

INTRODUCTION

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This is a summary of the book 'Rapid Current' (in Dutch), which is the tangible result of a study project of the Netherlands Study Centre for Technology Trends (STT). STT explores future developments at the interface of technology and society. 'Rapid Current' deals with the interaction of electrical technology and developments in society. The project was concluded in 1999. More than 60 authors participated in the project. This summary offers a survey of the major trends and conclusions, with the aim to inform a wide audience.

'Rapid Current' is based on the increasing theoretical knowledge and practical experience of power electronics. This allows for more efficiency and efficacy in the application of electrical power for industry, companies, domestic purposes, transportation and all products and services that play a role in the total electrical chain. In addition, many other developments in technology and society come into play:

- New semiconductors, conductors, insulators and magnets.
- New electrochemical processes.
- Integration of information technology in power electronics.
- Liberalisation of the electricity market.
- Decentralisation of electricity generation.
- Sustainable energy management and energy saving.
- Demand for technology serving economy and environment.

Together, these developments may result in an increased pace of innovation in the entire electricity chain ('rapid current'). Thus, a century after the introduction of electricity in our society, the next electrical wave may be induced. This vision is supported in the book. Of the overall energy expenditure, the fraction of electricity is increasing, and in turn the importance of electrical technology increases too. This mutual development is coined 'electrification'. Also, electrical technology can be used to save energy. Even more importantly, electrification ameliorates sustainable energy management, since sustainable energy often becomes available in the form of electricity. Electrical innovations are crucial for the economic feasibility of the production of sustainable energy. 'Rapid Current' is a sequel to the publication of 'Electricity in

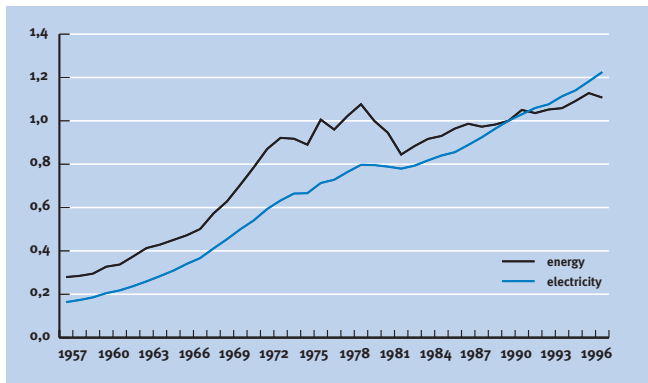


Figure 1 Electrification: In recent years, the Dutch electricity expenditure has increased faster than total energy expenditure as a result of the proliferation of electrical technology. To show this clearly, the expenditures of 1990 have been set to 1. In 1990, 10,7 % of total expenditure was by means of electricity. After [CBS, 1997; CBS, 1998].

perspective' (1992) that was mainly focused on industry. In the Netherlands the process industry is the largest consumer of energy. 'Rapid Current' deals with products and processes outside industry. The book consists of two parts. Part 1 offers a future vision from the perspective of historical development, the local, national and global grids, urban innovations and electrical transportation. Part 2 displays the technical developments that support the vision of part 1. Both parts combined lead to the conclusion that various goals for economy and environment can be met by electrification.

ELECTRIFICATION, ECONOMY AND ENVIRONMENT

Electricity production and supply will be fully liberalised in 2020. Transport and distribution will be separated from production, and will be the responsibility of independent entities that are regulated by government. Producers, traders and brokers will compete on the free electricity market. Scaling up and globalisation will be the key words for the traditional production sector for the coming years. It is expected that in 2020, in addition to many regional independent utilities, a few global players will control large scale electricity generation. Distribution companies will distinguish themselves by offering new energy-related services, such as the management and control of electricity consumption of domestic appliances. Short-term investments in energy saving, environmental improvement and sustainability by competitors on the electricity market will be reduced by low return on investment. The ratio of sustainable and fossil energy prices is of crucial significance. Government policy therefore must encourage such investments, for instance by demanding rigid environmental performance requirements or by acting as a launching customer.

