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Chapter 8

Integration of Renewable Energy into Present and Future Energy Systems

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Chapter 8 has been allocated a total of 102 pages in the SRREN. The actual chapter length (excluding references & cover page) is 125 pages: a total of 23 pages over target. Expert reviewers are kindly asked to indicate where the Chapter could be shortened in terms of text and/or figures and tables.

Reviewers are also asked to note that a number of references in the text are not yet reflected in the reference list.

In addition, all monetary values provided in this document will need to be adjusted for inflation/deflation and then converted to USD for the base year 2005.

Chapter 8: Integration of Renewable Energy into Present and Future Energy Systems

CONTENTS

EXECUTIVE SUMMARY

For the world to achieve an atmospheric stabilisation level below 450 ppm CO_2 equivalent, renewable energy (RE) will have to make a significant contribution to heating, cooling, electrical and mobility services. In order to achieve this, percentage growth of RE technologies over the next few decades will need to be far more rapid than has been the case to date. Integration of RE with conventional energy supply systems, (dominated by fossil fuels and nuclear energy), is the way to achieve this ambition.

This chapter explores how conventional power supply systems, natural gas grids, heating/cooling schemes and petroleum transport fuel supply and distribution networks as well as vehicles, can be adapted to accommodate greater supplies of RE than at present. The many types of RE technologies range from mature to those at the early-concept demonstration stage. They rely on cost-effectiveness, social acceptance, reliability, and political support at national and local government levels in order to gain a greater share of the present energy markets.

RE has the potential in the longer term to provide the major share of global energy. Indeed some towns are already close to achieving 100% RE supply, including for local transport. Over the long-term and through measured system integration, there are few, if any, technical limits to the level of penetration of RE in the many parts of the world where sufficient resources exist. It could provide the full range of energy services in the future to large and small communities in developed and developing countries. However, the necessary transition to a low carbon, RE future will require considerable investments in new infrastructure, (including energy storage, intelligent electricity grids, novel transport methods and distributed energy systems) and improved energy efficiency of both the supply-side and final consumption.

In the shorter term, integration of RE in the present energy supply system, together with the complimentary use of all RE sources, can enhance system reliability, energy security, electricity and gas network security, greenhouse gas mitigation, sustainable development and access to energy services for all. Integration strategies that increase deployment of RE in both urban and rural areas will depend upon local and regional resources, demand patterns, financing methods and energy markets.

The general and specific requirements for better integration of RE into heating and cooling networks, electricity grids, gas grids, transport fuel supply systems and autonomous buildings or communities are highlighted. Through several case studies, the chapter outlines the options and constraints for RE integration through the optimum combination of technologies and social mechanisms, given the limitations of specific site conditions, RE resources, and local energy demands. Comparative assessments of the costs of RE integration options have not been found in the literature and therefore future research needed to provide data for modeling scenarios was identified. For example, how the projected trend towards decentralised energy supply systems might affect future costs and demand for large, centralised systems has not been fully assessed. Other risks and impacts involving the integration and deployment of RE in a sustainable manner, including use of materials, capacity building, technology transfer, and financing have been discussed separately where appropriate for each of the transport, building, industry and agriculture sectors of the global economy.

To develop a coherent framework in preparation for higher levels of RE penetration requires a good understanding of the current energy supply systems.

- In the electricity sector, international experience of integration of variable RE, mainly wind, shows that high levels of penetration are feasible and economically beneficial for society.

Integration is facilitated by methods and investments that increase flexibility of conventional power supply systems such as system control and operation over the network, demand-side response, energy storage, more flexible thermal power plants and an enabling electricity market framework. Not all RE sources fluctuate and baseload options using hydro, geothermal and bioenergy combined heat and power (CHP) systems are mature technologies. For the electricity sector, it is difficult to standardise on a method for the significant departure from a traditional to highly flexible system as each electricity system, large or small, has its own particular governance, inter-connection, technologies, market and commercial issues to deal with. To increase the penetration of RE resources, stakeholders associated with each "electricity industry" will probably need to determine their own pathway whether the industry serves a village or a continent.

- In the building sector, many successful examples of heating and cooling exist utilising biomass (for domestic cooking, heating, CHP, district heating schemes); geothermal (for high temperature process heat or low temperature, small-scale ground source heat pumps); and solar thermal (for water and space heating as well as cooling at the domestic, community or district scales). Building-integrated electricity generation technologies provide the potential for buildings to become energy suppliers rather than energy consumers. Integration of RE into existing urban environments, combined with efficient "green building" designs, is key to further deployment.
- The industry sector is highly diverse, ranging from very large, energy-intensive basic material industries to small and medium sized enterprises. Energy efficiency, material recycling, carbon dioxide capture and storage and fossil-fuel substitution for CHP generation, are relevant for the integration of RE into present and future energy systems at the large scale. In addition industry could provide demand-response facilities that could achieve greater prominence in future electricity supply systems.
- Agriculture, whether large corporate-owned farms or subsistence farmers, is a relatively low energy consuming sector, with pumping of water for irrigation and indirect energy for the manufacture of fertilisers the greatest contributors. RE sources including wind, solar, crop residues, animal wastes, are often abundant for the landowner to utilise locally or to earn additional revenue from exporting useful energy carriers such as electricity or biogas off the farm.
- Transport presently uses very low inputs from RE, mainly as liquid biofuels blended with petroleum products. The development of advanced biofuels, that are more fungible with today's petroleum fuels and distribution systems, could permit greater penetration. The on-going development of electric- and hydrogen-powered vehicles is advancing and could enable the wider use of a variety of widely available RE sources. However, many uncertainties and cost reduction challenges remain concerning future technologies, source of the energy carriers and the related infrastructure.

Integration of the various transport, electricity, building and industry energy supply systems is conceivable in the future, thereby creating a paradigm shift and a step towards the energy transition being sought.

Regardless of the energy systems presently in place, whether in energy-rich or energy-poor communities, increased RE integration with the existing system is desirable. The rate of penetration will depend on an integrated approach, including policy framing, life-cycle analysis, comparative cost/benefit evaluations, and recognition of the social co-benefits that RE can provide.

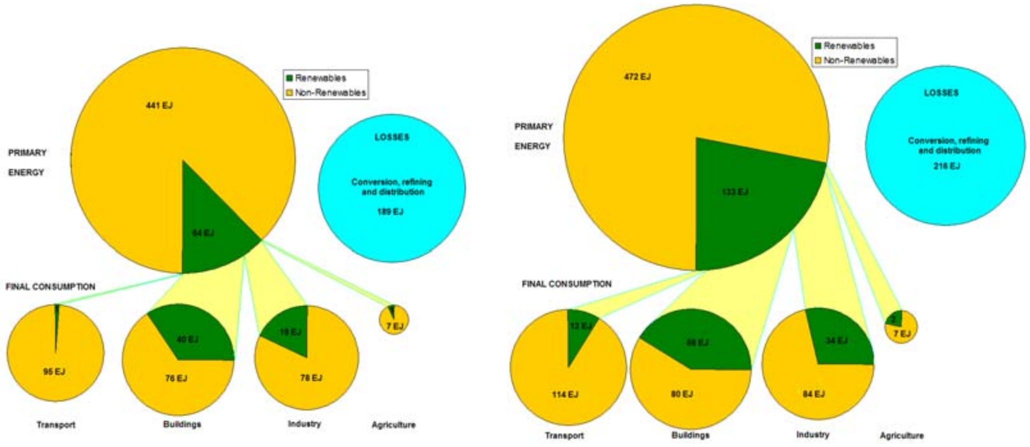
8.1 Introduction

This chapter examines the means by which larger shares of renewable energy (RE) can be integrated into the energy supply system at the national and local levels. Since the 1950s, nations have invested in roads, building and infrastructure designed around the expectation that cheap and available energy supplies would continue. Now that a number of problems with the continued use of conventional fossil fuels and nuclear power have been identified, and many countries are striving to reduce their dependence on imported energy supplies, there is a growing desire to increase alternative energy sources. To enable RE systems to provide a greater share of global heating, cooling, transport fuels and electricity, and thereby displace a portion of fossil fuel supply in the mix, a major transition will be necessary. This will require the adaptation of conventional power supply systems, natural gas grids, heating/cooling schemes, and liquid transport fuel supply and distribution networks, so that they can accommodate greater supplies of RE than at present.

Building on the technology chapters 2 to 7, this chapter outlines the barriers and possible solutions to greater integration. Technologies that can help overcome specific technical barriers to increase deployment of a single technology (such as synchronizing units for wind turbines, co-firing of solid biomass with coal, and back-up requirements for solar water heating systems) have been discussed in the earlier chapters. Here, more general issues, including economic and social barriers, are identified and broad solutions outlined that might overcome them. Differences in the potential uptake of renewables due to their current market status, geographic region, and the varying political ambitions of OECD and non-OECD countries, are also discussed.

Other than the promise of climate change mitigation, RE systems can offer opportunities for sustainable development and improved energy supply security (IEA, 2007c). Energy security is a major challenge facing many nations since prolonged disruptions in supply could cause major economic turmoil. Security risks include the inability of an electricity infrastructure to meet growing load demands; the threat of attack on centralized energy facilities, transmission networks or pipelines; extreme price volatility; or geopolitical actions restricting supplies, particularly oil and natural gas. Diversifying supply by increasing domestic capacity and using a portfolio of local RE sources to meet an increased share of future energy demand growth can make a positive contribution to energy security and reliability (Awerbuch, 2006). Although RE systems can help mitigate supply risks from energy market instabilities, they can carry their own energy security risks such as technical system failure, natural variation in availability, physical threats to infrastructure from extreme weather events, and relatively high costs under some conditions. These issues need to be addressed.

Conventional energy systems are mainly based on oil, coal and gas. To achieve the rapid transition desired to reach a low carbon technology future, the wide range of RE technologies, as outlined in Chapters 2 to 7, will each need to continue to increase market shares. At present, in spite of the long-established contribution to total primary energy supply coming from mature hydropower, modern bioenergy and geothermal technologies, together with the recent impressively high market penetration rates of wind, solar PV and solar water heaters (though all from a low base), the total shares of consumer energy supplied by RE systems remain low (Fig. 8.1). Shares in 2007 were around 16% of global electricity generation from large hydro plants (IEA, 2009a); 2-3% of electricity from wind, geothermal and solar; 1.5% of total transport fuels from biofuels (IEA, 2008a); and 2-3% of total direct heating from solar thermal, geothermal and bioenergy (IEA, 2008a). The latter excludes traditional biomass consumption in rural communities that accounts for around 10% of world primary energy. To make the transition to atmospheric stabilisation of greenhouse gases at 450 ppm CO_2 equivalent will require a rapid ramp up of RE technology deployment (along with energy efficiency, nuclear and CCS) (IEA, 2009a).



2007 **2030**

Figure 8.1: RE shares of primary energy and final consumption in the transport, buildings, industry and agriculture sectors in 2007 and the shares in 2030 under a 450ppm Policy Scenario. (Based on IEA, 2009a).

Notes: Area of circles approximately to scale. Non-renewable energy includes coal, oil, gas and nuclear. Energy efficiency improvements included in 2030 projection.
Building sector RE includes traditional biomass used in developing countries. that is projected to be partly replaced by modern bioenergy by 2030.

Around 1.6 billion people, or 25% of the world's population, mainly living in non-OECD countries, rely on traditional biomass, not always sustainably produced, to provide them with minimal energy services for cooking and keeping warm. Several of these countries, however, are also leading the world in specific RE developments. For example China has over 50% of the world's solar water heaters (SHC, 2007), and Brazil has over 50% of its total transport fuels for light duty vehicles presently supplied from sugar cane ethanol, either blended with gasoline at around 24% by volume or used in higher blends up to 100% in flex-fuel vehicles (Zuurbier & van de Vooren, 2008). Such integration of RE systems with conventional energy systems exemplifies the possible approach needed to achieve further uptake in all regions. Denmark, for example, produced around 19.7% (7180 GWh) of its total power generation in 2007 from wind turbines integrated with other forms of generation (mainly coal- and gas-fired) and with imports/exports of electricity to and from neighbouring countries (DEA, 2009). In Spain, the 2000 Barcelona Solar Thermal Ordnance resulted in over 40% of all new and retrofitted buildings in the area having a solar water heating system installed (EC, 2006). This integrates with the conventional power supply system by reducing demand for electrical heating services. In New Zealand, over 60% of electricity demand has been met from hydropower plants for several decades, but now new back-up, thermal plant capacity has been built to meet demand in recent dry periods.

There are significant regional and local differences in the potentials for RE integration. What is successful in one region may not be so in another, even where conditions are considered to be similar. Integration of RE into the energy supply system and infrastructure of many non-OECD countries today raises challenges that differ from many OECD countries. A paradigm shift is required to supply the millions of people currently with limited access to electricity and other energy services. Integration of variable RE generation into an isolated power supply system is different to integration into a region which already has high shares of RE, or where cross-border transmission options are possible. Many developing country governments place a higher priority on future economic development than on climate change mitigation. The deployment of low-carbon technologies, particularly renewables, could be a win/win solution, but may need political support or external aid funding to gain greater deployment. Small-scale, distributed RE systems may be able to avoid the high capital cost of constructing the infrastructure presently lacking, and hence leapfrog conventional energy systems.

It is anticipated that the current trend to increased urbanisation will continue and that by 2030 cities and towns will house around 60% of the world's population of, by then, 8.2 billion people (UNDP, 2007). There is good potential in many urban environments to capture local RE resources and thereby help meet a growing share of future energy demands (IEA, 2009b). For small towns surrounded by rural areas, this share can be higher than for urban areas contained within mega-cities. Even so, the potential still exists to integrate RE systems into the buildings and infrastructure, as well as to convert municipal and industrial organic wastes to energy. Conversely, existing local planning regulations of some local governments may restrict the potential deployment of such technologies.

As RE systems develop and their market shares increase, competition could result. This is in addition to competition with incumbent fossil fuel-based technologies and other low carbon technologies. Failing to recognise the future competition from other technologies can result in an over-estimation of the potential of any single technology. For example, if an urban-based company encouraged the uptake of solar water heating systems and ground-source heat pumps in the local community by offering good promotion, cheap installation, and future maintenance services, but then the local municipality supported the development of a large biomass-fuelled district heating scheme, the solar and geothermal systems could be made redundant. On a larger scale, should a large nuclear or thermal power plant with carbon dioxide capture and storage (CCS) attached be developed in a region to provide enough power capacity at low carbon emissions to meet future electricity demand for some years (possibly with government support), then this could constrain the development of a proposed nearby wind, solar, geothermal or bioenergy plant for some decades even where good resources exist. Similarly in the transport sector, it is uncertain whether hybrid vehicles using biofuels, hydrogen fuel cells or electric vehicles will become the dominant drive-chain technology in the future, or indeed if all three will compete with each other. Therefore, energy systems need to be flexible enough to cope with the future integration of the range of RE technologies as they evolve.

Hydrogen, as an energy carrier, can be produced in many ways using a range of energy sources including by gasification of coal or biomass, steam reforming of natural gas and other liquid and gaseous fuels, or electrolysis. In Chapter 2, hydrogen production from biomass using a range of processes is discussed. In this chapter, only hydrogen from electrolysis using "green" electricity generated from RE systems is covered, with the hydrogen to be used in either stationary or vehicle applications.

A major objective of this chapter is to determine how problems of integration might affect the future deployment of RE technologies into the conventional energy system. Regardless of the technology, adhering to the national and local planning and consenting processes will involve some costs, but accurately predicting the future acceptance by the general public of a RE plant, (or indeed of a nuclear or CCS plant), in any given location is difficult. Adding to this complexity, some RE technologies are already mature but failing to gain wider acceptance in the market, whereas others, only close-to-market, are enjoying premature integration into the energy supply system due to government support. Relative costs are an important factor, but often other co-benefits exist (such as energy security, employment opportunities, improved health). These can be the driving reason for governments to offer supporting policies (IEA, 2008c). Overall, given these complexities, uncertainties, and a deficit of analysis in the literature, it is not possible to accurately evaluate the future costs of system integration that modellers might wish.

Many energy scenarios show that a wide range of energy efficiency initiatives across the building, industry, transport and energy supply sectors will probably reduce future energy demand baseline projections significantly (see for example Chapter 11 of IPCC, 2007). Whether reduced energy demand will encourage the greater uptake of RE over and above other energy sources is difficult to determine, but reduced demand could facilitate a greater share for RE of the growing energy market. For example, a building owner should be encouraged to initially invest in energy saving measures before contemplating the installation of solar water heating, a wood pellet stove for space heating, or a small roof-mounted wind turbine for power generation (IEA, 2009b). The required capacity, and hence cost, of a RE system will be less if it is designed to meet a lower energy demand.

The transition of the global energy sector away from the present dominance of fossil fuels, needs to include a greater share of RE. This will take time and involve significant investment costs (IEA, 2009a). Other low carbon technologies, particularly nuclear power and CCS linked with coal- or gas-fired power generation, as well as industry applications, will all have a role to play (IPCC, 2007). Many energy models have been produced to project how the various energy supply sources could, together, meet future energy demands (see Chapter 10). It is therefore not the aim of this chapter to attempt to assess the future share of RE as a result of improved integration.

This chapter discusses the integration of RE into centralised, decentralised and off-grid systems to provide desirable energy services (heating, cooling, lighting, communication, entertainment, motor drives, mobility, etc.). Regional differences between the potentials for various systems are highlighted, as are the barriers to deployment depending on the system presently in place. Successful deployment depends upon the local energy resources, current markets, density of population, existing infrastructure, the ability to increase supply capacity, financing options and credit availability. The specific costs of each of the various technologies are covered in Chapters 2 to 7. Since any additional costs relating to integration are complex, site-specific, and not clearly identified in the literature, it was not possible to provide them in this chapter.

8.1.1 Structure of the chapter

Factors such as technology experience cost curves, advances in existing technologies and RD&D developments are discussed in the specific technology chapters (2 to 7). Each of these chapters also examines issues of integration related to their specific technology. However, integration issues relating to RE supplies are more complex. This chapter looks at cross-cutting issues across RE technologies relating to such factors as energy distribution and storage. Non-technology cross-cutting issues are also discussed, including market flexibility, project financing, system reliability, energy balances, energy supply security, system flexibility, transmission of energy carriers, ownership, sense of independence, social acceptance of the technology, the public’s awareness and acceptance, and the need for a transition of the energy sector as a major component for mitigation of climate change. External factors such as future carbon and oil prices are covered in Chapter 10.

Section 8.2 discusses the integration of RE systems into existing and future supply-side systems for electricity, heating and cooling networks, gas grids and liquid fuel distribution as well as autonomous systems. Where relevant, the integration benefits of system design, technology components to facilitate integration, including storage, ownership, operation and maintenance strategies, are discussed. The potential for small-scale distributed energy systems is reviewed on the one hand, along with high voltage, trans-continental, super-grid systems on the other.

Section 8.3 outlines the strategic elements and non-technical issues needed for transition pathways for each of the transport, building, industry and agriculture sectors in order to gain greater RE deployment. The relevance of energy efficiency is included. The current status, possible pathways to enhance increased adoption of renewables, the related transition issues, and future trends are discussed for each sector. Major differences between sites and regions, as well as the different approaches necessary for centralised, decentralised and stand-alone RE supply systems are assessed for either OECD or non-OECD countries.

8.2 Integration of renewable energy into supply systems

Conventional energy systems have evolved over many decades to enable cheap and efficient distribution of electricity, gas, heat and transport fuels to end-users. Increasing the deployment of RE systems requires their integration into the existing infrastructure. This section outlines the issues and barriers involved as well as some solutions.

8.2.1 Electric power systems

8.2.1.1 Features and structure of power systems

In order to facilitate a proper understanding of the integration issues and solutions for the electricity sector, the basic features of the structure and operation of power supply systems are first outlined. These concepts, within the context of integration of renewables, are explained in more detail in the literature (see for example, Ackermann, 2005 [TSU: Reference is missing in reference list]; EWEA, 2005; Ummels, 2009).

8.2.1.1.1 Power systems and electricity networks

Renewable energy integration impacts the complete power system, from generation to demand, because some RE resources are exploited on the demand-side (such as roof-mounted PV), and others, on the supply-side for example, in the form of generation based on stochastic, non-storable RE fluxes (e.g. wind or solar energy). The latter are easier to integrate and accommodate using various counter-measures such as end-users with flexible energy services adjusting their demand for energy supply to match the time-varying pattern of the RE flux availability. The characteristics of primary energy resources and their implications must also be carefully considered. Therefore the boundary of an electricity industry must be drawn sufficiently broadly to encompass all relevant primary energy resource and end-use service issues. These will be context-specific. The concept of a power system should therefore consider a range of industry characteristics, including geographical location, state of technological development, social acceptance and innovativeness in its ability to absorb unfamiliar types or levels of RE resources.

Basic characteristics of power systems

Power systems are designed to provide reliable electricity supply while minimizing cost. The stakeholders in the process are system operators, regulators, governments, generators, industry, utilities and users.

Reliable operation requires that demand for electricity is matched in real time by generation (real and reactive) throughout the system. A sustained, substantial imbalance in real or reactive power could eventually lead to catastrophic system failure resulting in blackouts (Novosel et al., 2004) [TSU: Reference is missing in reference list]. The system must also be able to maintain supply-demand balance even with variability and a degree of unpredictability in both demand and generation. For example, the power system must be robust enough to avoid significant contingencies or faults, such as a near-instantaneous, unplanned loss of a large power plant, or the loss of a large transmission line.

Power systems benefit from the aggregation of a large number of different generation resources and types of demand that help to provide reliable operation (Awerbuch, 2006). Systems with access to tens or hundreds of different generation resources can be less expensive than if providing the same level of reliability with only a few power plants. The benefits of aggregation are accessed through a network of transmission/distribution lines and a communication infrastructure that allows for the transfer of power and coordination throughout the network.

