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Luxembourg: Office for Official Publications of the European Communities, 2003
ISBN 92-894-6262-0
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Printed in Belgium

Printed on white chlorine-free paper
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G L O S S A R Y

CHP Combined Heat and Power
DER Distributed Energy Resources
DCS Distributed Control Systems
gDG Distributed Generation
gDSO Distribution System Operator
gERA European Research Area
gERG Embedded Renewable Generation
FACTS Flexible AC Transmission Systems
GHG Greenhouse Gas
GW Gigawatt (10^9 watts)
ICT Information and Communication Technology
IPP Independent Power Producer
kW Kilowatt (10^3 watts)
MW Megawatt (10^6 watts)
OECD Organisation for Economic Cooperation and Development
PANDA Plan and Data Acquisition system
PV Photovoltaic
RTD&D Research, Technological Development and Demonstration
RES Renewable Energy Source
SME Small and Medium-Sized Enterprise
SCADA Supervisory Control and Data Acquisition
TSO Transmission System Operator
TW Terawatt (10^{12} watts)
UPS Uninterruptible Power Supply
WT Wind Turbine
Philippe Busquin, European Commissioner for Research

Nowadays most of Europe’s energy needs are supplied from shrinking fossil fuel resources (oil, gas and coal), largely imported into the European Union. As energy demand continues to grow, this external dependence could grow from 50 to 70% in 25 years or less. Meanwhile, climate change and pollution are issues of increasing concern to European citizens.

To ensure the future well-being and economic prosperity of our citizens, a key strategic objective of the EU in the energy domain is to secure a supply of energy that must be clean, sustainable and economical. Furthermore, the establishment of a European liberalised internal market for energy will bring benefits in terms of improved energy efficiency, increased choice and reduced costs to all consumers.

With these overall objectives in mind, the EU has developed a long term energy RTD strategy, spanning from renewable energies to fusion. The Sixth Framework Programme provides the elements required for the implementation of such a strategy1.

In addition to acting on the demand side and improving efficiency, ensuring the security of supply of clean energy requires the complete development of new sustainable energy generation and transformation technologies, such as renewable energies and fuel cells. Energy grids will need to be reinforced and managed by innovative supervisory systems, enhancing reliability and minimizing risks of major disruptions, such as the recent blackouts that occurred on both sides of the Atlantic. The final goal is to develop a sustainable system where hydrogen and electricity will be the main interchangeable energy carriers, with fuel cells having the ability to transform one into the other.

What is known as Distributed Generation is a new model for the power system. It is based on the integration into electricity networks of small and medium size generators based on new and renewable energy technologies. It may create a new era, where thousands or millions of users will own their generators, becoming both producers and consumers of electricity. All these generators will be interconnected through a fully interactive intelligent electricity network. This revolution will require sophisticated control and communications technologies to ensure smooth operation of electricity networks, the establishment of new models for power distribution, as well as the development of advanced energy storage technology, power electronics and superconducting devices. In addition, it will require multidisciplinary actions for co-ordinating basic research whilst keeping close interaction with normative and regulatory developments involving social and economic factors, and addressing policy, legal and administrative challenges.

Further to the benefits for citizens and society at large, the market potential for these new technologies, the new distribution models and associated business services in both the developed and developing regions of the world are tremendous. To exploit these opportunities, it is crucial to place the European industries and SMEs at the forefront of these technological developments.

With this brochure we intend to raise the public and political awareness of the area and associated RTD activities financed by the European Union. It offers a vision of future electricity grids based on the integration of renewable energies and distributed generation, describes the technical challenges in front of us, and provides an overview of ongoing RTD efforts in the area supported by the EU.

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1 Energy related activities are covered by the area “Sustainable energy systems” of the thematic priority “Sustainable development, global change and ecosystems” of the EC Framework Programme, and by the entire Euratom Framework Programme.
The EU strategy for sustainable development, endorsed by the Gothenburg European Council in June 2001, calls for the integration of social, economic and environmental policy objectives. Energy has deep and broad relationships with all three pillars of this strategy. It is a precondition for economic development, essential for social well-being, and a decisive factor for environmental improvement. In addition, the growth in global energy demand is rapid, especially in the developing world where some 2 billion people are without access to modern energy services.

In the European Union, the satisfaction of energy needs is crucially linked to security of energy supply and commitments to reduce greenhouse gas emissions. The development of distributed generation and renewable electricity generation technologies are essential to achieving these goals. In the longer term, Europe has a vision of a sustainable energy system where hydrogen and electricity act as the two main energy forms with fuel-cell technology providing the bridge between them. Together, these interchangeable energy carriers provide a unique pathway to gradually decreasing our dependence on fossil fuels, and reducing greenhouse gas emissions and pollutants.

Energy research is the mainstay of any long-term energy policy. It has to provide scientific knowledge and technological options to make energy systems more efficient, affordable, accessible, and environmentally friendly. Research and technology activities must support energy strategies that facilitate the transition from a fossil fuel energy economy to a sustainable energy regime. Strategic objectives include ensuring security of energy supply, minimising environmental impact, and boosting the competitiveness of European industry – both in terms of enabling reduced energy costs through a fully functioning European liberalised electricity market and providing new technologies and service opportunities with huge commercial potential around the world.

An increasing part of Europe’s energy needs is imported and action is required to reduce economic vulnerability to external factors. No single energy option has the capacity on its own to fulfill all energy demands, so there is a need to develop and incorporate diversity of supply. An increased role for electricity is essential to enable such diversity.

Research and development is the cornerstone of continuous invention, adoption and improvement of more energy efficient systems, products and processes. New and renewable energy sources and related technologies are essential components of the path towards sustainable development. The European Union has set a target of doubling the share of renewables in total energy consumption to 12% and achieving 22% electricity generation from renewable sources by 2010. Although renewable sources represent the fastest growing energy source in the world, they still have to overcome many technical and financial barriers to achieve their full potential in the market.

The integration of renewable and other efficient distributed power generation sources into existing and future unified electricity systems represents an enormous technological challenge. This brochure demonstrates the actions being undertaken by the European Commission, in conjunction with the electricity industry and research institutions, both now and in the future, to meet that challenge and to provide Europe with a new era of sustainable electrical energy.
By 2050, the World Energy Council envisages the global energy mix will be made up of at least eight energy sources (coal, oil, gas, nuclear, hydro, biomass, wind and solar) with none expected to have more than a 30% share of the market.