Sustainable electricity

Hydroelectric power currently takes care of 80% of global sustainable electricity. The Netherlands currently has no potential hydroelectric sites. Nevertheless, the Netherlands can generate large amounts of sustainable electricity. The prime potentials for large scale generation are in tapping wind- en solar energy. The continental shelf offers a site for large- scale wind parks, in theory sufficient to cover the total Dutch energy *consumption* of 1996. On favourably situated roofs in Holland, there is room for photovoltaic modules covering up to 10% of the *electricity consumption* of 1996. Sustainable photovoltaic electricity may be imported more economically via the so-called ‘connector-grid’ (the connector between national grids) from southern countries with higher solar irradiation. The same applies for electricity from biomass, hydropower, geothermal power etc. The connector-grid needs to be expanded for this.

Globally, sun and wind offer the best potential for growth. In both cases, the accumulated potential is dependent on the available surface area and may reach a multiplicity of total world energy consumption. The maximum fraction of hydroelectricity is 50 - 70% of electricity consumption, but for social and ecological reasons the contribution will probably be limited to 3 - 4 PWh, or 10 - 15% of the electricity demand in 2020. Tidal energy is limited to certain locations and can supply not more than 0.7 - 2.2 % of electricity consumption in 2020. The estimated potential of wave energy is about 5%, but the associated technology still needs to be developed. Biomass continues to play a role, but in the long term it will have to compete with agriculture for the use of soil.

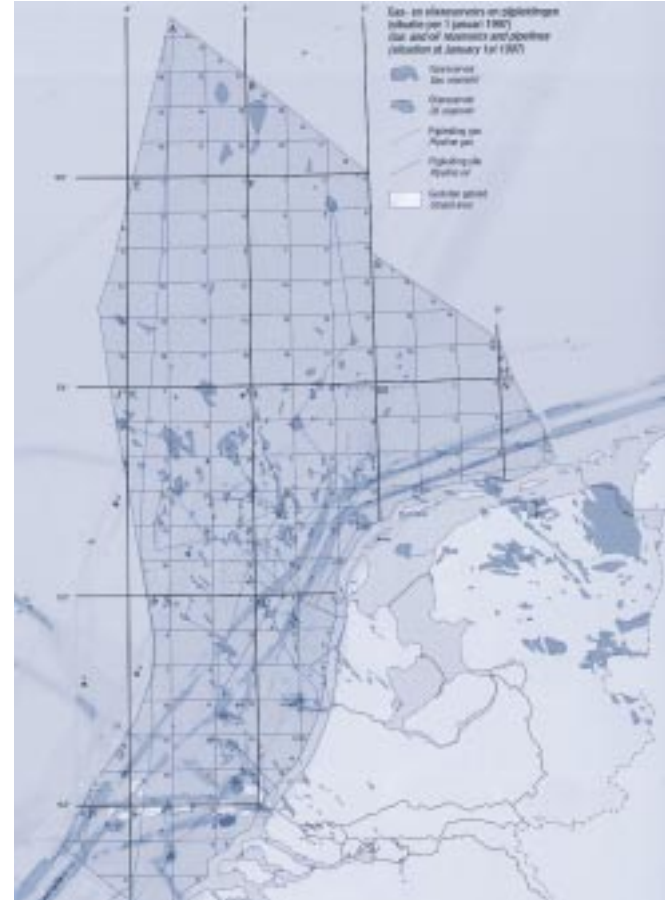


Figure 2 The Dutch continental shelf offers a site for sustainable electricity from windmills. It may be brought to land with HVD connections. Locally explored natural gas can be converted to electricity as well and transported using the same HVDC connection.

The increased connectivity of electrical grids

Through liberalisation and large-scale generation of sustainable electricity at remote locations, transport of considerable amounts of electricity over long distances will be necessary. Not just for national use, but also for transport between countries and adjacent continents. The interconnector evolves into a net for bulk transport. Should the international transports increase, then higher capacity connections with the Dutch 380 kV net and the foreign grids will have to be installed to prevent deterioration of the reliability. The same applies for the 380 kV grid itself. Increasing supply from the interconnector calls for an expansion of the transformer capacity of the sub-grids and subsequently an increase of the amount of connection points with these grids.

