Thirty-six of these turbines are to be installed off the coast of Egmond aan Zee on the Near Shore wind farm of Noordzeewind, the Shell-Nuon consortium, in 2005.

WMC

Another important facility that has come into operation is the test lab for research on materials and wind turbine blades. This is run by the Wind Turbine Materials and Constructions (WMC) knowledge centre, a non-profit organisation set up by ECN and Delft University of Technology. The lab is in the Wieringermeer water park, a new offshore site in the IJsselmeer, about four kilometres from the wind turbine test farm. Wind turbine rotor blades can be ferried in by ship. The WMC is Europe's largest facility for the independent testing of rotor blades for large wind turbines, which are subjected to precise external stresses and deflections. The stresses are applied using hydraulic cylinders. Blades of up to sixty metres in length can be tested for fatigue behaviour and strength in the testing hall. Materials research is also being conducted. The first experiments began in the autumn.

Design of wind farms

In classic wind farm designs each turbine is set up so as to extract the maximum amount of energy from the wind individually. This approach does not produce maximum output from the farm as a whole. The new approach involves some turbines extracting less than the maximum amount of energy, allowing the others to produce more: this increases the overall output from the farm and decrease the stresses on the turbines—obviously an ideal combination. ECN has protected this invention with two patent applications (see inset). Current projects have been modified to take the new ideas into account: in the Large Offshore Farms project the design of a model wind turbine has been modified to enable Heat & Flux and Controlling Wind experiments to be carried out. The model turbines with a rotor diameter of 25 cm create a wake typical of 100 m diameter turbines. This modification is also conducive to the original aim of the project. Experiments on these model turbines have been conducted in TNO's wind tunnel in Apeldoorn: this was the first time that two model wind farms had been set up in a wind tunnel simultaneously to measure differences. The new ideas are being added to the Wind Farm II design package.

The running of wind farms

Inspection and servicing are essential if the cost of keeping a wind farm up and running over its entire useful life is to be minimized. Future offshore wind farms will be exposed to more extreme conditions and less accessible for maintenance. The challenge is to overcome





The first concept, known as Heat & Flux, makes turbines on the windward side of the farm more transparent to the wind, raising the wind speed in the wake. This decreases the output from the turbines on that side, but output on the leeward side increases more, as the turbines on this side have to cope with more wind but less turbulence and therefore reduced stresses. The result is that the farm as a whole produces more wind power with lower stresses. Wind tunnel experiments have since confirmed the principle. The second concept, known as Controlling Wind, involves setting up the turbines on a farm in such a way that together they create large-scale circulations, which systematically drive out wakes and draw fast undisturbed air in from a greater height. A wind farm is expected to produce five percent more power if both principles are employed at the same time.

these problems economically. One way is to service components only when they require it. ECN has therefore been putting a lot of effort into finding ways of monitoring the condition of offshore turbines in recent years and it is developing a maintenance strategy based on this. The ultimate aim is to develop an approach that helps the wind farm operator to make the most cost-effective choices as regards day-to-day running. Major progress was made in 2003 with the development of a system to monitor the condition of rotor blades. In the Fibre Optic Blade Monitoring research project, which is being carried out jointly with Fibre Optic Systems (FOS) in France and the WMC, ECN devised algorithms in 2003 which enable rotor blade degradation to be identified at an early stage, based on strain and stress measurements. Laboratory experiments using Wireless

LAN instead of slip rings to transmit data (thus avoiding the problem of transmitting data from the rotating hub to the nacelle) have proved successful. Experiments to see how the system works in turbines are to take place in 2004. The first phase of developing a detection system for bird collisions (WTBird) was completed last year, and initial tests involving simulated collisions show that it works well.

As part of the Connect6000 project ECN and KEMA made recommendations to the Ministry of Economic Affairs and Novem on the offshore electrical infrastructure needed to achieve the government's aspiration of having a total offshore wind power capacity of 6,000 MWe by 2020.



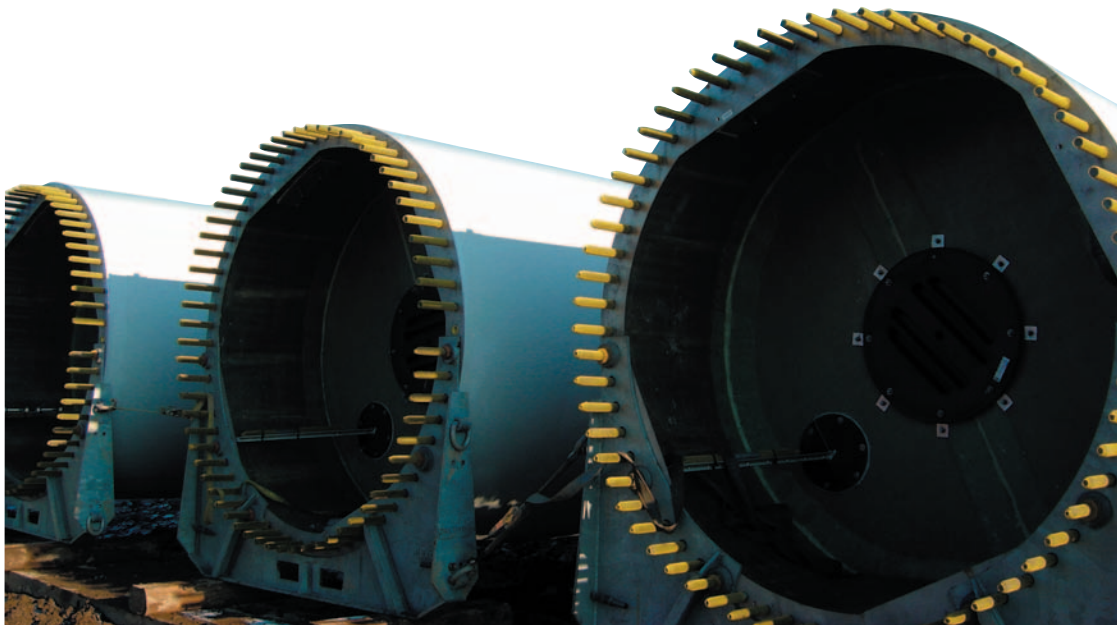
Additional strengthening for the foundations of the WMC complex.

Wind turbine technology

With the sharp rise in the size and investment cost of wind turbines it is increasingly important to reduce design uncertainties and at the same time find ways of reducing stresses on turbines. Lower uncertainty translates into better reliability (less maintenance and fewer shutdowns), smaller safety factors and ultimately lower-cost power production. This requires knowledge of aerodynamics, structural dynamics and control technology. Aerodynamics determines the external stresses on the turbine, and structural dynamics determines how these are translated into internal material stresses. Smart control systems can be used to adapt the turbine configuration to the prevailing conditions so as to increase output and/or reduce stresses. The knowledge developed in these areas is incorporated in the design software, which is used to assist the design process and is needed to compute stresses for wind turbine certification. This ECN cluster serves both the Dutch industry and part of the international industry. Work continued last year on characterising the stability of the inevitable system vibrations. We demonstrated how details of the blade structure, which determine the nature of the vibration, can be used to improve vibration damping using aerodynamic forces. The aerodynamic model for computing forces was also brought up to date, and part of this, a 'free eddy wake' method, was completed. Another milestone was the completion of Control Tool 1, a design tool for advanced wind turbine control systems, which has attracted a lot of interest from the international wind industry.



Test system in wind tunnel shows wake effect of wind farms.



Rotors for the Nordex wind turbines ready for installation on the EWTW.

Biomass is defined as any organic matter that is not of fossil origin, examples being wood, manure, plant remains and organic materials produced as a by-product in the food industry. The waste material we produce every day in our homes thus contains a large proportion of material referred to as biomass. Biomass has taken up the carbon it needed to form from the biosphere, so converting it into energy in such a way that the carbon returns to CO₂ makes no net contribution to the greenhouse effect. Because of this, biomass is a commodity that can be regarded as sustainable when used to produce energy. To enable it to be used as cleanly, efficiently and safely as possible, ECN's Biomass programme unit is researching and developing a number of applications that will be of great importance to future energy supplies, not only here in the Netherlands but also in the neighbouring European Union countries. With this aim in mind ECN has divided up its biomass research into three areas: combined heat and power, power generation, and products and fuels. All three applications are based on a spectrum of advanced technologies, with gasification playing a major role. We are looking into biomass pre-treatment, gas scrubbing, the actual gasification or combustion process, ash behaviour and the synthesis of synthetic products such as synthetic natural gas and transport fuels. The unit recently joined a Network of Excellence on the subject of Bio-energy involving seven leading research institutes in Europe under the auspices of the EU's Sixth Framework Programme.

Total energy applications

In order to enable biomass to be used in systems that supply combined heat and power ECN is developing a fluid bed system that gasifies the biomass into a combustible gas which can be used as fuel for a gas engine or

The patented OLGA gas scrubbing system.



gas turbine, and in future even for a fuel cell. The resulting fuel gas needs to be intensively cleaned to make it suitable for this purpose. Meanwhile the gasifier will be used with limited gas scrubbing to supply fuel gas for a heating boiler: the engineering company of HoSt is to supply in Romania the first 5 MWth system, and a second one (a chicken manure gasifier for Friesland) is in preparation. The principal contaminant in the gas from a biomass gasifier – fuel gas – is tar, which is a by-product of gasification. It is not only harmful to health, it also has a tendency to condense and cause blockages as the gas cools. It has a high calorific value, however, so when burned in a boiler it contributes to the full value. For more advanced applications such as combined heat and power these tars need to be removed from the fuel gas, and hitherto this has been the biggest problem with gasification technology. ECN has now developed a patented gas scrubbing technology in collaboration with the Dahlman Industrial Group in Maassluis, called OLGA (oil-gas-water), which is able to remove these tars. Last year saw a milestone with the construction of a test system on the ECN site, which is designed to prove that the laboratory scrubbing process also works on a pilot scale. This system, for deep-cleaning fuel gas, is to be connected to the gasifier on the ECN site in 2004. We shall also be looking into the possibility of feeding the tars removed from the fuel gas back into the gasifier and converting them into clean fuel gas so as to maximise the output of gas from biomass. With the fuel gas scrubbing process as described we are in effect taking it for granted that tars are formed which subsequently have to be removed. It would be better to integrate the gasification process with tar removal or suppress tar formation, and it is with this in mind that the TREC (Tar REDuction with Char) principle has been developed. Here the still hot carbon formed during the gasification process is used to break down the tar. The principle was demonstrated in 2003 and is now to be developed in a European joint venture.

