ANALYSIS OF ENERGY R&D PROGRAMS

This final section of the report presents program level descriptions of Dutch public sector energy R&D programs. In this section, only the budgets of specific identifiable energy R&D programs will be discussed, i.e., it is likely that some university funded energy R&D that is supported through the "primary flow" subsidy for university-based research is not fully accounted for here. Not all energy R&D resources in the Netherlands are allocated through specific or thematic programs. Specifically, this section will detail the energy R&D programs of Novem, the energy R&D activities of ECN, specific energy-related programs of NWO, and energy research projects supported through the Economy-Ecology-Technology (EET) program, which is currently the most important subsidy supporting general R&D.[1]

The changes in Dutch energy R&D priorities that were formulated in the recent Memorandum on Energy R&D are not detailed here (although sometimes mentioned) because many of the programs that will implement these new priorities have yet to be developed (Ministry of Economic Affairs, 1998b).

Energy Efficiency R&D

Energy conservation accounts for 38% of all Dutch public energy RD&D, making it the single largest energy R&D program area (Struker, April 1998). Energy efficiency R&R budgets increased 9% between 1994 and 1997. The main objective of public sector energy efficiency research is to assist in achieving the government's stated objective of reducing energy consumption by 33% by the year 2020 (Ministry of Economic Affairs, 1995).

Industrial Energy Efficiency *$32.7 million (1996)*

The largest part of the energy efficiency RD&D budget is devoted to industrial energy efficiency research. These programs account for 65% of all energy conservation RD&D and approximately 25% of total government energy RD&D expenditure (Struker and de Jager, April 1998). Novem has supported industrial energy efficiency research since the first oil crisis in the 1970s. One major industrial energy efficiency program is the Tender on Energy Conservation (TIEB, since 1990) program ($*7 million, 1998)*, which attempts to stimulate the introduction of available innovative energy conservation techniques in industry.

Novem also supports industry-specific and inter-industry energy efficiency research programs *($16.0 million, 1998)*. For example, the program on inter-sectoral new technologies (MINT, 1994-1998) stimulated the development of crosscutting energy conservation technologies, e.g., energy management, process control and electrical engineering, process integration and residual heat, heat transfer, and physical process equipment. This program ended in 1999 and will be continued through the SPIRIT program (1999-2002) *($42 million)*. It aims to accelerate the

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[1] The EET programme was recently initiated by the Ministry of Economic Affairs and is a part of the "Knowledge in Action" program (Ministry of Economic Affairs, 1995). EET has an annual budget of approximately $20 million, which supports research in the areas of environmentally friendly product development, transportation technologies, renewable energy, and sustainable industrial production technologies. EET will provide a maximum annual subsidy of $5 million per project. The percent of the project's total cost that is subsidized depends on the characteristics of the project (i.e., 62.5% subsidy for basic research, 40% for industrial research, and 25% for precompetitive technology development). Projects are required to be capable of delivering a substantial "breakthrough," must be carried out cooperatively with another entity, must deliver "economic," "ecology," and "technology" benefits and must be focused on developing technologies which could be implemented in the medium (5-10 year) to long term (10-20 year).

application of industrial "breakthrough" technologies in the market. Budget available in 1999 is about $5 million. Novem's sector-specific programs support industries, which have first signed a Long Term Agreement, in which they committed themselves to realizing increased energy efficiency. Currently, the government is sponsoring industrial energy efficiency research that is relevant to the following industrial sectors: building materials, ceramics and glass, chemical and oil refinery, light industry, pulp and paper, textiles, basic metals, rubber and plastic processing, and agricultural.

ECN's Energy Efficiency Unit conducts research on optimizing industrial processes in order to reduce raw material use and realize energy efficiency gains. Research is focused on controlling industrial processes and developing breakthrough technologies (e.g., modeling and simulation of the recovery of heat through for example heat pumps, developing new materials for heat exchangers and heat-resistant and corrosive-tolerant membranes, and the development of fuzzy logic for advanced measurement systems. In addition, the unit is developing needed software, advanced material components (ceramic materials and advanced coatings), demonstrations and experimental equipment.