In the long run, a new large capacity Ultra High Voltage AC or DC supergrid may evolve, connecting all supply and demand between adjacent continents. The capacity of the connection with the grids will most likely have to be upgraded as well. 'Unified Power Controllers' will then be needed to equalise the power on all connectors. Under certain circumstances the HVDC connections may then be applied to stabilise the existing AC-grids. In addition, developing countries will shift from local grid use to international connections. Some of these countries may become net exporters of sustainable energy by connecting to the global supergrid, supplying the centres of demand. Continental supergrids may thus offer interesting advantages for environment and economy. Social and economical stability is a prerequisite for the success of such projects. The economic feasibility of transnational connections increases with the intensity of power exchange.

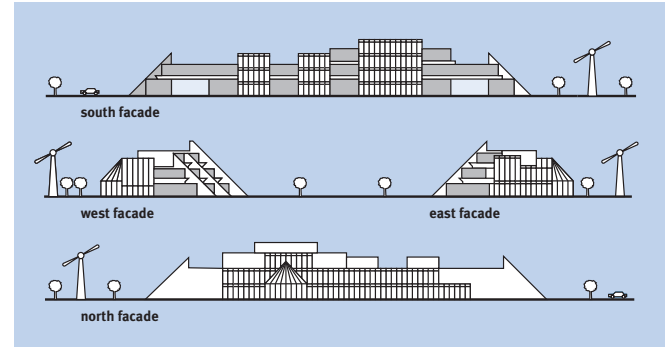


Figure 3 Design of a self supporting domestic 'unit' with 12 homes.

The future situation of bulk transport over long distances, combined with a lot of irregular local power generation, gives reason to worry about the stability of the electrical system. With large-scale implementation of wind and solar energy, storage may buffer the difference in time of supply and demand. Such buffers may improve stability. Most importantly, hydropower units will be used for storage. In addition, other storage systems will become important. For instance, the rapid power availability needed for stability may be accumulated in SMES (Superconducting Magnetic Energy Storage), flywheels, batteries or rows of capacitors.

HOMES AND OFFICES

Already, domestic energy consumption in the Netherlands and in many other countries amounts to over one fourth of the total. Also, domestic electricity demand is rising. It is therefore appropriate to focus on residences. The new residential areas that will be built in the next twenty years will largely consist of low-energy homes, if

possible supplied with means to generate heat and electricity. The Dutch government aims for a million photovoltaic roofs in 2020, with an average of 15 m² solar panels per roof. Orientation to the south (with the majority of the roof's surface area oriented between south-east and south-west) and low temperature heat transfer systems are important to use that power optimally. With integrated systems in the residential area, including offices, a considerable fraction of sustainable energy in relation to total energy consumption can be realised, with local electricity generation from sustainable sources as an option. The urban dwellings 'Autark' and 'Synergy' described in the book exemplify that integrated systems approach.

Without intermittent storage, photovoltaic energy may be used in offices and commercial buildings where electricity is needed during the day for airconditioning and appliances, and hardly needed at night. For homes this is different. The supply curve of solar energy has a mirror shape with respect to domestic demand, both during the 24-hour cycle as well as the annual cycle. Average wind energy supply is reasonably coherent with domestic demand. This leads to the question whether sustainable, locally generated electricity should be supplied to the grid to satisfy existing demand elsewhere, or whether it should be stored, waiting for local demand. It turns out that for low voltage (photovoltaic) electricity, the losses that occur with transport across the low and medium voltage grid are smaller than the charge and discharge losses in currently used lead-acid batteries. Should the electricity demand occur at very remote locations, in such a way that electricity has to be transported over the high-voltage power lines, then local storage in lead-acid batteries is more efficient.