Power generation

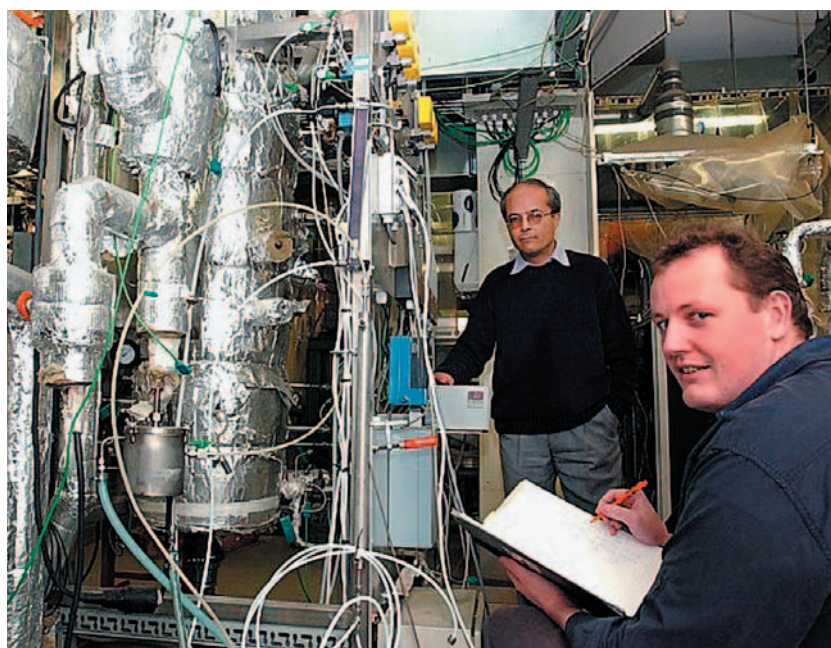
To enable electricity to be produced from biomass ECN is developing technologies for burning it as a supplementary fuel in existing coal and natural gas-fired power stations. This is generally a question of adapting existing technologies for this purpose and overcoming the technical problems involved. The aim is to allow coal-fired power stations to burn 15-20% biomass (in terms of energy). This would enable the Netherlands to reduce CO₂ emissions by 3.3-4.5 Mtonne per annum. Work is also being done on optimising fuelling techniques, e.g. by putting a biomass gasifier at the front of the chain, so that the gas produced can be used as fuel in an existing coal or gas-fired power station. Last year a number of cheap technologies were developed for pre-

testing the suitability of various types of biomass for use as a supplementary fuel in coal-fired power stations, the quality of the fly ash has to be such that it can be reused, and the grate or hearth and the heat exchangers in the boiler are not contaminated. A start has also been made in a European context on identifying the effect of using biomass as a supplementary fuel on emissions of fine particles and heavy metals. As regards the option of including a biomass gasifier at the front of the chain, research at ECN has yielded more information on two major problems, (a) contamination and blockage of the gas cooler between the gasifier and the boiler and (b) impeded flow behaviour in the gasifier due to agglomeration. Based on this information, measures have been developed to bring these problems under control. There is increasing interest in torrefaction, a technique for pre-treating biomass by making it brittle: this makes it easier to grind and feed to a gasifier or burner in powder form, as well as making it hydrophobic (water-repellent), which facilitates transport and temporary storage. ECN is developing this pre-treatment technology for various specific applications in collaboration with a number of industrial partners. Smart combinations of treatments are also used in the development of MISO (Multiple-Input Specific-Output) concepts: these are ways of converting mixed biomass flows of different origins and with different properties into a small number of fuels with well-defined properties.

Fuels and products

Gasification of biomass and deep gas cleaning produces a clean synthetic gas that can in turn be converted into gaseous energy carriers, transport fuels or other 'products', possibly combined with heat or power production. Unlike in the production of fuel gas by gasification, here air cannot be used as the gasification medium, and steps have to be taken to ensure that no nitrogen gets into the gas. In this way biomass can help to make the existing and future energy infrastructure more sustainable. The obstacles at present are the cost of biomass and the need to adapt the technological chain, which is still giving rise to problems and uncertainties. Last year we demonstrated that synthetic 'green' natural gas (Substitute Natural Gas or SNG) can be produced from biomass using gasification: following this successful test ECN has decided to develop the technology, and support in Dutch industry for producing green natural gas is growing. ECN is currently preparing to expand the testing facilities, e.g. by adding a bench-scale gasifier, which can be used either as an oxygen-blown fluid bed gasifier, a steam-blown or an indirect gasifier, enabling the whole process of biomass pre-treatment up to SNG production to be tested in practical conditions. A consortium is to be set up to develop this technology in 2004. A relatively new element in ECN's biomass research is developing biorefining

technologies, which involve micro-organisms such as algae and bacteria making useful products from biomass. A strategic plan is to be drawn up in 2004 which will serve as the basis for a medium-term research and development plan. ECN intends to implement the plan in collaboration with Agrotechnology and Food Innovations BV in Wageningen and some other companies and universities.



Hamid Mozaffarian and Robin Zwart at the 'Green Gas' production plant.

3.4 Clean and Efficient Fossil Fuels

Fossil fuels i.e. natural gas, coal and oil, will continue to become scarcer in years to come. Nevertheless, until such time that their availability becomes severely limited, fossil fuels will remain a major source of energy. The use of fossil fuels leads to environmental problems, ranging from climate change and global warming to acid rain, over-fertilisation and even deterioration of human health. In order to relieve the environment and to use these declining fossil fuel resources in a more economic manner, it is necessary to provide technologies that facilitate their clean and efficient use. The programme unit Clean Fossil Fuels develops concepts and technologies for a cleaner and more efficient use of fossil fuels. Research into fuel cells is a direct consequence of these objectives, and has been clustered into the separate programme unit Fuel Cell Technologies since 2003.

Clean Fossil Fuels

Combustion of fossil fuels is detrimental to the environment. This is not only a result of the formation of greenhouse gases, but also due to the emission of aerosols. Additional emissions such as nitrogen oxides are acidic in character. This has harmful consequences on both nature and bio-diversity. Exposure to and presence of these pollutants in the environment represents a risk for humans, plants and animals. In order to take effective measures against such pollutants, it is important to characterise both their presence and effect, while developing technologies to reduce or even prevent their production. ECN Clean Fossil Fuels carries out such research and studies the costs and effectiveness of proposed measures in the clusters Emission Reduction and Energy and Environmental Quality. The cluster Climate Neutral Energy Carriers develops technologies for CO₂ separation, capture and storage.

Climate Neutral Energy Carriers

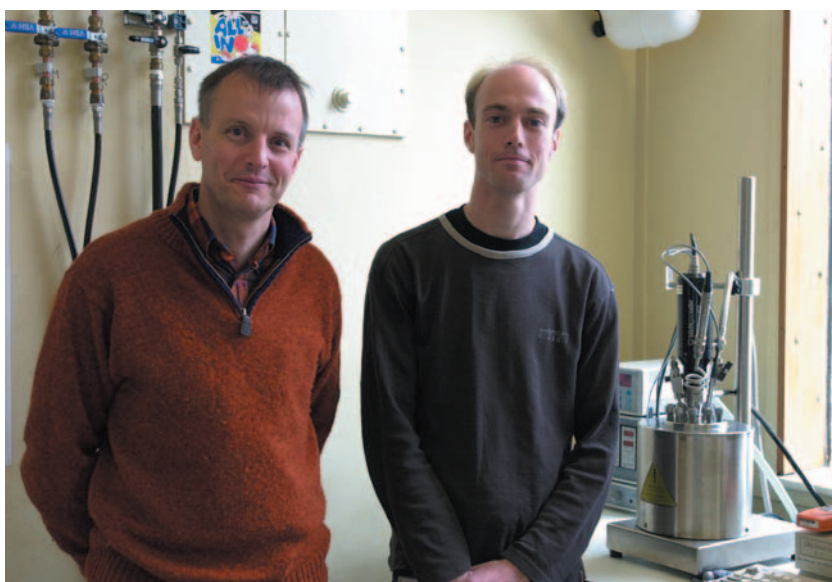
Electricity and hydrogen will become the most important energy carriers. They can be produced in a climate neutral manner from fossil fuels through the use of CO₂ separation, capture and storage. ECN is developing

such technologies for power generation systems and for hydrogen production systems. The aim is to reduce the additional energy consumption required to do this with at least 50%. An additional objective is to reduce the economic costs to less than euro 30 per tonne of CO₂ avoided. In next five years, these developments will be an integral part of the programme CO₂-capture, transport and storage (CATO). The programme is financially being supported by the Dutch Ministry of Economic Affairs (50%), through its agency SENTER, and by the participating firms and institutions (50%). In CATO, ECN is working together with TNO, the University of Utrecht, the World Wildlife Fund and industrial partners such as Shell and Gasunie.

Natural gas (methane) can be converted to a mixture of hydrogen and CO₂ in a process called reforming. In this past year a suitable sorbent has been found to extract the CO₂ from this mixture by adsorption. The nature of the chemical equilibrium of the reforming process results in increased methane conversion when CO₂ is removed from the mixture. This means that not only can the process be carried out effectively at lower temperatures, but also that the yields are significantly enhanced. When combined with a commercial catalyst for the reforming process, lab tests have shown that complete methane conversion can be achieved at 400°C as opposed to 800°C in a conventional reactor. Parallel to the investigation of reforming in combination with the adsorption of CO₂, reforming has also been investigated in palladium membrane reactors. Here, hydrogen is separated from the mixture, leaving pure CO₂.

A second possibility for efficient CO₂ capture is nitrogen-free conversion of natural gas in a solid oxide fuel cell (SOFC). SOFC's intrinsically separate oxygen and nitrogen whilst producing power. Thus in a SOFC, only oxygen from the air is exposed to the fuel, while nitrogen, that would otherwise be unfavourable to the storage of pure CO₂, is prevented from coming into contact with it. Since this type of fuel cell cannot achieve complete fuel conversion, the remaining fuel still

Rob Comans, group leader of Environmental Risk Assessments supervises PhD student Wouter Huijgens in his research into mineral CO₂ sequestration.



needs to be combusted in a nitrogen-free atmosphere. This, for instance, can be achieved with Oxygen Conducting Membranes (OCM). In a combined SOFC-OCM system, the fuel can be totally converted into a mixture of steam and CO_2 . After condensation of the steam, practically pure CO_2 remains. An alternative to the OCM is to use the water-gas shift reaction to convert any remaining fuel to hydrogen and CO_2 . The hydrogen can be separated by a palladium membrane, after which pure CO_2 remains. Both OCM and palladium membranes are being developed at ECN.

As part of a PhD research, the possibilities of mineral sequestration of CO_2 in solid industrial wastes are investigated. Examples of such solid wastes are residues of fossil fuel combustion (coal fly ash) and Municipal Solid Waste. These materials contain significant amounts of calcium, which makes them apt for binding CO_2 in the form of carbonates. These carbonated materials are then suitable for use in construction materials. Lab experiments involving the binding of CO_2 to steel slag have produced promising results. It is estimated that in the Netherlands 200 kton CO_2 per annum could be sequestered in solid waste materials. Leaching experiments are being performed to assess whether this product also complies with the environmental standards.

Emission Reduction

Besides CO_2 , other pollutants result from the use of fossil fuels. Aerosols, various nitrogen oxides (including laughing gas) and methane can also be emitted. The cluster Emission Reduction develops technologies to reduce or eliminate the emission of these harmful gases.

Aerosols are fine liquid and solid particulates, such as the small carbon particles that are present in the exhaust of diesel engines. Such particulates contribute towards smog formation and have a negative influence on human health. Several years ago, ECN invented a method for measuring aerosols, that has in turn led to the development of a particulate capture technology called the Steam Jet Aerosol Collector (SJAC). The technique has been proven to work, and a prototype is being designed. The apparatus will capture coke particles from the exhausts of diesel motors that are used in river shipping. Various organisations with interests in shipping have shown this project a great deal of attention.

Nitrogen oxides that are present in the exhausts of large stationary gas engines are generally removed by catalytic reduction with ammonia. ECN is developing catalysts that, instead of ammonia, use the unconverted methane that is also present in the exhaust as a reducing agent. This has the additional benefit of reducing also the amount of methane in the exhaust. This is an important advantage, because methane is a 21-times stronger greenhouse gas than CO_2 . Besides, there is also an economic benefit, as no equipment for ammonia



The iron-zeolite catalyst for N_2O decomposition developed by ECN.

dosage is needed. During the first industrial test, the catalyst turned out to be less efficient than expected on basis of the laboratory experiments. However, there is still a large potential for increasing the stability of the catalysts under these conditions.

Laughing gas (N_2O), a strong greenhouse gas, is released in large quantities during the production of nitric acid. In the Netherlands, 19 kt N_2O is released annually, which is equivalent to same global warming potential as 6.5 Mt CO_2 . ECN is developing catalysts that can decompose N_2O into nitrogen and oxygen. These materials represent an extremely cost-effective method for reducing the emission of greenhouse gases. Lab tests have shown the effectiveness of this technology, with more than ninety percent of the N_2O being decomposed by a catalyst that remained stable for at least 500 hours. In association with Dutch nitric acid plants owners, industrial tests are being prepared.