The Technology Foundation (STW) of NWO is running a four-year, $4 million program entitled "Process Renewal to Create a Cleaner Environment" (1997-2001). The major research focus of this program is the development of multi-functional catalysts and overall processes that would use these catalysts, e.g., intrinsically clean oxidation processes, application of enzymes and catalytic end-of-pipe processes. This research is performed at universities. The Foundation (STW/NWO) is also supporting basic research that would improve the scientific basis for crystallization separation processes (about $ 1.2 million per year) as well as university-based sensor technology development (e.g., chemical, electrical, mechanical, magnetic and radiation sensors).

The EET program is subsidizing three exemplary industrial energy efficiency RD&D projects: the development of a biological treatment of process water in a paper mill to close the water cycle; the development of an automated sensor and control system for the use of water in a closed horticulture system; and the development of capillary modules of membrane technology to purify process water (removal of organic components and salts) to enable reuse of water in the food & beverage and chemical industries.

Building Energy Efficiency *7.5 million US$ (1996)*

In the building sector, the government's program principally emphasizes information dissemination and market introduction activities. R&D plays a minor role. About 15% of the government's energy conservation RD&D effort is devoted to buildings energy efficiency RD&D in the residential and commercial sectors (Struker and de Jager, April 1998). Buildings energy efficiency research budgets decreased from 1990 to 1995. However, recently Novem has started new programs in this area (e.g., heat pumps and building energy infrastructure). The Programme on Long-term Research in the Built Environment (LTGO) ($ 2.5 million, 1998) seeks to bring about the realization of "energy neutral cities" by the year 2010. Energy neutral cities will be brought about by the introduction of energy saving technologies and the deployment of renewable energy technologies. The government is also developing concepts for energy neutral houses. For 1998, the focus within the program is on the development of energy efficient concepts for newly built urban areas and commercial buildings ($ 0.9 million) and on test-bed experiments ($ 1.5 million).

Government-funded building energy efficiency research also plays an important role in shaping national energy conservation policy, e.g., helping to set new Energy Performance Standards for

appliances. Another aspect of this synergy between building research and environmental policy and standards is found in the Optimal Energy Infrastructures (OEI) project ($0.5 million 1998). This project provides advice regarding energy conservation and the implementation of renewable energy technologies in large, new building areas in the Netherlands (so called VINEX locations, a combination of residential housing and new business areas). Additional funds ($1 million 1998) are provided to demonstrate and stimulate the introduction of gas-fueled appliances in houses and commercial buildings (e.g., washing machines, refrigerators, cooling). Novem also has budgeted approximately $2 million for 1998 to realize various building energy efficiency policy goals, such as enhancing energy efficiency in new commercial buildings, intensifying municipal policy regarding building energy efficiency, and stimulating energy efficiency in government-owned buildings.[2]

Novem also plays a role in attempting to catalyze the introduction of "sustainable buildings" by bringing together the forces of technology push and market pull together. The National Centre for Sustainable Building (DuBo) was established in late 1996 to validate and disseminate relevant information to the private sector on sustainable building practices.

The ECN Renewable Energy Unit also focuses some of its efforts on the practical integration of renewable energy and energy efficiency technologies in the built environment (e.g., optimum insulation levels, correct installation of heat sources, heat recovery from ventilation air, optimum sun-facing position for buildings, solar collectors, energy roofs and energy poles,[3] cogeneration, heat storage, automated lighting). The EET program is also supports Ecobuild, a program to decrease energy use in houses by 50% with only minimal additional cost and to introduce new technologies that reduce the lifecycle impact of the entire building.

Traffic and Transport Energy Efficiency *$6.7 million (1996)*

The transport sector is responsible for about 20% of Dutch energy consumption. The government devotes approximately 13% of all energy conservation RD&D to transport-related energy efficiency research in order to help reduce energy consumption, pollution (e.g., NO_x emissions), and congestion problems associated with this sector (Struker and de Jager, April 1998).

Novem's transportation energy efficiency program covers a wide array of activities: developing technology, improving logistics, and stimulating the adoption of more fuel-efficient cars. The program on Rational Energy Consumption in Traffic and Transport (REV) ($ 2.5 million, 1998) aims at developing efficient vehicles (e.g., hybrid drive systems, flywheels, lightweight materials), developing and applying alternative transport fuels, and efficiently using transport vehicles (e.g., efficient transport of goods by improving logistics). The renewed REV program is restricting its focus to transport systems, demand reduction and logistics (i.e., it is less technology oriented). A second program in this area, Quieter *($ 2.5 million, 1998)* which is focused on cleaner and more fuel-efficient traffic and transport in urban areas, is focused on reducing urban environmental problems by developing and deploying more environmentally friendly mass transportation and delivery or fleet vehicles and the necessary infrastructure (i.e., fueling station facilities).