TRANSPORTATION

The energy demand of transportation in the Netherlands is comparable to that of homes, and half of that of industry. In terms of energy saving, electrification is therefore worth studying. Electric vehicles are at least 20% more efficient than their combustion engine counterparts, taking into account the efficiency of electricity generation. The big advantage of electric transportation is clearly the reduced emission of NO_x and SO₂. Electrification of transportation will therefore save both energy and the environment.

The first successfully electric powered road vehicles will be hybrid cars, with an electric motor and a combustion engine. Serial hybrids, with both engines connected in series, are constructed with less mechanical parts than so-called parallel-hybrids. Also, they can profit from ongoing improvements of internal combustion engines.



Figure 4 *The Eco-Car: example of a half-width commuter.*

Source: Brink Dynamics.

With strong policy and strong support from society, battery-electric transportation may constitute up to 20% of the total fleet of cars. Battery-electric transportation, however, will proliferate only when the *specific energy* (in kWh/kg) of the battery amounts to 4 - 5 times the capacity of lead-acid batteries, and as soon as technology for rapid charging will allow for occasional charging when on the road. The first successful battery-electric vehicles will therefore be small and lightweight, designed for short distances to replace the second car generally used for shopping or commuting. By replacing mopeds with two-stroke engines by electrical versions, considerable environmental progress can be made.

Batteries

Promising types of batteries for transportation are currently the NiMH and the lithium-ion batteries. It appears that future cars with lithium-polymer batteries can compete with internal combustion engine cars. If we take the life cycle in terms of charge cycles into account, then the new battery types - provided they are industrially produced - will be significantly cheaper in use than conventional ones. Super capacitors may be used in hybrids and battery-electric vehicles to buffer the voltage-spikes and deliver the power needed for peak performance, thus increasing the life and the performance of the battery system.

To charge a battery of 30 kWh of an electric vehicle in 15 minutes, a rapid charger of 120 kW is needed. Such chargers may be located at gas stations, where they can be coupled to the medium voltage grid. This setup will cause no power problems. Rapid charging at home with chargers of 11 kW (which is the highest available power with 3 phase connections and 3 hours charging time) would con-

tribute largely to the possible success of battery-electric cars with advanced batteries. However, if only a small fraction of people in a residential area try to charge their cars at the same time, there will be blackouts in the low voltage grid. A temporary solution may be offered by power management. The only permanent solution, however, is expansion of the capacity of the supply grid.

The fuel cell will show up at first in a hybrid system (with batteries and supercapacitors to reclaim brake energy) in combination with a reformer for liquid fuel. The moment of introduction depends on the cost development of fuel cells and the development of onboard reformers. Recent publications point out that such reformers for fossil fuels may become available within five years. Driving without carbon dioxide production will only be possible if fuel can be generated from biomass, or if reliable, economical and safe methods for hydrogen storage become available. The larger the support in society for sustainable energy management and the larger the economic progress, the more electric cars will show up on the street.

Zoning and stimulating specific vehicles for dedicated areas will probably help to electrify transportation. It is expected that transportation concepts such as car sharing systems, electric rail transport, environmentally friendly city transport and rental systems may also have a positive influence on the electrification of people movers. Electrification of freight transportation can further be intensified by electric rail transportation and the realisation of centres for urban distribution. Electric rail transportation will intensify, and it will become more energy-efficient. At large railway stations, significant amounts of energy can be saved by storing the braking energy via the overhead contact wire and subsequently making it



Figure 5 *High power semiconductors. The sizes of these chips as well as the power density increase, allowing for the switching of tremendous powers.*

available for the next departing train. Also, braking energy storage in the train itself is possible.

Electrification of ships may offer some specific advantages, not in the least increased knowledge and spin-off technology. Dredgers already display an increased level of electrification. Given the increased interest in the application of electric propulsion, it may be worthwhile to investigate the possibilities for generating electricity from onboard windturbines. In addition, electrification allows for innovative propulsion design, such as the shaftless propeller. Electrification of airlines is not an issue, but small airplanes and -ships for research or satellite purposes are being conceptualised and tested.