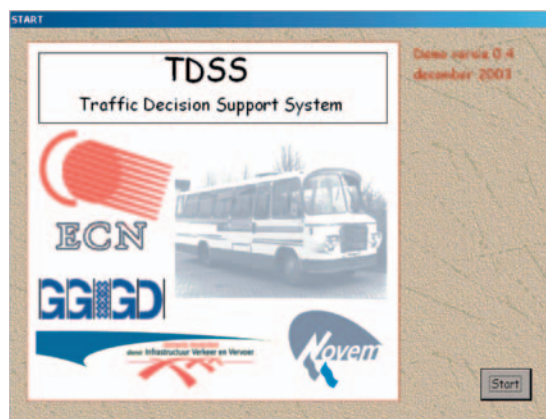
Energy and Environmental Quality

ECN researches the environmental impact of fossil fuels within the cluster Energy and Environmental Quality. The influence on the environment of the production, distribution and conversion of various energy carriers is being evaluated for the Netherlands Ministry of Spatial Planning, Housing and the Environment (VROM). In particular, the relationship between aerosols, climate change and human health are being assessed. Furthermore, attention is being paid to the interaction between aerosols and gases with the atmosphere and biosphere, which are also known to have an influence on the greenhouse effect and acidification of the environment. Additionally, the release (leaching) and distribution of emissions from industrial wastes is studied, in particular those applications where industrial wastes could usefully be employed to reduce emissions.

Nitrogen oxides (NO_x) are the cause of several environmental problems, such as smog, acid rain, climate change and depletion of the ozone layer. International meetings are frequently organised on solving these complex problems. Following the 2nd Nitrogen conference last year in the US, the International Nitrogen Initiative (INI) was set up, in order to promote levels of nitrogen containing compounds in the soil, ground water and air suitable for sustainable levels of agriculture and energy production. ECN participates in both the scientific advice group and at the management level. As part of INI, a European Nitrogen Centre has been established in which ECN has the role of co-ordinator.

The influence that different emissions and pollutants have on one another increases the complexity of many environmental problems. The interaction between ammonia and secondary aerosols, which are mainly sulphates and nitrates of ammonia, has been studied within the European network NEPAP (Network for the support of European Policies on Air Pollution). Decreasing the emission of ammonia has a greater effect on decreasing the emission of aerosols than in the situation where only nitrogen oxides and sulphur dioxide emissions are tackled. This also has a pronounced effect on the regional distribution of aerosols and particulates responsible for acidification. A number of models have been completed with which these environmental effect can be quantified, namely Decision Model for North Brabant DIAS, and the European Deposition Model EDACS.

In 2003, the role of ammonia in climate change was studied in the project 'Climate Change and Aerosols' financed by the Ministry of Economic Affairs (EZ). Within the framework of this project, ECN researcher Martijn Schaap obtained his PhD. He quantified and modelled the amount of nitrate aerosols in Europe. This expanded the insight into the cooling and with that the blanketing effect of aerosols on the radiation balance of the Earth. The modelling of different scenarios all lead to the conclusion that influence of nitrate aerosols will continue to increase.

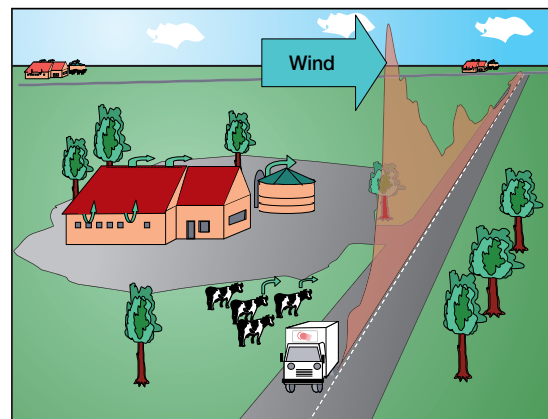


Traffic Decision Support System for using clean drive technologies in cities.

ECN has developed the Traffic Decision Support System (TDSS). The model can be used to quantify the environmental benefits of using clean drive train technologies in cities. The gain that can be achieved is expressed in terms of improvement in local air quality and the associated decline in illness and mortality rates. The parameters can be used to quantify the savings to be made in health provisions, which can also be weighed against the necessary investment costs. In consultation with the municipalities of Amsterdam, Groningen and Utrecht, four case studies have been defined and calculated. In three of the cases, the effect of cleaner public transport on air quality, health and the financial consequences thereof were calculated.

Within the framework of the European project GREENGRASS, emissions of greenhouse gases from cattle have been studied. Further, the effect of governmental policy on emission has been quantified. The emissions of methane, a strong greenhouse gas, were found to be much higher than expected. This has the consequence that the national emission of CO₂-equivalents is higher than has been supposed until now. However, this also has the consequence that there has been a substantial decrease in greenhouse gas emissions in the Netherlands since 1990 as a result of the rapidly declining livestock.

ORCHESTRA is a model that has been developed in order to determine the distribution of pollutants. Through it, an insight has been gained into the dynamics and multiplicity of materials that are dispersed via soil and water, also known as geochemical speciation. On the basis of data generated in the laboratory by commonly available analysis methods, it is possible to identify and graphically represent the components directly from a database. Not only does this decrease the time needed to perform such an analysis, but it also increases both the accessibility and applicability of such calculations in projects. This unique database and expert system developed by ECN represent a new and unchallenged industry standard.



Mobile measurements with "tunable laser diode" to determine the dispersion of methane from a farm.

At the moment, European guidelines are being prepared with respect to soil, purification waste and compost. These directives make reference to standards, but this is becoming increasingly complex and confusing as these different disciplines use different standards for the same parameter. The solution is to develop standards across the different disciplines, also known as horizontal standardisation. The European project HORIZONTAL, co-ordinated by ECN, is attempting to achieve this. The rejection of the usual per discipline vertical standardisation approach has had a profound effect on the standardisation world.

The current fossil fuel based energy supply system can be made more efficient and virtually non-polluting by the use of fuel cells. Hydrocarbon based fuel cell systems have zero or extremely low emissions of nitrogen oxides, aerosols, carbon monoxide, hydrocarbons and sulphur containing compounds. What remains is the emission of water and CO₂. The CO₂ emission will be gradually reduced to zero as soon H₂ from renewable energy sources such as wind, solar and biomass will replace fossil fuel derived hydrogen. Thus, fuel cells will aid to realise the transition to a renewable energy supply system.

Using fossil fuels such as natural gas requires that the fuel cell is combined with a reformer. A reformer converts hydrocarbons in H₂ and CO₂. Even small-scale onboard production of hydrogen from petrol in automotive applications is possible. Until the switch to the so-called hydrogen economy is made, this route offers benefits to the environment, to public health and in terms of the security of supply.

Since the beginning of 2003, all fuel cell related research at ECN is organised in the programme unit Fuel Cell Technology. The research covers the SOFC and PEMFC, as well as the development of the hydrogen production technology and systems required to match these fuel cells with hydrocarbon fuels. The research projects are clustered in accordance with the two major applications envisioned: micro and mini Combined Heat and Power (mCHP), and fuel cell vehicles. The SOFC, a fuel cell that operates at temperatures between 800°C and 1000°C, is typically being developed for stationary applications. The high operating temperature makes fuel preparation relatively simple, but limits the choice of construction materials. The PEMFC, currently operating close to 80°C, is in development both for stationary and mobile applications. Because of the low operating temperature, most of the components of the PEMFC can be cheaply manufactured, using low-cost materials. The disadvantage of the low operating temperature becomes apparent when the PEMFC is combined with a fuel processor for hydrocarbons. This type of fuel cell is very sensitive to impurities such as carbon monoxide. Therefore, fuel preparation is more complex for the PEMFC.

In 1999, ECN founded the subsidiary InDEC, which operates a pilot plant for the production of components for solid oxide fuel cells based on ECN technology. An important milestone in 2003 was the official transfer of the majority shareholding of InDEC to H.C. Starck, part of the Bayer Group. ECN is very content with its new partner, a company with much knowledge and experience in the manufacturing high-quality ceramic products.



A SOFC-cell is installed by BCT-employee Hans van Wees before testing.

In 2003, ECN strengthened its research infrastructure by the completion of a significant number of experimental facilities. The new infrastructure now comprises a complete fuel processor for testing of fuel cells and complete stacks in combination with reformate. The test rig is also suited for testing of individual fuel processor components on a scale equivalent to 50 kW of fuel cell power. The facility was partly financed by the Dutch ICES-KIS program.

Micro Combined Heat and Power

In the cluster Micro Combined Heat and Power, ECN cooperates with commercial partners to develop systems that deliver both the heat and electricity for an individual house. They can be considered to be central heating systems with a built-in power plant. The programme unit Fuel Cell Technology develops components for these systems, in the form of SOFC and PEMFC cells and stacks, and the technologies required for small-scale hydrogen production.

During the last few years, several parties have raised the expectation that micro combined heat and power systems using fuel cells would become commercially viable in the first half of the decade. This prospect has failed to become reality. The technology is not yet sufficiently mature, mainly because of a limited lifetime and too high cost. With respect to the latter, a substantial part of the costs is not actually related to the fuel cell itself. In small systems, the so-called Balance of Plant components represent a relatively large fraction of the total cost. Since these cost do not scale linearly

with system power, systems with an output power of 25 – 200 kW are good candidates to make an early market entry. ECN has enhanced its existing co-operating with commercial partners active in this market segment.

In households, heat and electricity are often not required at the same time. This asymmetric demand means that a household with a micro-CHP installed will often produce more electricity than needed at that particular moment. For the private owner feeding this electricity to the grid is not commercially attractive due to the existing system of tariffs. One possible solution is the temporary storage of the surplus in produced electricity, or for that matter, heat. It is also possible to optimise the system on the basis of electricity demand instead of heat demand. Improving the cost-effectiveness of micro-CHP systems has been the subject of studies during 2003. These studies will be continued in 2004.

Niche markets are important stepping-stones in the commercialisation of new technologies that in the beginning are too expensive to penetrate on a large scale. Addressing such markets is a legitimate way of progressing the technology, especially if the scale end processes involved to not differ much from what is needed for the ultimate application, being natural gas fed micro- and mini-CHP systems. For this reason, attention is also given to niche markets such as generators for yachts and electricity production at remote sites. Here, natural gas typically is not the fuel of choice. Therefore, ECN has now included LPG and propane reforming in its R&D programme.

SOFC

In the past year, ECN has optimised the production process for SOFC type fuel cells. The mechanical stability and strength of the fuel cells have been increased by a

factor three. At the same time, a cost reduction of 15 to 20% was realised. These improvements have enabled ECN to satisfy the product specifications of the market leader in complete SOFC micro-CHP systems.

Fuel Processing

Many of the materials that are used in fuel cells and natural gas reformers are sensitive to sulphur-containing compound tetrahydrothiophene (THT). In the Netherlands, THT is added to natural gas to serve as an odorant. In 2002, ECN discovered a material that is highly suitable for removing THT from natural gas. Outside the Netherlands, other odorants are used as well, and other gaseous fuels such as LPG are more commonly used for domestic applications. Varying mixtures of mercaptans and/or thiophenes are added to both LPG and natural gas. The feasibility of using the newly developed material for removing such other sulphur compounds has been investigated. As a result, the material was substantially improved over the last year. It is now capable of removing both mercaptans and thiophenes, from natural gas as well as LPG. The modifications have resulted in a patent application.