The EET is financing two exemplary transportation projects: the development of an optimized drive by using a continuous variable transmission system in combination with a flywheel to store

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[2] The government has set a goal of increasing the energy efficiency of government-owned buildings by 17% by 2000 compared to 1989 energy usage patterns.

[3] "Energy roofs" combine a heat exchanger, heat pump, and solar collector to augment traditional heating technologies. "Energy poles" are buried to store underground heat and cold for later use by the heat pump.

and reuse brake energy; and the development of lightweight semi-manufactured components for the transport sector by using renewable resources such as natural fibers like hemp.

Other energy efficiency *$3.6 million (1996)*

Heat pumps are an important aspect of Dutch energy efficiency measures because of the continued widespread availability of low-temperature waste heat. Approximately 3% of all government energy efficiency research is directed towards heat pump R&D (Struker and de Jager, April 1998). Novem is also funding ($1.5 million 1998) a heat pump program which encourages the application of heat pumps in the residential sector, service/commercial buildings and in industry. The principal impediments to the further introduction of heat pumps in these three sectors are the high prices of heat pump systems and the lack of experience and systems knowledge of vendors and users. Novem is also trying to establish a Covenant for Heat Pumps to bring together suppliers, energy utilities, and the government to facilitate the development of new, improved products and to create a market for these technologies. Both of these activities are focused on the dissemination and market penetration of heat pump technology. Other Novem programs (such as MINT and NECT) deal with more research-oriented aspects of heat pump technology (e.g., the development of new types of chemical heat pumps, hybrid heat pumps, replacement of ozone-depleting working fluids).

Renewable Energy R&D

Renewable energy research accounts for 16.5% of the total government energy RD&D budget (Struker and de Jager, April 1998). The government is increasing the resources devoted to photovoltaic (PV) and biomass research (e.g., the "Action Programme on Renewable Energy", Ministry of Economic Affairs, 1997). Solar energy currently receives 55% of all government renewable energy R&D, wind energy accounts for 24 % of renewable energy RD&D, and biomass accounts for 22%.

Solar energy *$11.8 million (1996)*

Novem has research programs that focus on both thermal solar technologies and PV technology, with the clear emphasis being on PV-related research. The $2.5 million (1998) National Programme on Thermal Solar Energy (1996-2000) has as its highest priority the deployment of solar domestic hot water (DHW) systems. The government would like to see 400,000 solar DHW systems deployed by the year 2010 – a substantial increase from the current 26,000 DHW systems in use. A nation-wide campaign and a Voluntary Agreement (1999-2002), involving (among others) the solar heating industry, energy distribution companies, Holland Solar, and the Dutch Ministry of Economic Affairs, will promote the development and use of commercially competitive solar DHW systems. The program is also providing some support for technical research and development, and stimulating the market deployment of large-scale, custom-built systems and the wider use of passive solar energy in new buildings and renovation projects. Some longer-term exploratory research is also supported to integrate thermal solar energy systems with heat pumps and with seasonal energy storage. Most R&D activities in this field are carried out with international cooperation through the International Energy Agency.

The publicly supported PV research program in the Netherlands covers all different types of PV cell types (amorphous silicon, silicon thin layer cells on ceramics, organic cells, high efficiency "tandem cells"). The PV program also supports R&D on how to scale up PV manufacturing production and advanced deposition technologies. Recently, Novem launched a second PV research program, Photovoltaic Solar Energy (NOZ-PV 1997-2000) ($15 million, 1998), to prepare the market and the manufacturing capabilities for the large-scale implementation of PV

solar energy in the twenty-first century. The government hopes to improve the price-performance ratio of PV systems by a factor of four by the year 2010. Half of the cost reduction is expected to come from advances in R&D, half from economies of scale once the market is better developed. The government-funded program is also looking at improving and expanding industrial capabilities in the areas of optimizing inverter technology, AC-modules, PV roof tiles and roof-integration techniques. The government has set aside $8 million for a "Learning Programme" to increase knowledge about how to implement wide-scale deployment of PV systems and what the impact of wide-scale deployment of this technology would be (e.g., roof integration, exploring ownership issues, effects on the grid, storage requirements). The ECN Renewable Energy Unit focuses on system/infrastructure technologies for both grid-connected and standalone systems. A competitive production technology has been developed for crystalline silicon solar cells.