8.2.1.1.2 Variable electricity demand

Reliable and least cost operation of the power system is typically ensured through many different mechanisms that can be broadly categorized as planning and operations, depending on the time horizon of interest.

In real-time operations, at time scales from seconds to hours, power systems operate in a way that recovery from significant contingencies can occur virtually automatically without the need for operator intervention. For example, to accommodate rapid changes in power flows that occur after significant faults, system operators can rely on strong transmission connections to neighbouring power systems and margins left between the capacity of transmission lines and the maximum operating point. System operators also rely in part on the inertia of the collective large spinning mass of all on-line and synchronized generation and demand to maintain supply-demand balance even after severe faults.

System operators schedule generation capacity or responsive demand to provide reserves that can be available in a short period to compensate for the possible loss of generation or transmission, inaccurate forecasts or schedules, or to maintain a near-instantaneous supply-demand balance. Flexible resources used to provide these services include partially-loaded thermal plant, transmission interconnections between systems, hydropower units, storage systems, various forms of demand response, and controlling the output of RE plants. Based on short-term forecasts, system operators can provide economic dispatch signals to adjust the output of such resources within minutes subject to their ramp-rate constraints and operating limits. Over longer periods, resources can be started or stopped depending on demand, generation availability, and the minimum start and operating time of individual generators.

System planning enables reliable operation in real time. It encompasses evaluating a system to provide reliable operations in real time over long periods. Power system planners use complex models of the system and its operations to evaluate the adequacy of the transmission infrastructure. They also evaluate the adequacy of the generation resources connected to the system to reliably meet demand, based on the load carrying capability of the power system. Depending on the performance of these resources, planners assign a capacity credit to different resources based on their contribution to the load carrying capability (capacity needs) of the system. The capacity credit of a resource can be broadly defined as the amount of additional demand that can be served due to the addition of the generator, while maintaining the existing levels of reliability (Billinton and Allen, 1996).

Box 8.1: Principles of power balancing in the system

Power system operation covers time scales ranging from seconds to days and, within that timeframe, it is the responsibility of the system operator to ensure that the power balance between generation and consumption is continuously maintained. The essential parameter in controlling the energy balance is the system frequency because it reflects stored kinetic energy. If generation exceeds consumption at a particular moment, both stored kinetic energy and frequency rise; if consumption exceeds generation, both stored kinetic energy and frequency fall.

Small supply-demand imbalances occur all the time. Large imbalances occur less often, for example due to the tripping of a thermal unit, the sudden disconnection of a significant load, or the tripping of a major transmission line. Primary reserve is activated automatically as a result of frequency fluctuations to re-instate the power balance, typically within 30-60 seconds for small disturbances if sufficient primary reserves are available. If not, or in response to very large disturbances necessary, shedding of pre-determined load can also occur automatically within seconds to prevent a system collapse.

Secondary reserve is where active or reactive power is activated manually or automatically in 5 to 15 minutes after the occurrence of a frequency deviation from nominal levels. It backs up the primary reserve and will remain in operation until long-term reserves are brought on line. The secondary reserve consists of spinning reserve (hydro or thermal plants in part-load operation) and standing reserve (rapidly starting gas turbine power plants and load shedding by manual disconnection). Because large supply-demand imbalances are not typically predicted or scheduled in advance, primary and secondary controls should always be available for use.

Consumption of electrical power varies by the minute, hour, day and season. Because the power balance must be continuously maintained, generation is scheduled to match longer term variations. Economic dispatch decisions are made in response to anticipated trends in demand (while primary and secondary controls continue to respond to unexpected imbalances). For example, during the early morning period an increase in load usually occurs from approximately 7:00 am to midday. After the daily peak is reached, the load declines, finally reaching a daily minimum late at night or very early in the morning.

Some generators require several hours to be started and synchronized to the grid. That means that the generation available during the mid-day peak must have been started hours in advance, in anticipation of the peak. In many cases, the shut-down process is also lengthy, and once shut down, thermal generating units may require several hours of cooling and preparation prior to re-synchronizing. Moreover, once started, thermal generating units used for base load should continue to run for one or more days in order to be economic, depending on specific generator characteristics and operational practice. Peaking plants are operated when needed.

In a wholesale electricity market, power producers bid in before any given market interval (ranging from 5 to 60 minutes or even days before dispatching balancing reserve power) and their bid is then accepted or rejected. The system operator manages the balancing task in that market interval. The power system operation of this time scale is called unit commitment, and it can range from several hours to several days, depending on specific generator characteristics and operational practice. This is cost effective, as the deviations of individual producers and loads smooth out when aggregated. Only the net imbalances in the system then need to be balanced to control the frequency. System operators have access to information schedules for production, consumption and inter-connector usage. These schedules are either made by the operators or are provided by the electricity market or other actors involved (producers, balance-responsible players, or programme-responsible parties). Operators can also use on-line data and forecasts of load and RE generation to assist in their operational duty.

8.2.1.1.3 Departure from the traditional model to enable RE integration

A significant departure is necessary in order to efficiently integrate large amounts of RE into conventional power supply systems that are characterized by centralized power plants, limited inter-connection capacity between systems and distribution grids with limited grid management possibilities. Governance of the process is as important as the technical system. The traditional model, (prior to competitive markets introduced in several states and countries) has market arrangements and a market structure that is inhomogeneous and fragmented, with long-term delivery commitments, lack of transparency and limited competition. Conversely, the conceptual design of future power supply systems should include adequate flexibility in generation and demand, a higher degree of inter-connection and long distance transmission, adequate network management, smart distribution grids, as well as an integrated, transparent and fast-operating power market (with support mechanisms needed for near-commercial RE systems; IEA, 2008c).

For grid connection of a large number of decentralized RE generators, new power system architectures could emerge in the future. A promising initiative in this respect is the Danish Cell Controller Pilot Project (Lund, 2007) that investigates how decentralized generation units can be used to support security of supply. If the high-voltage transmission network should fail, then many of the consumers could be supplied from decentralized sources.

A reorientation of power systems for integration of renewables is in line with efforts to deal with other design drivers such as increasing electricity consumption worldwide, replacement of ageing generation and network assets, more economical and efficient power production. Designing power systems that can deal efficiently with variable output renewables will also bring significant benefits to society by more sustainable power production, improved competition from additional generators, and improved sustainability with reduced dependence on fossil fuels.

8.2.1.2 Characteristics of renewable energies

8.2.1.2.1 Differences between renewable power generation and ‘conventional’ plants.

Although on a system wide level RE plants generate electricity just like any other power plant, many of the generators have distinctive features compared to conventional generation. Understanding these characteristics, and their interaction and impact with the other parts of the power system, is the basis for proper system integration. Bioenergy and geothermal power and CHP plants are more closely allied to conventional thermal power plants as the fuel for combustion and heat can be stored. However, typically, characteristics of other RE systems differ from conventional generation.

- *Variability and predictability.* The power output from RE generation from hydro, wind, solar PV, wave and tidal fluctuates with the variability of the local resource. Fluctuations can be predicted to various levels of accuracy but do not necessarily correlate with the fluctuating power demand.

- *Resource location.* The location of the RE generation is determined by the primary renewable resource location and, particularly at the large scale, cannot be easily relocated to be close to the transmission networks and demand centres.

- *Electrical characteristics.* RE power plant capabilities can be different from conventional thermal and nuclear power plants.

Variability and predictability

A major issue for the integration of RE into a power system is the additional imbalances introduced by variable sources (IEA, 2009). Dealing with variability is an intrinsic quality of power systems (as outlined in 8.2.1.1).

Analyzing RE variability on different time scales is necessary to understand the impact on the power system (EWEA, 2005). RE can be categorized by the variability time-scale of the available natural resource (Fig. 8.2). The variability time-scale for hydro power using dams, biomass, geothermal, ocean salinity and ocean thermal systems ranges from seasonal to decades, whereas, for “variable resources” including small and run-of-river hydro, wind, solar PV, wave and tides, variations occur in shorter time scales from minutes to days, in addition to longer term variations (Holttinen, 2009b). Discussion on variable resources often focuses on wind power because it exhibits variability over a range of time scales. In this respect, it also represents other variable renewables.

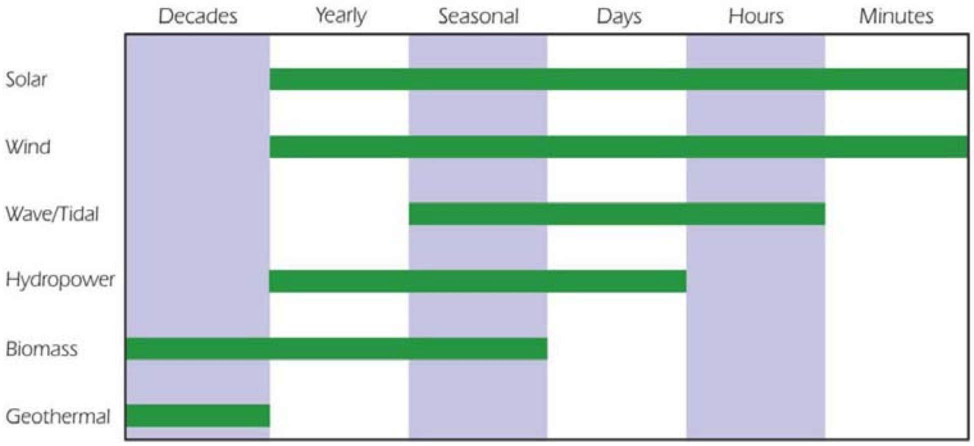


Figure 8.2: Time-scale of the natural cycles of RE sources (IEA, 2008 f).

Geographically dispersed, variable RE systems can be combined to reduce power fluctuations (see for example, case study 8.2.1.6.1). Over large areas, the correlation of output between RE plants is often small due to variations in the RE resource at any given moment (Giebel, 2007). As a consequence the aggregated output of multiple RE generators usually fluctuates less in fractional terms than that of individual plants (Holttinen, 2009b; IEA, 2008f). RE technologies are often referred to as “intermittent”, but this term is considered misleading because, when aggregated at the system level, and over different types of RE, the total output does not change instantaneously between zero and full power, but fluctuates at a rate dictated by meteorological and geo-physical effects (IEA, 2008f; EWEA, 2005).

Predictability is the key to dealing with RE variability. The ability to accurately predict a variable RE resource is significant for bulk commercialization, cost reduction and industrial uptake. From the technical perspective, if RE prediction methods are effective, grid integration and accommodation of variable resources in the system becomes more manageable from the technical and economic perspective. For example major improvements in the forecast accuracy of wind power have been accomplished (Lange *et al*., 2009; Kariniotakis *et al*., 2006; Giebel *et al*., 2003; and section 7.5.2.). Aggregated PV generation over a wide geographic area is more predictable using the smoothing effect (see section 3.5.4), and tidal variations are fully predictable being diurnal. Estimation of wave characteristics involves less uncertainty than for wind speeds owing to their slower frequency of variation and direct dependence on wind conditions over the wave fetch.

Resource location

Unlike conventional thermal or nuclear generation where the coal, gas, oil or uranium fuel can be transported to the plant, for most RE systems the power production is strongly dependent on the local availability and power density of the resource, which is not necessarily close to demand or existing networks. This characteristic of RE has consequences for distribution and transmission network infrastructure (see section 8.2.1.3). Small-scale RE systems can often be installed at the location of the demand such as biogas plants and solar PV integrated into buildings. Medium size wind farms and bioenergy CHP plants are often widely dispersed over the network but close to demand centres. Such RE-based distributed generation brings advantages for grids but also poses new challenges mainly requiring better controls, smart meters and intelligent grids (IEA, 2009b). In other cases, the RE resource can be remote such as large scale solar PV and concentrating solar power plants located in deserts, off-shore wind, geothermal, forest biomass and hydro. Where RE plants are installed in areas primarily linked to the location of the resource and away from the load or existing electricity networks, substantial new transmission infrastructure may be required.

Electrical characteristics

Experiences from various projects confirm that RE can make a significant contribution to the support of power system operation. Modern RE electrical conversion systems, especially at high penetration levels, can provide grid services such as voltage and frequency control ancillary services (Cardinal, 2006; Burges, 2003). These capabilities are inherently linked to the specific technologies that can be used where the cost to deliver an ancillary service is an important consideration (Jansen, 2007).

8.2.1.2.2 Energy conversion characteristics

The capacities of conversion technologies to extract energy from RE sources have varying physical dimensions (such as surface area), in order to harness the same amount of energy from selected RE resources (see technology chapters 2 to 7). The primary difference in energy extraction capacity arises from energy density, water being a denser medium than air for example (Fig. 8.3). Some conversion technologies, such as wave energy devices, are capable of extracting the incident energy from an effective surface area many times larger than the actual device.

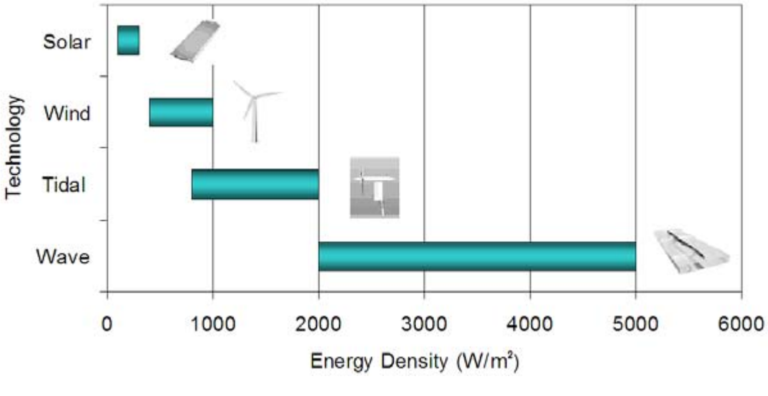


Figure 8.3: Energy density of some variable RE resources (Falnes, 2005).

Conversion technologies for harnessing marine energy conversion technologies for tidal currents are analogous to wind, whereas those for harnessing waves operate on diverse principles and may require cascaded conversion mechanisms (Fig. 8.4).

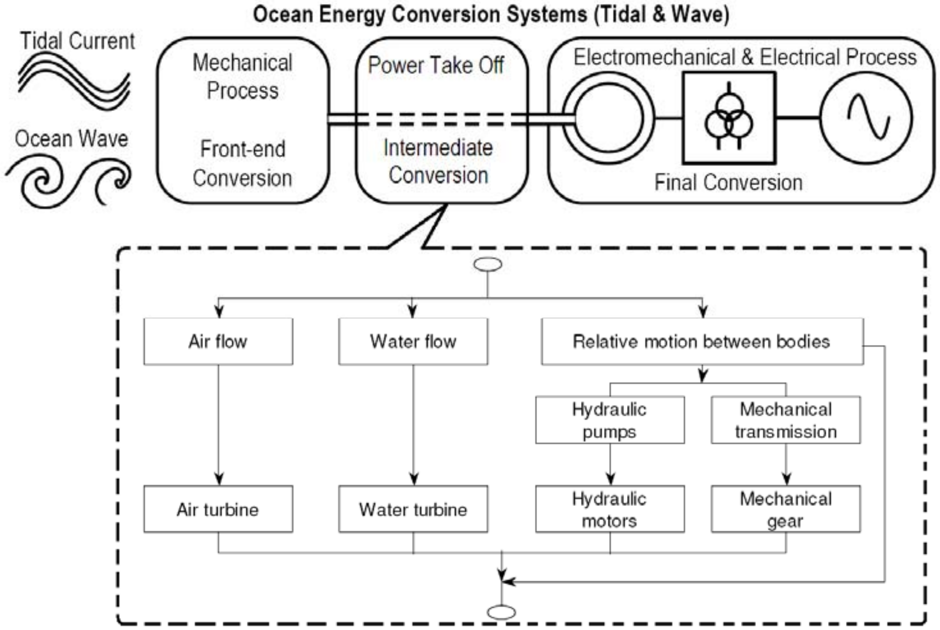


Figure 8.4: Dynamic characterization of wave and tidal current technology conversion systems (Khan et al., 2009).

8.2.1.3 Challenges for integrating renewable energies

8.2.1.3.1 Impacts

The magnitude and type of impact that RE generation could make on a power system need assessing because they determine the evolution and future design of power systems. Impacts are primarily dependent on the penetration level of RE in a given power system that, in the mid-term, may increase to more than 20-30% and in the long-term, up to 100% coverage of total annual electricity demand by renewable electricity. Impacts can be both positive and negative.

Physical impacts on the power supply system regarding control, efficiency, adequacy and planning at the generation, transmission and distribution levels, are due to variability, degree of predictability (affecting, for example, operating system reserves and generation adequacy), power plant characteristics and location of the resource with respect to demand affecting network issues. Furthermore, low marginal costs of RE systems can impact on the economic dispatch merit order of a power system.

Short-term and long-term impacts.

Short-term effects are caused by balancing the system at the operational time scale (minutes to hours), and the interaction of RE systems with grid voltage and stability. Long-term effects are related to the contribution that RE can make to the adequacy of the system in terms of its capability to meet peak load situations with high reliability.

Local and system-wide impacts.

Locally, RE plants, like any other power station, interact with the grid concerning voltage deviations from the steady-state, power quality, and voltage control at or near the generation sites. Depending on the specific technology, RE plants can provide voltage control and active power control as well as reduce transmission and distribution losses when applied as embedded generation in a demand area. At the system-wide scale, other effects to consider include those impacting on voltage levels and power flows in the network and system stability. These effects can be beneficial to the system, especially when the plants are located near load centres and at low penetration levels. On the other hand, high penetration levels of RE may necessitate additional upgrades in transmission and distribution grid infrastructure, as may be the case when any new power plant is connected to a grid. In order to connect remote high-resource site plants to the load centres, new transmission lines may have to be constructed, (just as it is necessary to build pipelines for new oil and gas reserves or new lines for new conventional power plants).

In order to maximize the smoothing effects of geographically distributed RE, and to increase the level of firm power (also termed “capacity credit” or “capacity value”), the opportunity for cross-border power flows could reduce the challenge of managing a system with high levels of RE.

RE can play a role in maintaining system stability. Different types of RE generators have different stability impacts and possibilities to support the system in normal and system fault situations (time scale seconds to minutes). More specifically this is related to voltage and power control and to fault-ride through capability. RE also contributes to the system adequacy and security of supply (Table 8.1).

Table 8.1: Power system impacts of RE systems with the impacts of wind power generalised to all RE systems (EWEA, 2005).

	Effect or impacted element	**Area**	**Time-scale**	**RE potential contribution**
Short term effects	Voltage management	Local	Seconds to minutes	RE plants can provide (dynamic) voltage support (design dependent).
	Unit commitment and production efficiency of thermal and hydro	System	1-24 hours	Impact depends on how the system is operated and on the use of short-term forecast.
	Transmission and distribution efficiency	System or local	1-24 hours	Depending on penetration level, RE plants may create additional investment costs or benefits. RE can reduce network losses, except for example, off-shore wind and concentrating solar power (CSP).
	Regulating reserves	System	Several minutes to hours	Appropriately designed RE plants can contribute to primary and secondary control.
	Stability	System	Seconds / minutes	Depending on power plant capabilities, RE may support system during fault situations.
Long term effects	System reliability (generation and transmission adequacy)	System	Years	RE capacity can contribute (capacity credit) to power system adequacy depending on the possibility to aggregate over large areas and across types of generation.

RE generation requires measures for regulating (balancing) control just as any other technology. It should not be treated in isolation in the system as it depends on penetration level and local network characteristics and can impact on the efficiency of other generators in the system (and vice versa). In the absence of sufficient intelligent and well-managed power exchange between regions or countries, a combination of (non-manageable) system demands and generation may result in situations where specific variable RE plants have to be curtailed.

Impacts of wind power in different time and geographical scales are relevant for integration studies (Fig. 8.5) (Holttinen, 2009b) and can be classified from local to system-wide and from seconds to year. Relevant for integration is whether the power system can deal with these impacts and to identify the specific challenges that should be addressed.

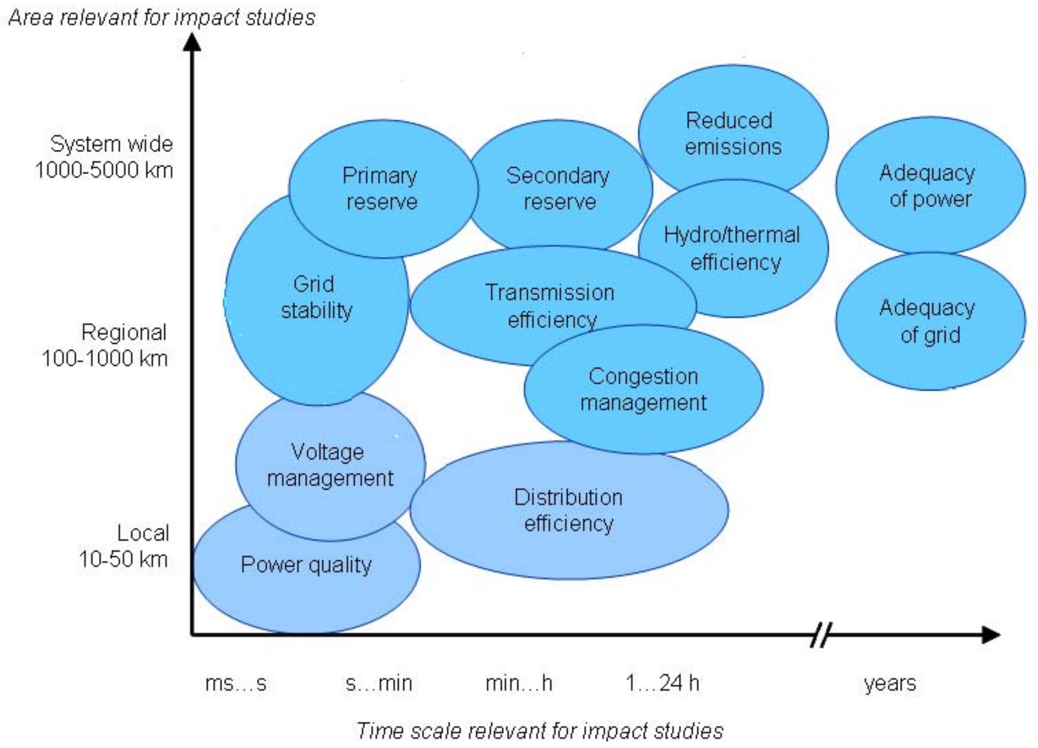


Figure 8.5: Impacts of wind power on power systems by time scale and area (Holttinen, 2009a).