Electricity can make this diverse supply portfolio possible whilst simultaneously meeting global energy and environmental demands. According to the International Energy Agency, in the coming decades, electricity’s share of the total energy market in OECD countries is expected to grow from 24% in 1970 to 40% in 2020, as more efficient and intelligent processes are introduced into industry, business, homes and transportation.

Electricity is the most critical strategic infrastructure in our society today and its importance will increase in the future. Its direct importance in reliably delivering energy to point of use enables every other major technological infrastructure in our society. Together with hydrogen, it is seen as the dominant future energy form. Using fuel-cell technology, the two forms are effectively interchangeable providing the potential for hydrogen to be a large-scale storage medium for electricity.

Today, a complex reorganisation of the electricity power industry has started in Europe, encouraging competition in both the wholesale and retail sectors of the market. To facilitate the creation of an open single market in electricity, further effective interconnection of Member States’ national grids is needed.

In the near future, power utilities may still operate regulated distribution systems but, in the longer term, the production, brokerage and sale of electricity, and new power services, will be a competitive function of the unified electricity market.

This will require the transformation of the conventional electricity transmission and distribution grid into an interactive and unified power supply network. Major technological and regulatory changes will be the basis of this new electricity service paradigm which is itself a prime driver for the substantial European research effort in this area. Removing the geographical constraints on the delivery of power supplies will lead to increased competition and enhanced quality, reliability, security and safety.

Distributed generation (DG) will play a key role in this novel concept. It covers a broad range of technologies, including many renewable technologies supplying small-scale power at sites close to users. Highly efficient combined heat and power (CHP) plants, back-up and peak load systems are providing increasing capacity. Together with renewable energy, these technologies offer new market opportunities and enhanced industrial competitiveness. To pave the way to a sustainable energy future based on a large share of DG, there is a clear need to prepare the European power system for the large-scale integration of both renewable and other distributed energy sources including fuel cells.

The greatest potential market for DG is displacing power supplied through the grid. On-site production minimises transmission and distribution losses as well as transmission and distribution costs, a significant part (above 30%) of the total electricity cost.

As the demand for more and better quality electric power increases, DG can offer alternatives for reliable, cost-effective, premium power for homes and business.

DG can provide customers with continuity and reliability of supply, when a power outage occurs at home or in the neighbourhood, restoring power in a short time. In other words, convenience, security and peace of mind are potential major drivers following several blackouts which have been experienced lately.
DG also provides advantages to those customers with sizeable heat loads, through the operation of CHP units, to those with access to low-cost fuels, for example landfill gas or local biofuel, and to those with favourable climatic conditions who can exploit renewable-based units.

DG can also stimulate competition in supply, adjusting prices via market forces. A DG operator can respond to price incentives reflecting fuel and electricity prices. In a free market environment, a DG operator can buy or sell power to the electricity grid – exporting only at peak demand and purchasing power at off-peak prices. DG can act as a physical ‘hedge’ against volatile electricity prices.

A liberalised market allows IPPs to contract with other producers and market actors for back-up electricity, voltage or reactive power support, frequency responsive spinning reserve, black-start capabilities, and other ancillary services.

DG can also offer additional value to the grid system operators by:

• Deferral of upgrades to transmission and distribution systems;

• Reduction of losses in the distribution system; and

• Provision of network support or ancillary services.

DG is based to a large extent on RES or is characterised by very low emissions. In addition, the operation of DG can contribute to the reduction of losses, thus making further contributions to energy saving.

What is Distributed Generation?

Distributed generation can be defined as a source of electric power connected to the distribution network or the customer site. This approach is fundamentally distinct from the traditional central plant model for energy generation and delivery. The wide development of DG requires a thorough examination of all technical and non-technical aspects of an increased use of renewable energy resources and other decentralised generation units in distribution networks.

Opportunities for barriers to DG

A recent survey undertaken by ENIRDGnet to assess the driving forces creating demand for DG in European countries indicated that the most important drivers are:

• Environmental concerns

• Deregulation of the electricity market

• Diversification of energy sources/energy autonomy

• Energy efficiency

These drivers have translated into a variety of country-specific incentives and tax policies to promote DG uptake.

The same survey found that the main barriers to uptake of DG are technical constraints, such as design procedures, limitations on rural network capacity, and fault level restrictions in urban areas, and a lack of interconnection standards. Increasing difficulties in obtaining planning permission, particularly for wind turbines and the electricity lines to connect them, is also an obstacle in many countries.
Today's electricity network is the result of technological and institutional development over many years, with most of the electricity generated in large central power stations and transmitted through high-voltage transmission systems. The power is then distributed to consumer via medium- and low-voltage local distribution systems. In this paradigm, power flows only in one direction: from the central power station to the network and to the consumers. The system from power generation to consumers is often controlled by a monopoly national or regional supplier acting as both transmission system operator (TSO) and distribution system operator (DSO).

As the market is liberalised, monopoly control of the system will change with multiple TSOs and DSOs operating it transparently to enable the market, and without discrimination under the governance of a regulator. To operate successfully, all players in the system must have a common set of guidelines. It will also require a more active role for DSOs in controlling network stability, optimising central and distributed power inputs, interconnection and, of course, metering and billing.

The drivers for these changes are multiple and symbiotic. However, they all have their basis in the common concerns to use primary energy as efficiently as possible, with the least possible environmental impact whilst ensuring that energy supply is secure, safe and supplied at an agreed quality universally and at a competitive cost.