In 1995, NWO launched the "Solar Cells for the 21st Century" program ($ 4.5 million over 4 years). This program will focus on amorphous silicon cell research (structure; optical doping a-Si; tandem solar cells, plasma, thermal arc and large-scale deposition, deposition modeling), multi-crystalline silicon PV cells (optical doping, electrical passivation, organo-functional materials, light confinement); and hybrid solar cells (fabrication and optimization, modeling of hetero-junction). Within the EET program four exemplary projects are financed: (1) using Epitaxial Lift Off Technology (ELOT) in developing a (trial) manufacturing process for highly efficient tandem solar cells; (2) the development of a prefab roof profile that integrates the functional requirements of a roof with PV technology in modules which are easy to implement; (3) the development of technologies to guarantee large-scale competitive manufacturing of crystalline silicon solar PV modules; and (4) the development of a greenhouse in the horticultural sector that does not require natural gas for heating but instead minimizes energy requirements and optimizes the use of renewable energy technologies (e.g., solar energy, heat storage).

In 1997, the government and various private sector actors[4] signed a Voluntary Agreement in which they committed themselves to realizing 7.7MW of installed PV capacity by 2000 and 10PJ of solar power by 2020.

Wind energy *$5.1 million (1996)*

Dutch government wind energy programs have existed since 1976. Dutch public sector wind energy research, concentrated at ECN and Delft Technical University, focuses on optimizing the aerodynamics, producing fatigue-tolerant rotor blades, reducing the wind turbine manufacturing cost, and validating structural fatigue models and airfoil models. Research is also conducted on: structural dynamics, strength and fatigue research on full-scale turbine blades, electric conversion, reliability analysis and field experiments. Every two years since 1996 these two partners along with Novem formulate a national R&D plan to increase the synergy between government funded wind research and industrial needs related to wind energy. This industrial input helps to shape specific national priorities for wind energy research (e.g., design rules for the aerodynamics of the rotors, development of new rotor concepts, development of a dynamic model for offshore wind turbines, increased knowledge of the applicability of new materials). Novem has launched the Use of Wind Energy in the Netherlands (TWIN-2) program ($ 5.5 million, 1998) to increase the installed wind energy capacity. The TWIN-2 program (1996-2000 approximately $35 million) was launched because the current installed capacity of only 325 MW (in 1998) is far below the government's target of 1,000 MW by the year to 2000. Specific aims for TWIN-2 include the installation of at least of 100 MW each year and a 30% improvement in

[4] The Ministry of Economic Affairs; several electricity distribution companies; EnergieNed; Shell Solar Energy (producer of PV systems); producers of inverters, roofing tiles; real estate developers; consultants; municipalities (e.g., new residential areas).

the price/performance over the period 1995-2000. Clearly, the focus in TWIN-2 is not purely R&D. The program principally focuses on ways to stimulate the market, contribute to the development of sites (including off-shore and semi-off shore), and strengthen societal acceptance of wind energy (e.g., overcome the so-called NIMBY syndrome). The EET program supports two exemplary wind energy projects: the development of an offshore wind turbine and the development of rotors produced by using natural fibers.

Biomass energy *$4.7 million (1996)*

The government believes that if it is to meet its objective of having renewable energy contribute 10% of primary energy by 2020 biomass (both waste products and "clean biomass") must play a major role. Accordingly, R&D budgets for biomass are increasing (Struker and de Jager, April 1998). In 1996, government support for biomass energy RD&D accounted for approximately 22% of all renewable energy RD&D.