8.2.1.3.2 Issues and challenges

The challenges brought by variable, distributed RE systems, highlight the need to address specific aspects of the power system. Integration issues for high penetration levels have been analysed extensively, primarily for wind power because of the rapid pace of implementation. The experience with wind energy has more general relevance because it represents a “worst design case” for power systems in view of its high variability and relatively high penetration levels.

From experience to date with wind energy (Milligan, 2009; Holttinen, 2009; EWEA, 2005), the main challenges for power systems are:

a. system operation, balancing and the need for additional system reserves;
b. network reinforcement, extension and inter-connection;
c. appropriate connection rules and codes for RE;
d. system adequacy with high penetration of renewables due to the low capacity credit of several variable RE technologies; and

e. electricity market design and corresponding market rules.

These challenges have technical, institutional and regulatory and market design aspects.

a. System operation and balancing

- *Increased reserve requirements.* In the absence of a perfect forecast, system balancing requirements and costs are increased by random fluctuations and by forecast errors, both of variable RE and of load demand, since these are generally not correlated. Power balancing requirements in large-scale power systems mainly address reserve power in secondary control time scales that is offered on the balancing market. For wind, these costs have been extensively analysed (Holttinen, 2009b) and there is a modest increased need for additional reserve with growing wind penetration. For an isolated system or one with limited inter-connection, (at various penetration levels up to 10-15% in some areas or higher elsewhere), unpredicted imbalances can be countered with existing reserves (DENA, 2005). Several national and regional specific system studies indicate additional balancing costs in a narrow range (e.g. EUR 0 - 3/MWh for wind) for levels of wind power penetration up to 10% (on an energy basis) despite large differences between systems.

- *Need for forecasting.* Accurate RE power output forecasting is critical to economic operation of RE plants in the system, as confirmed by experience in countries with significant penetration (Denmark, Spain, Germany, Ireland). In the absence of accurate forecasting, uncertainty leads to increasing balancing costs (Lange, 2009).

- *Excess RE production.* Where RE output exceeds the amount that can be safely absorbed while still maintaining adequate reserves and dynamic control in the system, a part of RE generation may have to be curtailed (for example in low demand, high wind situations). However, it may prove more economic to increase demand under ‘demand side management’, for example by additional pumping at pumped storage facilities, use of heat pumps and/or water supply reservoirs. Increased inter-connection and improved power exchange rules between neighbouring countries can avoid wasting RE output in such situations (Beharrysingh, 2009; Ummels, 2009).

- *Ancillary services.* Apart from balancing requirements, the power system requires ancillary services. These range from operating reserve and reactive power through short-circuit current contribution and black start capability. All RE plants can provide part of these services (Burges, 2003; Jansen, 2007; Syczynski, 2009) noting that if reserve is provided with variable RE, this is at the cost of lost production, so it will not be the first or most frequent option to deploy. In addition, appropriate equipment should be maintained in the system to provide the ancillary services that cannot be delivered by RE power plants.

- *System operation at transmission and distribution levels.* RE generation has implications for the operation and management of the network.
  - *Management of congestion and unpredicted flows.* Specific combinations of RE production and demand, in terms of level and geographical location, cause changes in the magnitude and direction of power flows in the transmission grid. The effects of these can be mitigated by accurate forecasting of the renewable generation, combined with monitoring technologies to reduce the impacts using the on-line SCADA (supervisory control and data acquisition) information for the RE plant and WAMS (wide-area measurement systems). Operational issues include congestion management (also termed “connect and manage”), priority access of RE plants and priorities in curtailment in critical situations (for example the combination of low demand and high

RE production). As a positive impact, RE may keep parts of the system operational in the event of transmission failures which otherwise would cause black outs.

- *Management of distribution grids.* Connection of RE generation to distribution grids introduces similar effects as in transmission grids including changing direction and quantity of real (active) and reactive power flows, which may affect operation of grid control and protection equipment. There is less active management of distribution grids than at the transmission level. Nevertheless, distribution grids have to cope with varying distributed generation levels without reducing the quality of supply. Weak distribution grids may be supported by RE and end-users may be better served because RE can contribute to grid voltage and power quality control. Power generated within a local distribution network can go directly to local users, thereby avoiding transmission costs and line losses.

b. Network infrastructure

Upgrading transmission infrastructure to handle large penetration of variable RE is a complex process subject to strategic long term planning which has to proceed through various stages, following the gradually increasing penetration of RE. Transmission systems in several parts of the world have been developed in a compartmental way by being confined within countries or to limited network areas. National transmission system operators (TSO) and regulators deal with grid issues, balancing, and power exchange in a way that is determined by national legislation and the grid topology, geographical situation and historical developments.

Relatively low penetration (< 10%) of variable RE in existing networks could add to existing transmission congestion. The extent to which transmission upgrades are required depends on the effectiveness of congestion management and optimization of the transmission system.

At higher penetration levels, or in order to access new remote resources, new lines have to be added. Planning methods should avoid the classic ‘chicken and egg’ problem by jointly considering RE power projects and the associated transmission network requirements. At very high penetration levels of variable RE, large-scale storage systems may become economically attractive.

Transmission network upgrades are needed for large-scale integration of wind power in many countries (Holttinen, 2009; Lew, 2009; Corbus, 2009; EWIS, 2009). Different studies use various methods of cost allocation, distances, and grid reinforcements assumptions, but, in general, estimated costs in the literature are in the range of USD 100-200 /kW for wind penetration levels up to 50% (though costs vary widely with specific conditions).

Transmission planning

Over planning horizons sufficient to add new infrastructure, planners evaluate the power system using a variety of tools to ensure adequate transmission and generation resources to reliably balance generation and demand. Though these same planning methods can be used to evaluate the adequacy of the system with the addition of significant amounts of RE, planners must also appropriately account for its variable characteristics.

Evaluating the adequacy of transmission capacity with significant additions of wind, for example, needs to account for the locational dependence of wind resources, the relative smoothing benefits of aggregating wind over a large area, and the transmission capacity required to access flexible resources to manage wind’s variability. The locational dependence of wind energy means that, in many regions of the world, new transmission infrastructure will be required to move power from the best wind resource areas to demand centres. The most efficient and economic way of transporting bulk electrical energy over such distanced is via large, high-voltage overhead transmission systems.

In some cases transmission planning practices for conventional generation are not as appropriate when applied to RE. For instance, transmission planning rules that encourage generation to be sited where existing transmission capacity is available ignores the strong dependence of RE resources on location. Additionally, transmission lines are often much less expensive per unit of capacity the larger the line is, and RE plants are often located in regions that can support much more capacity than the size of an individual plant. Increasing transmission capacity and coordination between different parts of an inter-connected system also reduces the total variability in the demand that must be managed by power system operators (Milligan and Kirby, 2008). Finally, transmission lines can take a decade to plan, permit, and construct whereas individual wind plants can be built in a period of a few years. As a result of these factors, transmission capacity expansion is most economic if planned for quantities of RE much larger than the size of individual generation plants, and there is a strong rationale for building transmission proactively in anticipation of growth in RE rather than planning transmission in reaction to individual RE plants (Mills et al., 2009). At the same time, public opposition to transmission lines is expected to be a major factor in the integration of large amounts of wind energy (Vajjhala and Fishbeck, 2007; Vaccaro, 2008).

Various solutions to proactive transmission expansion are being investigated, but solutions will vary depending on geography, the design of the pre-existing power system, and the regulatory environment. In the U.S. efforts focused on proactive transmission planning and Europe is similarly considering ways to proactively plan transmission to integrate RE particularly through improvement of transfer capabilities between transmission system operators (EWEA, 2005; EASAC, 2009). One recent development in Europe is the founding of an organization to coordinate network planning across Europe called the European Network of Transmission System Operators for Energy (ENTSO-E). It should be noted, though, that more research is required to identify the extent to which such new transmission infrastructure would be cost effective.

c. Connection rules for inter-connection of RE generators

TSOs impose grid connection requirements, such as inter-connection regulations and grid codes, on RE plants just like on any other generator. This is to keep good order in the system and to prevent negative impacts on the network. For example, in countries facing significant wind power development, the specific rules for wind power are continually being refined to allow a larger penetration and at the same time maintain an adequate power supply. Grid codes are country and system-specific, resulting in a wide disparity of requirements that equipment manufacturers, developers and RE plant operators face across the globe. Internationally harmonized connection requirements for RE plants would avoid unnecessary costs for manufacturers and operators (EWEA, 2008).

d. System adequacy

Variable RE generation can only replace a minor part of the capacity of conventional plants, which as a consequence have to be retained in the system and gradually replaced with more efficient and flexible resources where necessary. The load carrying capability of variable RE generation can be high at low penetrations but decreases at higher penetration levels. Energy storage can contribute when aiming to realize 100% RE penetration in the long term.

In situations with low wind penetration and high capacity factor at times of peak load, the capacity credit of wind power can be as high as 40%. In high wind penetration, low capacity factor at times of peak load, or when regional wind power output profiles correlate negatively with system load profile, the capacity credit can be as low as 5% (Holttinen, 2009; Boyle, 2007). Aggregation of RE output over larger areas, for example by providing more inter-connection between control zones, is beneficial for aggregated capacity credit (Van Hulle, 2009). Planning the optimum generation mix with high shares of RE requires further research in order to develop probabilistic system adequacy forecast methods.

e. Electricity market design

Technical solutions will not work unless matched by market design enhancements including market aggregation and faster operation. Many electricity markets across the world still have structural deficiencies and inefficiencies in their balancing and settlement procedures. For example, long gate closure times (invented when there was only dispatchable generation) and few balancing means available in smaller markets discriminate against variable-output RE. In addition market characteristics can cause unnecessarily high costs of integration. Therefore, a re-design of corresponding market structures and procedures is considered to be a pre-condition for integrating significant amounts of RE into national and international networks. Changing the rules is a matter of principle rather than physics, and does involve little cost, whereas the benefits would be significant.

8.2.1.4 Options to facilitate the integration of RE into power systems

This section discusses how to manage challenges described in 8.2.1.3 by for example making power system more flexible and better interconnected. The basic technical options to facilitate the integration of RE are more and better networks, changes in the power system with respect to balancing (including generation flexibility, demand side control and storage), and addressing system stability in an innovative way. Non-technical issues also need to be addressed.

Variable RE generation induces power flow fluctuation which needs voltage regulation or power flow control in a transmission/distribution system as well as demand-supply balance in the total power system. The technology options to facilitate RE integration into the power system are categorized as outlined below.

8.2.1.4.1 Technical options

Voltage regulation technology

Traditionally, the terminal voltage control of a generator, tap change control of a power transformer, and switching of shunt power capacitors and shunt power reactors are the major reactive power control measures in a power system. Although their importance will probably be maintained in future, further control measures are possible. Reactive power control technologies are divided into two categories:

- a series device inserted between the nodes of the power system, and
- devices which inject or absorb reactive power at a node such as a static var (volt/ampere reactive) compensator (SVC) and a static synchronous compensator (STATCOM) (Xu et al., 2006).

All voltage regulation technologies are commercialized but their performance can be enhanced with the progress of R&D investment in power electronic devices. Energy storage technologies which are nearby or at the same location as RE generation can compensate for power flow fluctuations and eventually, voltage regulation. Currently, electric energy storage technologies are more expensive than reactive power control technologies so are not selected just to stabilize voltage.

Power flow regulation technology

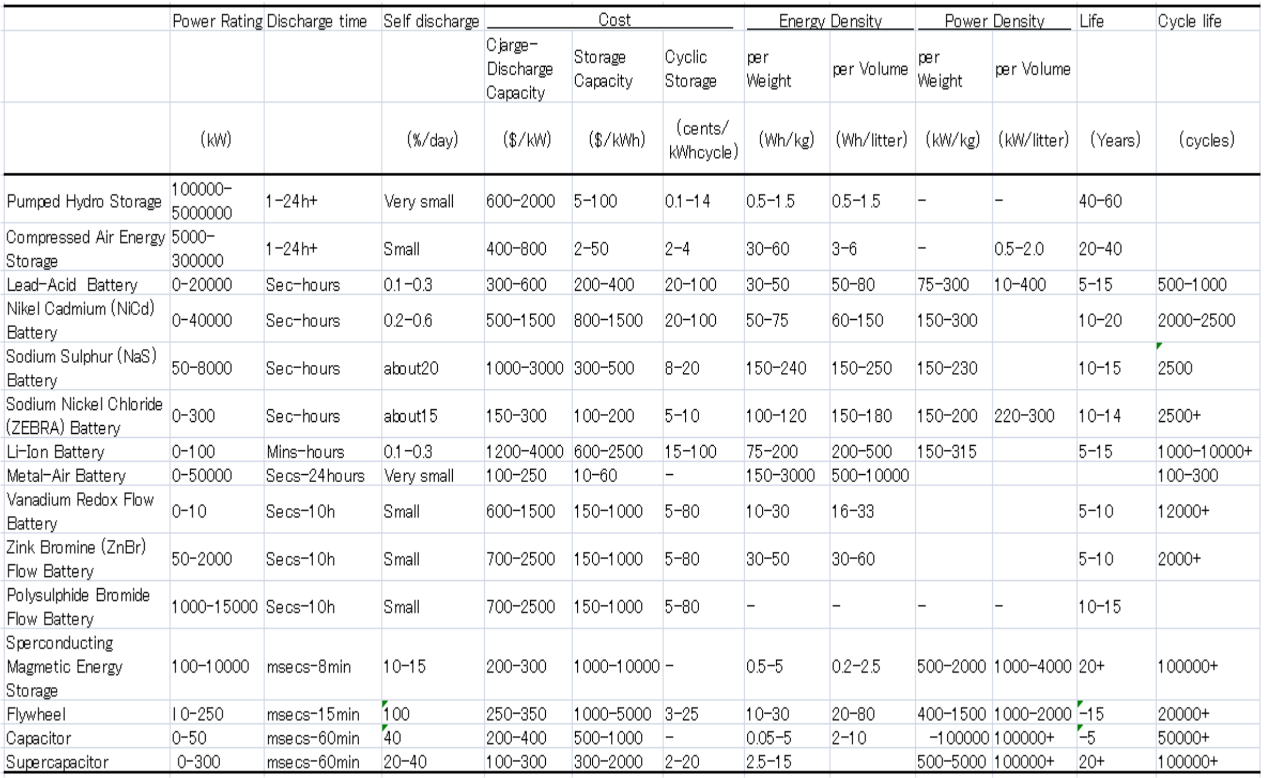
Large power flow fluctuations on a transmission system can lead to overloading of series components and result in a single outage or cascading outages of a transformer or transmission line. Series control devices such as thyristor-controlled series compensators (TCSC), static, synchronous series compensators (SSSC), and thyristor-controlled, phase-angle regulators (TCPAR) can control the power flow through the modification of voltage phase differences between the nodes to alleviate line overloads. Combined series–shunt controllers, such as unified power flow controllers (UPFC), can control voltage and power flow (Ye and Kazerani, 2006).

Power flow regulation technologies are close to commercialization. The overload of series components can be alleviated through an appropriate combination of power system operation, total power system expansion, and power flow control technologies.

Electrical energy storage technology

There is a difference between dedicated energy storage and system level storage. The latter is usually not an economically attractive option in inter-connected systems until high RE penetration exists (Ummels, 2009; O'Malley, 2008; Holttinen, 2009a). The requirement of energy storage should be decided based on the difficulty of aggregated power supply-demand balance and economy. In essence, in isolated power systems with high RE penetration there is a need for storage whereas in inter-connected systems, storage is not economically viable until RE penetration reaches high levels. There are many varieties of electric energy storage (EES) technologies (Table 8.2).

Table 8.2: Technical characteristics of electric energy storage systems (Chen et al., 2009).



	Power Rating	Discharge time	Self discharge	Cost			Energy Density		Power Density		Life	Cycle life
				Cjarge-Discharge Capacity	Storage Capacity	Cyclic Storage	per Weight	per Volume	per Weight	per Volume		
	(kW)		(%/day)	($/kW)	($/kWh)	(cents/ kWhcycle)	(Wh/kg)	(Wh/litter)	(kW/kg)	(kW/litter)	(Years)	(cycles)
Pumped Hydro Storage	100000-5000000	1-24h+	Very small	600-2000	5-100	0.1-14	0.5-1.5	0.5-1.5	-	-	40-60	
Compressed Air Energy Storage	5000-300000	1-24h+	Small	400-800	2-50	2-4	30-60	3-6	-	0.5-2.0	20-40	
Lead-Acid Battery	0-20000	Sec-hours	0.1-0.3	300-600	200-400	20-100	30-50	50-80	75-300	10-400	5-15	500-1000
Nikel Cadmium (NiCd) Battery	0-40000	Sec-hours	0.2-0.6	500-1500	800-1500	20-100	50-75	60-150	150-300		10-20	2000-2500
Sodium Sulphur (NaS) Battery	50-8000	Sec-hours	about20	1000-3000	300-500	8-20	150-240	150-250	150-230		10-15	2500
Sodium Nickel Chloride (ZEBRA) Battery	0-300	Sec-hours	about15	150-300	100-200	5-10	100-120	150-180	150-200	220-300	10-14	2500+
Li-Ion Battery	0-100	Mins-hours	0.1-0.3	1200-4000	600-2500	15-100	75-200	200-500	150-315		5-15	1000-10000+
Metal-Air Battery	0-50000	Secs-24hours	Very small	100-250	10-60	-	150-3000	500-10000				100-300
Vanadium Redox Flow Battery	0-10	Secs-10h	Small	600-1500	150-1000	5-80	10-30	16-33			5-10	12000+
Zink Bromine (ZnBr) Flow Battery	50-2000	Secs-10h	Small	700-2500	150-1000	5-80	30-50	30-60			5-10	2000+
Polysulphide Bromide Flow Battery	1000-15000	Secs-10h	Small	700-2500	150-1000	5-80	-	-	-	-	10-15	
Sperconducting Magmetic Energy Storage	100-10000	msecs-8min	10-15	200-300	1000-10000	-	0.5-5	0.2-2.5	500-2000	1000-4000	20+	100000+
Flywheel	10-250	msecs-15min	100	250-350	1000-5000	3-25	10-30	20-80	400-1500	1000-2000	-15	20000+
Capacitor	0-50	msecs-60min	40	200-400	500-1000	-	0.05-5	2-10	-100000	100000+	-5	50000+
Supercapacitor	0-300	msecs-60min	20-40	100-300	300-2000	2-20	2.5-15		500-5000	100000+	20+	100000+

The required EES power ratings range from 10% to 100% of the RE generating capacity. The required energy storage times range from 10 seconds for wind fluctuations to several hours for weather change; 10 hours for daily cycles and 1-3 months for seasonal changes. The shorter storage requirements are for uninterruptible power supply (UPS), power quality and reliability needs, and the longer ones are for energy management or load levelling/shaving.

Pumped hydroelectric storage (PHS), is deployed widely around the world. It is a centralized, site-specific technology that will continue to be deployed when appropriate. Compressed air energy storage (CAES) is another site-specific technology and two plants have been deployed in Germany and the USA.

Other technologies are still under development, with the exception of the lead-acid battery which is widely used as a UPS resource. Electrical energy storage for RE integration has to have good economy but with low environmental/ecological impacts in order to gain broad deployment. This will need large efforts in technology R&D.

Vehicle-to-grid (V2G) is a concept whereby battery-powered electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) can be used as EES to give GWs of capacity. However, their more widespread deployment will only be possible when EVs and PHEVs have batteries with enough durability, economy, and capacity for power control use.

To store electricity, it must first be converted into another form of energy and transformed back when needed. Possible techniques for energy storage include mechanical, chemical, and thermal forms. Many technologies exist, but comparison is difficult because of their different stages of development.

Through the transformation of low-cost primary energy sources used in regular power plants, the intermediate energy obtained from electricity can be stored and used at an appropriate time as a substitute for the expensive primary power used in peak-load power stations, or for the “virtual energy” as a result of a breakdown in supply. There are two modes of energy production for which storage is clearly important:

- conventional energy production where storage could compensate for a temporary loss of production of a generating unit and fulfil a commercial obligation of pre-sold energy supply, and thus avoid penalties; and
- RE production (CSP and PV) where the storage adds value to the supplied current by making this type of energy predictable (e.g., the delivery of electrical power during peak hours). However, the cost of buffer storage should be considered. The stored power could only satisfy a portion of the nominal production capacity, while the energy should be made available as a result of a contractual compromise.

Network imbalance can be caused by temporary production deficits, which could possibly be predicted. Imbalance could also be the result of production failures. Storage and retrieval systems can help provide instant response to demand and, as a consequence, add flexibility to the network in terms of load levelling. Load-levelling also helps to reduce fluctuations to a minimum, making the supply more predictable. Effective load-levelling would make it possible to use the existing transmission and distribution facilities for many years to come.