In general, distributed generation reduces energy transmission losses – estimates of power lost in long-range transmission and distributions systems is of the order of 7% in OECD countries – and helps to bypass ‘congestion’ in existing transmission grids. It enables the use of waste heat (via CHP) improving overall system efficiency. Power quality and reliability can also be enhanced. From an investment point of view it is generally easier to find sites for RES and other DG than for a large central power plant and such units can be brought on-line much more quickly. Capital exposure and risk is reduced and unnecessary capital expenditure avoided by matching capacity increase with local demand growth.
The opportunities presented by these technology changes are multiple. The increased penetration of RES and other DG, together with higher energy efficiency, will help security of supply by reducing energy imports and building a diverse energy portfolio. The new technologies developed and the experience of implementing new energy management models will provide invaluable expertise and knowledge with immense export potential. Wide-scale use of RES will reduce fossil fuel consumption and GHG emissions as well as noxious emissions such as oxides of sulphur and nitrogen (SOx/NOx) therefore benefiting the environment. Increased opportunities for smaller-scale generators will revolutionise production for the benefit of consumers and the distribution system itself, whilst the integration of RES and other DG themselves will create new markets and business opportunities – in particular for SMEs specialising in ICT and electricity marketing issues.

Architecture of future electricity systems

The models for the architecture of future electricity systems recognise the fundamental fact that with increased levels of DG penetration the distribution network can no longer be considered as a passive appendage to the transmission network – the entire system must be designed and used as an integrated unit. In addition, this increasingly complex operation must be undertaken by a system under multiple management.

Three conceptual models have been envisaged: Micro- (or Mini-) Grids (see box), Active Networks supported by ICT, and an ‘Internet’ model – all of which could have an application depending on geographical constraints and market evolution.

Active networks are envisaged as a possible evolution of the current passive distribution networks and technically and economically may be the best way to facilitate DG initially in a deregulated market. Active networks have been specifically conjectured as facilitators for increased penetration of DG and are based on a recognition that new ICT technology and strategies can be used to manage the network actively.

The model employs two novel concepts. The first is that the primary role of the network is to provide connectivity – i.e. the network is a highway system that provides (multiple) links between points of power supply and demand.

Micro-Grids are small electrical distribution systems that connect multiple customers to multiple distributed sources of generation and storage. Micro-grids are typically characterised by multipurpose electrical power services to communities with populations of up to 500 households with overall energy demands of up to several thousand kWh per day, and are connected via low-voltage networks. These hybrid systems have the potential to provide reliable power supply to remote communities where connection to transmission supply is uneconomical. A number of demonstration projects have been undertaken in the Greek islands using this type of system.

The model could also have a more general application. Micro-grids can be established and operated in parallel with the bulk high-voltage transmission supply system in some conditions and in transition to ‘island’ (or stand-alone) operation during abnormal conditions such as outage in bulk supply or during an emergency. This type of grid structure offers the potential for improvements in power supply efficiency, reliability, power quality and cost of operation in comparison to traditional power systems. It can also help overcome constraints in the development of new transmission capacity that are beginning to impact the industry. The low-voltage-only approach could yield significant cost savings and power quality improvements as well as safety benefits. The development of special control and generator protection systems would be needed to ensure proper operation of such a system.
The second is that the network must interact with the consumer. The current system essentially provides an ‘infinite’ system in that the network itself remains virtually unaffected whatever happens on the supply or demand side. If customers require such a supply then they should pay for this ‘premium’ service.

The structure of this model is based on increased interconnection as opposed to the current mostly linear/radial connections, relatively small local control areas, and the charging of system services based on connectivity. The active network has some analogies to telephone networks and requires active management of congestion, unlike conventional passive systems that rely on Ohm’s law to determine power routing. With increased distribution of power input nodes as a result of DG, bi-directional energy flow is possible and new technologies are emerging that can enable the direct routing of electricity. New power electronics systems offer ways of controlling the routing of electricity and also provide flexible DG interfaces to the network. Flexible AC Transmission Systems (FACTS) and Custom Power Devices at lower voltages offer the potential to manage the routing of power supply in an active manner.

Each node, whether a gigawatt natural-gas power station or a single solar photovoltaic panel, needs to be controlled and the necessary number of combined control tasks multiply. Application of FACTS, or similar technology, increases the number of control parameters. Accurate information on the state of the network and coordination between local control centres is essential using state-of-the-art ICT.

Electricity transmission in the system is not dependent on a single route, so failure due to a single component problem is reduced. However, an inherent risk of interconnected networks is the ‘domino effect’ – that is a system failure in one part of the network can quickly spread. Therefore, the active network needs appropriate design standards, fast-acting protection mechanisms and automatic reconfiguration equipment to address potentially higher fault levels.

The greatest change in the active network model is at the local control area level where each defined area has its own power control system managing the flow of power across its boundaries. The system would be ICT-based with management enabled by remote actuators controlling the system. The central area control computer would ‘negotiate’ with neighbouring areas on the exchange of power. If an area was isolated, then the system would react by disconnecting enough load or generation to maintain the correct power balance. This could lead to considerable improvements in the reliability of the supply system as a whole. This model requires relatively little further investment in infrastructure, except to reinforce some areas of the network to provide increased interconnection and investment in automated switch gear.

The internet model effectively takes the active network to the global scale but distributes control around the system. The flow of information around the World Wide Web/Internet uses the concept of distributed control where each node, web host computer, e-mail server or router acts autonomously under a global protocol. In the analogous electricity system, every supply point, consumer and switching facility corresponds to a node.

The vision of the Internet model is:

“Every node in the electrical network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming – and interconnected with everything else” [Source: The Wired]

An agreed protocol for exchange of information about power demand and supply could make it possible to distribute the control of the electricity distribution system to a much smaller scale. Each node would ‘listen’ to the rest of the network, adjusting its power pro-
duction or consumption in relation to the global state of the electricity network.

The intelligent FACTS at the nodes between producers and consumers would ‘route’ power between the nodes in the same way as e-mail is routed from node to node on the Internet. The integration of ICT into the centralised grid transforms it into a fully interactive intelligent network. Sensors and intelligent agents embedded in the grid provide instantaneous information on energy conditions throughout the system, allowing current to flow exactly where and when it is needed and at the cheapest cost. This information and control layer would extend into the home: systems already exist that can adjust domestic thermostats to ‘shed load’ at times of network ‘stress’.

The internet model allows the easy addition of new sub grids as the level of control is at the level of the nodes themselves. The ‘power’ protocol would provide standard components and interfaces giving ‘plug-and-play’ capability for any new entrant to the network as long as they managed their operations in a manner compatible to the protocol.