The Dutch government sees negative value waste streams as a niche application that can improve the early adoption of biomass technology in an economically attractive way through the use of waste incinerators and co-combustion (e.g., waste wood and sludge) in coal-fired power stations. Over the longer term, the focus for biomass use must shift to more advanced options such as biomass gasification. Dutch biomass R&D focuses on the characterization of conversion properties; the pre-treatment systems for conversion of biomass; and the design, modeling, and optimization of different biomass or waste-to-energy conversion systems (combustion, gasification, pyrolysis, fermentation). Novem implements the Energy from Waste and Biomass ($ 4.5 million, 1998) program, which concentrates on ensuring the sufficient availability of biomass fuels, e.g., the production of biomass, the use of waste streams (e.g., organic waste, waste from agricultural production, wood and sludges), and the importation of biomass. This program also funds research on pre-treatment systems; conversion technologies such as combustion of biomass, co-combustion in coal fired power plants, CHP, gasification of biomass, pyrolysis, liquefaction or carbonization, landfill gas, fermentation, and improved conversion in waste incinerators; and market conditioning and efforts to increase the societal acceptance of biomass energy. The development of conversion technologies occurs together with energy utility companies and the waste industry. Production of biomass in the Netherlands is studied in cooperation with the agricultural sector (e.g., the semi-public research institute DLO). Novem is currently implementing the GAVE program, which will stimulate the development of gaseous and liquid bio-fuels.

The government's programs to reduce CO_2 emissions and its investment program to stimulate innovative cogeneration-projects (NEWS) also fund many biomass-related projects. For example, Nedalco, a producer of ethanol, is planning to build a plant to produce bio-ethanol from melasse, a byproduct of sugar production. Biomass research at ECN's Fuels, Conversion and Environment Unit covers system comparisons of different conversion routes, modeling activities, fuel conditioning and fuel gas and flue gas cleaning, lab and bench scale measurements, and characterization of different biomass/organic waste streams and ash agglomerates in a database (using e.g., the fluidized bed gasifier BIVKIN). EET funds a program that is attempting to produce "crude oil" by converting wet wood shavings under high pressure and high temperature (known as the HTU Process).

Other renewable energy sources *< 0.5 million US$ (1996)*

The Dutch government's support of other renewable energy R&D such as ocean energy, geothermal energy and hydropower accounts for less than 0.5% of the total government renewable energy RD&D budget. Besides some paper system studies, the government is supporting some research on the storage of hydrogen in metals, and the development of

membranes to separate hydrogen. At present, the government does not fund any research directed at the large-scale application of hydrogen in the energy system. The government funds a small program "Market Implementation of Energy Storage in Aquifers" *($ 0.5 million, 1998)* that is exploring the viability of the market introduction of thermal energy storage in aquifers for use in commercial buildings and in industrial processes (e.g., replacing cooling with ground water). The EET program is financing the development of a prototype for the "Archimedes Wave Swing," a system that will generate electricity from the undulation of the sea.

Fossil Energy

Coal R&D *$4.4 million (1996)*

The Dutch government has continuously reduced its support for clean coal technologies over the course of the last ten years. Clean coal technology research (e.g., combustion, conversion and flue gas cleanup) accounts for approximately 3.5% of the government's total energy RD&D budget (Struker and de Jager, April 1998). The focus of Dutch coal-related research has always been on ways to improve the efficiency of the conversion process. In the area of coal gasification, ECN's Fuel, Conversion and Environment Unit supports research in the following areas: coal conversion and mineral matter behavior in modern pulverized coal fired boilers, combined SO_x/NO_x removal from flue gases, and the further development of integrated gasification combined cycle technology (e.g., mineral matter behavior in both the gasifier and in downstream equipment, co-gasification of coal, biomass and high temperature gas cleaning). A 250 MW_e coal gasification demonstration unit in Buggenum was recently competed. Novem is currently closing out most of its coal-related research. It will still support some research related to coal gasification, co-combustion of coal (with biomass), CO_2 capture and sequestration, and underground coal gasification (a European Union project with field trails underway in Spain), and coal bed methane recovery (using CO_2, with a net sequestration of CO_2). There is growing interest in this coalbed methane / CO_2 storage program. Since 1990, R&D for CO_2 capture and sequestration has become increasingly interesting to the Dutch government. In particular, the availability of depleted natural gas fields and research related to advanced clean coal conversion technologies stimulated the government's attention. The Ministry of Housing, Spatial Planning, and Environment and Novem have funded research on CO_2 capture and sequestration focused on the potential for carbon dioxide capture in the Netherlands. Currently, both TNO and ECN are involved in developing CO_2 sequestration technologies. TNO is developing gas absorption membranes for CO_2 capture, and ECN is supporting ceramic membranes for CO_2 capture, which ECN believes is preferable way of separating CO_2. Currently, there is no specific, readily identifiable budget for CO_2 capture and sequestration.