Demand control technology

The mitigation, modification, or time shifting of demand can improve the power demand-supply balance by responding to variations in RE generation, often referred to as demand response (DR). The demand of residential and commercial sectors may be more responsive than that of industry because industrial demand is heavily linked to its production schedules. In the near future, the power demand of heat pump water heaters and the charging of EVs and PHEVs, could also be responsive, as could that of refrigerators, washing machines, and air conditioners. In order for this to happen, advanced metering infrastructure (AMI), energy management technology, and control interface technology for appliances used in households, commercial buildings and factories, together with information technology (IT) for communication, are all essential. These technologies will realize direct/indirect control of the appliances using a control signal or an incentive signal such as a dynamic pricing of electricity. Once customers set demand response into their energy management controller, the direct/in-direct controls become automatic in accordance with the signal from the power system (NETL, 2008). Distributed generation technologies, such as CHP and PV, can be included in the DR category as an active supply source (Chicco and Mancarella, 2009).

Sub-marine and long-distance transmission

Excluding DC power distribution systems which are in the early stages of evolution, the power system are usually configured as alternate current (AC) systems, with 50 Hz or 60 Hz frequency. Using efficient and economic power transformers and other AC technologies, the power generated at power stations is transmitted and distributed to near-by and remote loads reliably, economically and flexibly. AC transmission and distribution systems are composed of a set of classes of different rated voltages, for example, from 765kV to 120V in North America. For longer distances, transmission as high-rated AC voltage with high performance and capital costs can be adopted, as well as high voltage, direct current cables. AC power transmission is neither economic nor applicable in the following cases:

- large capacity and long distance transmission -for example, 5 GW over >1000 km;
- long distance submarine cable transmission of, for example, >50 km;
- difficulty of power flow control in mesh-structured systems; and
- non-synchronizing inter-connection between incompatible AC power systems such as with different frequencies.

Direct current (DC) transmission technology can be adopted to overcome the above limitations. It uses an AC to DC converter and a DC to AC inverter based on power electronic devices.

Although many traditional HVDC systems are based on current source converters utilizing thyristor devices, the development of a new power electronic device, insulated-gate, bipolar transister (IGBT) has enabled a new HVDC system “HVDC Light” to be developed using a voltage-sourced converter (Jones et al., 2007). The converter, being able to independently control active and reactive power in addition to the essential power transmission, offers effective active and reactive power control of an AC power system (Ruan et al., 2007). It is an attractive future technology for both off-shore and on-shore grids but some technical issues still need to be resolved before multi-terminal HVDC variable speed control can be commercially implemented.

Using HVAC and HVDC technologies, several proposals could realize “super grids” to give large-scale, RE integration into a power system including:

- a conceptual transmission plan to accommodate 400 GW of wind energy (US DOE, 2008a); and
- the trans-Mediterranean grid inter-connecting the best sites for RE use in EU, Middle East and North Africa (DLR, 2005).

Variable RE generation analysis and forecast technologies

Knowledge about the characteristics of variable RE generation is needed for long-term capacity planning and everyday operation as RE penetrates more into the power system. Aggregating RE from larger areas improves its predictability since forecast error decreases with the size of the area. Hence there is need for larger balancing areas, which can be realised by market organisation and inter-connection. Experience with wind generation in regions with high RE penetration implies that the forecasting technology should enable a substantial reduction in balancing costs and improve system security when using a high level of variable RE.

Accurate short-term forecasting is industrial practice today and commonly implemented in control rooms of plant and system operators (see Chapter 7). Day-ahead forecasts now have an error of only around 6% in Germany. There is still room for improvement with wind speed forecasts remaining the most researched and tested.

Various forecasting techniques have been proposed for predicting 1 hour to 1 day-ahead forecasts for a single turbine, a wind farm, or a region with many wind farms (Ramirez-Rosado et al., 2009; Kavasseri et al., 2009). Solar radiation forecasts for PV and solar thermal generation have also been researched (Reikard et al., 2009; Cao and Lin, 2008).

For demand-supply balance of a total power system, the analysis of generation characteristics of aggregated RE becomes more important than those of individual generation. The aggregated generation will have less variation, thus requiring fewer counter-measures, and will reduce the integration cost of investment and operation subject to network flow constraints.

Operating power systems with variable RE does not need to be drastically different than operating power systems without, especially in the near term with moderate levels of RE penetration. Specifically, variability can be managed through scheduling and dispatching conventional resources to maintain a balance between expected generation and demand, whereas uncertainty can be managed through an increase in reserves to accommodate imperfect forecasts. Several modifications to conventional system operations, however, will increase access to flexible resources and reduce the additional uncertainty from variable RE. These modifications include the inclusion of a centralized forecast in the scheduling and dispatch of generation and decreasing the time between generation scheduling intervals.

Reserves are generation or demand capacity that are scheduled to be available to restore the supply-demand balance in the event of an unforecasted demand or generation deviation. Because some variable RE sources are predictable over short periods of time (minutes), the need for providing additional reserve from the fast reserve categories is small. On longer time scales (in the order of hours or more), wind forecast errors grow substantially. Forecast errors over longer periods consequentially increase the need for additional slower reserves (Doherty and O'Malley, 2005). The need for both fast and slow reserves increases with wind penetration levels.

Contingency reserve, a particular category of fast-acting reserves, cater for very sudden changes, typically the loss of a the largest in-feed contingency (generating unit or interconnection to other systems). Unless a RE plant connecting through a single line is the largest in-feed (such as a large off-shore wind farm), RE is not expected to add substantially to contingency reserve requirements. Some severe weather conditions, however, may require scheduling increased reserves. An extreme weather pattern hitting a large concentration of wind plants, for example, will increase the risk that multiple wind turbines will shut down due to high wind speeds.

System operators can manage this risk by incorporating severe weather forecast alerts in system operations and increasing reserves accordingly. Similar actions are often taken by system operators in response to forecasted lighting storms, which increase the risk of transmission line outages (NERC, 2009). Incorporating wind forecasts into the scheduling and dispatch of the system provides more opportunities to accommodate changes in wind generation over all time-frames of interest to power system operators, and therefore can reduce the reliance on reserves. Inclusion of state-of-the-art wind forecasts, for example, has been found to reduce scheduling costs (Smith et al., 2007a). Similarly, operational decisions based on knowledge that forecasts are not perfect, through stochastic unit-commitment, allow for more conservative and lower-cost scheduling decisions (Tuohy et al. 2009).

Centralized/decentralized energy management

Traditionally, a transmission system operator monitors the major status of a power system including frequency, voltage and power flow at central/regional operation centres, as well as controlling on-line/off-line system control devices on the supply side. In order to manage more frequent and wider variations of RE generation outputs, central energy management is required to realize more robust and sophisticated power system control. The deployment of phasor measurement units (PMU) and wide-area measurement systems (WAMS) are emerging technologies to strengthen the monitoring of power systems (Wang et al., 2007). They improve system performance including recovery from various system disturbances (Zhang et al., 2008).

In order to keep the supply-demand balance of the power system with higher penetration levels of variable RE generation, it is necessary to deploy more effective measures. Decentralized energy management can realize optimum demand-side controls for a residential building, commercial building, group of buildings, or an industrial area, can be harmonized with power system operation by information exchange. This scheme is often called a "smart grid" (Litos, 2008). The EU has been investigating smart grid technologies in the European Technology Platform initiative since 2005 (Bouffard and Kirschen, 2008). In the US, smart grids have been incorporated in energy policy by the Energy Independence and Security Act (EISA) 2007, which promotes their development through a matching programme to states, utilities and consumers. The EISA assigns the National Institute of Standards and Technology as a coordinating body for the development and modification of a number of standards that relate to the smart grid.

A virtual power plant (VPP) is a combination of the above-mentioned monitoring and control technologies to give a business model akin to a power utility. Distributed locations of substantial amounts of generation capacity can be virtually regarded as a single generation plant. When they meet a load or a group of loads, their power production and consumption are monitored and the demand-supply balance is managed through an appropriate energy management control (van Dam, 2008).

For rural electrification involving RE generation, it is important to take a long-range view using a comprehensive planning methodology involving the use of geographical information systems (GIS) (Amador and Dominguez, 2006). This includes decisions as to whether a particular district will become integrated into a large power system or remain an off-grid, autonomous system, based on the total life cycle costs of the alternatives (Kaijuka, 2007).

8.2.1.4.2 Institutional aspects facilitating integration

Integrated long-term energy planning is a key to enabling future energy supplies and identifying strategic generation, transmission & distribution infrastructure needs. The first step for an integrated energy planning process is to identify and quantify RE resources and socio-economic benefits from their uptake. Identification of the near- and long-term practical potential of these resources could then be integrated with existing and future electricity infrastructure plans and identifying barriers. Lack of an integrated planning process could cause a significant barrier for the uptake of renewable electricity. A project by project approach would not address cumulative effects nor provide a signal to stakeholders for the best development option. In a competitive electricity industry, these tasks may be delegated to a market that is supported by advisory functions because future costs and benefits may be matters of opinion rather than objective facts.

A systematic approach that accommodates generic electrical system issues in an integrated manner could provide guidance on how best to facilitate uptake of mature and emerging RE resources. Through scenario analysis, coupled with steady state and dynamic network investigations, the challenges and opportunities associated with large-scale integration of renewable electricity could be identified. Current and future power generation characteristics, local distribution & transmission control areas, cross-border networks, load growth, and future network expansion plans should be considered. Outputs from such integrated analysis could provide framework for developing an optimized planning process and appropriate policy instruments to enable cost reductions and market deployment.

An approach to deploy a high penetration of various types of variable RE technologies across a large geographical region has been developed (NERC, 2009).

- Deploy advanced control technology designed to address ramping, supply surplus conditions and voltage control.
- Deploy complementary, flexible resources such as demand response, reversible energy storage and performance enhancements for non-renewable generation that can provide ramping and ancillary services to facilitate higher penetration of the variable resources.
- Enhance and extend transmission networks to move energy reliably from the new RE generators to demand loads and support the use of complementary resources.
- Improve market designs for energy and ancillary services to provide appropriate commercial incentives and penalties for variable RE and complementary resources.
- Enhance measurement and forecasting of variable generation output.
- Adopt more comprehensive planning approaches, from the distribution system through to the bulk power system.
- Explore further possibilities for interconnection to extend the geographical scope of power systems that have high penetrations of variable RE generation.

In Australia, despite the progress that has been made in preparing for RE integration (AEMC, 2009; Outhred and Thorncraft, 2010), the Australian Energy Market Operator (AEMO, 2009) suggests that more needs to be done, often involving institutional aspects, with respect to:

- convergence of electricity and gas markets, particularly gas market evolution;
- efficient utilisation and provision of electricity networks, particularly generator locational incentives and congestion management;
- connecting remote generation, particularly boundary, interaction and coordination issues between dedicated and shared network assets;
- inter-regional TUOS in the context of the National Electricity Market;
- retail market price caps, prudential frameworks and retailer failure risks;
- generation capacity in the short-term, where a single, well structured and coherent set of arrangements is needed;
- system operation with intermittent generation, where AEMO is re-starting its network support and control services review.

European electricity transmission system operators (TSOs) have been engaged in a wind integration study with funding support from the European Commission. Their July 2008 Interim Report (ETSO, 2008) notes that they are already active in addressing issues associated with efficiently accommodating wind into the transmission networks by:

- establishing direct connections to large wind farms both onshore and offshore;
- planning the connections and interfaces with increasingly active distribution networks connecting wind generation;
- reinforcing network pinch-points within and between national networks;
- participating in market developments, such as establishing intraday markets, market coupling, and forming regional markets;

- developing balancing arrangements through enhanced control arrangements and commercial mechanism; and
- developing appropriate grid codes to facilitate large scale wind entry.

The above experiences all point to the need to address institutional aspects of RE integration consistently across the full physical scope of a power system prior to reaching high levels of RE penetration in that power system (AEMC, 2009). Addressing institutional aspects may require close cooperation between multiple jurisdictions. For example, a recent study on optimal wind power deployment in Europe (Roques et al, 2009) highlighted the need for more cross-border inter-connection capacity, greater coordination of European RE support policies, and for support mechanisms and electricity market designs to provide local incentives. Similarly, Van Hulle et al., (2009) that integration of wind power in Europe had been slowed by planning and administrative barriers, lack of public acceptance, insufficient economic incentives for network operators and investors to undertake transmission projects of European interest, and a generally fragmented approach by the main stakeholders.

8.2.1.5 Benefits & costs of large-scale penetration of renewables

In broad terms, the benefits of RE generation arise from:

- the displacement of fossil fuels, with ensuing reductions in fuel costs and external fossil-fuel impacts such as climate change emissions and acid rain;
- reduced reliance on imported primary energy resources with energy security and balance of trade benefits; and
- the development of a RE industry with ensuing benefits of employment, export earnings and the fostering of an innovation culture.

The operating and investment costs associated with RE generation integration arise from:

- network augmentation and/or extension to accommodate the possibly fluctuating electricity flows associated with RE generation; and
- investment in, and operation of, complementary electricity generation, storage and end-use technologies that can respond in a flexible and efficient manner to the fluctuating energy flows associated with non-storable RE forms.

RE generation with intrinsic storage, such as biomass or pumped-storage hydro, behave in a similar manner to fossil fuel thermal generation and thus raise no additional technology-specific costs when integrated into power systems. However, the situation is different for variable RE generation without intrinsic storage. Wind energy is the first non-storable RE technology to reach high levels of penetration and most cost-benefit investigations have focussed on the additional technology-specific costs that arise when wind energy is integrated.

For low levels of penetration, the costs and benefits associated with wind energy depend on the pre-existing electric power system (generation, network and load characteristics) and can be estimated by simulation studies that extrapolate from the pre-existing state. Holttinen et al. (2009a) presented and analysed the results from ten studies of this kind in Europe and the USA undertaken under the auspices of IEA Wind Task 25 (www.ieawind.org.AnnexXXV.html[TSU: URLs are to be cited only in footnotes or reference list.]). These studies addressed three key power system issues:

- balancing (managing short-term wind energy fluctuations from seconds to hours by maintaining sufficient generation reserves);
- power adequacy (reliability of supply, often assessed by calculating “capacity credit”); and

- grid (congestion management, system security and grid reinforcement).

Estimates depend on the forecast lead-time. In practice, reserve requirements are highest when wind energy generation is high and thus other, displaced generators should be available to provide reserves, subject to their operating flexibility constraints. Balancing costs due to wind energy are expected to vary with wind penetration (Fig. 8.6).

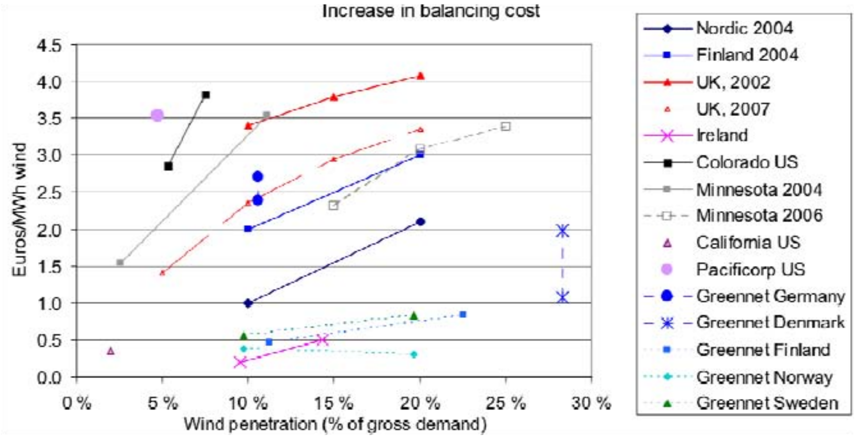


Figure 8.6: At higher levels of wind penetration, the additional balancing costs of the entire power system are higher, as shown by several power supply system studies (Holttinen et al., 2009a).

Holttinen et al., (2009a) concluded that "at wind penetrations of up to 20% of gross demand (energy), system operating cost increases arising from wind variability and uncertainty amount to about EUR 1-4 /MWh [TSU: Also needs to be presented in 2005 US$]", which represents around 10% or less of the wholesale cost of wind energy generation.

With respect to the capacity credit of wind energy generation, Holttinen et al. (2009a) recommended calculating the effective load carrying capability (ELCC), which requires detailed chronological data for wind generation and load and availability information for generators with intrinsic primary energy storage. Figure 8.7 summarises the results from eight studies undertaken in Europe and the USA [TSU: Holttinen et al, 2009a was cited above as covering ten studies across Europe and the USA – discrepancy should be clarified]. The capacity credit estimates (as % of installed capacity) show considerable variation due to the differing nature of the wind regimes and their correlation with electricity demand as well as a general reduction trend with increasing wind penetration.

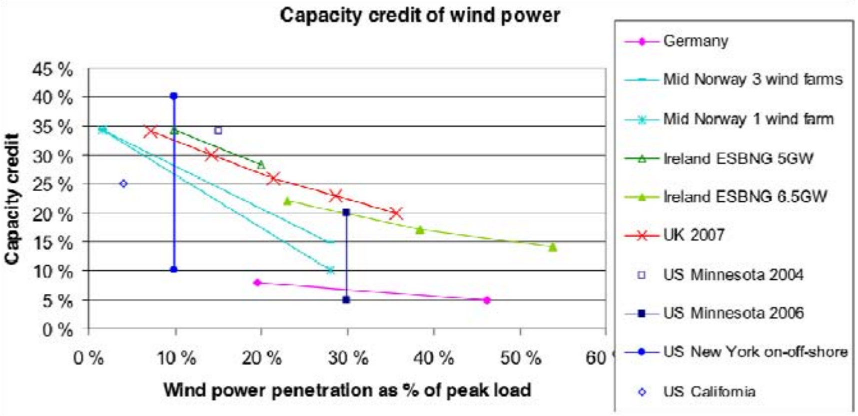


Figure 8.7: Capacity credit declines as wind power penetration increases (Holttinen et al., 2009a).

When moving beyond penetration levels of 20% of wind energy on an annual energy basis, Van Hulle et al., (2009) suggest that new directions need to be followed for both the design and operation of the power system and the electricity markets to give consistent policy decisions. Hence it is critical that the decision-making processes are well thought through, for example, on grid reinforcement, technical standards, market rules etc. A similar conclusion has been reached in Australia, where a holistic approach has been taken since 2003 to integrating non-storable RE resources, including wind energy, into the Australian national electricity market.

Holtinnen et al., (2009) identify large unconstrained transmission regions, flexible complementary resources and efficient intra-day trading, as factors that can help to minimise the costs of wind energy integration. They also suggest that augmenting wind energy with high penetration of PV or ocean power would help to smooth variability and thus reduce, at least in a per-unit sense, overall integration costs.

The EU and Australian experiences are discussed further as case studies below. However carefully chosen policies and commercial incentives will be required to bring forward an appropriate mix of "complementary resources" (generation, network, reversible storage and flexible end-use) and to maximise the benefits that wind energy or other non-storable RE resources can bring whilst minimising the costs. The resulting resource mix, and the effectiveness of such a strategy, will be context-specific and evolve over time.

8.2.1.6 Case studies

8.2.1.6.1 European large-scale wind integration: TradeWind

The TradeWind project (2006-2009) coordinated by the European wind industry association EWEA and sponsored by the European IEE Programme (Van Hulle et al. 2009) was a recent study to investigate the adequacy of European power systems for large scale wind integration (www.trade-wind.eu[TSU: URLs are to be cited only in footnotes or reference list.]).

TradeWind assessed the options for improved interconnection between European member states and the corresponding power market design to enable large-scale wind energy integration in Europe. Optimal power flow simulations were carried out with a Europe wide network model to look into the effects of increasing wind power capacity and more specifically of possible grid dimensioning situations on cross border flow. Future wind power capacity scenarios up to 300 GW in the year 2030 were investigated. The TradeWind simulations show that increasing wind power capacity in Europe leads to increased cross border energy exchanges and more severe cross-border transmission bottlenecks in the future, especially with the amounts of wind power capacity expected in 2020 and 2030. Also the effect of passing storms on cross-border flow was investigated. Wind power forecast errors result in deviations between the actual and expected cross-border power flows on most interconnectors during a substantial part of the time and will further exacerbate these congestions. Significant economical benefits of network upgrades that would relieve existing and future structural congestion in the interconnections have been quantified. More specifically, a staged upgrade at 42 interconnectors would benefit the European power system and its ability to integrate wind power. These upgrades would lead to savings in operational costs of power generation amount of 1500 M€/year[TSU: Also needs to be presented in 2005 US$], justifying investments in the order of €22 billion[TSU: Also needs to be presented in 2005 US$], for wind power scenarios up to 2030 [TSU: Source?].

The project looked also specifically at the benefits of transnational offshore grid topologies for integrating offshore wind power. A meshed offshore grid linking future 120 GW offshore wind farms in the North Sea and the Baltic Sea and the onshore transmission grid compares favourably to a radial connection solution of individual wind farms, due to the higher flexibility and the benefits it offers for international trade of electricity. Such offshore grid supposes further upgrade of the onshore network, which needs to be studied in follow up studies[1].

The European wind power time series were also used to calculate the effect of geographical aggregation on the contribution of wind power to the generation adequacy. It was found that aggregating wind energy production from multiple countries strongly increases the capacity credit of wind power (firm power added in the system by adding wind power capacity). The greater geographic area the grouped countries represent, the higher is the capacity credit (Fig. 8.8). If no wind energy is exchanged between the European countries, the capacity credit of 200 GW wind power in 2020 in Europe would be 8 %, which corresponds to 16 GW firm capacity. When Europe is calculated as one wind energy production system and wind energy is distributed across multiple countries according to individual load profiles, the capacity credit almost doubles to 14 %, which corresponds approximately to 27 GW of firm power in the system.