The development and acceptance of such a protocol would require the involvement of a large number of stakeholders and could be a complex negotiation. Looking ahead, the development of accompanying commercial measurements would also be necessary. However, in the advent of DG shifting the responsibility of electricity production to a larger number of actors generating on a much smaller scale makes the idea of such distributed networks becomes advantageous.

New business roles

The arrival of new distribution paradigms and increased DG penetration in a single market will bring new business opportunities. The communication systems required to operate the energy market will be open systems and an effective energy ‘stock market’ will be enabled. Such systems will require uniform energy and information interfaces to be established, probably using Internet-based information networks.

Access to this information will allow new roles for energy brokers, the establishment of ‘virtual energy’ companies and variable energy tariffs. Trading in energy futures and other financial instruments will be much wider than it is today.

The virtual utility

The Internet has created many new opportunities. A conventional power station generates electricity in one location, using (usually) one type of generating technology and is owned by one legal entity. A virtual power station is a multi-fuel, multi-location and multi-owned power station. Both stations supply energy reliably at predetermined times. Today this means making a power supply contract for each hour of the next day. The power stations must be able to change their power output quickly and sell this capability as ancillary services to the grid operator.

For a grid operator or energy trader, purchasing energy or ancillary services from a virtual power station is equivalent to purchasing from a conventional station. The concept of a virtual power station is not in itself a new technology but a method of organising decentralised generation and storage in a way that maximises the value of the generated electricity to the utility. Virtual power stations using DG, RES and energy storage have the potential to replace conventional power stations step by step until a sustainable energy mix has developed. Extending this concept to a virtual utility merely extends the services available.
RES includes wind power, hydroelectric, solar photovoltaic power, concentrated solar power, ocean power, geothermal, and biomass. They are outlined below together with other new clean technologies, such as fuel cells, which have low environmental impact.

There is a huge potential for renewable energy sources to provide a sustainable electric power supply. However, currently they are making a disappointingly small contribution of around 6% to the EU-15’s overall gross inland energy consumption, two-thirds of which (4%) represents the contribution of hydropower. The total figure equates to around 14% of EU electricity generation.

In 2001, the EU adopted a Directive on electricity production from RES under which Member States undertake to comply with national targets for future consumption of electricity produced from RES, to set up a system of guarantees of origin of green electricity, and to introduce accompanying measures to facilitate the market penetration of green electricity in the internal market. Within this regulatory framework, by 2010 22% of the electricity consumed in the EU should be produced from RES. For comparison purposes it should be noted that total EU-15 electricity generation was around 2 500 TWh for 2002 and the estimated electricity generation for 2010 is about 3 025 TWh, while a higher figure is expected for the EU-25.

Looking ahead during this period and beyond, planned increases in generation capacity over the coming years are expected to result in valuable but incomplete system reliability coverage. Future architecture of electricity systems can play a role in improving power reliability and quality, as well as allowing a transition towards interconnected grids using common European planning and operational systems based on a large share of both renewable and other distributed energy sources.

Wind power is a great success story for RES, with some areas of Europe achieving a significant percentage of total generation capability – approaching 100% of baseload at certain times. Growth in wind power generation is significant and over 30 GW of capacity had been installed worldwide by the end of 2002, the vast majority (over 22 GW) of this being in Europe. An assessment of resources in Europe has identified a capacity of some 1 000 TWh per annum. Currently, the largest wind turbines can deliver up to 4.5 MW with typical commercial installations rated at 1.5-2.5 MW. WT research is concentrating on widening the conditions for competitive operation both on- and offshore. Today’s market for wind turbines is some 3 billion per year and growing strongly. A US survey estimates a global market size of $49 billion by 2012.

Hydroelectric is the most important RES, from a global perspective. The global exploitable capacity exceeds 14 000 TWh, of which some 2 500 TWh is utilised. Small hydropower plants rated at an installed capacity of 10 MW or less currently contribute more than 37 TWh per annum or 2.5% of the European electricity market. Modernisation, reconditioning and the exploitation of new sites will mean that around 50% of the remaining small hydropower sites in Europe will be exploited by 2015. Hydropower has the potential to become more economically attractive via improved turbine designs and cost-effective plant construction in combination with new technologies for control and operation. From an operational standpoint, a hydropower station can start very quickly and the power output can be controlled accurately.

Photovoltaic (PV) is a potentially clean, reliable and consumer-friendly RES. The cost of producing PV electricity has fallen dramatically over the past decades, but it is still only competitive in niche (usually remote) ‘stand-alone’ applications. Such systems generally involve storage systems, and hybrid systems...
also include one or more auxiliary power generators to ensure continuity of supply. Large (1 MW+) projects have also been undertaken with all electricity supplied to the grid through an inverter. Worldwide PV sales could reach 6 GW by 2010 with an important portion for decentralised power generation; one US survey estimates the market for PV equipment in 2012 to be $27.5 billion. In the EU, it is estimated that significant market potential exists, perhaps as high as 2 000 MW in 2010, compared with 52 MW in 1995 and around 200 MW in 1999. During 2002, installed PV capacity in the EU grew from 3 862 MW in 1995 to 8 766 MW in 2010, especially for biomass applications in decentralised plants and for substituting fossil fuel in electricity generation.

Future trends are likely to be towards larger unit sizes of 50-100 MW and increases in efficiency of up to 50%. New technologies, including biomass-integrated gasification combined cycled are increasing the efficiency of biomass generation for electricity. Efficiencies of up to 80% are possible in CHP operations. Multi-fuel operations are likely to be enhanced, in particular as the results of incorporating biomass use into CHP installations.

Concentrated solar power (CSP) is suited for medium to large applications from MW to hundreds of MW range with a minimum size of about 5 MW. The technology is available but expensive and obviously has seasonal and intermittent characteristics. Studies have shown a significant solar energy potential for CSP across the Mediterranean region. Research is looking to the development of more efficient and cost-effective components and plant schemes including solar-chemical applications, especially for the production of hydrogen.

Ocean energy (OE) is starting to show reliable results for a small number of prototype installations. Better suited to medium to large power production, the minimum size of an offshore OE installation, as for an offshore wind farm, will be 10 MW and will be of a seasonal and intermittent character. The energy potential for OE along the Atlantic coast of Europe is some 600 TWh per annum. The research emphasis is on the development of cheaper and safer installation methods and production, better availability and predictability of deliverable energy, and on establishing technically proven concepts.