In the past, ECN developed a catalyst for the preferential oxidation of carbon monoxide in the presence of hydrogen. This catalyst formed a solid basis for co-operation with Shell. In 2003, ten reactors furnished with this catalyst were supplied to fuel processor manufacturer Hydrogen Source. The stability of the catalyst and reactor were demonstrated in a 1700-hour test. This enabled the company to produce and commission a 150 kW (electrical power) installation.

Panoramic view of the Fuel cell laboratory.



PEMFC

The past year has also seen the improvement of the resistance of PEMFC-anodes to carbon monoxide poisoning. The use of a so-called double layer electrode concept has limited the drop in cell potential that occurs when the cell is exposed to H_2/CO_2 mixtures, even to the point where several hundred ppms CO were introduced. Improvements have also been made in the area of stack technology by increasing the robustness of the stack. Several stacks have now been sold via the Dutch company NedStack.

Systems

The combination of a 2kW electrical power ECN PEMFC-stack with a Johnson Matthey fuel processor has provided much insight into the typical functioning of such a combination. Furthermore, a 10kW micro-CHP system has been designed for a Greek customer. The design is based on a combination of ECN stacks and third party steam reforming technology for use with bio-ethanol.

Fuel Cell Vehicles

In the cluster Fuel Cell Vehicles, ECN develops fuel cell and fuel processing technology for automotive applications. In order to bring substantial reduction in energy use and in the emissions of CO_2 , pollutants and noise, such technology is developed for the huge market of passenger vehicles, vans and trucks. However, as in the stationary application, niche markets are the place where the technology can be introduced at an earlier stage. Examples of such niche markets are special vehicles for use in urban areas and ships. For these markets, the availability of a fuel processor for low cost and commonly available fuels such as LPG or diesel is of great importance. Especially in view of the fact that



In Amsterdam there are since late 2003 three city buses driven by PEM-FC technology. This is part of the CUTE project. ECN investigated the options for the production of Hydrogen.

a widespread hydrogen infrastructure will only become available in conjunction with the large-scale introduction of the fuel cell car.

Fuel processor

Research on fuel processing is aimed at technologies for multiple fuels, such as diesel, petrol and bio-ethanol. Most of this research is carried out within EU-projects. The partners in these projects range from universities to industries including car manufacturers. Research work is also carried out in 1:1 contracts, e.g. for Shell. In these projects, ECN makes use of its vast infrastructure for testing reactors separately or as lined-up reactors.



A Fuel Processor test installation is taken into operation. This installation is able to convert fuels into Hydrogen on a 50 kWe scale. On the picture BCT-employee Wilko Planje.

Tests of several fuel processor configurations have demonstrated that for low sulphur ethanol and gasoline stable operation could be achieved. The resulting $H_2/CO_2/N_2$ -mixtures exhibited CO concentrations that were sufficiently low for direct use in a PEMFC.

Super Capacitors

Fuel cell vehicles in essence are electric vehicles. They require drive trains that are completely different from the current mechanical drive trains. The typical use of a car makes that the demand for electrical energy displays large fluctuations, occurring on a short time scale. The demand for power can even be reversed during regenerative braking, when reclaiming energy increases efficiency. Conventional batteries are not suited for this type of operation. Super capacitors however are perfectly fitted to both supply and store peaks in electrical energy. ECN is developing a new type of super capacitor based on an innovative and patented electrode material. Much knowledge had been generated about the relationship between the structural properties and the electrochemical performance of this material. ECN is now co-operating with a leading material manufacturer in order to develop an electrode production process that can be applied in an industrial process.

PEMFC

In the past few years, it has become increasingly apparent that the heat and water management of the current PEMFC introduces major problems on system level. The associated cost and loss in versatility of PEMFC systems may prove to be an obstacle in the widespread introduction of the PEMFC as a replacement of the internal combustion engine. To overcome these problems, a proton conducting material capable of operation at extremely low relative humidity and at temperatures of at least 100-120°C is needed. The higher operating temperature will ensure that the dissipation of heat will be

greatly simplified, that waste heat is more easily used, and that the sensitivity to CO will be reduced. The complete system can become more compact, cheaper and less complex. Raising the operation temperature in combination with a very low relative humidity requires the development of a completely new polymer. After a thorough evaluation of various potential development paths, a successful start has been made in preparing polymers from which new types of proton conducting membranes will be developed.

Systems

ECN is the co-ordinator of the EU-project FRESCO. In this project, an existing scooter from Piaggio will be converted to a fuel cell version. Packaging of all the fuel cell system components in the scooter required the design of a new stack. The new design has been tested on sub-stack level. Furthermore, the total system design and control strategy are completed.



Fuel processor installation for producing hydrogen from bioethanol on a 10 kW scale.

4. Technological Services and Consultancy

Technological Services and Consultancy (TS&C), ECN's technical support division, provides the high-quality technological support needed to carry out energy research at the highest level. This ranges from designing and building experimental systems to data processing, information transfer and materials classification. It also includes the building, fitting out and maintenance of complete laboratories with all the technical and other facilities required. In general terms the job of TS&C is to build up and maintain the knowledge and skills the research units need to fulfil their missions. Thanks to the broad range of supporting knowledge and skills it is able to provide a fast, efficient service. Operating at the interface between technology and science, TS&C is increasingly providing a 'nursery' for innovation. About a third of TS&C's projects are external contracts.

Wind turbine test farm

The process of supervising and coordinating the building of the ECN wind turbine test farm at Wieringermeer (EWTW) reached a high point with the installation of the first wind turbine in February 2003 (see *chapter 3*).

Neutron diffraction furnace

Last year a neutron diffraction furnace was developed (neutron diffraction is a technique for ascertaining the atomic structure of solids and analysing e.g. residual voltages). The furnace is needed for the analysis of advanced high-temperature composites, which have to be heated to 1,450°C for this purpose. The materials being analysed are contained in cylindrical samples with a diameter of 50mm and a length of 100mm. The furnace performed satisfactorily in the tests and requires less than 1 kW power.

A precondition was that the furnace should capture as few neutrons as possible, so it was decided to heat the cylindrical sample from the inside by irradiating it using a molybdenum heating element. In this way the heating element does not get in the way of the neutrons. To protect both the composite and the molybdenum heating element a vacuum is created in a quartz glass enclosure. Graphite radiation screens are used to achieve a homogeneous temperature and reduce power consumption and the temperature of the quartz. To prevent degradation of the molybdenum an 'oxygen collector' is used to remove the residual oxygen.

The OLGA system

Test systems were completed for the various research areas in 2003. The 'OLGA' and GasReip systems were installed for the biomass research: these remove tar and ammonia from the gas produced by gasifying biomass.

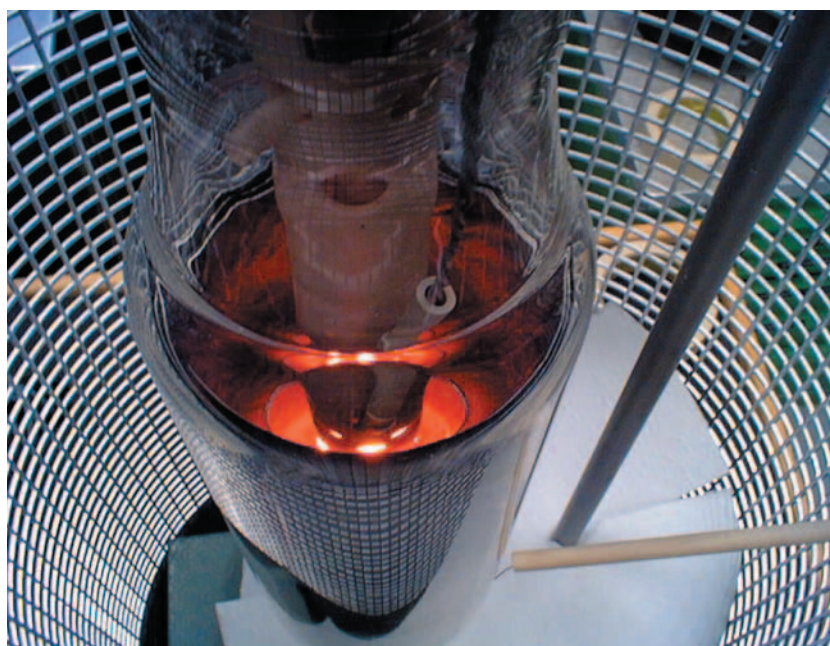
Electrical power converter for fuel cells

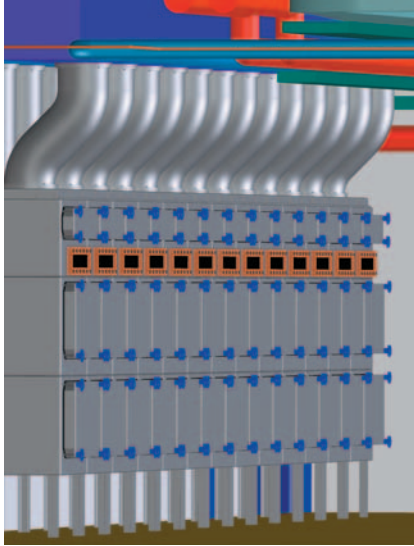
The electrical behaviour of fuel cells depends on the running conditions. Where fuel cells are used as a power source in vehicles this means that a control system is needed to optimise efficiency. Last year an electronic power converter was built that automatically adjusts the electrical load on the fuel cell to the voltage and current profile at the optimum working point. At the same time the converter adjusts the power to be transmitted e.g. to the electric motor within the permitted voltage tolerance. The converter needs to be highly efficient (over 95%) as well as compact, mechanically robust and cheap to produce, so it was decided to use a number of autotransformers. These are phase shifted in relation to one another, resulting in very low ripple currents and high efficiency. The power stored in the transformer is controlled on both the input and output side by a high-frequency circuit. This enables the optimum working point to be set and the 'power source' to supply a constant current or a constant voltage.

Molybdenum production

For the expansion of the NRG and Tyco Mallinckrodt's molybdenum production facility, the extraction and filtering system was modified to enable output to be doubled. Given the limited space the system, with the necessary pipework, was first tried out in a 3D model before it was built.

Furnace for the analysis of advanced high-temperature composites.





Exhaust- and filter installation.



SQL server. The experimenters can then analyse the data and display it graphically using a MATLAB application. An HTML interface has been developed for the application using the MATLAB webserver. A user can enter the input parameters on a web page and launch the computation, and the results can then be displayed on another web page. All the powerful functions of MATLAB's graphics can be used, enabling charts and other visualisations to be displayed.

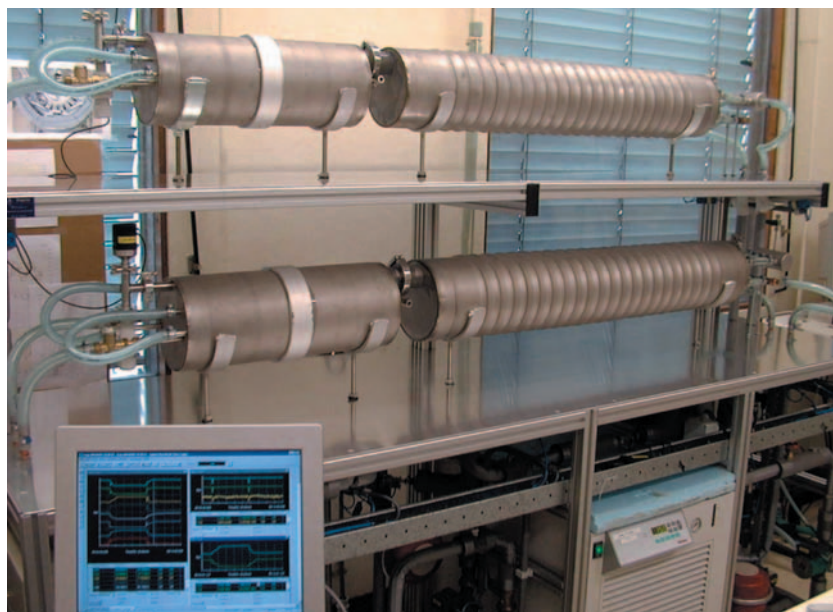
Thermochemical heat pump

A prototype SWEAT (Salt Water Energy Accumulation and Transformation) system was designed for the development of the thermochemical heat pump. The design, including the associated measuring system, was built. To improve performance a new evaporator was designed. As this is a salt water system, particular attention was paid to anti-corrosion measures in both design and implementation.