In addition to transmission needs, TradeWind also evaluated the effect of improved power market rules and quantified these in terms of reduction of the operational costs of power generation. The establishment of intra-day markets for cross-border trade is found to be of key importance for market efficiency in Europe as it will lead to savings in system costs in the order of EUR 1-2 billion[TSU: Also needs to be presented in 2005 US$] per year as compared to a situation where cross-border exchange must be scheduled day-ahead. In order to ensure efficient interconnector allocation, they should be allocated directly to the market via implicit auction.

Intraday rescheduling of the generation portfolio, taking into account wind power forecasts up to three hours before delivery, results in a reduction in operational costs of power generation of EUR 260 M/yr[TSU: Also needs to be presented in 2005 US$] (compared to day-ahead scheduling) thanks to the decrease in demand for additional system reserves. Consequently, the TradeWind analysis concluded that the European electricity market needs intraday rescheduling of generators and trade, a consolidation of market areas, and increased interconnection capacity in order to enable efficient wind power integration.

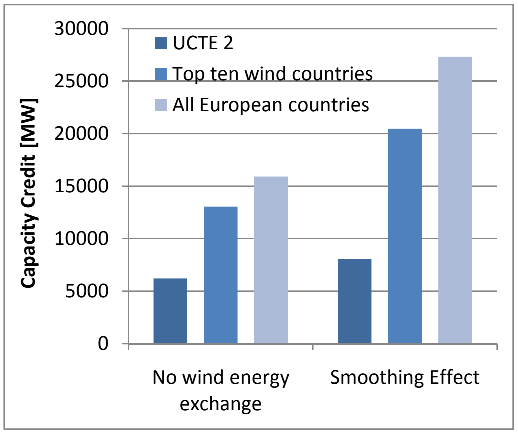


Figure 8.8: Increase of the capacity credit in Europe through wind energy exchange between the countries in the TradeWind 2020 M scenario (200 GW, 12% penetration) (Van Hulle, 2009).

UCTE 2= Union for the Co-ordination of Transmission of Electricity for France, Belgium, Netherlands, Luxemburg, Germany, Switzerland and Austria www.ucte.org [TSU: URLs are to be cited only in footnotes or reference list.]

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[1] Based on the findings of TradeWind, EWEA has proposed a long-term plan for offshore grid development (EWEA, 2009). The technical, economic and regulatory options for such an offshore grid delivering 12% of Europe's demand are further researched in the frame of the IEE Offshore Grid project (www.offshoregrid.eu).

8.2.1.6.2 Desertec

The “Desertec Industrial Initiative GmbH” is a consortium of twelve large German and Spanish engineering, financial and energy companies that, in 2009, launched a USD 560 billion [TSU: Needs to be presented in 2005 US$] investment scheme aiming to produce 15% of Europe’s electricity demand in 2050 (Global Insight, 2009). The concept was initiated in 2003 by the German Club of Rome global think-tank. It aims to harness solar energy from the desert areas of Middle East and North Africa (MENA) using concentrating solar power (CSP) technologies spread over nearly 17 000 km^2. The electricity will be transmitted to Europe through high voltage, direct current (HVDC) cables, some sub-sea. Interconnections between Europe and MENA (Fig. 8.9) could enable the present 16% share of renewable electricity to rise to 80% in 2050 (Trieb and Műller-Steinhagen, 2007). The venture is in the very early stages of planning with many major technological, fiscal, logistical and political barriers identified as needing to be overcome.

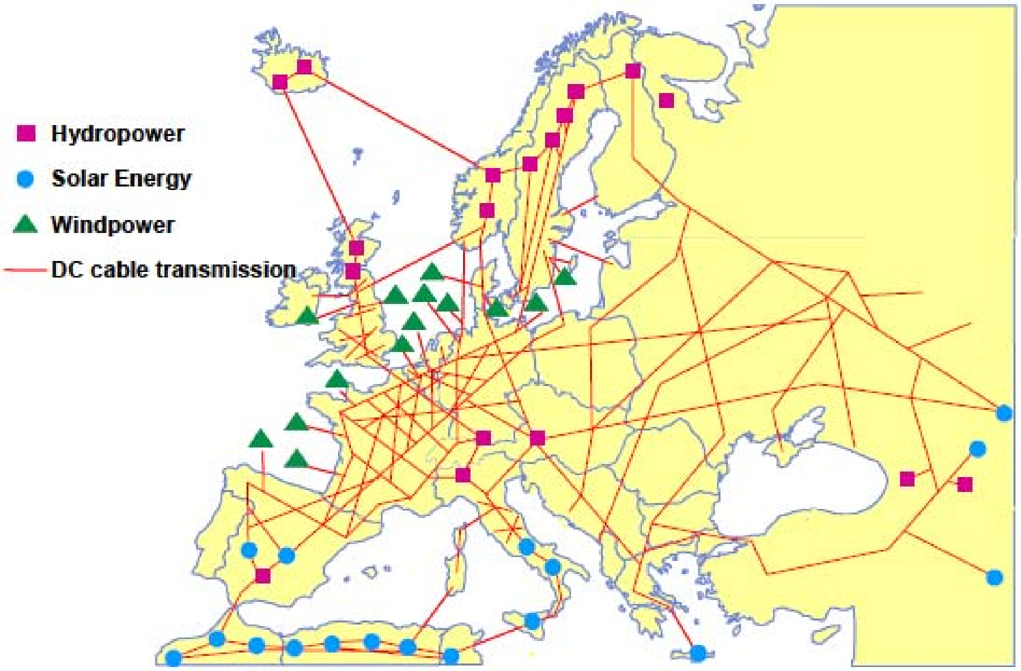


Figure 8.9: The concept of an inter-connected electricity grid between Europe, North Africa and Middle East based on high voltage DC transmission “highways” to connect with the existing AC grid and power plants (Asplund, 2004).

Around 85% of the investment cost will be for the solar power plants and the remainder for the 20 or more transmission cables. The partner Abengoa is already developing integrated CSP installations combined with combined-cycle gas plants in Morocco and Algeria. The two demonstration plants are:

- a USD 212 million[TSU: Needs to be presented in 2005 US$], 472 MW plant in Ain Beni Mathar, Morocco, of which only 20 MW is solar; and
- a 150 MW system in Hassi R’Mel, Algeria, with 35 MW solar.

Some private funding is involved (along with funding from international agencies) but in spite of government facilitation, this has been difficult to attract.

The main barriers anticipated to developing the Desertec project are: possible damage to the solar mirrors from desert sandstorms; public resistance against limited water supplies being diverted for cooling turbines and cleaning the solar mirrors; the need for thermal or fossil-fuel balancing capacity to cover for fluctuations in output; and the challenge to meet the increasing local demand for electricity outweighing the option to export power. For MENA nations that have failed to meet their growing electricity demands in recent years, knowing the demand will rise over three times by 2050 compared with around 1 000 TWh per year today, with a further 500 TWh/yr probably needed for desalination to meet the projected water deficit in 2050 (Trieb and Műller-Steinhagen, 2007), then the concept of exporting power will be difficult to promote. Several North African states already have solar targets in place for the medium term, but establishing commercial-scale CSP facilities has been constrained by their relatively high cost, in spite of feed-in tariffs being in place in Algeria and Morocco. However, CSP generation costs are expected to decline over time to around USD 50/MWh by 2030.

There is unresolved debate whether in Europe, improved energy efficiency measures and the advent of distributed generation (including solar PV) will be a cheaper option than massive investment in the Desertec project infrastructure (Global Insight, 2009). This option would also involve a major upgrade of the existing transmission networks throughout Europe, so further work to assess the combined effects and costs of having a portfolio of all renewables is warranted. The location of the curved solar mirrors, turbines and solar thermal storage systems is also under debate; deep in the Sahara desert and Arabian Peninsula, or closer to populated areas where a supply of water is more readily available are the options.

Close agreement between all stakeholder governments will be needed for the Desertec project to succeed, yet historically this has proved difficult for some of those involved. Exploitation of the local solar resource by foreign-owned companies is already under question. The initial 3 year study led by The German Aerospace Centre, confirmed the feasibility of the project and until 2012 the consortium will concentrate on accelerating the implementation of the Concept by creating of a favourable regulatory and legislative environment and developing a plan for development (Desertec Foundation, 2009). It will have to consider how to manage the political issues, as well as to ensure the technological barriers can be overcome, the CSP plant components can be manufactured at the rate required, and that the inevitable transmission losses can be kept low enough to make the venture profitable.

8.2.1.6.3 ISET renewable combi-plant

This project, a combined RE power plant system, is an initiative of leading German manufacturers of RE technologies. It is supported by partners from the REsector and by the Institute for Solar Energy Supply Systems (ISET) at the University of Kassel, Germany. The objective is to demonstrate the feasibility of RE to cover 100 % of electricity demand and dispel the major arguments against a massive penetration of renewables, including variable generation, poor predictability and lack of controllability (Mackensen et al, 2008a).

The concept is to produce a virtual power plant (VPP) consisting of several decentralized stations, each generating electricity. Photovoltaics, wind turbines, combined heat and power (CHP), and storage devices, are combined plus a central control consisting of system management, forecasting, and a primary control unit (Arndt et al., 2006).

The difference with other VPP projects is that the Renewable Combi-Plant works only with RE technologies. These are all produced in Germany. The grid supply capacity is calculated by adding all decentralized generation including existing renewable power production. The outputs of CHP systems are considered as constant baseload, because their output can not be rapidly varied to follow demand.

The first step to create the scenario for 100% power supply of Germany by RE sources was to estimate the potentials of wind, solar PV and biomass. The resulting electrical power production gave a potential of 448 TWh per year, around 10% higher than the current annual German demand of around 420 TWh. To demonstrate the integration of RE power systems, the VPP was designed to represent a future scenario of supplying the yearly electricity requirements of a small town of 12 000 households. Around 10 000 such VPPs would therefore be needed to supply all of Germany (Mackensen et al, 2008b).

The system aggregates and controls the power generation from three distributed wind farms, 20 solar PV plants, four biogas-fired CHP plants and a pumped storage hydro system (Fig. 8.11) in such a way that the output matches the specified load at all times. The capacities for the system components (Table 8.3) reflect current technology and make it possible to compare the results with real power plant outputs integrated into the Renewable Combi-Plant. The total produced energy is 43.5 GWh/yr including imports/exports and storage.

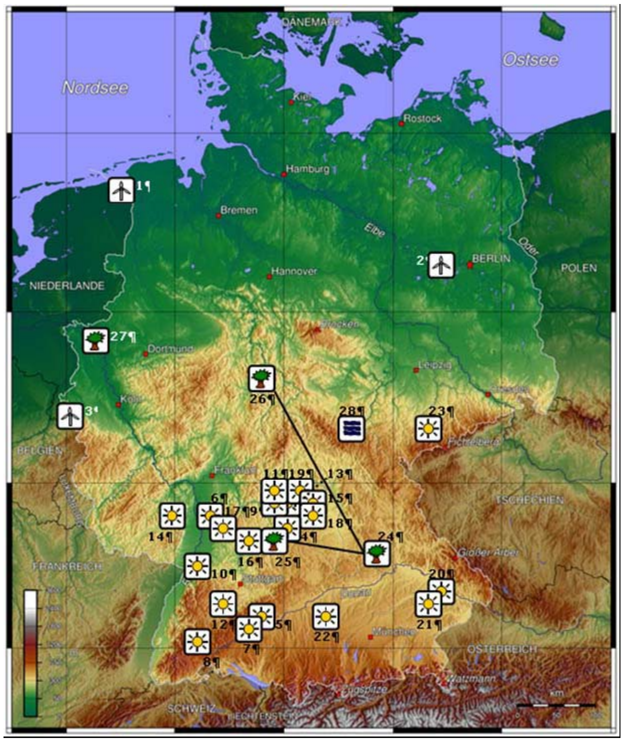
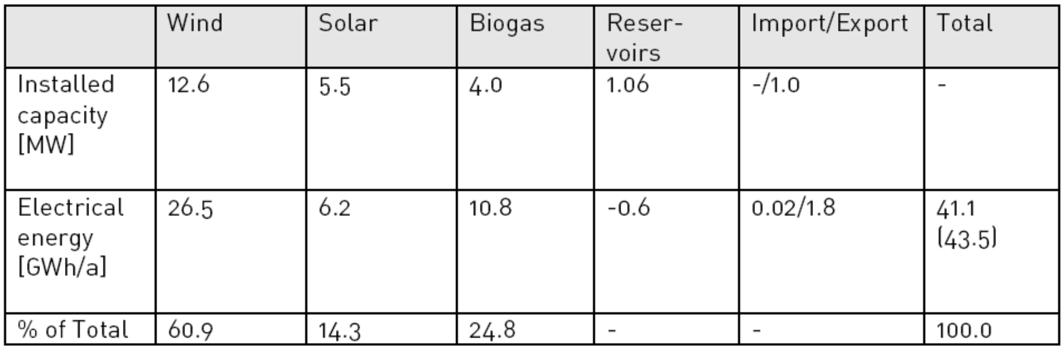


Figure 8.10: Components of the Renewable Combi-Plant depicted by wind (1-3), solar (4-23), biogas (24-27) and pumped hydro (28) (Mackensen et al, 2008b).

Table 8.3: Electrical energy generation and capacity global portfolio of RE technologies (Mackensen et al, 2008a).



	Wind	Solar	Biogas	Reser-voirs	Import/Export	Total
Installed capacity [MW]	12.6	5.5	4.0	1.06	-/1.0	-
Electrical energy [GWh/a]	26.5	6.2	10.8	-0.6	0.02/1.8	41.1 (43.5)
% of Total	60.9	14.3	24.8	-	-	100.0

The wind and solar power components of the combi-plant are geographically spread in order to take advantage of smoothing effects due to different weather conditions in the German regions. These are combined with controllable biogas-fired CHP outputs and the hydro storage reservoir. The plants are real, except for the pumped hydro storage device, with electricity currently being fed into the public grid (Mackensen et al, 2008b).

The use of intelligent control and regulation technology enables the decentralized installations to be linked together so that fluctuations in the amount of electricity fed into the grid can be balanced. The central control unit (CCU, Fig. 8.11) is where the various output forecasts and measurement values are balanced. Based on the data, the control process is carried out in two steps (Mackensen et al, 2008a).

a. Forecast and scheduling

The CCU receives weather and demand forecasts and, based on these, anticipates the necessary amount of power to be produced by wind and solar plants (Rohrig, 2003). To balance out the difference between the actual demand and the electricity generated by wind/solar energy, it calculates and sends a schedule to the biogas plant operators. If there is still a surplus or shortage, this is balanced out by using the pumped storage power plant and, as a last resort, by exporting and importing to and from neighboring grids.

b. Comparison of actual data

The CCU receives feedback from all power plants on the actual current output and compares this data with the immediate demand. Differences compared with the forecast values are balanced through short-term adjustments to the biogas electricity outputs within minutes. The algorithms created for the concept were verified and a prototype has been in operation since May 2007.

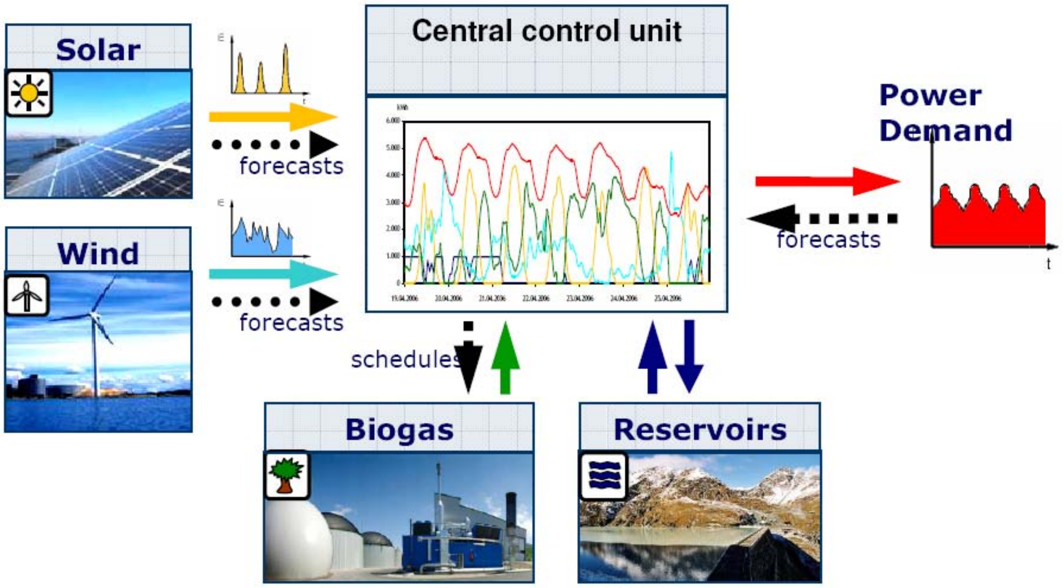


Figure 8.11: Operating principle of the Renewable Combi-Plant (Mackensen et al, 2008a).

To deal with a large portion of fluctuating power, it is necessary to install more total capacity than peak load demand. The Renewable Combi-Plant needs storage capacities to be able to constantly meet the demand. When supply exceeds the demand, the surplus can be shed, stored or exported to neighbours through the Union for the Co-ordination of Transmission of Electricity (UCTE). Exporting energy leads to additional costs for grid reinforcement and expansion. Creating new storage capacity also involves a cost. In addition, storing and transmitting electricity always results in losses.

At higher penetrations of fluctuating energy producers, intelligent integration into the supply system is required to balance production with demand. Integration into the electricity markets requires an adequate payment system as a replacement for the fixed tariffs defined by EEG, the German Renewables Act, 2000. For example a bonus for cogeneration or storage of electrical power would allow transferring the responsibility for compensating for fluctuating power generation to the producers. Under the existing law with a fixed tariff system, neither operators of RE plants nor transmission system operators seek steady energy production, combination with demand side management, or the integration of storage devices. Presently, situations sometimes arise when selling electricity on the free market is valuable, but we can assume that these situations will appear more often because of rising prices and the declining tariffs of the EEG.

This project confirms that it is possible to supply Germany with 100% renewable electricity. To achieve this will depend on the speed of research and development, political will and societal support for the concept.

8.2.1.6.4 Wind integration in the Australian national electricity market

Perhaps uniquely, the Australian national electricity market (NEM) was designed from the outset to accommodate non-storable RE resources. The electricity market design concepts (Schweppe et al., 1980; Outhred and Schweppe, 1980) were incorporated into the Australian NEM. This was partly motivated by an expectation of “increasing exploitation of distributed RE resources often by independent groups that wish to sell excess power to utilities and buy back-up power when needed” (Outhred and Schweppe, 1980). Thus since the NEM commenced in 1998, its centre piece has been a multi-region, real-time energy spot market that implements a competitive security constrained 5-minute dispatch across a power system network that extends over 4000 km, one of the largest in the world. The real-time energy market is supported by co-optimized, real-time ancillary service markets, centralized security management and decentralized derivative markets. These form co-designed, decision-making regimes in an over-arching decision making framework for the stationary energy sector (Outhred and Thorncraft, 2010). In the year to June 2009, wind energy supplied approximately 15% of the 13.1 TWh of electricity consumed in the South Australian region of the NEM. Further increases in wind penetration are anticipated (ESIPC, 2009). While wind penetrations are lower in other NEM market regions, they are also expected to rise.

The Council of Australian Governments (COAG) established a Wind Energy Policy Working Group (WEPWG) in mid 2004 to consider the range of policy level issues associated with the anticipated entry of large amounts of wind generation into the NEM in coming years. In turn, WEPWG requested that the NEM Management Company[2] (NEMMCO) establish the Wind Energy Technical Advisory Group (WETAG) consisting of industry participants to assist the WEPWG with the analysis of technical and policy aspects of wind penetration in the NEM. WETAG identified a number of key tasks (MCE, 2006):

- review technical standards for grid connection;
- manage the impact of “intermittent generation” on network flows;
- investigate wind-farm behaviour in respect of power system operational implications;
- require appropriate information disclosure; and

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[2] The National Electricity Market Management Company was absorbed into the Australian Energy Market Operator (AEMO) in July 2009. AEMO is responsible for both electricity and gas markets.

- review cost recovery for regulation frequency control ancillary services.

NEMMCO itself undertook a series of investigations into RE integration. Significant issues identified in NEMMCO (2003) included forecasting, frequency control ancillary services and network management and connection issues. NEMMCO (2004) reported on the issue of forecasting and recommended that steps be taken to create a forecasting capability, with associated obligations on wind farm owners to contribute data.

The Australian Government then funded NEMMCO to specify and implement an Australian Wind Energy Forecasting System (AWEFS). This is now fully integrated into the security and commercial decision-making regimes in the NEM (see www.aemo.com.au/electricityops/awefs.html[TSU: URLs are to be cited only in footnotes or reference list.]).

AWEFS has a set of forecasting horizons from five minutes to two years and draws on SCADA information from all transmission-level wind farms connected to the NEM. Amongst other functions, AWEFS will support recently implemented “semi-scheduled” arrangements whereby wind farms will be required to participate in the dispatch process if an associated network flow constraint appears likely. Further research is underway to ensure that AWEFS has adequate capacity to forecast large, rapid changes in aggregated wind farm output (Cutler et al., 2008). AWEFS will also be used to forecast other RE resources such as solar energy, when justified by their level of penetration.

The Australian Energy Market Commission (AEMC) has recently completed a comprehensive review of energy (electricity and gas) market frameworks in light of climate change policies for the Council of Australian Governments. Its final report (AEMC, 2009) concluded that “subject to implementation of the framework changes we are recommending, the energy market framework is generally capable of accommodating the impacts of climate change policies efficiently and reliably”. The report recommended the following framework changes:

removal of electricity retail price regulation (where still in force) or at least the introduction of flexibility mechanisms to allow timely adjustment of regulated prices;

bringing forward the implementation of a national framework for energy customer protection developing network connection arrangements that achieve efficiency gains from connecting clusters of generators, developed over time, using common network assets;

- introducing transmission charges between market regions of the NEM in recognition of the likely increased importance of fluctuating inter-regional flows increasing the extent to which generator network charges vary by location as well as the extent to which spot market energy prices reflect congestion within market regions;
- regularly reviewing the spot market price cap (presently approximately USD 10,000 /MWh) for adequacy with respect to bringing forward complementary resources to manage fluctuations in the output of generators based on non-storable RE resources; and
- reviewing the effectiveness of reliability intervention powers of the Australian Energy Market Operator (AEMO).