Geothermal energy (GE) could provide Europe with up to 800 TWh per annum via the hot dry rock (HDR) concept, if this is technically and economically feasible. This technology aims at ‘mining’ temperatures of 200-250°C, which are available in many places in the EU at a depth of 5 000 m. GE depends on similar technology to that of the oil industry.

GE is a possible medium-to-large RES without seasonal or intermittent production characteristics, but the market potential for 2010 is unlikely to exceed 2 700 MW, unless cost can be brought down. Research and development is concentrating on new reservoir management techniques, cheaper drilling technologies, and more cost-effective power cycles.

Combined Heat and Power (CHP) plants use their fuels for the production of both electric power and heat and thus operate at high efficiency. Compared to traditional boiler plants or conventional electricity production, CHP can save around 30% on primary energy consumption. In addition, this leads to a reduction in CO2 emissions of roughly 0.5 kg per kWh of electricity produced. CHP is especially useful for consumers with a continuous and steady heat demand.

In the EU, CHP accounted for 72 GW of capacity and 11% of total electricity generated in 1998, although regional penetration was not uniform with 80% of total CHP installed in industry. Most CHP currently installed is large
growth in the smaller-scale applications is slow but may be set to rise, in particular for commercial applications involving reasonable cooling loads and as micro-CHP is commercialised for domestic use. Europe has a target of 18% of electricity produced by CHP units by 2010.

Fuel cells (FC) are a key emerging technology with the potential to replace a very large proportion of current energy systems in all applications from mobile phones through vehicles to DG. They provide a clean technology that uses hydrogen (from a fuel source) and oxygen (from the air) to generate electricity and heat, the only basic emission being water vapour. There are several types of FC that are classified according to the nature of their electrolyte, which also determines at what temperature they operate. In theory, FC can use a wide range of hydrogen-containing fuels.

FCs suitable for DG operate between 80 and 1,000 °C and in CHP mode can deliver efficiencies of over 80%. Small (1-10 kW) FCs could be developed for residential power generation – the ultimate DG. In the long term, FCs are a key part of a 100% RES-based energy supply, where hydrogen and electricity are the principal energy forms. FCs are therefore a crucial strategic technology with a huge potential global market set to emerge over the next ten to 20 years. Market forecasts predict very large (40-60%) average annual market growth, while the market for all FC applications could be around $12.5 billion by 2012.

Reciprocating engines represent the most common current form of DG installed capacity. The OECD survey indicated orders for 16.2 GW of reciprocating engines (1-30 MW) between June 2000 and May 2001. Engines are used over a wide range of output from small units of 1 kVA to about 10 MW and are usually fuelled by diesel or natural gas. With modern emissions control technology they can achieve low environmental impact and can be run using biomass-derived fuels. Operation in a CHP mode is possible using heat recovery. Typically used for continuous or back-up emergency power, they have operational characteristics including fast start up and controllable power output.

Stirling engines are essentially external combustion engines. They require very little maintenance, are non-fuel specific and have high efficiencies. They can also be very small but are currently very expensive. Stirling engines are the subject of increased research activity and they might reach their large potential market during the next few years.
To pave the way to a sustainable energy future based on a large share of DG, there is a clear need to prepare the European electricity system for the large-scale integration of both renewable and other distributed energy sources. To this end, research into the key technologies will allow a transition towards interconnected grids using common European planning and operational systems.

The research will assist in removing barriers relating to finance, policies, technologies and technology standards. In addition, RTD actions aimed at the adaptation of technical grid infrastructures, the establishment of necessary institutions, and the harmonisation of related regulatory frameworks and market conditions need to be undertaken.

The planning of the optimised unified European grid needs to be accompanied by strategic studies on the impacts of such a system on areas such as cost-effectiveness and economic aspects, CO2 reduction targets, and emissions trading schemes.

Above all, system reliability and power quality must be ensured in this vastly more complex operation, including huge volumes of hourly and daily transactions and more participants involved in the movement of power from sources to users. Innovation and novel power-delivery technologies will also be essential to achieve a broad and sustainable future European energy service network.

Power reliability and quality
When power is injected into the network at the distribution level, flows of electricity are changed which leads to technical issues affecting the stability of the network and power quality.

Power quality is a term that describes the interaction between producers of all sizes and consumers of power, whether they are a household boiling a kettle or an industrial site melting steel. Perceptions of acceptable power quality are different among various consumer segments. Strengthening the grid to achieve the standards required by a minority of consumers is not economical, so UPS systems are installed. UPS systems currently use various energy storage technologies but offer a potential market for novel DG technology.

A number of electrical parameters are used to characterise power quality – or, more accurately, voltage quality – at any point in the system. Maintaining a steady-state voltage is very important – a fairly wide tolerance is acceptable for long-term ‘static’ voltage but fast small variations can cause problems especially in remote areas where networks are ‘weak’. Short-circuit power level is a measure of the ability of the network to absorb disturbances – effectively describing its relative ‘strength’ or ‘weakness’ at any point. Depending on the electrical equipment installed with DG, they may be able to operate in weak conditions.

Voltage flicker and variation caused by fluctuating loads or production are the most common cause of complaint about power quality. Harmonics are a measure of the distortion of the voltage sine-wave and are becoming more important to power quality. They are produced by many types of electrical equipment, including power electronics such as linear-drive motors and personal computers, and affect both supply and demand sides.

Reactive power is produced in capacitive components of a network (e.g. cables) and consumed by inductive components (e.g. motors, transformers). High reactive currents lead to higher losses in power transmission and cause voltage instability in networks, therefore TSOs and DSOs work to minimise them. Depending on the type of generation,
DG may supply or consume reactive power. DGs connected via power electronic interfaces can support the network voltage, given appropriate market incentives.

Mains electricity supply in Europe has a fixed frequency of 50 Hz. Increasing electrical load tends to reduce the frequency, and frequency control systems act to bring the system back to equilibrium. DGs can provide frequency responsive spinning reserve or support the network operation participating in the secondary frequency reserve arrangements, if the appropriate ancillary service markets encourage such participation.

Network connection of any DG is constrained by power quality considerations. Appropriate technical standards are being developed that ease the wider uptake of DG but do not affect acceptable power quality standards.