Monitoring system for HFR experiments

A measuring system was developed for NRG last year to monitor radiation experiments in the High Flux Reactor (HFR). This is an extension of DACOS, the HFR's current monitoring system. A link to a database was developed to enable DACOS monitoring data to be stored on the local network. Authorised users can access the data on the experiments via a link with the

Prototype SWEAT thermochemical heatpump.



5. Nuclear Technology

NRG celebrates its first five years

In 2003, NRG celebrated the first five years of its existence. NRG was established as a general partnership in 1998 by the Energy Research Centre of the Netherlands (ECN) and KEMA Nucleair bv. The partners ECN and KEMA hold 70% and 30% of the shares respectively. After a turbulent 2002 with some negative publicity regarding the supposed lack of safety culture at the High Flux Reactor (HFR), 2003 was characterised by working further on a healthy future. The Partners appointed a new general director to succeed the interim director. The new board of NRG is composed of a director and a general director.

Great efforts were made to further improve the safety culture in 2003. This resulted in a significant improvement, as recorded by the International Atomic Energy Agency (IAEA) in Vienna, among others. Constant attention to this aspect in the organisation continues to be of major importance.

It can be safely said that interest in the application of nuclear technology grew further in 2003. Both internationally and in the Netherlands, there is a growing belief that, now and in the future, nuclear energy will play a role in responsibly satisfying the worldwide growing demand for energy. In this respect, in addition to reducing the greenhouse effect, delivery assurance is an increasingly important theme.

High Flux Reactor

The High Flux Reactor in Petten is being exploited by NRG and is playing a major role in the research that NRG is conducting. Main areas are developing construction materials for new fission and fusion reactors as well as innovative fuels – both fields in which NRG enjoys a worldwide reputation.

Research into reducing the half-life of radioactive waste from hundreds of thousands of years to hundreds of years is an important social theme in striving towards sustainable nuclear energy.

It has been decided to change from using high-enriched uranium to low-enriched uranium as fuel for the HFR. An environmental impact assessment and a permit application were submitted to the relevant official bodies at the end of 2003. To make the organisation of the HFR more transparent, it was decided – partly on the advice of the IAEA – to transfer the new permit from the European Commission's Joint Research Centre, the owner of the HFR, to NRG. This means that both the operational management and exploitation of the reactor are in the hands of the permit holder. This simplifies and clarifies communication with the responsible government bodies. It is expected that the new permit will be granted in the second half of 2004 and transferred

Mission

As the leading Dutch knowledge centre for nuclear technology, NRG provides independent research, studies, consultation, information and services for government, business and private individuals. Prerequisites of these activities are the safe, ecologically responsible and peaceful application of nuclear technology. Expert personnel, high-quality knowledge, access to international networks and a complete nuclear infrastructure are at the service of our clients.



at the same time. Naturally, the European nature of the HFR will continue to exist in the future.

To safeguard the great importance of the installation in the long term, not just for research but also for healthcare in Europe, a project was started in 2003 to replace the reactor with a new irradiation facility at the end of its expected life in approximately the year 2015. In view of the European importance of this, the work will take place in an international context.



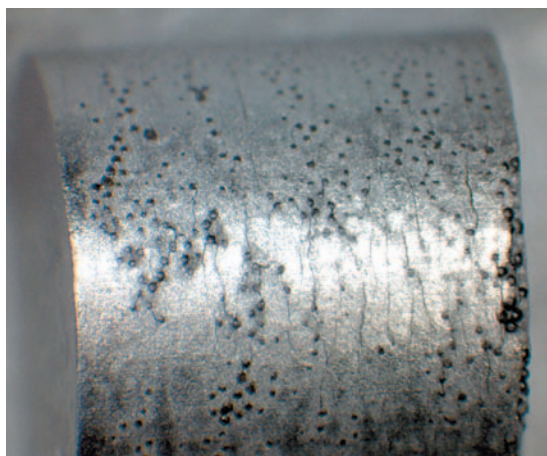
Here follow a few examples of NRG's activities in 2003.

New material for accelerated destruction of nuclear waste

An important environmental issue associated with the use of nuclear energy is the resulting radioactive waste. A socially acceptable solution for this has yet to be found. This concerns nuclear waste from burnt fuel rods that remain radioactive for a very long time – approximately 100,000 years.

In other words, a generally acceptable solution for the waste problem is a major determining factor in the future of nuclear energy.

The long-term environmental impact of nuclear energy can be reduced by selectively separating out the most radiotoxic and longest-living waste components and re-irradiating these with neutrons. This is known as transmutation. Fission converts the most radiotoxic nuclides into more short-lived or stable isotopes. Developing an innovative fuel to transmute nuclear waste efficiently is a major challenge in which various physical aspects play an important role. At NRG, extensive research is being conducted into these nuclear physics and materials science factors. These are achieving symbiosis in the irradiation tests in the High Flux Reactor where the transmutation of nuclear waste is tested in practice. The high materials science requirements set for the nuclear fuel, such as good radiation resistance, high melting point and good heat conduction, are essential. In addition to this, it is important to the design of such experiments that no 'problem nuclides' are formed during transmutation.



The photo shows a cermet, ceramic microspheres embedded in a metallic molybdenum matrix. Following completion of the test phase, where the microspheres are free of radioactive material, it will be possible to load the matrix with plutonium containing microspheres. After manufacturing in NRG's actinides laboratory, these pellets will be sintered at a temperature of 1650° C for 5 hours. The diameter of a pellet is 8.0 mm and its height is 6.5 mm.

The packaging in which the nuclides to be transmuted are embedded must therefore be free of uranium or, in more general terms, inert. This means using compounds of aluminium, silicon and magnesium oxides or zirconium oxide.

In 2003, research was begun into another, innovative type of fuel for transmutation. The matrix of this fuel consists of the metal molybdenum. Metals not only have great compression and tensile strength but also intrinsically high heat conductivity. This contrasts with most ceramic materials that are bad heat conductors. Because of this, the heat released during transmutation can be quickly discharged so that the temperature of the fuel remains relatively low, which is beneficial to safety. Initial experiments have shown that composites with a molybdenum matrix have favourable manufacturing properties, enabling a load of up to roughly 40 volume percent of plutonium. This is considerably higher than can be achieved with the usual recycling mixtures of uranium and plutonium oxide. Moreover, because this innovative fuel is uranium-free, no new plutonium is formed. This makes it possible to achieve an efficient destruction of long-living components in nuclear waste.

Reactor systems for the future

NRG occupies a leading position in developing gas-cooled, high-temperature reactors in both the analytical and experimental fields. In 2003, this type of research was embedded in the international 'Generation IV' programme in which the Netherlands took part via the European Commission. Of the six nuclear systems selected in this programme, the High Temperature Reactor (HTR) has the highest priority. To enable more



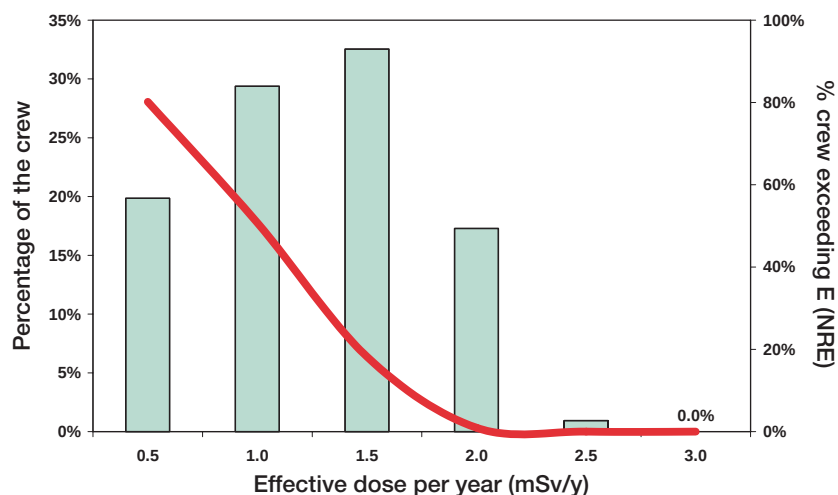
Preparing the manufacture of inert matrices for the test phase of transmutation of nuclear waste components.

efficient use of the fissionable material in the HTR and its associated reduction in the amount of waste, NRG has developed a concept for what is known as Deep Burn operation. In this, apart from the usual fuel pellets of low-enriched uranium, the reactor is also loaded with fuel consisting of self-produced long-lived transuranics (plutonium, americium, neptunium and curium). The results turned out to exceed all expectations: physics calculations predict that the reactor intended for power generation, i.e. a special 'burner' reactor, three quarters of the transuranics produced can be burned up. The 'life' of the waste can also be significantly reduced: the period in which the nuclear fission waste is more radioactive than the ore from which the original uranium was extracted can be shortened by half.

For the permit procedure for the demonstration unit of the so-called Pebble Bed Modular Reactor (PBMR) to be built in South Africa, the calculation carried out by the South African company PBMR (Pty) Ltd. must be backed up by calculations carried out by an independent party using other computer codes. For this, NRG focussed in 2003 on the verification and validation of the thermal hydraulic analyses carried out. In addition, NRG was commissioned to develop and test a simulation model for the PBMR 400 MWth design. Work has started on developing the simulation models for the main components of the system and, based on these results, an integrated simulation model for the PBMR installation will be put together and tested. The thermal hydraulic safety analyses for the PBMR system will be carried out by PBMR (Pty) Ltd. in co-operation with the South African University of Potchefstroom. The licensing authority granting the permit attaches high priority to the validation and verification of the software used. In view of the fact that little experimental data are available for testing the software, comparing the simulation results with the results of other codes developed and applied fully independently is an important activity in the validation process of the PBMR safety analyses. The analyses that NRG is carrying out at the moment with the SPECTRA code will be included as supporting evidence for the safety analyses carried out by PBMR (Pty) Ltd. in the new version of the PBMR Safety Report.

Aircraft crew radiation doses

In the Euratom basic safety standards, it states that 'each member state shall make arrangements for undertakings operating aircraft to take account of exposure to cosmic radiation of air crew who are likely to be subject to exposure to more than 1 mSv per year'. With the introduction of the Radiation Protection Decree, this obligation has also been implemented in Dutch legislation. On behalf of the government, NRG administers the National Dose Registration and Information System (NDRIS). This records and monitors the radiation doses of all radiological workers, such as workers in nuclear reactors, laboratories, hospital personnel, etc.



On behalf of the government, NRG administers the National Dose Registration and Information System, which also includes radiation doses for aircraft crew.

Because aircraft crew remain at high altitude for a longer time during their flights and are thus exposed to more radiation than the average Dutch person, it is important that their doses are also included in this. Radiation from the cosmos (galactic radiation) consists primarily of protons and alpha particles. The radiation dose or the dose rate vary according to the height above the surface of the earth because the earth's atmosphere provides a certain amount of shielding. The dose rate at ground level in the Netherlands is limited to approximately 0.04 microSv per hour (0.35 milliSv per year). At flying altitude, this is 100 times higher on average. In view of the constant nature of galactic radiation, the doses received by aircraft crews can be computed accurately. NRG does this every month for the Dutch airlines. These companies provide a crew list for each flight and the flight plan. The latter are generated by computer for each flight and describe the planned route in waypoints: location, altitude and time. A study has shown that there are no major differences between the doses calculated with the aid of the flight plan and the route actually flown. Calculations can therefore be based on the flight plan. Furthermore, it was found that relatively minor deviations in the route (up to 200 nautical miles) do not lead to significant differences in doses.