8.2.2 Integration of renewable energies into heating and cooling networks

8.2.2.1 Characteristics

A district heating or cooling system is a piping network that allows multiple energy sources to be connected to many energy consumers by pumping hot or cold water as the energy carrier. Technologies used for district heating and district cooling are can facilitate the use of renewables, especially in dense urban, commercial and industrial areas. The concept creates the opportunity to access a broad spectrum of RE sources to provide heat or cold to a large number of users.

Historically, district heating systems were mainly developed in countries with long, cold winters. After the oil crises in the 1970s, several countries developed district heating systems in combination with combined heat and power (CHP) generation to increase overall energy efficiency. Some countries, in particular in Scandinavia, have a district heating market penetration of more than 50% and in Iceland, the share, using geothermal resources, reaches 96% (Fig. 8.12). Today, district heating is also used in lower latitude countries and district cooling is increasingly being used in many regions of the world, either through the distribution of chilled water or by using the district heating network to deliver heat for heat-driven absorption chillers. The Swedish town of Växjo, for example, uses excess heat from the biomass CHP plant in summer for cooling in one district (SESAC, 2009), and a further 2MW chiller is planned (IEA, 2009b).

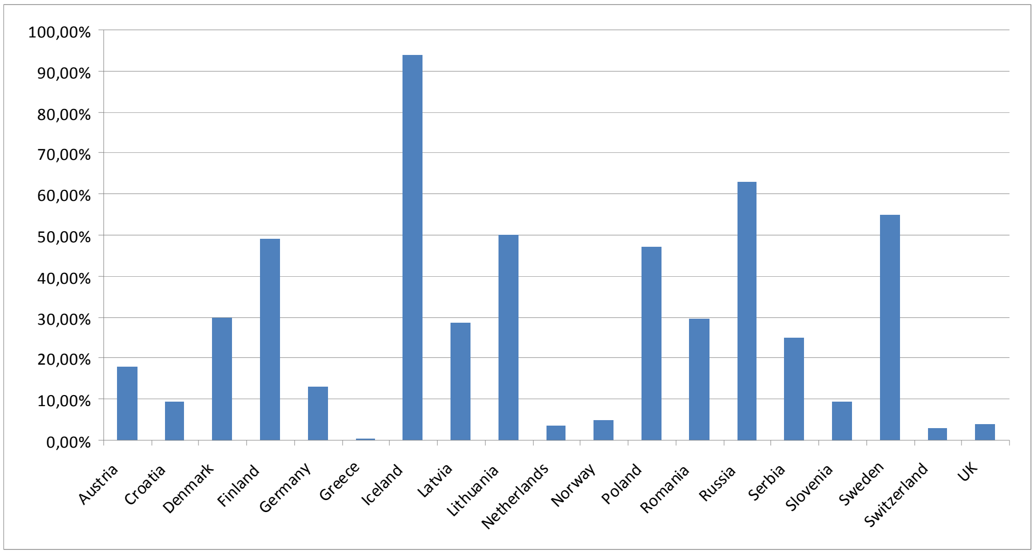

Figure 8.12: Share of district heating in total heat demand in selected countries (Euroheat & Power, 2007).

District heating systems offer benefits both on the demand side and on the supply side (Fig. 8.13) the cost-effective use of large scale geothermal, solar or biomass technologies, and fuel flexibility. In the future, new-low carbon and renewable sources can be integrated as soon as they become available and a network can quickly be extended as appropriate to provide an easy way to supply a larger number of customers. Those connected to a district heating system do not need to care about operation and maintenance of their own individual boilers, but can rely on a professionally managed central heating system.

- In the case of deep geothermal systems, the commercial exploitation of large heat flow volumes is required to compensate for the high drilling costs. In most cases, such a large heat demand is only available through district heating networks. Also enhanced geothermal systems (EGS) usually require to be operated in CHP mode coupled with district heating networks in order to be cost-effective.

- Woody biomass or crop residues can be more efficiently used in a district heating integrated CHP plant than in individual small scale burners. The operation of a centralised biomass CHP plant with lower specific investment costs facilitates the operation of cost-effective emission reduction measures.

- The costs of solar heating of water, space or both can be reduced by shifting from small-scale, individual solar thermal systems to large-scale, solar heating plants. Higher solar shares can be achieved by using seasonal thermal storage systems, for which the integration into a district heating system with a sufficiently high heat demand is again a prerequisite.

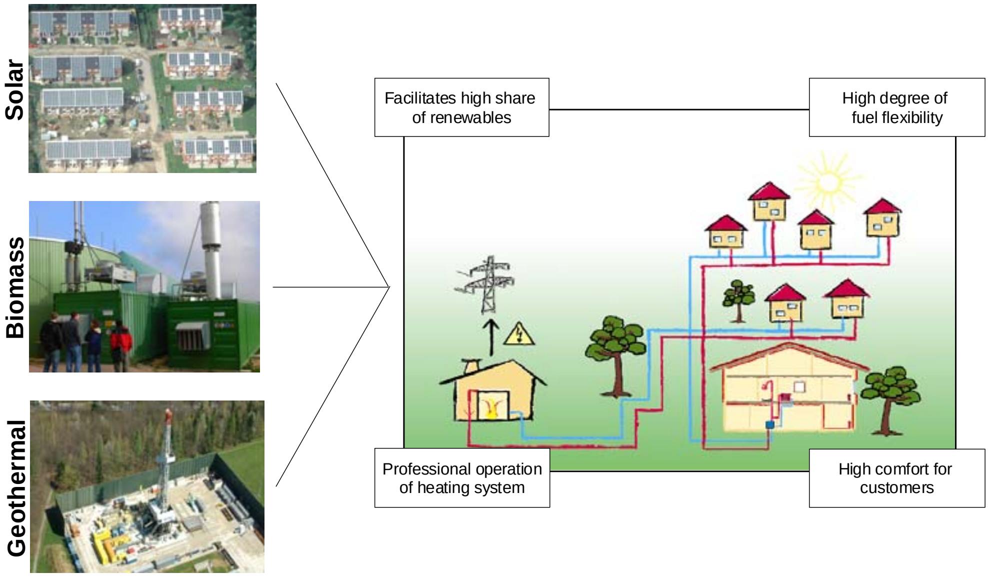

Figure 8.13: A district heating system, often linked with power generation from a CHP plant, offers several benefits for heat users.

By 2007, the more than 200 Mm^2 area of solar collectors installed worldwide produced 146.8 GWth (Weiss et al., 2009). The power output from 1 Mm^2 of flat-plate solar collectors is on the order of 700 MW during the middle of the day (assuming 1,000 W/m^2 incident radiation and 70% collector efficiency). Thus, the peak power capacity of solar water heaters in a number of countries already exceeds 1,000 MW and makes a significant contribution to the energy supply system. The impact of the installation of a large number of solar domestic water heaters to replace electrical heating on the operation of an electricity grid depends on the load management strategies of the utility.

Large-scale implementation of solar water heating can benefit both the customer and the utility. For a utility that uses centralised load switching to manage electric water-heater load, the impact of solar water heaters is limited to fuel savings. For utilities that do not, then the installation of a large number of solar water heaters may have the additional benefit of reducing peak demand on the grid. Maximum solar water-heater output corresponds with peak summer electrical demand, and there is a capacity benefit from load displacement of electric water heaters. Emission reductions can result, especially where the solar water heating displaces the marginal and most-polluting generating plant used to produce peak-load power.

Combining biomass and solar thermal energy could provide high capacity factor solutions suited to areas with lower levels of direct-beam, solar radiation due to greater cloud cover. Such areas often have good availability of biomass due to increased rainfall. Since solar technology is more land efficient than biomass (in terms of GJ energy supply per hectare), its use reduces the need for land to grow the biomass and the related transport costs. The optimum ratio of solar thermal to biomass to supply heat would be site-specific.

8.2.2.2 Features and structure

Thermal energy in the form of hot water or steam is distributed by pipelines from central plants to individual buildings. Energy is extracted at the buildings and return pipes bring the water back to the heating plant. In order to be economically viable, the heat demand density must be sufficiently high.

District heating systems are most commonly operated in densely populated urban areas. However, district heating can also be economically feasible in less densely populated areas, especially where an industrial low-to-medium grade heat load also exists (such as the kiln drying of timber). The annual cost to supply around 18 MWh/yr of heat to a single family, Danish house (130 m²) has become around 30% lower for biomass district heating versus an oil-fired central heating system (Fig. 8.14), partly due to the increased oil price (Dansk Fjernvarme, 2007).

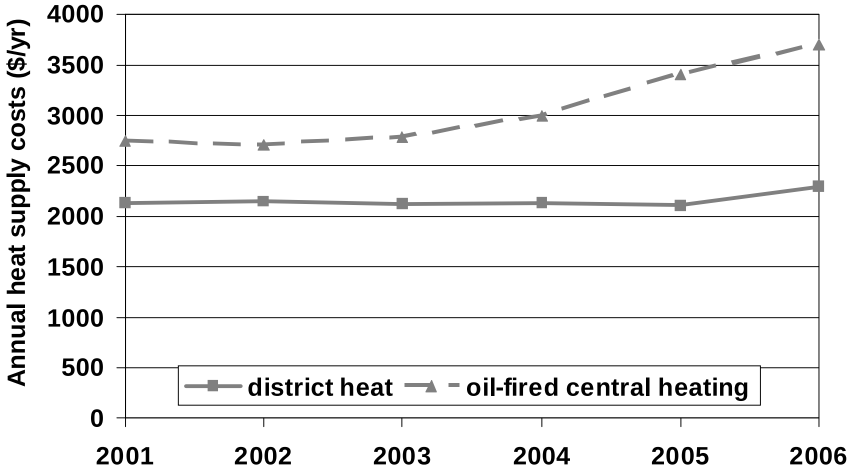

Figure 8.14: Annual heat supply costs for a single family house in Denmark (130 m², 18.1 MWh/yr) supplied either by district heating or by oil-fired central heating (Dansk Fjernvarme, 2007).

8.2.2.3 Challenges caused by integration into heating networks

The cost of district heat supply varies strongly with the heat density of the consumer area. In Denmark, about 80% of the district heating companies face an average heat density within the range of 330 to 1400 kWh per metre of pipeline per year (Bruus & Halldor, 2004). In small towns, the average heat density is typically somewhere between 280 to 550 kWh/m/yr, while centres of large urban areas can have densities above 2800 kWh/m/yr. In Germany, the average economically viable heat density is around 4000 kWh/m/yr as a result of high heating network installation costs due to technical and administrative reasons (although current legislation provides incentives for expanding district heating systems into regions with lower heat densities than this). By comparison, in Denmark the distribution cost component per heating unit is acceptable where heat density is above 550 kWh/m/yr (typical of an urban area with a moderate population density). The total supply cost remains well below the cost of individual fossil-based heating of apartments.

In the future, very energy efficient buildings in new residential areas will have a heat density well below 300 kWh/m/yr.[TSU: Source?] This will flatten the load curve and require only relatively small amounts of heat for space heating during winter and for hot water throughout the year. Heat distribution network investment costs, depending on site specific conditions, are therefore likely to become the predominant part of the total heat supply costs. Heat pumps or other local alternatives could supply much of this baseload heat. Therefore district heating could end up being of interest only for industrial areas or as occasional back-up to meet peak load demands. However, expected reductions in heat distribution costs, through improved design and reduced losses, suggest that the expansion of district heating will become economically feasible to consumer areas with a heat density of only around 150 kWh/m/yr (Bruus & Halldor, 2004). Improved designs includes the co-insulating of smaller diameter forward and reverse flow distribution pipes.

8.2.2.4 Options to facilitate integration into heating networks

8.2.2.4.1 Storage

Thermal storage systems are essential components for system integration, as they can bridge the gap between intermittent, discontinuous or unsynchronised heat supply and demand. The capacity of thermal storage systems ranges from a few MJ up to TJ, the storage time from minutes to months, and the temperature from -20°C up to 1000°C. This is possible only by using different storage materials (solid, water, oil, salt, air) and the corresponding thermal storage mechanisms.

In household applications with natural gas or electrical heating, hot water cylinder heat stores are commonly used. Solar systems can displace some or all of the energy demand, the gas or electricity becoming the back-up. For integrating large-scale, solar systems into district heating networks, the development of systems for seasonal heat storage (Fig. 8.15) has made considerable progress and several demonstration plants have been realised. Heat storage systems using latent heat of fusion or evaporation (phase change materials, PCMs), or the heat of sorption, offer higher storage densities. Sorptive and thermo-chemical processes allow thermal storage for an almost unlimited period of time, since heat supply or removal occurs only if the two physical or chemical reaction partners are brought into contact. Both latent and sorptive heat storage technologies are in a relative early development phase.

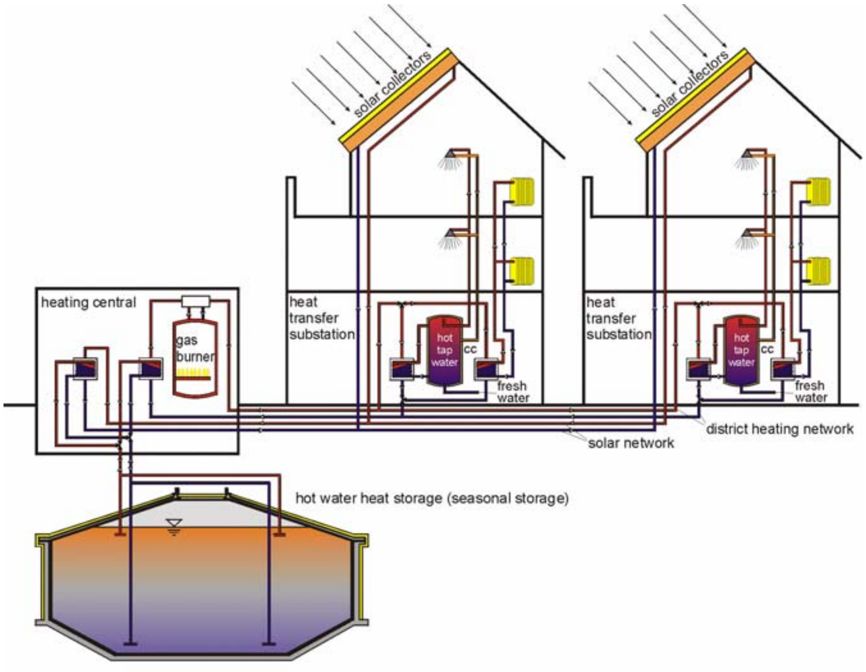

Figure 8.15: Central solar-supported heating plant with seasonal storage connected to a district heating system (Heidemann and Müller-Steinhagen, 2006).

The type of hot water storage system depends on the local geological and hydro geological conditions. Currently four different storage types have been developed (Heidemann and Müller-Steinhagen, 2006).

- A water-filled containment of steel-enforced concrete, partly submerged into the ground, has the widest range of utilisation possibilities, as it can be used independent of local geological conditions. It is usually small, but sufficient to provide heat storage for several days. A glass fibre tank is an alternative option.

- A gravel/water heat storage consists of a pit sealed with a water-proof synthetic foil, filled by a storage medium consisting of gravel and water. No static support structure is necessary.
- In a duct storage system, heat is conducted directly into water-saturated soil via probes. These poly-butane U-tubes are inserted into bore holes with a diameter of 100-200 mm and 20 to 100 m deep. The operational behaviour is slower than for the other heat store types as heat transfer from the store occurs mainly by heat conduction to the heat carrier in the tubes.
- Aquifer heat storage uses naturally existing, closed layers of ground water for storing heat. The ground water is taken out of the store via well bore holes, heated, and then pumped back into the store through other bore holes.

Specific storage costs are a function of storage volume (Fig. 8.16), expressed as “water equivalent” to be able to compare storage technologies. The storage costs, as taken from demonstration and pilot systems built in Germany, significantly depend on specific site conditions. A reduction of costs occurs with increasing storage volume. Investment costs for storage systems with a volume of more than 10,000 m³ are currently between USD 90/m³ and USD 150/m³[TSU: Needs to be presented in 2005 US$/m^3] water equivalent. The economic performance of a storage system depends not only on the investment costs, but also on the thermal performance of the storage and the connected thermal system as well as the rate of heat extraction when needed.

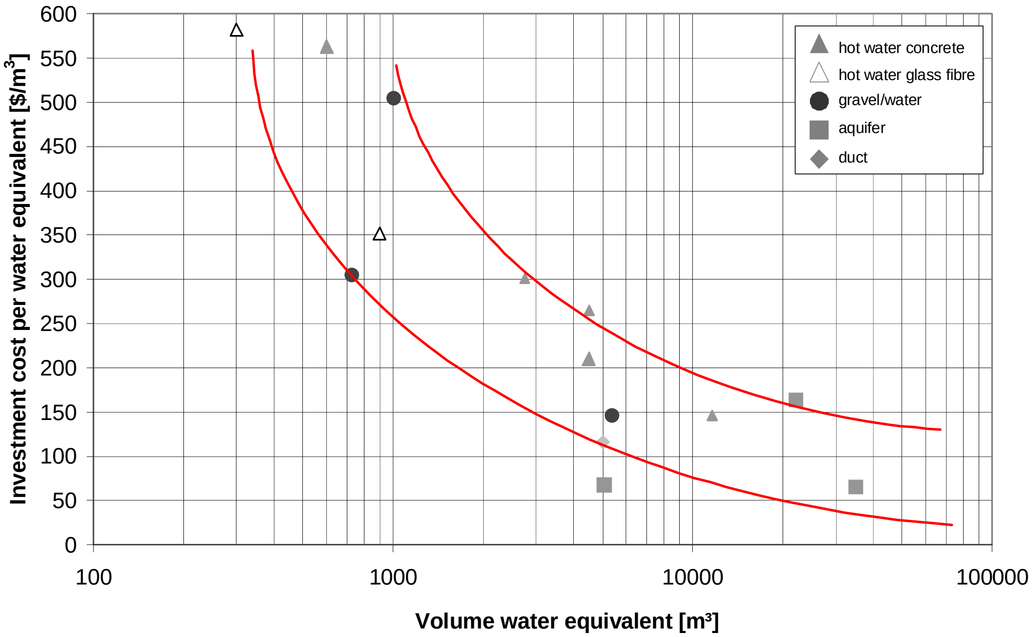

Figure 8.16: Costs of different seasonal heat storage pilot and demonstration systems in Germany (Heidemann et al., 2005).

8.2.2.4.2 Institutional aspects

District heating and cooling is capital intensive mainly due to the piping network. Such schemes have typically been developed in centrally planned economies, Western European countries with multi-utilities, and cities controlled by local municipalities where strong planning powers exist. The liberalisation of energy markets has had a significant impact on district heating operation. Electricity, the direct use of natural gas, and small-scale heat pump, biomass, solar and geothermal systems, are strong competitors to district heating. The introduction of competition in electricity and natural gas markets resulted in price reductions in many countries – at least in the short-term. Lower prices favoured the installation of individual gas or electric boilers so that district heating utilities had to adjust their heat prices downwards to compete. Subsidised gas prices for residential customers in some regulated markets is a key economic barrier hindering the expansion of district heating operations.

In theory, third party access to district heating networks could lead to a more competitive market for heating services, resulting in decreasing heat prices and thus consumer benefits. Markets for district heat by nature are local, contrary to electricity and natural gas markets. If a new competitor invested in a more efficient and less expensive heat generation plant and could use the network of the existing district heating utility, the incumbent utility would then be unable to sell its heat to existing or new consumers, the only choice being to reduce the price or accept lost revenue. In this case, the stranded asset cost can thus be higher than the customer benefit obtained from having a new third party producer, resulting in a total net loss. More pronounced competition could be obtained if at least five producers operate in the same network. Most district heating systems however are too small to host that many producers. Thus it remains debatable whether or not third party access in an existing district heating system is financially sustainable and beneficial for the customer.

In the former centrally-planned economies, district heating prices were regulated because of a social policy to sell heat below its market price. Today, in many countries with large district heating schemes, an independent regulatory body ensures appropriate pricing where natural monopolies exist. For instance the Danish district heating law has been a major factor in the development of the sector. This law recognises the ownership of district heating grids and the sale of heat as a monopoly and so provides general regulation regarding pricing and conditions of sale for the heat. A regulatory authority was established to oversee the formation of regulated prices and solve disputes between consumers and utilities (Euroheat&Power 2007). Other countries with a high share of district heating, such as Sweden, do not have price regulation in place, but use tax incentives to support efficient district heating schemes. Tax on fossil fuels has been a strong incentive to switch to renewable heating options, biomass in particular. In Germany, a Market Incentive Programme for renewable energies currently supports investment into new district heating schemes by granting $100/m[TSU: Needs to be presented in 2005 US$/m] in existing settlement areas, and $75/m[TSU: Needs to be presented in 2005 US$/m] in new development areas if the share of renewable energies is above 50% (BMU, 2009). In addition, the district heating system operator receives $2240[TSU: Needs to be presented in 2005 US$] for each consumer connected to the new district heating system (consumer station owned by the system operator).