For example, fixed-speed wind turbines connected at weak feeders can produce flicker because of periodic changes in the wind turbine output. The technical requirements for the connection of WTs, however, limit this possibility. In regions where there is a very high WT penetration, grid operators can face large changes in the power supplied from combined WT capacity, as the wind varies.

The current operating practice is to maintain power capacity in a standby mode (called spinning reserve) to ensure stability. Large-scale energy storage systems can compensate efficiently for the intermittent nature of wind and other RES-based DG sources in combination with new and flexible energy management tools equipped with improved wind power forecasting functions to enable efficient management of the spinning reserve.

**Power systems technologies**

New technologies and concepts for the operation and exploitation of the networks which are able to cope with the integration of RES and other DG will encompass new command and control systems and algorithms and standards for generator and storage dispatch to match instantaneous supply with demand in a predictive and cost-effective manner.

The new concepts and strategies for control and supervision must ensure secure operation of a Unified European Electricity Grid and the proper utilisation of the increasingly complex grid structure with new intermittent energy sources. The implementation of interactive service networks will require novel control and supervision schemes.

The development of many intermittent and grid-connected RES will require new ways of securing energy services to end-users. New common planning methods will need to be developed that take into account the interchangeable roles of DG energy producer and user. The future grid has to be able to handle situations where the consumer of energy services becomes producer when there is a surplus of local supply.

Technologies bundled into the DG system will increasingly include interfaces for connection to local supervisory control and data acquisitions (SCADA), distributed control systems (DCS) and possibly internet systems. Other technologies that are necessary or complete a system include developments in metering, protection and control, automated (decentralised) dispatch and control, and site optimisation of electrical/thermal outputs.

SCADA systems have only become feasible with the development of modern communication methods. SCADA systems are tending to increase the degree of automatic control in networks. In parallel, following the establishment of liberalised electricity markets, plan and data acquisition (PANDA) systems have been developed to allow for the exchange of information on production and consumption schedules, measurements of
actual production and consumption, and to allow for the settlement of traded contracts and balancing of power.

It is logical to combine these two parallel systems into one integrated control/market information system that has open architecture and the ability to handle the massive information flow that the future network will produce.

**Enabling technologies**

Key enabling technologies will facilitate the development of interactive energy networks with high power quality and security of service. To build the new type of grid structure it is essential to bring to market low-cost technologies that can efficiently bridge between local networks to form a truly pan-European network with the capability of integrating significant RES input.

**These technologies include:**

**Storage.** The availability of cost-effective energy storage technology is a crucial element of integration activity in DG as well as for other energy applications. Energy storage enables the smoothing of transient or intermittent loads, and could allow for the downsizing of baseload capacity with substantial potential for energy and cost savings. It is a prerequisite for using RES in remote locations and for increasing the penetration of DG technologies, such as wind turbines, at reasonable economic and environmental cost.

A wide variety of technologies are being studied for various storage applications of different storage capacity and duration. The technologies include batteries of various types (conventional lead acid, gel and AGM lead, NiMH and lithium-ion and lithium polymer), supercapacitors, reversible fuel cells and redox batteries, superconducting magnetic energy systems (SMES), flywheels, thermal storage and compressed air storage.

In the long-term vision, hydrogen can act as a large-scale, even seasonal, storage medium for electricity. Today, hydrogen is stored and transported as compressed gas or cryogenic liquid to achieve a reasonable energy density. Compressed hydrogen needs tanks capable of withstanding high pressure, and liquefied hydrogen consumes high energy in its production. Solid materials, such as metal hydrides and carbon nanotubes, have the potential to absorb large volumes of hydrogen and could provide safe, high-energy-density storage for future mobile and stationary applications.

**Information and Communication Technology (ICT)**

**Power electronics.** Devices such as FACTS are critical components of a future grid control infrastructure. Based on wide-bandgap semiconductor materials, research is focused on dramatic cost reduction.

**Superconductivity.** With the advent of high-temperature superconducting (HTS) materials, research is looking at applications that can triple current carrying capacity in existing conductors at half the current cost.

**Power line communications.** Using the power lines themselves as channels for wide-bandwidth information exchange is an option for handling the massive information flow that future networks will require. The technology would also open up opportunities for new service provision for consumers, and facilitate remote metering and other system operations.

**Commercial and regulatory challenge**

The use of novel technical solutions would reduce the costs of connection and operation, but also lead to the need to utilise and/or share the existing infrastructure more fully where adjustments are made to both generation and demand in relation to overall system dynamic needs.

Such arrangements, as well as being technically more challenging, call for new ways of charging for use of networks and ancillary services, and incorporate market signals and recompense when consumers or generators deviate from an otherwise unconstrained pattern.

Markets, regulators and tariffs do not exist for such arrangements, except at transmission level, and there are significant organisational challenges in applying this logic to distribution networks.

Early moves to allow for the development of new approaches are essential.
A European research programme on the integration of RES and DG is entirely justified. Today, the Member States are interdependent, both with respect to the issues of climate change and the completion of the internal electricity market. Energy has assumed a new Community dimension and RTD on electricity must do the same.

Both RES and the integration of RES and DG received significant funding in both the Fourth and Fifth Research Framework Programmes (FP4 and FP5). In FP5, the activities fell within the priority theme ‘Energy, Environment and Sustainable Development (EESD)’.

Continuation of these efforts in FP6 is in the ‘Sustainable Energy Systems’ work programme as a medium-to-long-term priority.

However, it is widely recognised that such EU effort needs to be coupled with national research programmes to address issues that are particularly important for the competitiveness of European industry and have major political and social implications. The creation of the European Research Area (ERA) will address issues of fragmentation and duplication of effort, and increase critical mass and effectiveness in order to achieve ambitious and challenging targets.

Running activities in FP5
Integration of renewable energies and distributed generation was a Key Action during the FP5 programme. A selection of projects funded under FP5 in this area are described below. The projects cover a number of technologies and issues such as socio-economics, regulations and grid management.

A large cluster of projects on distributed energy resources (Integration of RES + DG) will continue over four years with a budget of 34 million and over 100 partner organisations from industry, utilities and research organisations. The cluster aims to coordinate knowledge among seven strategic projects funded under FP5, including national programmes in this area as well as with projects funded in the US, Japan and other OECD countries.