Natural Gas and Oil R&D *$8.1 million (1996)*

Natural gas and oil are important raw materials in the Netherlands -- natural gas mainly as raw material for the energy supply system (both electricity and heat), oil as a resource for the (chemical) industrial activity. The Dutch government has funded little or no research on exploration, production and distribution of oil and natural gas in the Netherlands. This area of research has traditionally been adequately supported by the large Netherlands-based oil and gas companies. Research related to oil and gas recovery, refining and transport receive 6% of governmental energy RD&D (Struker and de Jager, April 1998). There is some government support for natural gas use through the industrial specific programs (see above under Energy Efficiency). Dutch universities (Delft Technical University, VU-Amsterdam and Utrecht University) do conduct research in the area of geology and geophysics supported by the government and industry. Most of this academic research is directly in line with the R&D needs

of the industry: processing of seismological data, characterization of rock behavior, ground mechanics, complex fluid flows, modeling activities, and reservoir management. There is well-embedded (e.g., joint PhD's) cooperation with key companies like Shell, Amoco, Schlumberger and the NAM. The presence of large natural gas deposits in the Netherlands has also stimulated the development of a research infrastructure and advanced physical infrastructure and industrial activity in the area of natural gas. The research activities of Gasunie Research and GasTEC cover exploration, distribution and end use of natural gas. These institutes also cooperate with the public research institutes (e.g., combustion research).

Electric Power and Storage *$15.2 million (1996)*

Electric power and storage technologies account for 12% of the government's energy RD&D budget with approximately 70% of these resources being devoted to research on combined heat and power and fuel cells. The remainder is devoted to research on improving electricity transmission and distribution. The government devotes relatively little funding to energy storage, e.g., electrochemical storage and thermal storage (Struker and de Jager, April 1998). Novem supports research on new conversion technologies, primarily carried out through the New Energy Conversion Technologies (NECT) program *($ 3 million, 1998)*. NECT's research activities are focused on increasing the conversion efficiency of decentralized (gaseous) fuels (e.g., natural gas, biogas, low-caloric gases, hydrogen) to produce heat (or cold) and/or power. The program supports research on advanced combustion (e.g., ceramic burners, vortex burners, catalytic burners), innovative combinations (e.g., fuel cells and gas turbines, or adsorption cooling and gas turbines), the development of micro-CHP (using the Free Piston Stirling Engine), small gas turbine technology, and new heat pump technologies (e.g., hybrid and adsorption heat pumps).

STW/NWO subsidizes university research projects in the area of "Clean and Efficient Combustion" *(about $ 4 million per year)*. Funded projects cover e.g., deflagration in flowing and burning gas mixtures, modeling activities regarding turbulent flames, combustion and gasification processes of pulverized coal, laser diagnostics of the combustion process in diesel engines, and development and application of new simulation and laser measurement technologies for combustion processes.

The government has supported R&D for fuel cells since 1986. In 1990, the Dutch Fuel Cell Corporation (BCN BV) was established, through which ECN, Stork N.V., and the Royal Scheldegroep B.V. cooperate in developing and commercializing molten carbonate fuel cell (MCFC). Government funding for this fuel cell program has been quite substantial, but in recent years has been declining as this technology gets closer to the marketplace. Novem's current fuel cell program (1996-2000) *($ 3.5 million, 1998)* is focused on stimulating through research, development and demonstrations the wider application of MCFC, solid oxide fuel cells (SOFC), and solid polymer fuel cell (SPFC). Within this program, ECN is supporting the development of a second generation MCFC that incorporates direct internal reforming so that CH_4 can be supplied directly to the fuel cell. Research is also focused on extending the lifespan of the MCFCs by developing alternative electrolytes. The SOFC program is carried out collaboratively between the Technical University of Delft and European Union partners and is directed towards the development of ceramic components (membrane electrode assembles, MEA's), required to develop micro- and mini-cogeneration systems. Other SOFC research activities are focused on methanol fueled application in transport. ECN is developing a methanol-reformer for SPFC application in hybrid vehicles.