8.2.2.5 Options to facilitate integration into cooling networks

The design of buildings in hot countries has for centuries provided cooling. With good design and careful planning a building can be designed to be comfortable for people to live and work in, in almost any hot climate by using shading (including by trees), reflection from white surfaces, natural ventilation, orientation to provide a natural breeze, together with suitable materials, thermal mass, earth sheltering, and adequate insulation. For example, the Romans used the sun warming the outside of a tall external “solar chimney” painted black to encourage the more rapid upward convection of hot air and thereby drawing cooler air into the building below. Variations of this passive solar cooling concept are often used in modern building designs. The evaporative cooling tower is another traditional passive cooling concept whereby water at the top of a tower attached to the building evaporates and hence cools the incoming air causing a downdraft of the denser air inside the tower that then cools the associated building space (IEA, 2007a).

Modern district cooling systems from 5 to 300 MW have been operating successfully for some years in cities and towns near to a good water supply. Similar to district heating systems, a network of pipes carries cold water from the supply to a series of buildings where it is passed through simple heat exchange systems. Paris, Amsterdam, Lisbon, Stockholm, and Barcelona use chiller/heat pumps, absorption chillers, compression chillers or a cold water distribution network. Expansion of demand will depend in part on the other options available for cooling building space. Solar energy is not currently utilised at this scale. Sea water can be used but is more corrosive than cold fresh water sources. Where natural aquifers, waterways, the sea or deep lakes are utilised as the source of cold, then this could conceivably be classed as a form of RE. Seasonal storage of cold during winter for use in summer is possible through aquifer, snow or ice storage (see case study below).

National and state building code standards can have an impact on building designs and networks for cooling. Existing apartment buildings, commercial buildings and individual dwellings cannot be easily modified to reduce the solar gain so the addition of air-to-air-conditioning has become the accepted method of cooling[3]. Unit costs have declined over recent years due to mass production. In many countries rapid uptake has led to increased power generation in summer with peak electricity demands occurring. New building codes and developments should be designed with these factors in mind. The principles of passive solar design[4] can also be applied, at least in part, when retrofitting existing buildings.

Cooling demands have grown recently because of increased internal heat loads from computers and other appliances, more rigorous personal comfort levels, and more glazed areas that increase the in-coming heat. The ratio of building surface to volume has also been rising but ingress of heat can be reduced by thermal insulation. Overall, modern building designs and uses have tended to increase the demand for cooling but reduced the demand for heating. This trend has been amplified by recent warmer summers in many areas that have increased the cooling demand to provide comfort, (particularly for those living in many low-latitude developing countries). Cooling load reductions can be achieved by the use of passive cooling options and active RE solutions.

To use renewable cooling most efficiently from a quality perspective it is possible to set up a merit order of preferred cooling technologies from an economic point of view (IEA, 2007a) although this order may often differ by specific local conditions.

1. Energy efficiency and conservation options in buildings and industry sectors.
2. Passive cooling options e.g. passive building design measures, summer night ventilation without the need for auxiliary energy.
3. Passive cooling options using auxiliary energy, e.g. cooling towers, desiccant cooling, aquifers.
4. Solar-assisted, concentrating solar power, or shallow geothermal all driving active cooling systems.
5. Biomass integrated systems to produce cold (possibly as trigeneration – see below).
6. Active compression cooling and refrigeration powered by renewable electricity.

Active cooling systems involve a range of technologies such as the production of cold through absorption cooling driven by a renewable source. Solar-assisted cooling (SAC) is promising but these technologies tend to be relatively costly at this early stage of their commercialisation,

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[3] They discharge heat from the building to the outside air to provide internal cooling, but are usually considered to be an energy efficiency measure by reducing the electricity demand of traditional building cooling systems. Therefore they are not covered in detail in this report on renewable energy.

[4] See for example IEA Solar Heating and Cooling for details at www.iea-shc.org.

although the cost is declining with experience in system design (IEA, 2007a). Solar-assisted cooling for air-conditioning and refrigeration systems is therefore gaining interest.

Open cooling cycles use desiccant and evaporative cooling systems that directly condition the air. One advantage of solar-assisted cooling technologies is that peak cooling demands often correlate with peak solar radiation and hence offset peak electricity loads for conventional air conditioners.

Closed systems, including both adsorption and absorption chillers, can be used for central or decentralized conditioning. This thermally driven process is complex, being based on a thermo-chemical sorption process. A sorption chiller is a heat pump used mainly as a central air-conditioning system with decentralised fan coils or cooled ceilings. It is based on a chemical heat driven process rather than electrical so has a higher coefficient of performance. A liquid or gas refrigerant can either be attached to a solid, porous material (adsorption) such as silica gel or absorbed by another liquid or solid material (absorption) such as lithium bromide.

Both solar adsorption and solar absorption designs have reached the early commercial stage with several companies offering products from 15kW to several MW scale. Plants are operating for example at Munich airport (3.6MW), Cologne airport (2MW) and Hornsby library, New South Wales, Australia (60kW) (IEA, 2009b).

Ground source heat pumps can be used virtually anywhere in the world for space cooling (air-to-ground) in summer as well as for space heating (ground-to-air) in winter. Commercially available at small- to medium-scales (10-200 kW), they use the heat storage capacity of the ground as an earth-heat sink since the temperature at depths between 15 and 200 m remains fairly constant all year round at around 12 to 14 °C. Vertical bores enable heat to be drawn out in the winter and concentrated within a building to reach the necessary temperature by a heat pump. Over the winter the ground nearby normally cools to below 10 °C as a result. This ground temperature enables water to be circulated through the system in summer for cooling and thus used in heat exchangers to lower the internal building temperature. Initially this is usually sufficient to provide the desired cooling but if increased cooling is required later in the season, the heat pump can be operated (in reverse). The cost of drilling bores remains a high proportion of the total system cost so shallow horizontal pipes around 1-2 m depth can be an alternative system but these give lower operating efficiencies.

Trigeneration (or combined cooling, heating and power generation CCHP) can use a single renewable heat source including, synthesis gas, liquid biofuels or solar energy as well as natural gas. The heat from the power generation is utilised for heating in the winter or cooling in the summer so high efficiencies result.

As is the case with district heating, the uptake of energy efficiency, deployment of other cooling technologies and structure of the market will determine the viability of developing a district cooling scheme.

8.2.2.6 Benefits and costs of large scale penetration

The use of geothermal energy, solar energy or biomass in a district heating or cooling system provides heat at low or zero CO_2 emissions. The costs and benefits of a RE based district heating or cooling system very much depend on site specific conditions such as the availability of RE resources, the availability of appropriate infrastructure, or the heat demand density.

Because of high capacity factors of biomass and geothermal systems, high penetration levels are not a technical problem and in general result in favourable economic performance. There are many geothermal and biomass heating or CHP plants integrated into district heating systems that are successfully operating under commercial conditions. Many other cities and towns have opportunities for CHP development as well as for district heating and cooling (DHC). CHP and DHC often do not need financial incentives to compete in the market place, although government attention to address non-financial barriers such as planning constraints, could aid greater deployment (IEA, 2008d).

Several large scale solar thermal systems with collector areas of around 10,000 m² were recently built in Denmark (Epp, 2009). The integration of the solar collectors into existing district heating systems redeems within less than 10 years without any subsidies. At solar shares of up to 20%, the large number of customers connected to the district heating system ensures a sufficiently large demand for hot water even in summer, so that high solar yields (~ 500 kWh/m²) can be achieved. Pilot plants with a solar share of more than 50% equipped with seasonal heat storage today demonstrate the technical feasibility of such systems (see case study below).

8.2.2.7 Case studies

8.2.2.7.1 Solar assisted district heating system in Crailsheim, Germany

In Crailsheim, Germany, a former military area has been transformed into a new residential area with 260 houses, a school and sports hall with more than 50% of the total heat demand to be covered by solar energy. A prerequisite for achieving such high solar shares is the use of a seasonal heat storage facility.

The new residential area consisting of the former military barracks, a school and a sports hall equipped with 700 m² of solar collectors and others installed on new single family buildings (in rows and semi-detached houses). The residential area is separated from a commercial area by a noise protection wall, on which the main area of the solar collectors has been installed. The first phase of the project, which was put into operation in summer 2008, focused on the realisation of 260 accommodation units with an expected total annual heat demand of 4,100 MWh. The total solar collector area is 7,300 m². A borehole thermal energy storage system with 75 boreholes at a depth of 55 m serves as seasonal storage. In a second phase, the residential area will be extended by 210 additional accommodation units. The total collector area will then be around 10,000 m², and the seasonal storage system will be expanded to 160 boreholes (Mangold and Schmitt, 2006).

The solar system is separated into a diurnal part and a seasonal part (Fig. 8.17). The diurnal part consists of the solar collectors on the modernised buildings, the school and the sports hall together with a 100 m³ buffer tank. Energy from this part of the system is mainly used to directly cover the instantaneous heat demand from the residential area. The solar collectors on the noise protection wall together with the borehole thermal storage system and a second 480 m³ buffer tank constitute the seasonal part of the system. The second tank is required to design the borehole storage system according to the required heat storage capacity (which is quite large in summer days), rather than to the heat discharge capacity. The integration of a 530 kW heat pump allows the discharge of the borehole storage system down to a temperature of 20°C. This leads to reduced heat losses in the storage system and to higher efficiency of the solar collectors due to reduced return temperatures. It is expected that the borehole storage system will heat up to 65°C by the end of September and the lowest temperature at the end of the heating period will be 20°C. Maximum temperatures during charging will be above 90°C. The whole system is designed to achieve a 50% solar fraction of total heat supply. Solar heat costs are estimated to be around $0.152005/kWh (Mangold et al., 2007).

The annual heat production of the solar thermal system today is 3 million kWhth, which is equivalent to the consumption of 300,000 litres of fuel oil. By halving the fossil fuel consumption and by providing the remaining heat with a highly efficient fossil heating station linked to the district heating network, CO_2 emissions can be reduced by more than 1,000 tonnes per year (Wagner, 2009).

Figure 8.17: Solar assisted district heating system in Crailsheim, Germany with diurnal and seasonal heat storage systems. [TSU: Source?]

8.2.2.7.2 Biomass CHP district heating plant in Sweden

District heating in Sweden expanded rapidly between 1960 and 1985 but was entirely dependent on oil up until the second oil crisis. Thereafter the fuel mix has changed considerably and in 2007 biomass accounted for 44% of fuel supply in Swedish district heating.[5] The town of Enköping is a documented and illustrative case of this transition and it also demonstrates an innovative approach for how to integrate CHP, short rotation forestry and waste water treatment. The district heating system was constructed in the early 1970s and was using to oil fired heat-only boilers until fuel switching started in 1979. After going through a period of using a mix of oil, biofuels, coal, electric boilers and LPG the transition to near 100% biofuels was completed in 1998. The transition was driven by carbon dioxide taxes, other policy instruments and a local decision to completely avoid fossil fuels (McKormick & Kåberger, 2005). An important step in this process was the construction of a biofuel fired CHP plant in 1994-1995 with a capacity of 45 MW heat and 24 MW electricity.

What makes Enköping different from other district heating systems is the unique cooperation between the local energy company, the sewage plant and a local farmer that started in 2000. The energy company was interested in diversifying fuel supply fearing that there may not be enough forest residue fuels in the region to meet future demand. The municipal sewage plant was obligated to reduce nitrogen discharges by 50 percent. The use of willow (Salix) as a vegetation filter system was identified as a cost-effective approach to reduce nitrogen discharges and at the same time produce biofuel. A 80 ha willow vegetation filter was established in the year 2000 on farmland close to the sewage plant. The agreement involves contracts by which the farmer is paid for receiving wastewater and sewage sludge, and for delivering fuel to the CHP plant at market prices. There are several factors explaining the success of this model: parties were proactive and open to new solutions, advisors have worked as catalysts, regional and local authorities have been positive and interested, and risks have been divided between the three parties (Börjesson and Berndes,

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[5] The remaining production was based on 9.9 TWh of municipal solid waste (18%), 5.8 TWh of industrial waste heat (10%), 2.9 TWh of coal (5%), 2.0 TWh of oil (4%), 2.3 TWh of natural gas (4%), 2.8 TWh of peat (5%) and 5.8 TWh of heat from heat pumps (10%) (IEA, 2009c).

2006). In 2008 the local area of willow plantations had increased to 860 ha and it is the ambition of the energy company to continue increasing the currently 15% salix fuel share in the system.

8.2.2.7.3 District heating in South Korea

Although most district heating and cooling schemes have been developed in Europe and North America, the Korea District Heating Corporation claims to be the world's largest district heating energy provider (www.kdhc.co.kr [TSU: URLs are to be cited only in footnotes or reference list.]) with heat production capacity from 11 plants exceeding 3.5 GW, including 1.5 GW of heat purchased from CHP plants operated by Korea Electric Power Corporation and from 85 MW of waste-to-energy incinerators owned by several municipal governments. It was established in 1985 as a government corporation for the purpose of promoting energy conservation and improving living standards through the efficient use of district energy. The state-run district heating business aims to save energy as well as to promote the public benefits of district heating and cooling and its convenience for customers. The corporation has constructed over 1100 km of twin forward and return pipes as part of the Seoul metropolitan heating network.

District heating is provided by the company to over 60% of the nation's total households with the aim to steadily expand the business and provide district cooling and heating services to 2 million households nationwide by 2015. Particular business emphasis is given to RE sources, including landfill gas, and the long term company plans are to develop community energy services as well as to enter the relatively untapped Middle East market through a joint business venture with Tabreed Company from the United Arab Emirates, the largest district heating and cooling company in the region.

8.2.2.7.4 District cooling systems

Few if any district cooling schemes have resulted from policy framing developments. Most have been commercial decisions made by the local municipality or building owners. The IEA Implementing Agreement “District Heating and Cooling” (that also includes CHP) provides details of several examples of cooling demonstration schemes. As a result of several successful demonstrations, the opportunity now exists for governments to encourage further deployment of cooling projects based on RE sources. A few examples are described below.

Deep water cooling allows a relatively high thermodynamic efficiency by utilizing water at a significantly lower heat rejection temperature than the ambient temperature. This temperature differential and higher efficiency results in less electricity being consumed as a lower volume of water needs to be pumped. For many buildings, lake water is sufficiently cold that, at times, the refrigeration portion of the air-conditioning systems can be shut down and all the excess building interior heat is transferred directly to the lake water heat sink. Power is needed to run pumps and fans to circulate the lake water and the building air but this is generally much less than would be the demand for refrigeration chilling to produce the same cooling effect.

Successful projects include the Cornell University, Ithaca, USA, 51 MW cooling project based on pumping around 20 m^3/min of 4°C water from the bottom of nearby Cayuga Lake through a heat exchanger before storing it in a 20,000 m^3 stratified thermal storage tank. A separate water loop runs back 2 km before passing through the air-conditioning systems of the 75 campus buildings and Ithaca High School. In this USD 58M scheme, the lake water is discharged back to the lake at around 8-10°C and mixed by injection nozzles with the surface water to maintain stable water temperatures. The 1.6 m diameter intake pipe has a screen at 76m depth and this and the 38 discharge nozzles were carefully designed to minimise maintenance and environmental problems, having first closely monitored the ecology, hydro-dynamics, temperature strata and geophysics of the lake.

Greenhouse gas emissions have been reduced significantly since the project started in 1999 compared with the original refrigeration based cooling system, from both reducing the annual power demand by 20 GWh (around 80-90% of the previous electricity demand for cooling) and avoiding the 12-13t of CFCs used in the 6 chillers.[TSU: Source?] However there remain some concerns about bringing up phosphorus rich sediments from the bed of the lake and discharging them near to the surface, hence possibly encouraging algae growth.

Stockholm has a similar but smaller district cooling system based on sea water from the harbour and since 2004 Toronto has used cold water drawn from Lake Ontario 5 km away for a 207 MW cooling project of 3.2 Mm^2 of office floor area in the financial district. The lake water intake pipe at 86m depth runs 5 km out into the lake to ensure clean water is extracted since this is also the supply for the city's domestic water system. No warm water return discharge to the lake therefore results.

Solar district cooling systems based on the heat-activated refrigeration principle of absorption chillers are less well developed. 'Single-effect' chillers require heat delivered at 70 to 90 °C, meaning solar hot water can possibly be used as the main heat-transfer medium in a simple heat-delivery mechanism at the small scale. However at the larger district heating scale, 'double-effect' chillers require heat to be delivered at temperatures above boiling point, meaning pressurised water or steam has to be generated by concentrating solar collector systems.

The Malaysian company Solar District Cooling Sdn Bhd (SDC) is planning to build its first solar district cooling plant having had experience of several solar cooling projects for individual buildings (www.sdc.my[TSU: URLs are to be cited only in footnotes or reference list.]). The solar cooling technology will be located in Cyberjaya and used initially for office and residential applications, though it is hoped that rapid uptake of the cooling service will also attract larger customers such as hospitals, schools, district councils and airports. Natural gas is planned for back-up, though in cases where suitable heat storage is included in the system design for use during night-time and cloudy days, this can be minimised. Although absorption chiller technology is reliable and becoming well understood, the typical payback time of more than 10 years has remained a deterrent to wider deployment of this technology to date. Policy support measures by interested governments could help bring down the manufacturing, project design and installation costs of this technology as a result of the traditional experience learning curve (IEA, 2008c).

8.2.3 Integration of renewable energies into gas grids

The main objective of a gas grid is to transport gas from producers to consumers. The system consists of gas productions plants, transmission and distribution pipelines, gas storage, and industrial or private gas consumers. The basic design of a gas system depends mainly on the type and source of energy, the end-user demand, and the locations of these.

Over the past 50 years large integrated natural gas networks have been developed in several parts of the world including USA, Europe, and Japan. The European natural gas grid is, arguably, one of the most integrated and developed gas grids in the world with major transmission lines coming in from the North, East, and South. This gas grid, which currently includes 27 countries (EU27), has a total of 1.8 M km of pipelines of which about 155,000 km are high-pressure transmission pipelines. It also has 127 gas storage facilities with a total working volume of 75,000 Mm^3, and supplies more than 110 million customers (Eurogas, 2008).

Over the past decade there has been an increased interest to "green" existing natural gas grids. In Europe the EU-directive 2003/55/EC opened up the gas grid to carry other gases such as hythane, hydrogen, and biogas (Persson et al., 2006; NATURALHY, 2009). In Germany the target for 2020 is to substitute 20% of CNG (compressed natural gas) for transport with biogas (1.12 PJ/year), while the target for 2030 is to substitute 10% of natural gas in all sectors with biogas (382 PJ/year)

(Müller-Langer et al., 2009). Similar directives and initiatives have been made for the natural gas grid running through the United States along the West Coast of North America (USA and Canada). In this regard, a Bioenergy Action Plan (CEC, 2006), has been brought into action by the Governor of California in his Executive Order on Biomass.

Gaseous fuels from renewable sources are largely produced from biomass sources including municipal solid and industrial wastes, agricultural residues, animal by-products, energy crops and wood-fuels. They can be produced by thermo–chemical (syngas) or anaerobic digestion processes (biogas) routes (Sims et al., 2008). Currently about 40% of the total gas produced from biomass in the world comes from aerobic digestion of organic wastes contained in landfills (Sims, 2007).

Biomethane (from biogas or syngas) can be combusted to produce electricity and/or heat. It can also be fed into natural gas grids or distributed to filling stations for use in dedicated or dual gas-fuelled vehicles, although these applications first require the biogas to be cleaned and upgraded. Gasification of biomass can be highly efficient, especially for electricity production in combined cycles. The gas produced (a mixture of CH4, H2 and CO) can be used to produce a range of liquid fuels using various processes or it can be used in gas engines or gas turbines (internal combustion engines) to produce heat and electricity.

8.2.3.1 Characteristics of RE with respect to integration into gas grids

There are several ways to integrate RE gases into gas grids (Fig. 8.18).

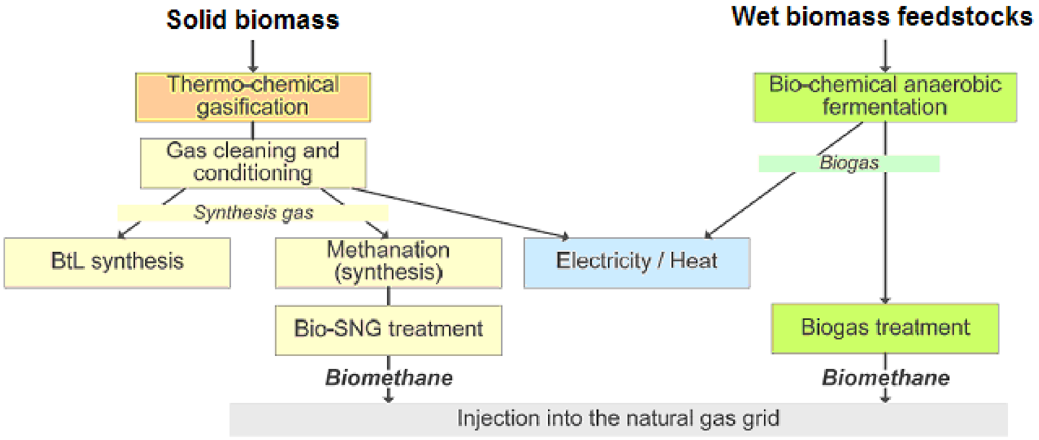


Figure 8.18: Injection into the natural gas grid of example gases produced from solid biomass or wet biomass feedstocks such as green crops or organic wastes (Müller-Langer et al., 2009).

Biogas can be upgraded to natural gas quality, blended with natural gas, and transported via existing or new gas grids. Until now most of the biogas produced around the world has been distributed in local gas systems primarily dedicated for heating purposes, and in some cases it has been transported via trucks to gas filling stations for gas vehicles (Hagen et al., 2001; Persson et al., 2006). However, the biogas business is growing rapidly and is currently being commercialized by large industrial players (Biogasmax, 2009). Several large gas companies around the world are now making plans on how to upgrade large quantities of biogas and feed them at the required quality into national/regional transmission gas pipelines (NationalGrid, 2009). If made feasible, it will offset some of the demand for natural gas in existing and future markets.