Strategic importance of electricity in FP6
Building on new policy initiatives leading to decentralised generation (see box) and the experiences and knowledge generated during the projects in FP5, the new Sixth Framework Programme (FP6) has increased efforts in the area of future sustainable energy networks based on a large share of renewable and distributed generation.

In a rapidly evolving commercial environment, heavily influenced by the liberalisation of the energy markets, substantial progress can be made through better coordination of, and coherence between, Member State and European research actions – both within and beyond the European Union. By coordinating know-how and resources efficiently and involving stakeholders in a genuine dia-

### EU policy towards the decentralised generation

- Meeting Kyoto objectives: 8% CO₂ reduction between 2008 and 2012 compared to 1990 levels
- Liberalisation of internal market for electricity
- Improving energy efficiency
- Improving security and diversity of supply
- RES and CHP directives
- Towards the hydrogen energy economy
logue, the technical and non-technical barriers to the increased use of DG and RES can be broken down more quickly, which will contribute to the establishment of a European Research Area (ERA) in this field.

Medium- to long-term research is aimed at preparing for the transition to a sustainable energy economy based on hydrogen and electricity as the main interchangeable energy forms. This will require substantial effort in the adoption of innovative technologies for the management of energy demand in the medium to long term.

It also requires the preparation of the European energy system for the large-scale integration of Distributed Energy Resources (DER). This concept will play a key role in transforming the conventional electricity transmission and distribution grid into a unified and interactive energy service network using common European planning and operation methods and systems.

The two main medium- to long-term targets in the area of electricity are:

• Full and effective integration of DG through an interconnected transmission network (‘New Unified European Electricity Grid’)

• Triggering the traditional energy and power supply into an interactive (customers/operators) service network.

The two large projects selected in the first call are:

○ EU-DEEP – In this Integrated Project, a group of nine leading European energy utilities have joined forces to remove, during the next five years, most of the technical and non-technical barriers which prevent a massive deployment of distributed energy resources (DER) in Europe. In partnership with manufacturers, research organisations, professionals, national agencies and a bank, they follow a demand-pull rather than technology-push approach. This new approach will provide five ‘fast-tracks options’ to speed up the large-scale implementation of DER in Europe, by defining five market segments which will benefit from DER solutions, and fostering the R&D required to adapt DER technologies to the demands of these segments. To achieve these objectives, a set of iterative R&D tasks will be required by utilities, research laboratories, manufacturers of generator sets, storage and grid connection equipment, and investment bodies to qualify the prospects of the newly defined market segments.

○ ALISTORE – A number of internationally leading research groups from seven Member States and three candidate/associated members working in lithium-ion batteries are combining their efforts within this Network of Excellence to reduce redundancy, ensure complementarity, optimise collaboration to achieve vital research objectives, and to share expensive facilities and resources in the field of nano-materials applications for battery design. They represent more than 70% of the European Li battery research in the EU-25. This Network of Excellence will not only secure a sound scientific platform for battery research and training programmes to ensure long-lasting leadership, but will also provide, through the creation of an European Economic Interest Group, a more powerful and focused mechanism for interacting with European industry and handling patent rights.
Selected projects from FP5

The cluster of projects for integration of renewable energy sources and distributed generation:
CLUSTER RES+DG (http://www.clusterintegration.org/)

- **DISPOWER** (http://www.dispower.org)
  Covering a wide range of electricity and ICT-related topics the project will prepare a new DG structure for power supply in regional, local and island grids. This project is investigating basic solutions for technical problems involving DG in distribution networks, demonstrating the best solutions in both the laboratory and the field, and assessing the impacts. Research topics include grid stability and control, power quality and safety, socio-economic issues, planning, trading and operation tools, information, communication and electricity trading, and test facility provision.

- **SUSTELNET** (http://www.sustelnet.net/)
  Although technical developments are decentralising the electricity infrastructure and services, no initiative exists to consider how to open the internal market to ensure effective participation by DG and RES. This project provides the analytical and organisational foundation for a new regulatory process that can achieve a level playing field between centralised and DG power supply. The institutional changes and economics of supply are being analysed to give a regulatory road map towards a sustainable electricity system.

- **ENIRDGNET** (http://www.dgnet.org/ENIRDGnet/index.jsp)
  This consortium advocates the concept of DG and RES integration by increasing stakeholder awareness of the increased efficiency and sustainability of the technology, removing technical, business, regulatory and cost-related barriers to new grid interconnections and raising acceptance of intermittent RES and DG without risk to quality and safety. It will produce recommendations on institutional policy and regulatory frameworks and further RTD.

- **MICROGRIDS** (http://microgrids.power.ece.ntua.gr/)
  Interconnection of small modular generation sources to low-voltage distribution systems creates a new type of power system that can operate autonomously or as part of the main power grid. Micro-grids will study and demonstrate the operation, control, protection, safety and telecommunication infrastructure of such a system and assess its economic and social benefits.

- **DGFACS** (http://dgfacts.labein.es/dgfacts/index.jsp)
  This group will extend the FACTS power electronics concept to systems with high DG penetration to address issues of network stability, power quality and reliability. Optimum supply requirements for high DG networks will be specified and prototype DGFACTS equipment produced for operation in ‘stand-alone’ DG networks and DG networks integrated into larger supply operations.
CRISP
(http://www.ecn.nl/crisp)
Advanced intelligent ICT technologies can be exploited for cost-effective, fine-grained and reliable monitoring, management and control of power networks with a high degree of DG and RES penetration. CRISP is exploring ICT strategies and scenarios and building software tools and architectures for e-markets and intelligent agents for power applications which will be tested to give practical recommendations for the strategic use of intelligent ICT in high DG networks.

INVESTIRE
(http://investire-network.com/)
This thematic network has reviewed and assessed existing storage technologies in the context of RES applications. A summary of the state of the art was produced and the requirements for energy storage in various RES were defined. An evaluation of emerging technologies for intermittent RES applications was carried out. An RTD road map was also defined which covered requirements in technology improvement and standardisation.