THE TECHNOLOGY

Part 2 of the book provides an overview of technological developments in electricity and magnetism. To improve the management of the transmission of electricity over power lines and cables, advanced materials and manufacturing technologies are being implemented. Superconducting materials already have reached the stage of application for specific applications. An important factor in this is the advancement of cryogenic technologies. Applications such as current limitation and accumulation (SMES) therefore come within reach. Increased power capacity, voltage level and switching frequency is apparent in semiconductor switches. Moreover, they are more robust and cheaper than conventional switches. However, there is also an induced problem: the mutual influence of components can no longer be disregarded. The electromagnetic fields will influence the behaviour of the circuit as a whole. There is insufficient knowledge to predict this change in behaviour. More knowledge of the synthesis of electromagnetic fields is required, particularly with regard to the ongoing miniaturisation and integration of active and passive components.

Advanced power control has become available through coupling and even integration of semiconductor components with information technology. Information technology is the brain, and power electronics the muscles in controlling electrical power. Thus an electric motor can be controlled to deliver the maximum momentum at any rotation speed. This also allows (software) design of the acceleration behaviour of electric cars. Integration of these kinds of technologies leads to so-called smart power chips in which the software control is integrated with the power electronic semiconductors.

Integrated approach of the complete electricity chain from source through power electronics to traction is crucial to reach the optimum performance in driving characteristics of all electric vehicles. Many components will be fitted with sensors and interfaces. Timely standardisation of these interfaces between the various components of the traction system will lead to greater flexibility and cost saving.

Part 2 continues to deal with materials for electric isolation, conduction, superconduction, semiconduction and permanent magnets. Additionally, power-electronic transformers are described. These fundamental technologies are broadened with an overview of new technologies in all parts of the electricity chain. With respect to power generation, new principles of static and dynamic transformation are discussed and extrapolated to provide a long-term future vision, including nuclear fusion and space power stations. With regard to transmission and distribution, the choice between AC and DC is discussed including DC-converters and modern devices such as 'FACTS' (Flexible AC Transmission Systems) and 'Power Quality Conditioners'. Methods for on-line monitoring of components in the distribution system are also discussed, as well as wireless power transmission. Attention is then geared to storage systems with advanced batteries, (super)capacitors, SMES, flywheel systems and pump-accumulator systems. Obviously, new electrical conversion developments are being focused on extensively, with emphasis on energy saving. Classified into light, heat and cold, force, power supplies and separation and cleaning, more than 30 conversion technologies are discussed.

CONCLUSION

Many of the new technologies in this book will play an important role in developing a world-wide electricity system, combining free market and reliability. With an increasing diversity of small and large suppliers and users, the grid will evolve into an 'internet' for electricity.

Measures will remain necessary to curb the rise in global energy consumption that pops up in each future scenario. The technologies described in this book may be applied to assist these measures through energy saving and increased efficiency. Also, the technology offers possibilities to help fulfilling our wishes in terms of sustainability. Both large and regional projects for sustainable generation, transmission, storage, distribution and conversion of electricity will be crucial. The knowledge and know-how that are required for this transition are coming within reach. Whether the transition itself will create a rapid change in the world of electrical current is dependent above all on politics and economy.

PUBLICATION RAPID CURRENT

STT-publication nr. 61 '*Rapid current, The next wave of electrical innovation*' including this separate summary, can be ordered from STT (telephone +31 70 3029830). The price is f 125,- excluding postage and handling. (ISBN 90-804496-2-8).

NETHERLANDS STUDY CENTRE FOR TECHNOLOGY TRENDS

The Netherlands Study Center for Technology Trends (STT) was established in 1968 by the Royal Netherlands Institution of Engineers (KIVI) for the purpose of exploring future technological developments and, in particular, their significance for society in general. STT is able to carry out its work thanks to financial support from industry, the KIVI, and the government, and by the participation of Dutch and Flemish experts within the projects.

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