Wide range of medical services

NRG provides research, services and advice in various areas to pharmaceutical companies, hospitals, universities and other medical bodies. Examples of this are the production of medical isotopes in the High Flux Reactor, advice regarding the optimising of treatment doses in radiation therapy, radiation hygiene issues and personal dosimetry of radiological workers. 2003 was a record year that saw a rise of 20% in turnover for the production of radio isotopes.

NRG has a substantial market share worldwide in irradiating targets for the production of Molybdenum-99, Iridium-192 and Strontium-89, among others.

NRG works closely with various university hospitals in developing new products for cancer treatment. Promising new applications are based on radioactive Holmium-166 and Lutetium-177, with which experimental treatments have been carried out with positive results. Because of its unique nuclear infrastructure and high-quality expertise, NRG is the ideal partner for doctors developing new treatments that are steadily increasing in importance in the context of an ageing population.

Ru 99 12,7	Ru 100 12,6	Ru 101 17,0	Ru 102 31,6
σ 5,0	σ 5,8	σ 3,1	σ 1,30
Tc 98 4,2 · 10 ⁶ a	Tc 99	Tc 100 15,8 s	Tc 101 14,2 h
β ⁻ 4,0 γ 745; 652; σ 0,9 + ?	6,0 h β ⁻ 141... e ⁻ β ⁻ ... γ (322...)	β ⁻ 0,3... γ (80) σ 19	β ⁻ 3,4... γ 540; 591;
Mo 97 9,55	Mo 98 24,13	Mo 99 66,0 h	Mo 100 9,63
σ 2,2	σ 0,130	β ⁻ 1,2... γ 740; 182; 778... m; g	σ 0,199
Nb 96 23,4 h	Nb 97	Nb 98	Nb 99
β ⁻ 0,7... γ 778; 569; 1091...	53 s β ⁻ 0,3... γ (90) σ 19	51 m β ⁻ 2,0; 2,3... γ 787; 723; 1169...	2,6 m β ⁻ 3,2... γ 98; 254; 2642; 2854...; β ⁻ 3,1 γ 138; 98

A section of the table of nuclides. The isotopes marked in black are stable; the isotopes in blue are unstable (radioactive).



Recycling of Technetium generators in which molybdenum is transported to hospitals.

6. Annual Social and Environmental Report

In 2003 local authorities and ECN have detected several environmental and safety regulations offences. This caused the implementation of considerable essential improvements, vigorously put into effect by the ECN organisation and here employees.

Below are a few points from the ECN Annual Social and Environmental Report for 2003.

Social points

Pensions

No solution to the pension problem was found in 2003. Joining the ABP (the civil service pension fund) turned out not to be feasible, and the intensive consultations with Centraal Beheer Achmea failed to produce a solution. To keep pension contributions down, especially the cost of back service, ECN decided in 2003 not to raise the pensionable salary, even though a 2% structural pay rise as of 1 January 2003 had been agreed with the trade unions. Nor did ECN's pensioners come off unscathed: ECN decided not to index their pensions because of the financial situation.

Investing in people

Training and instructing staff remains an important part of ECN's work. There is a substantial need to develop knowledge and skills to enable the organisation to perform well. Staff completed a total of just under 700 courses in 2003. There is a great deal of interest in Quality, Safety and Environment-related courses in particular.

Near misses

Reporting near misses is a pro-active way of preventing accidents. It produces a substantial learning effect, not only because accidents are avoided but also because it makes people (not only the person reporting the problem but everyone involved in solving it) think and adopt different, safer and more environmentally friendly ways of working. A low-threshold reporting procedure has been in place since 1997.



ECN team in action during the boat race on the River IJ in Amsterdam (photo Eelko Hoek, ECN Solar Power).

Radio show "De Och-tenden" did a complete morning show at ECN about hydrogen.



Near misses (excl. NRG)

Year	Number of reports	Health and Safety incidents	Environmental incidents
1999	43	41	16
2000	35	34	11
2001	35	32	7
2002	34	34	12
2003	35	35	3

Conclusion: the number of incident reports is stabilising. Effectiveness, a measure of the efficacy of the measures, was again high in 2003, at 66%. The effect of most of the other incident reports cannot be ascertained: only a very small proportion were not effective. As the reporting system is certainly effective, a campaign was launched in 2004 to step up incident reporting. Initial signs are that this is proving successful.

Accidents

Overview of accidents in 2003 excluding accidents of outside contractors.

Year	FTE + trainees As of 31-12-2003	Number of accidents	Accidents involving absenteeism	IF Index*
1999	719.7	2	2	1.74
2000	746.5	6	1	0.84
2001	668.3	4	2	1.87
2002	625.0	6	2	2.00
2003	619.1	3	2	2.02
Gemiddeld				1.69

IF index = accidents involving absenteeism × 1,000,000/hours worked
(hours worked = FTE × 1,600)

Conclusion: the accident rate (the IF index) is stabilising, which is no cause for satisfaction. The situation is to be reviewed in 2004 with the aim of further improving the situation. The TS&C unit passed its VCA certificate, a safety diploma for contractors, with flying colours in 2004.

Sickness absenteeism (excl. NRG)

Overview of absences in 2003.

Year	Average frequency of absences	Average length of absence	Absenteeism percentage inc. maternity leave	Absenteeism percentage excl. maternity leave	Percentage of non-absentees
1999	1.31	8.24	2.87	2.58	34.97
2000	1.30	9.25	3.40	3.11	39.26
2001	1.32	11.27	3.39	3.14	37.48
2002	1.38	9.42	3.75	3.32	36.98
2003	1.43	10.10	3.97	3.65	35.75

Conclusion: there was a rise in both the frequency and length of absences in 2003. As a result the absenteeism rate rose by about 10% (from 3.32% to 3.65% (excl. maternity leave)). There is no obvious explanation for this. Because of the absenteeism trend, however, we need to talk to the Health and Safety Service and decide together how this trend can be brought to a halt.

Environment and Safety

Energy

The Energy research Centre of the Netherlands has its own targets for energy efficiency and CO₂ emissions: the figure shows the trend in emissions in 2003.

Conclusion: the proportion of green energy has gone up sharply, some of it generated on site, the remainder bought in.

Part of buildings 05 and 06 are to be closed or renovated in 2005. As these 'old' buildings are energy-hungry, this will reduce total consumption and increase efficiency. We are also working on a business plan for installing a number of small (approx. 300 kW) wind turbines on the ECN test field on the Zijper Dyke.

Aerial dispersal

An afterburner was installed in 2003 to break down harmful emissions from the BIVKIN biomass gasifier into less harmful or even non-hazardous compounds at high efficiency. A monitoring programme is to be carried out in 2004 to optimise the operation of the afterburner.

Dispersal into surface water

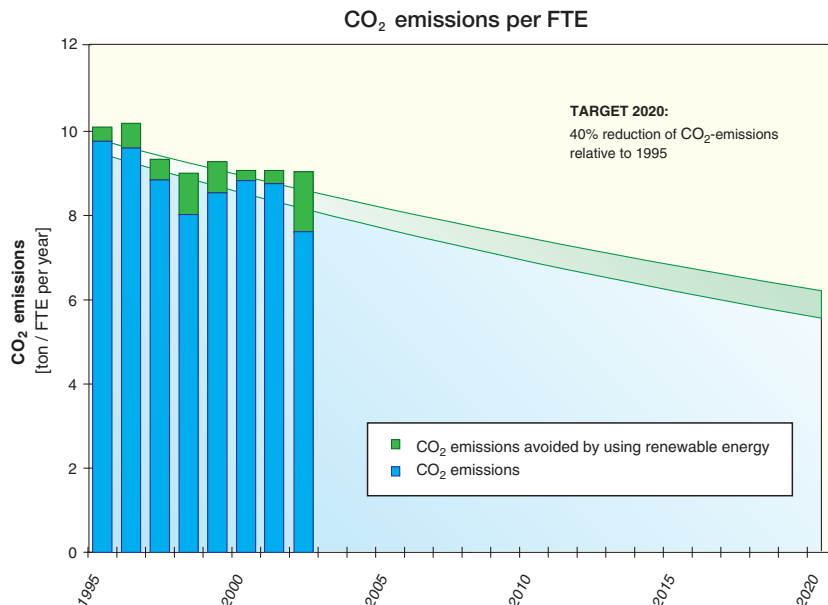
Both the licensing authority, the Hollands Noorder Kwartier water control corporation (HHNK), and ECN carried out extensive monitoring in 2003. We both, more or less simultaneously and independently of each other, detected various contraventions of the limits. It should be noted that ECN detected more of these than the licensing authority. The cases we detected were reported to the HHNK immediately and a plan of action drawn up straight away to put a stop to them. The plan of action, which will be complete at the end of June 2004, entails both installing sludge collectors and stressing careful discharging, as the problem often involves metals discharged in a highly water-soluble form, making them difficult to remove. Various courses of instruction have thus been given as a result of the contraventions. Apart from these, the levels monitored were in order in many respects. Unlike in the past, where it first issued a warning, this time the HHNK immediately imposed fines which were payable on the next contravention. No more contraventions were in fact detected in 2003.

Soil protection and decontamination

Decontamination of the automobile tank facility started in 2003. We did not manage to complete this by the end of 2003 as expected, so pumping will continue for an indefinite period in view of the contamination.

Noise and odour nuisance

No complaints were received from outside the research site in 2003.



External Safety

External inspections took place at the end of 2002, in particular under the Major-Accident Hazards Decree, which ECN is subject to. As a result fines were imposed on ECN to prevent further contraventions (these included failing to secure gas cylinders).

The IRMT (the police Inter-Regional Environmental Team, acting on the instructions of the Public Prosecutor) carried out various inspections regarding dangerous substances in October and November 2003, in which a small number of contraventions were again detected. These were different from those for which the fines had been imposed, however: some of them related to failure to use facilities that were in place. Vigorous action has been taken to remedy this. The plan of action drawn up, part of which has been implemented, covers the following: improving facilities; clearer and in some cases more stringent rules anticipating future policy; instruction; and a higher frequency of inspection. This will cost a lot of time and money in 2004 and virtually everyone will be involved.

Internal environmental care

ECN's new simplified management system (EMS for short) was up and running in 2003. The new simplified system on the Intranet is regarded as an asset. All unit managers have been trained as EMS auditors. The newly trained auditors carried out a successful autumn audit shortly after completing their training. Afterwards the vast majority of managers were enthusiastic about scrutinising their management system in this way. There will be a fresh audit in the spring, which will be dominated by recertification for the ISO 14001 environmental certificate in 2004.