Electricity transmission and distribution projects

OMASES
This open market access and security assessment system will provide an open methodology for assessing dynamic network security in real time. This will yield benefits in terms of increasing power flows, reducing outages, improving generating plant operation, and tuning protection schemes more accurately. A real-time simulation is being produced for operator training.

EuroMVCable
As there is a need for lower cost distribution cables, this project will assemble a harmonised pan-European specification for a new medium-voltage cable design providing reduced life-time cost.

ALTERNATIVE SF6
Sulphur hexafluoride (SF6) is a perfect dielectric medium but a very potent GHG. The target of this project is find a candidate to replace SF6 in electrical equipment, some 4 100 tonnes of which is installed in the European grid alone.

HVDC
This project will provide software and hardware tools to assess the benefits and impacts of embedding high-voltage direct current (HVDC) links in the largely HVAC European networks. It will also enhance understanding of the factors controlling the design and performance of HVDC cable systems. It is expected that HVDC will show benefits for system optimisation, reduced environmental impact, and greater flexibility to expand both the geographical physical network and the trading network.

Electricity storage projects

STAR-BMS
Autonomous power systems supplied by RES need energy storage for their operation. In addition to the storage device itself, a variety of energy management components are required such as a charge controller and charge indication. This project will develop standard test procedures for these components to allow performance comparison between existing and future products.

BENCHMARKING
This project will develop test procedures for benchmarking tests in energy storage systems and other components. The results will enable users to select the most suitable energy storage product for their specific application. The project will provide a framework for defining more detailed technical standards appropriate for a maturing industry.

AA-CAES
Compressed air could be a cost-effective and efficient medium for long-term storage of electrical energy. The project will address the development of heat storage devices that can enable effective adiabatic compressed air energy storage and associated component technology. The deliverables include fundamental thermophysical and economic results, conceptual designs for key system components, and an exploitation plan.
High-temperature superconductor (HTS) projects

- **ACROPOLIS**
  HTS cable and transformers suffer from AC energy loss. This project will investigate the problem and define optimum conductor design, material selection and production techniques. A final optimised assembled conductor will be machine produced and tested in various applications.

- **HOTSMES**
  Superconducting magnetic energy storage (SMES) is a possibility for effective energy storage in electricity networks. This project will use current HTS materials to construct a prototype SMES that will be characterised and tested under pulsed operating conditions.

- **HIPOLITY**
  The prime industrial goal with SMES is to provide storage capacity greater than 2 MJ with guaranteed system efficiency above 85% at reduced cost. This HTS SMES project will develop a simple test set up with a small HTS coil to study the electrical parameters of the system. A demonstrator system will be built which is capable of 500A/400V operation and ready for scale-up to higher voltages.

Integration projects

- **HYBRIX**
  Plug-and-play technology for hybrid power supplies will prepare a new generation of AC-coupled PV/wind/battery/diesel systems for use in the global rural electrification market. HYBRIX will produce modular systems with power output of up to 30 kW, allowing for expansion as demand grows.

- **REMAC 2000**
  This consortium will bring together decision-makers from public administrations and the RES industry to explore and stimulate new market initiatives to accelerate the growth of RES. Working with the International Energy Agency (IEA) and bodies from the emerging RES market in the EU, US and other countries, industry and technology scenarios will be evaluated and a road map will be published highlighting the actions required by public bodies to accelerate the RES market.

- **MED2010**
  This project has analysed methods to integrate large-scale wind and PV electricity production in the Southern and Eastern Mediterranean. The analysis will help select sites, produce integration plans, and address financing issues for the establishment of large wind and PV projects.

- **BUSMOD**
  New business models will be required in a world characterised by widespread DG. BUSMOD will develop new models taking into account all features of DG and the increased use of ICT. The positive impact of DG on the environment will be used to calculate the value of the increased use of DG.
The development of Distributed Generation (DG) is a necessary prerequisite for the large scale deployment of many clean technologies, the most important of which are:

- Renewable energy sources.
- Combined Heat and Power units.
- Stationary Fuel Cells and Hydrogen.
- Energy Efficient technologies requiring an effective Demand Side Management.

Relevant RTD actions are being undertaken today by the European Commission in conjunction with the electricity industry and research institutions to meet this future challenge and provide Europe with a new era of sustainable electrical energy. The following two actions are especially important for medium and long term research:

- Full and effective integration of DG through an interconnected transmission network (“New Unified European Electricity Grid”)
- Triggering the traditional power supply network into an interactive (customers/ operators) service network.

Research on key enabling technologies, such as RES and fuel cells, that can lead to the truly sustainable hydrogen/ electricity future energy vision are also important priorities.

The European research described in this brochure, both already underway and proposed, will integrate distributed generation and renewable energy resources within an advanced and unified European electricity network. These RTD actions will lay the sustainable foundations of a future European electricity system that will provide continued prosperity, improved supply and enhanced opportunity for all stakeholders.

These research challenges are only part of a portfolio of technical, political, legal and social challenges that need to be addressed to achieve a sustainable European single market in electricity that will provide the security of supply and quality of service that Europe requires at a competitive price. In particular the question of technical constraints and formulation of accepted international standards need concerted effort to support wider implementation of distributed generation.

The experience and expertise acquired to achieve these aims will provide global export opportunities for the European industry as the demand for sustainable energy solutions around the world increases.

In many areas of electricity technology Europe has developed a competitive lead. To enhance this position and ensure continued success increased cooperation between national partners will be necessary. The establishment of a dynamic ERA in energy research will advance the provision of a truly sustainable energy system for Europe: truly a new era for electricity giving increased power to Europe.
Electricity is one of the most critical strategic infrastructures in our society today. Its direct importance in reliably delivering energy to point of use enables every other major technological infrastructure in our society. In the European Union, satisfying future energy needs is crucially linked to the security of energy supply and environmental issues. The development of distributed power generation (DG) and renewable energy sources (RES) is essential to obtaining these goals. However, the integration of RES and DG into existing and future unified electricity systems represents an enormous technological challenge.

Energy research is the mainstay of any long-term energy policy, providing scientific knowledge and technical options to make energy systems more efficient, affordable, accessible and environmentally friendly. This brochure demonstrates the actions being taken by the European Commission, alongside the electricity industry and research institutions, to meet this challenge and provide Europe with the new ERA for sustainable electrical energy.