The ECN's Fuels, Conversion and the Environment Unit concentrates its attention on developing efficient and environmentally acceptable gas conversion technologies (also coal conversion technologies). Applied catalysis (essential for, e.g., fuel processing for various types of fuel cells,

natural gas combustors, coal gas cleaning, and off-gas cleaning) and advanced materials and ceramic technology (e.g., structural catalysts, ceramic membranes, absorbents for gas cleaning and ceramic burners) are main areas of attention. In the area of advanced gas technology, a micro-cogeneration unit (1 kW_e) is being developed on the basis of free piston Stirling technology combined with condensing boiler technology. The government is also sponsoring modeling activities (ASPEN+) to evaluate the technical, economic, and environmental aspects of conversion technologies such as coal and biomass integrated gasifier combined cycle systems; high temperature fuel gas cleanup systems; gas turbine combined cycles; natural gas fuelled CHP plants; coal and biomass-derived gas-fueled fuel cell systems (MCFC, SOFC); fuel cells for transportation (PMFC); CO_2 removal and disposal/utilization; H_2 production from fossil fuels; ceramic membrane applications; ceramic foam and catalytic burner applications; and pyrolysis of mixed plastics.

Nuclear (Fission & Fusion) R&D *$17.0 million (1996)*

In 1996, approximately 4% of the government's energy RD&D budget was devoted to fusion research and approximately 9% went to support fission research. Nuclear energy R&D institutes receive their funding directly from the Ministry of Economic Affairs, i.e., it is not channeled through an intermediary like Novem. The Netherlands fusion research activities are mainly performed at NWO's FOM-institute for Plasma Physics (Rijnhuizen). These fusion research activities are integrated with the European Union's fusion program, coordinated by EURATOM. The research is focused on low-activating construction materials, plasma physics, and heat transport in plasmas at high temperatures. Fission energy R&D is performed by the ECN's Nuclear Energy Unit, Delft Technical University, and KEMA. The focus of this research is on reactor safety and new safer reactor technologies such as HTR / INCOGEN, reactor materials, waste disposal (underground storage in salt layers), probabilistic safety assessments, reliability analysis, non-proliferation (e.g., recycling of the actinides) and decommissioning. In 1997, ECN and KEMA merged their expertise and experience (radiation technology, health physics, energy technology, engineering, and licensing assistance) to form the Nuclear Research & Consultancy Group (NRG).

Other Energy-Related R&D Programs

VROM/NWO National Research Programme on Global Air Pollution and Climate Change

In 1995, the Dutch government launched the second phase of the National Research Programme on Global Air Pollution and Climate Change *($ 27.5 million, 1995-2001)*. This program supports research currently carried out at more than 30 Dutch universities and research institutes focused directly or indirectly on climate change. This program supports research in four broad theme areas: understanding the climate system and its component parts (theme 1), the effect of climate change on natural and social systems (theme 2), societal causes and solutions for climate change (theme 3), and integrated assessment modeling and outreach efforts (theme 4). The activities supported by this program are undoubtedly broader than energy R&D. Sub-themes covered are land use; energy and materials; mobility and transport; population development, lifestyles, and patterns of consumption; perceptions, attitudes, and societal support; and structures, institutions and instruments.

NWO/Novem program to Stimulate University Energy R&D

By order of the Ministry of Economic Affairs and the Ministry of Education, Culture, and Sciences, Novem and NWO are developing a program for stimulating university-based energy R&D *($6 million in total)*. The principal focus of this research is to have the universities carry out interdisciplinary research to explore the social/technological factors that would influence the deployment of renewable energy systems aspects. It is also hoped that this program would bring more coherence to university-based energy R&D and strengthen interactions between basic and applied energy R&D programs.

In addition, STW/NWO is initiating a Programme on Renewable and Energy Efficient Energy Sources that will support university-based energy research in the areas of: PV solar energy, heat pumps, efficient coal combustion, and high-temperature superconductivity.

Top Research Schools

Two of the Netherlands' so-called Top Research Schools carry out research related to energy R&D. Top Research Schools are selected by the government based upon their demonstrated expertise in a given area and are awarded grants totaling $ 1.5 to 5 million a year over a maximum ten-year period. The Research School "Catalysis Controlled by Chemical Design" (a collaborative effort among 7 universities) focuses on developing tailor-made catalysts. The Research School "Materials Science Centre" (based at the University of Groningen) conducts research related to characterizing the structure and properties of advanced materials such as metals, ceramics and polymers.