7. Financial Report

Consolidated balance sheet at December 31 (in € × 1000)

Assets			Liabilities		
	2003	2002		2003	2002
Fixed assets			Group equity		
Intangible fixed assets	205	483	Equity	2,644	10,702
Tangible fixed assets	27,107	32,155	Result for the year	1,190	-/-8,058
Financial fixed assets:			Minority interest	919	578
• Participations in knowledge-based companies	551	276		4,753	3,222
• Other participations	278	519			
• Subordinated loan	0	18	Provisions		
• Securities	29,259	30,928	Provision for early retirement (FUT)	350	2,588
• Other receivables	12,198	5,549	Provision for redundancy	5,278	7,454
	69,598	69,928	Provision for transitional retirement regulation	2,936	0
			Provision for functional redundancy due to age (FLO)	2,007	1,985
Current assets			Provision radioactive waste	45,182	38,720
Work in progress	13,186	15,622	Provision for work in progress	3,158	784
Receivables and prepaid expenses	13,348	16,275	Other provisions	1,645	1,481
Stock	230	237		60,556	53,012
	26,764	32,134			
			Long term liabilities	0	1,315
Cash at bank and in hand			Short term liabilities	43,290	41,555
Delta Lloyd Bank NV	7	4			
ING/Postbank	2,062	0	Debts to credit institutions		
ABN/AMRO	10,168	3,550	ING/Postbank	0	6,512
	12,237	3,554			
Total	108,599	105,616	Total	108,599	105,616

Consolidated statement of income (€ × 1000)

	2003	2002
Operating revenues		
Financing and other revenues		
• Basic, ENGINE and Cooperative funding from the Dutch government	34,039	33,838
• Third party revenues	64,403	61,773
• Increase/decrease in work in progress	-/-4,810	1,016
	93,632	96,627
Capitalized corporate production	1,074	2,491
Other operating revenues	1,856	1,221
Total operating revenues	96,562	100,339
Operating expenses		
Wages and salaries	49,328	47,033
Social security contributions	11,772	18,908
Depreciation of intangible fixed assets	205	206
Depreciation of tangible fixed assets	5,566	5,891
Other operating expenses	27,910	33,565
Total operating expenses	94,781	105,603
Operating income	1,781	-/-5,264
Financial income and expenses	-/-610	-/-2,758
Earnings from normal operations before taxes	1,171	-/-8,022
Taxes on earnings from normal operations	0	0
Earnings from normal operations after taxes	1,171	-/-8,022
Share in the results of participating interests	356	-/-527
Minority interest in the result	-/-337	491
Net result	1,190	-/-8,058

Consolidated cash flow statement (€ × 1000)

	2003	2002
Cash flow from operational activities		
Operating result	1,781	-/-5,264
Depreciation	5,771	6,097
Adjustments to provisions, excluding interest compensation and Ministry of Economic Affairs contribution	8,209	-/-4,843
	15,761	-/-4,010
Movements in working capital		
- Work in progress ¹⁾	1,652	-/-1,016
- Trade debtors and other receivables	-/-3,714	6,376
- Trade creditors	-/-4,012	-/-1,547
- Other liabilities	5,747	-/-5,818
	-/-327	-/-2,005
Financial gains and losses	-/-610	-/-2,758
Direct income from sale of stocks participating interests	478	0
	15,302	-/-8,773
Cash flow from investment activities		
Movements in financial fixed assets, excluding participating interests	1,687	4,194
Movements in participating interests	-/-34	-/-169
Movements in intangible fixed assets	73	-/-73
Investment in tangible fixed assets	-/-3,003	-/-4,156
Disposal of tangible fixed assets	2,485	655
	1,208	451
Cash flow from financing activities		
Movements in long-term liabilities	-/-1,315	1,315
Increase in cash	15,195	-/-7,007
Balance of cash at January 1	-/-2,958	4,049
Balance of cash at December 31	12,237	-/-2,958
Increase in cash	15,195	-/-7,007

¹ Movements for work in progress listed in the cash flow statement do not correspond to those listed in the statement of income, as they are included the movements in provisions

General

All figures reported in the financial statements represent euro amounts, unless otherwise indicated.

ECN has its registered office in Petten, in the municipality of Zijpe. For information regarding the purpose of the foundation, please refer to the mission statement, which is described in the annual report. A number of reclassifications have been applied for purposes of comparison with previous financial years.

Change in accounting principles

A change in accounting principles was implemented in 2003, involving liabilities previously listed as expenses for the years in which the orders were incurred. The purpose of the change in accounting principles of this was to conform to current Dutch accounting procedures. Comparative figures have not been adapted. This had a positive effect of € 807 on earnings and equity in 2003.

Principles of consolidation

The consolidated financial statements for ECN have been prepared according to the accounting principles generally accepted in the Netherlands, as reported below. Valuations are based on historical costs, unless otherwise indicated. Assets and liabilities are recorded at face value, and income and expenditures are recognised in the year originated. Profits are recognised only after they have been realized.

The consolidated annual report includes the financial statements for ECN, the group companies NRG v.o.f., NRG Personeel v.o.f. and Wind Energy Facilities B.V. (WEF), all registered in Petten in the municipality of Zijpe. All internal receivables, debts and transactions have been excluded from the financial statements. ECN holds a 100% share in WEF and a 70% share in both NRG entities. The other 30% is owned by KEMA.

Valuation principles for assets and liabilities**Intangible fixed assets**

Intangible fixed assets are valued at purchase price.

Depreciation is calculated according to the straight-line method and occurs over a period of five years.

Tangible fixed assets

Tangible fixed assets are valued at purchase or manufacturing price, less applicable depreciation.

Depreciation is calculated according to the straight-line method and occurs over the following time periods:

• Industrial buildings	20 years
• Temporary buildings and site facilities	10 years
• Industrial installations and fixtures	10 years
• Instruments, machinery, etc.	5 years
• Computer equipment and software	3 years
• Goodwill	5 years

The site was acquired in 1957 through a long-term lease from the Dutch Forestry Commission.

In 1996, the term of the lease was extended from 2007 until 2032.

Financial fixed assets**Participating interests**

This report makes a distinction between participating interests in knowledge-based companies and other participating interests. ECN's unique expertise was a critical success factor in the establishment and/or continuation of the former concerns.

Participating interests are valued according to net equity value for interests greater than 20%. Net equity value is calculated using principles similar to those used by ECN for determining valuation and earnings. Other participating interests are included according to their value at acquisition, less applicable provisions for sustained devaluation.

Securities

The stock portfolio is valued as the lower of cost or market.

Bonds are valued at cost, with earnings adjustments for applicable premiums or discounts divided over the entire maturity period.

Current assets**Work in progress**

Work in progress is valued on the basis of associated costs, less a provision for expected loss.

Receivables and pre-paid expenses

Receivables are recorded according to face value, less a provision for uncollectables.

Securities

Securities are valued at cost, taking into account a provision for unsaleability.

Provisions

Provisions are reported at face value, unless otherwise indicated.

Notes to the consolidated balance sheet (€ × 1000)

Fixed assets

Intangible fixed assets

	31-12-2003	31-12-2002
Goodwill		
Purchase price	1,026	1,099
Cumulative depreciation	-/-821	-/-616
Total	205	483

The acquisition of TNO-CSD by subsidiary NRG involved an agreement for goodwill in the amount of € 1,026.

Tangible fixed assets

Movements in 2003

Tangible assets are specified as follows:	Buildings and site	Industrial installations and fixtures	Instruments and machinery	Fixed assets in progress	Total
Purchase price					
As of 1 January 2003	35,405	38,498	40,720	7,321	121,944
Investments	563	587	805	1,048	3,003
Disposals	-/-749	-	-/-213	-/-1,725	-/-2,687
As of 31 December 2003	35,219	39,085	41,312	6,644	122,260
Depreciation					
As of 1 January 2003	23,278	30,954	35,557	-	89,789
Depreciation during fiscal year	1,384	1,913	2,269	-	5,566
Disposals	-	-	-/-202	-	-/-202
As of 31 December 2003	24,662	32,867	37,624	-	95,153
Bookvalue					
As of 1 January 2003	12,127	7,544	5,163	7,321	32,155
Investments	563	587	805	1,048	3,003
Disposals	-/-749	-	-/-11	-/-1,725	-/-2,485
Depreciation during the fiscal year	-/-1,384	-/-1,913	-/-2,269	-	-/-5,566
As of 31 December 2003	10,557	6,218	3,688	6,644	27,107

The value of the disposal of fixed assets in progress concerns purchased assets that were fully reimbursed by NOVEM.

Participating interests (in knowledge-based and other participating interests)

	2003	2002
Balance as of 1 January	795	1,153
Results of participating interests	356	-/-527
Disposals	-/-322	-
Investments	-	169
Balance as of 31 December 2003	829	795

Financial fixed assets

Participating interests in knowledge-based organisations

		2003	2002
ECN share at the end of 2003			
• ENATEC B.V.	12.8%	0	244
• NEDSTACK HOLDING B	0.0%	0	3
• SWEAT B.V.	33.3%	71	7
• INDEC B.V.	36.5%	480	0
• MAN SOLAR B.V.	0.0%	0	18
• ASTER INTELLECTUAL PROPERTIES B.V.	20.0%	0	4
Total		551	276

Other participating interests

		2003	2002
ECN share at the end of 2003			
• DNC Nuclear Technology B.V.	100.0%	18	18
• RTC Noord-holland Noord B.V.	0.0%	0	123
• TIFAN B.V.	7.0%	9	10
• ECN-INTERNATIONAL B.V.	100.0%	16	18
• AWS B.V.	15.4%	0	71
• ENERSEARCH A.B.	12.5%	11	11
• RGS B.V.	100.0%	11	18
• SUNLAB B.V.	100.0%	122	18
• ECONCERN	2.0%	91	227
• HYDRORING B.V.	2.0%	0	0
• R3T	0.0%	0	5
Total		278	519

Securities

Bonds are mortgaged for the amount of € 15,000, the maximum credit facility extended by ING Bank. All other securities are freely at the disposal of ECN.

Bonds

The face value of the bond portfolio is € 29,731.
At the end of 2003, its market value was € 27,186.

Stocks

The stock portfolio is valued at the lower of cost or market.
The book value is equal to the market value of € 3,263.
At the end of 2003, the purchase price was € 5,582.

Other receivables

The following are classified under this heading:
Receivables from Tyco resulting from Molybdenum lease obligations.
Receivables remaining at the end of 2003 amounted to € 6,188.
Receivables from security by Ministry of Economic Affairs regarding provisions for radioactive waste amounting to € 6,000.

Current assets

Work in progress

Work in progress is included after subtracting a provision based on the assessment of individual projects.
The provision mentioned above appears as a credit in the balance sheet, to the extent that it exceeds the value of work in progress. The figures for 2002 have also been corrected for this provision.

Recapitulation:	2003	2002
Work in progress	13,186	15,622
Provisions for work in progress ^{*)}	-/-3,158	-/-784
Total	10,028	14,838

^{*)} Provisions for work in progress were included with gross work in progress in the 2002 balance sheet.

Receivables and pre-paid expenses

Receivables are listed at face value, less provisions.
They expire within one year and are specified as follows:

	2003	2002
- trade debtors	10,878	12,656
- receivables from participating interests	588	952
- other receivables	1,882	2,667
Balance as of 31 December 2003	13,348	16,275

Inventory

Inventory is valued at cost, corrected for unsaleability as necessary.

Cash

Cash is freely disposable. In the balance sheet, cash from the same credit institution is balanced.
ENC has credit facilities of € 15,000 with the ING Bank and € 4,538 with ABN/AMRO.

Group equity

Please refer to the notes on Corporate Equity in the Corporate Balance Sheet

Provisions

Provisions are predominantly long-term in character.

Provision for early retirement (FUT)

This provision is related to the introduction of the pre-retirement regulation of July 1, 1999 and to the elimination of the early retirement regulations that were then in effect.
The new retirement regulations include a transitional directive to compensate for early retirement benefits that were eliminated in the new retirement regulations.
The obligations for ECN with regard to the early retirement payments will decrease in 2005 to an amount of approximately € 350, of which € 1,536 has been released.

As of 31 December 2003 the provision is set up as follows:

	2003	2002
Balance as of 1 January	2,588	3,425
• Debit: withdrawal	-/-831	-/-984
• Debit: release	-/-1,536	0
• Credit: interest compensation	129	147
	-/-2,238	-/-837
Total	350	2,588

This provision is made in cash at 3%. As in previous years, interest is determined with an administrative yield of 5%.

Provision for redundancy costs

This provision is intended for costs associated with staff reductions resulting from reorganisation. Based on the situation at the end of 2003, a decision was made to release € 2,500 due to expected costs associated with components mentioned in the previous financial year. On the other hand, a new allocation of € 1,220 exists to cover the expected costs associated with contracting out certain support services that will no longer be performed by the company's own staff. As in the previous financial year, the interest supplement is based on an administrative yield of 5%.

The movement of this provision is as follows:

	2003	2002
Balance as of 1 January	7,454	8,833
• Debit: withdrawal	-/-1,271	-/-1,776
• Debit: release	-/-2,500	0
• Credit: interest compensation	375	397
• Credit: addition	1,220	0
	<u>-/-2,176</u>	<u>-/-1,397</u>
Total	<u>5,278</u>	<u>7,454</u>

Provision for transitional retirement regulations

This provision is based on guidelines included in the retirement regulation of 1 July 1999 regarding the previous retirement regulations. This transitional regulation will be effective until 2018. The provision is formed with the funds released from the personnel provisions, as described above.

The movement of this provision is as follows:

	2003
Balance as of 1 January	0
• Debit: withdrawal	0
• Credit: addition	<u>2,936</u>
	<u>2,936</u>
Total as of 31 December	<u>2,936</u>

Functional redundancy provision (FLO)

Employees working in shifts may make use of the Functional Age Discharge (FLO) regulation beginning at the age of 57.5 years.

The movement of this provision is as follows:

	2003	2002
Balance as of 1 January	1,985	1,865
• Debit: withdrawal	-/-421	-/-318
• Credit: interest compensation	103	98
• Credit: addition	340	340
	<u>22</u>	<u>120</u>
Total as of 31 December	<u>2,007</u>	<u>1,985</u>

Radioactive waste provision

This provision is intended for the costs of future treatment and storage of radioactive waste.

The movement of this provision is as follows:

	2003	2002
Balance as of 1 January	38,720	41,913
• Debit: funds used	-/-1,663	-/-5,573
• Credit: addition	6,135	316
• Credit: interest compensation	1,990	2,064
	<u>6,462</u>	<u>-/-3,193</u>
Total as of 31 December	<u>45,182</u>	<u>38,720</u>

Other provisions

This category includes provisions for building maintenance, Periodic Maintenance and Flexible Retirement (SFN) and work in progress.

	Work in progress	Main-tenance	SFN	Lead cells	DWT sludge storage	Total
Balance as of 1 January 2003	784	490	446	545	0	2,265
Debit: withdrawal	0	-/-227	-/-446	0	0	-/-673
Credit: addition	<u>2,374</u>	<u>358</u>	<u>0</u>	<u>0</u>	<u>479</u>	<u>3,211</u>
Total as of 31 December	<u>3,158</u>	<u>621</u>	<u>0</u>	<u>545</u>	<u>479</u>	<u>4,803</u>

Building maintenance provision

The building maintenance provision serves to equalise the costs of building maintenance tasks throughout the year.

Long-term liabilities

The long-term loan registered to WEF B.V. was paid in full during the fiscal year, using funds received from the negotiated sale and lease-back agreement. For further information, please refer to the notes to off-balance obligations.

Short-term liabilities

	31-12-2003	31-12-2002
1. Deferred income from third parties	17,160	20,742
2. Trade liabilities	6,372	10,490
3. Taxes	4,481	678
4. Other social charges and personnel costs	5,939	3,446
5. Miscellaneous liabilities and accrued expenses	<u>9,338</u>	<u>6,199</u>
Total	<u>43,290</u>	<u>41,555</u>

Off-balance rights and obligations

ECN has a put-option valued at approximately € 3,500 for its remaining shares of InDEC B.V., to be realised by 31 December 2006 at the latest, through sale of the stock in question.

The site was acquired in 1957 through a long-term lease from the Dutch Forestry Commission.

In 1996, the term of the lease was extended from 2007 until 2032.

The ground rent for 2003 was set at € 194 per year.

During financial 2003, a sale and lease-back agreement was negotiated by ECN Wind Turbine Testing Park Wieringermeer C.V. (with 100% participation by Wind Energy Facilities B.V., which is a 100% subsidiary of ECN) to finance a wind turbine testing field in which large wind turbines will be tested for their applicability to near-shore and offshore locations.

The lease obligation associated with this agreement will cost € 816 per year, for the period from 2004 until 2012.

Other contractual obligations entered into are:

Description	< 1 year	> 1 year < 5 year	> 5 year
Rent for Arnhem M01 and M05	401	0	0
Rent for Arnhem B48	113	226	0
Vehicle leases	101	357	0
NIB Lease obligation (WEF B.V.)	1,632	6,528	6,528

During 2003, ECN conducted a number of transactions with NRG. These transactions have been omitted from the financial statements.

An agreement has been reached with NRG that allows them, in order to strengthen their own equity and possibly to improve their liquidity, to request credit in the form of a subordinated loan, to be issued according to the distribution of shares held by the NRG partners, to a maximum amount of € 2,800.

In 2003, a claim was received concerning the indexation of the pensions of several former ECN employees. This claim is under review by the court. The directors of ECN dispute the validity of this claim and did not provide for this claim.

As of the balance sheet date, ECN has issued a total of € 929 in bank guarantees (€ 639 ING Bank, € 290 ABN/AMRO).

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

Operating revenues

Revenues

Basic, ENGINE and Cooperative funding

	2003	2002
Basic and ENGINE funding	16,883	15,877
Cooperative funding	17,156	17,961
	<u>34,039</u>	<u>33,838</u>

ECN receives an annual subsidy for research activities from the Ministry of Economic Affairs. This subsidy is recognised in its entirety as operating revenue.

Third-party Revenues

	2003	2002
Third-party assignments	61,245	61,773
Increase/decrease in work in progress according to revised provision	-/-4,810	1,016
	<u>3,158</u>	<u>-</u>
	<u>-/-1,652</u>	<u>1,016</u>
Total	<u>59,593</u>	<u>62,789</u>

The following is a summary of the item mentioned above, sorted by client.

Third-party assignments, including increase/decrease in work in progress

This item is specified as followed:

	2003	2002
Domestic trade and industry sector	21,698	21,510
Domestic energy sector	2,615	2,084
European Commission	10,056	10,017
Foreign trade and industry sector	10,356	10,921
Government agencies	2,079	6,105
NOVEM	12,789	12,152
Total	<u>59,593</u>	<u>62,789</u>

Capitalised corporate production

Capitalised corporate production involves operating expenses incurred through work carried out by the company's own staff and with its own assets, which can be allocated to investments or provisions.

Operating expenses

Wages and salaries

	2003	2002
1. Salaries for permanent employees	41,387	37,746
2. Costs for temporary employees	4,873	5,693
3. Other personnel costs	3,068	3,594
Total	<u>49,328</u>	<u>47,033</u>

Social security

	2003	2002
1. Social security	4,380	5,750
2. Pension charges	7,392	13,158
Total	<u>11,772</u>	<u>18,908</u>

The average number of employees (in FTE) was:

	2003	2002
Permanent contract of service	766.2	777.5
Temporary contract of service (including PhD candidates)	77.4	85.9
Total	<u>843.6</u>	<u>863.4</u>

The figures reported above do not include employees working through staffing agencies.

Depreciation

This item is specified as follows:

	2003	2002
- Industrial buildings, installations, fixtures and site facilities	3,297	3,396
- Instruments and other inventory	2,269	2,495
- Goodwill	205	206
Total	<u>5,771</u>	<u>6,097</u>

Financial income and expenses

This item is specified as follows:

	2003	2002
Interest income	1,986	2,807
Interest expenses	2,885	3,812
	<u>-/-899</u>	<u>-/-1,005</u>
Other financial income and expenses	289	-/-1,753
Total	<u>-/-610</u>	<u>-/-2,758</u>

Interest income includes € 812 of Molybdenum lease income.

Interest expenditures include € 2,539 in interest added to provisions and € 336 in interest on the current account.

Other financial income and expenditures consist mainly of appreciation in the securities portfolio in the amount of € 370.

ECN Corporate Balance Sheet as of 31 December (€ × 1000)

Assets			Liabilities		
	2003	2002		2003	2002
Fixed Assets			Equity		
Intangible fixed assets	26,376	30,465	Foundation capital	45	45
Financial fixed assets:			Other reserves	2,599	10,657
• Participating interests in group companies	3,114	2,094	Result for the year	1,190	-/-8,058
• Other participating interests	811	777		3,834	2,644
• Subordinated loan	0	18			
• Securities	29,259	30,928	Provisions		
• Other accounts receivable	12,198	5,549	Provision for early retirement (FUT)	350	2,588
	71,758	69,831	Provision for redundancy	5,278	7,454
Current assets			Provision for radioactive waste	43,637	38,406
Work in progress	9,811	10,926	Provision for transitional retirement regulation	2,936	0
Receivables from group companies	1,352	2,907	Provision for functional redundancy due to age (FLO)	879	1,072
Receivables from other participating interests	585	905	Provision for work in progress	775	0
Trade debtors	5,380	7,675	Other provisions	621	433
Securities	230	0		54,476	49,953
Other receivables	1,908	1,640			
	19,266	24,053	Short-term liabilities	25,214	25,228
Cash at bank and in hand			Debts to credit institutions		
Delta Lloyd Bank	7	4	ING/Postbank	4,205	19,367
ABN/AMRO	0	3,304	ABN/AMRO	3,302	0
	7	3,308		7,507	19,367
Total	91,031	97,192	Total	91,031	97,192

ECN Corporate statement of income (€ × 1000)

	2003	2002
Operating income		
Income		
• Basic, ENGINE and Cooperative funding from the Dutch government	25,232	25,192
• Assignments and other funding	31,587	30,767
• Increase/decrease in work in progress	-/-1,890	61
• Income from subsidiary NRG	7,487	7,182
	62,416	63,202
Capitalised corporate production	943	2,243
Other operating revenues	1,338	1,220
Total operating income	64,697	66,665
Operating expenses		
Personnel costs	40,765	43,393
Depreciation	5,080	5,395
Other operating expenses	18,954	20,781
Expenses from subsidiary NRG	383	1,235
Total operating expenses	65,182	70,804
Operating result	-/-485	-/-4,139
Financial income and expenses	-/-579	-/-3,048
Earnings before taxes	-/-1,064	-/-7,187
Taxes on earnings	0	0
Earnings after taxes	-/-1,064	-/-7,187
Share in participating interests earnings	2,254	-/-871
Net earnings	1,190	-/-8,058

Notes to the statutory statements (€ × 1000)

Principles of valuation

The principles of valuation described in the notes to the consolidated financial statements are also applicable to the corporate balance sheet.

Directors and Supervisory Board

The remuneration for (former) directors, including retirement costs, amounts to € 562. Remuneration for the Supervisory Board amounts to € 48.

Equity

	2003	Movements in 2003	2002
• Foundation capital	45	-	45
• Earnings since 1983	3,789	1,190	2,599
Balance as of 31 December	3,834	1,190	2,644

Participating interests in group companies

Changes in participating interests are as follows:

Balance As of January 1, 2003	2,094
Debit: 2002 NRG license fee	-/-921
Credit: Share in NRG participating interests result	1,734
Credit: WEF capital investment	45
Credit: WEF earnings	162
Balance as of December 31, 2003	3,114

Other information

Earnings of € 1,190 from 2003 will be added to the foundation's equity.

Petten, March 24, 2004

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

Dr. A.B.M. Hoff
Chairman of the Board of Directors

Auditors' report

Introduction

We have audited the financial statements of the Stichting Energieonderzoek Centrum Nederland, situated in Petten, for the year 2003. These financial statements are the responsibility of the foundation's 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 presentation of the financial statements. 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 of December 31, 2003 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 of Book 2 of the Netherlands Civil Code.

Amsterdam, March 24, 2004

Deloitte Accountants

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