Coal or waste-derived syngas has been widely used for heating, cooking and power generation, especially in areas where natural gas is not available. Synthetic gases can also be produced via gasification or partial oxidation of biomass feedstock. They consist of a mixture of carbon monoxide, hydrogen, methane, higher hydrocarbon gases, and carbon dioxide. The heating value of syngas is less than that of methane. The existing natural gas grid would need modification to use syngas directly due to its different flow and combustion properties. Modifying the system would need to include replacing meters and burners.

Once the energy feedstock for the gas has been established, it is important to determine the end-use of the gas, for heating, in combined heat and power (CHP) systems, as raw material for the chemical industry, or as fuel for vehicles. The optimal choice will depend on the electricity system and energy mix in the region where the gas grid is being considered. National and regional electricity and gas transmission grids must complement each other, in the long-distance transport of energy. Similarly, distributed gas grids must compliment local heating and cooling networks.

Local gas urban distribution systems have mainly been dedicated to space and water heating purposes. However, over the last decade there has been significant progress in the development of fuel cell technology (such as proton exchange membrane designs) which opens new opportunities for small to medium sized distributed combined heat and power systems based on gas (DeValve and Olsommer, 2006; Zabalza et al., 2007).

Hydrogen is another gas that can be produced from RE, for example by water electrolysis or biogas reforming (Sherif et al., 2005; Balat, 2008). Future production and distribution of hydrogen will depend significantly on the interaction with existing electricity systems (Sherif et al., 2005; Yang, 2007).

In the short to medium term (prior to 2050) it is more likely that hydrogen will be produced in distributed systems via small-scale water electrolyzers or reformers (Riis et al., 2006). This would mainly require local hydrogen storage and distribution pipelines (Castello et al., 2005). In the long-term, large-scale production of hydrogen via water electrolysis using wind power or via large-scale biogas-to-hydrogen reforming plants is conceivable. Blending of hydrogen with natural gas (up to 20%) and transporting long-distances in existing or new natural gas grids could be an option when building a large-scale hydrogen economy (NATURALHY, 2009).

8.2.3.2 Features and structure of gas grids

A natural gas grid typically consists of three types of pipelines (Fig. 8.19):

- high pressure (40-70 bar) gas transmission pipelines;
- medium pressure (8-40 bar) gas distribution pipelines; and
- low pressure (< 8 bar) gas distribution pipelines.

High pressure transmission pipelines go between the production plant and the distribution network, passing over public land and third party properties. They are typically used for long-distance transport of gas from large, centralized production plants to large power plants, CHP plants, large industry users, or distribution networks. Transmission pipelines can be placed over-ground, underground, or on sub-sea floors, while distribution pipelines can be located over-ground, underground, or integrated into existing infrastructure to give common gas feeds.

Medium pressure distribution pipelines are more suitable for medium sized CHP systems or chemical production systems. Distribution pipelines, including mains feeders, station connections and valves, are usually contained on the property (generally owned by the customer) at the end-use point (EIGA, 2004). They are typically used to transport the gas to domestic or low consumption end-users. Similar low pressure gas distribution systems can be found in dedicated rural gas distribution systems.

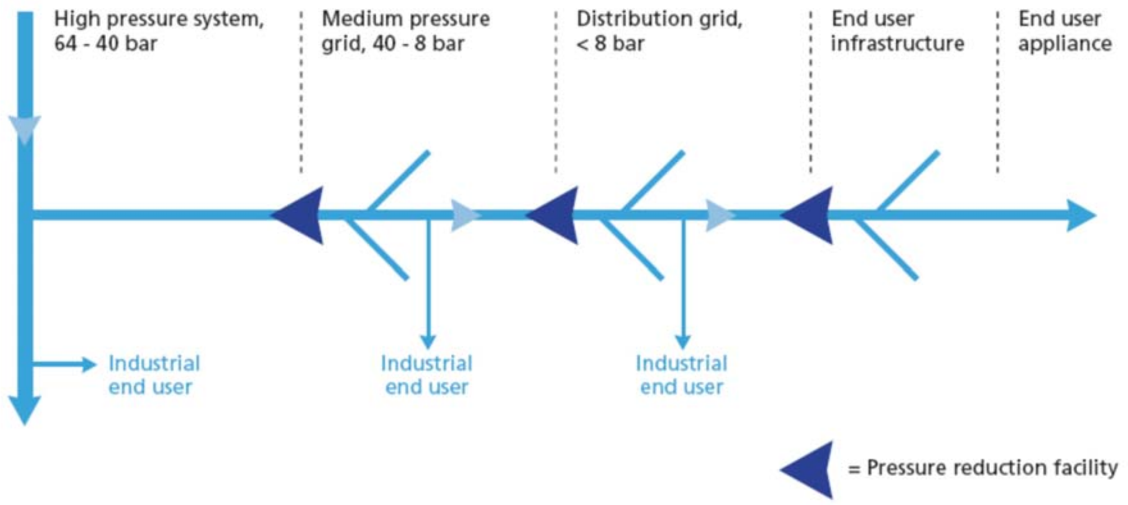


Figure 8.19: Typical natural gas grid with high, medium and low pressure pipe lines (NATURALHY, 2009).

The design of a gas transmission and distribution system depends on a variety of factors. The primary design criteria is to deliver adequate amounts of gas, when and where it is needed whilst meeting the user's required heating value, pressure, and purity. The gas flow rate depends on the scale and physical attributes of the gas (molecular weight, viscosity, specific heat). The larger the pipeline diameter and the higher the pressure drop, the more gas volume that can be moved over a given distance (Mohitpour and Murray, 2000). In the design of pipelines for high gas flow rates, there is an economic trade-off between increasing the diameter of the pipeline versus increasing the gas pressure. Either design choice could increase gas flow, the lowest cost solution depending on the situation. Larger diameter pipelines have a higher capital cost, but higher pressure requires a larger, and more costly compressor and more energy input. Often a compromise is best, where the pipeline diameter is kept relative small whilst "booster" compressors are located along the pipeline to keep the pressure (and flow rate) sufficiently high.

Long distance natural gas transmission pipelines that move large volumes of gas can operate at pressures up to 7-10 MPa and have diameters above 1 m. Such pipelines are commercially used in North America and Europe to deliver hydrogen to industrial users such as oil refineries. Hundreds of kilometres of hydrogen pipeline are currently in use. Using existing natural gas pipelines with hydrogen could work by blending hydrogen in with the natural gas, but pure hydrogen pipelines would require different steels to reduce leakage. Any conversion of a natural gas pipeline to pure hydrogen would have to be carefully examined for compatibility of materials.

Local gas distribution systems operate at lower pressures, and have smaller diameter pipelines. These widespread networks have smaller diameter pipelines (5-25 cm), and generally operate at lower pressures of 1-20 bar (0.1-2.0 MPa). One of the key issues is designing these pipeline systems to reach consumers with built-in redundancy so that gas could be supplied via more than one pathway. Natural gas distribution systems are often built around concentric rings, with feeder lines to individual users.

In order to balance supply and demand, gas storage also needs to be included at various levels in the system. The need for gas storage depends on how the gas is produced, the end use application, and how the gas can be integrated into the gas grid. In general, the size of gas storage is normally minimised to reduce costs and safety hazards. Most existing natural gas systems incorporate large-scale gas storage to account for seasonal demand. For example, in the United States, gas demand for residential heating peaks strongly in the winter. Underground gas reservoirs, as well as above ground gas storage, are part of the overall supply system.

The choice of material for the gas pipelines varies from system to system, depending on the basic type of pipeline (transmission or distribution), location (sub-sea, over ground, underground), operating conditions (pressure, temperature, corrosion), and type and quality of gas to be sent through the pipeline. Metallic materials are mainly used in transmission pipelines or pipelines tolerant to higher pressures and temperatures, while plastics are often used in distribution gas grids operating at lower temperatures (< ca. 100 C) and pressures (< ca. 10 bar). Metal based pipelines have the potential for internal and external corrosion problems (Castello et al., 2005).

8.2.3.3 Challenges caused by integration into gas grids

The payback time for integration of RE gases into gas grids is large due to high gas infrastructure investments. Payback time is also sensitive to the estimated long-term gas consumption and price. The price will be affected by future demand, taxation and carbon emission values which will be affected by the end-use for the gas. Large local and regional differences in existing infrastructure (and energy production and consumption) make planning on a national and regional level difficult.

Technical challenges relate to gas source, composition, and quality. The composition of biogas or syngas (and the calorific values) depends on the biomass source, gasification agent utilized in the process and reactor pressure. The heating value of syngas is about 10-15% of the heating value of natural gas. Landfill gas, produced by anaerobic fermentation, has concentrations of methane around 50%.

To produce syngas via the Fischer-Tropsch process, a distillation unit is required to separate the different fractions and an additional hydro-cracker may be necessary depending on operating conditions. Gas exiting the distillation column can be upgraded in order to recover the light hydrocarbons such as methane.

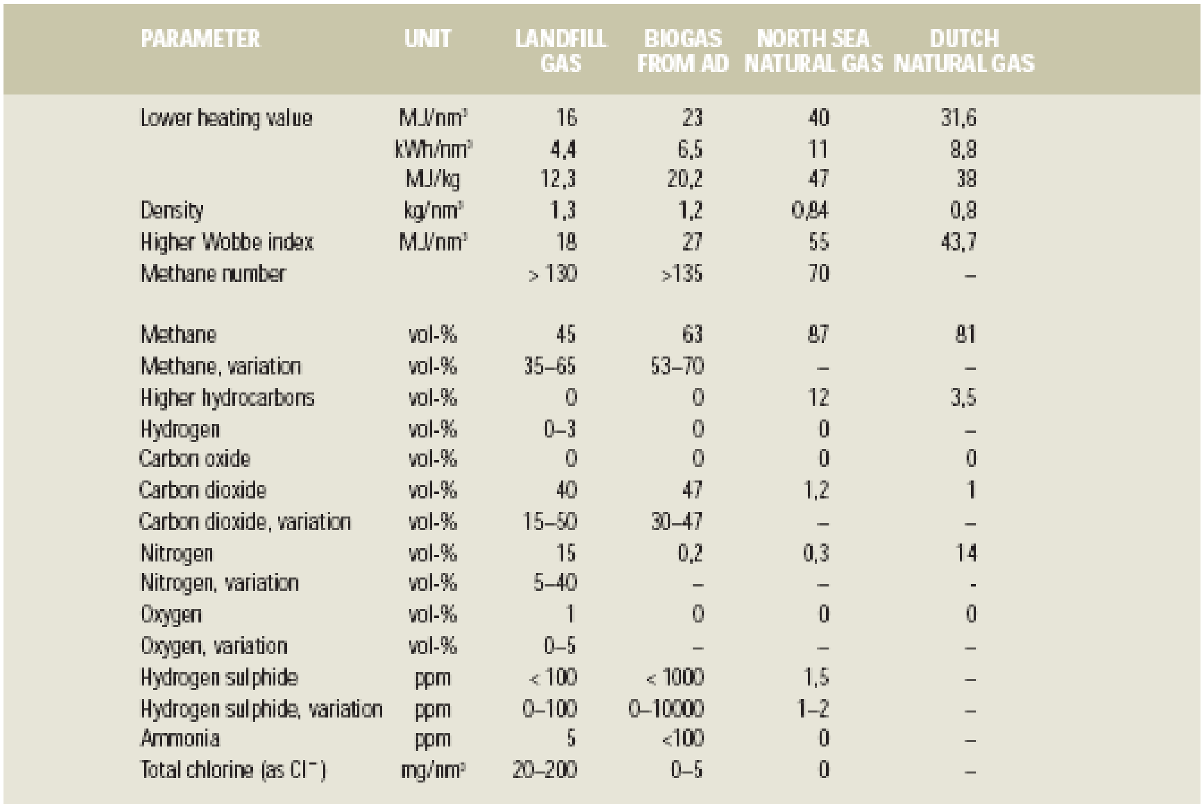
The removal of tar is another technical barrier for the advancement of biomass gasification, especially for power production. Pressurized IGCC (integrated gasification, combined-cycle) technologies can reduce tar concentrates but catalytic reforming followed by scrubbing, and hot gas clean up are still needed (Maniatis, 2001). Energy consumption of these processes is high, equivalent to 20% of the electricity output in some designs, making clean-up uneconomic. Recent R&D efforts are indicating areas of improvement (Nair, 2003; Wang, 2008; Arena et al., 2009).

Landfill gas typically has methane concentrations around 50% although advanced waste treatment technologies can produce biogas with 55-75% CH4. Methane can be concentrated in biogas up-grade systems to reach similar composition standards as natural gas then cleaned before being fed into the natural gas grids or used in vehicle engines. This process removes water, carbon dioxide and additional products from the gas stream. The cost of upgrading varies according to the scale of the facility. An equivalent 3-6% of the energy content of the gas is consumed in the form of electricity. Biogas must also be free from bacteria, pathogens and any other substances injurious to utility facilities, when considering its distribution in natural gas grids.

In order to increase the lower heating value of the biogas (before injection into the grid) most of the CO_2 must be removed (to reach below 5%). In some cases the biogas is blended with propane (LPG) in order to increase the heating value. Biogas upgrading plants have equipment to remove CO_2, hydrogen sulphide (H2S), trace gases such as halogenated hydrocarbons, siloxanes, oxygen, and nitrogen, and water vapour.

Gas clean-up is a critical step for biogas and syngas use. Only gases of a specified quality can be injected directly into existing natural gas grids (Table 8.4). Before gas is used, particulates and condensates must be removed. The main impurities are hydrogen sulphide, mercaptans, carbon dioxide, hydrocarbons, siloxanes, water vapour, nitrogen, oxygen and particulates.

Table 8.4: Composition and parameters of gas from different sources including landfill gas and biogas from anaerobic digestion (AD) (Persson et al., 2006).



PARAMETER	UNIT	LANDFILL GAS	BIOGAS FROM AD	NORTH SEA NATURAL GAS	DUTCH NATURAL GAS
Lower heating value	MJ/nm^3	16	23	40	31,6
	kWh/nm^3	4,4	6,5	11	8,8
	MJ/kg	12,3	20,2	47	38
Density	kg/nm^3	1,3	1,2	0,84	0,8
Higher Wobbe index	MJ/nm^3	18	27	55	43,7
Methane number		> 130	>135	70	–
Methane	vol-%	45	63	87	81
Methane, variation	vol-%	35–65	53–70	–	–
Higher hydrocarbons	vol-%	0	0	12	3,5
Hydrogen	vol-%	0–3	0	0	–
Carbon oxide	vol-%	0	0	0	0
Carbon dioxide	vol-%	40	47	1,2	1
Carbon dioxide, variation	vol-%	15–50	30–47	–	–
Nitrogen	vol-%	15	0,2	0,3	14
Nitrogen, variation	vol-%	5–40	–	–	-
Oxygen	vol-%	1	0	0	0
Oxygen, variation	vol-%	0–5	–	–	–
Hydrogen sulphide	ppm	< 100	< 1000	1,5	–
Hydrogen sulphide, variation	ppm	0–100	0–10000	1–2	–
Ammonia	ppm	5	<100	0	–
Total chlorine (as Cl^-)	mg/nm^3	20–200	0–5	0	–

CO_2 removal can be achieved by absorption in water (water scrubbing) or organic solvents (such as polyethylene glycols or alkanol amines), pressure swing adsorption (PSA), separation membranes (gas-gas (dry) or gas-liquid (wet)), or cryogenic separation. There are different operational issues and disadvantages for each of these techniques:

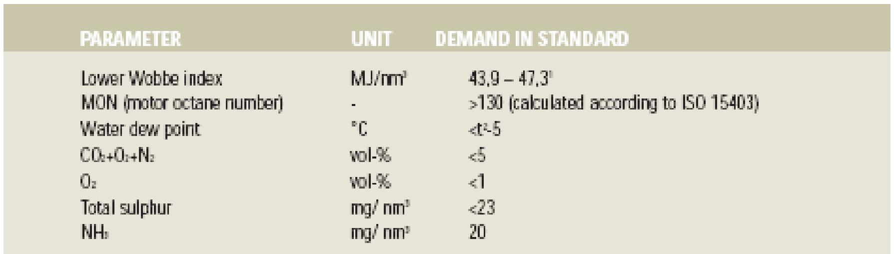
- water scrubbing requires large amounts of water and plugging of the equipment due to organic growth can also be a problem;
- organic solvents require large amounts of energy for regenerating the solvents;
- PSA-processes requires dry gas;
- separation membranes requires handling of the methane in the permeate stream (which increases with high methane flow rates in the upgraded gas stream), and
- cryogenic separation requires removal of water vapour and H_2S prior to liquefaction of the CO_2.

The removal of H_2S from the biogas is also necessary to protect upstream equipment, as this is corrosive and must not affect metal pipelines, gas storage, and end use equipment. Micro-organisms can be used to reduce the level of sulphide in biogas by adding stoichiometric amounts of oxygen to the process (around 5% air to a digester or biofilter). Alternatively, simple vessels containing iron oxides can be used as they react with hydrogen sulphide and can be regenerated when saturated. Finally, siloxanes must also be removed as these organic silicon compounds can form deposits on pistons and cylinder heads that are extremely abrasive and hence cause damage to the internal components of the engine (Hagen et al., 2001; Persson et al., 2006).

In the case of hydrogen, it is important to purify and dry the gas before it is stored and distributed. Hydrogen for use in low temperature fuel cells normally has to be high purity (> 99.9995% H2 and <1 ppm CO). Industrial hydrogen with lower purity can be transported in dedicated hydrogen transmission and distribution pipelines, so long as there is no risk for build-up of water vapour or any other substances that can lead to internal corrosion. For hydrogen, regular checking for corrosion and material embrittlement of pipelines, sealings and storage equipment is important (EIGA, 2004).

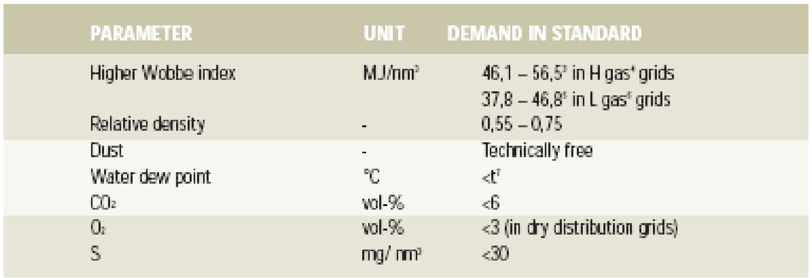
There is no international gas standard for pipeline quality of biogas or hydrogen. However, Sweden and Germany have developed their own national standards (Tables 8.5 and 8.6).

Table 8.5: Swedish national standard for biomethane injection into natural gas grids (Persson et al., 2006).



PARAMETER	UNIT	DEMAND IN STANDARD
Lower Wobbe index	MJ/nm^3	43,9 – 47,3^1
MON (motor octane number)	-	>130 (calculated according to ISO 15403)
Water dew point	°C	<t^2-5
$CO_2+O_2+N_2$	vol-%	<5
O_2	vol-%	<1
Total sulphur	mg/ nm^3	<23
NH_3	mg/ nm^3	20

Table 8.6: German standard G260/G262 for injection of biogas into natural gas grids (Persson et al., 2006).



PARAMETER	UNIT	DEMAND IN STANDARD
Higher Wobbe index	MJ/nm^3	46,1 – 56,5^3 in H gas^4 grids 37,8 – 46,8^5 in L gas^6 grids
Relative density	-	0,55 – 0,75
Dust	-	Technically free
Water dew point	°C	<t^7
CO_2	vol-%	<6
O_2	vol-%	<3 (in dry distribution grids)
S	mg/ nm^3	<30

Once methane, hydrogen, syngas or a mixture have been upgraded, purified, dried, and brought up to the prescribed gas quality, it is ready to be injected into the gas distribution grid. Then the main operational challenge is to avoid leaks and regulate the pressure and flow rate so that it complies with the given pipeline specifications (which vary). Compressors, safety pressure relief systems and gas buffer storage must be in operation continuously in order to maintain the correct pressures and flow rates in the grid.

8.2.3.4 Options to facilitate the integration into gas grids

8.2.3.4.1 Technical options

Hydrogen can be injected but may require some upgrading of pipelines and other components used in existing natural gas grids (Huttenrauch and Muller-Syring, 2006). Pure hydrogen has a lower volumetric density compared to natural gas so pipelines will need higher pressures or larger diameters (around 3 times higher) in order to carry the same amount of energy per unit time as existing natural gas pipelines.

Dedicated distribution gas pipelines for biogas or hydrogen can operate at low pressures and volume flow rates, and with less stringent gas quality requirements. This opens up the opportunity for simpler designs, where gas with a lower volumetric energy density can be distributed locally in polymer pipelines made of less costly materials. The required quality of the gas in such gas distribution systems will depend significantly on the end-use.

Renewable-based gas systems are likely to require a significant gas storage capacity to account for variability and seasonality of supply. Since RE gases can be produced regionally and locally, gas storage is likely to be located close to the demand of the end-user. The size and shape of storage facilities will depend on the primary energy source of production and the end use. In small applications, the pipe can also be the store (Gardiner et al., 2008). Solutions with several complimentary end users of the gas can reduce the specific infrastructure cost (less pipeline and gas storage per customer) and the overall need for gas storage due to synergies.

Options for large-scale storage of biomethane, will be similar to those of natural gas, namely compressed gas storage (CNG) or liquefied gas storage (LNG). In distribution gas grids, small to medium-sized gas storage buffers tanks can be introduced into the system to balance local supply and demand. Methane can be collected and stored for a few days in inflatable gas bags made of rubber. In more up-scaled and industrialized biogas process plants, the upgraded gas is normally stored at high pressures in steel storage cylinders (as used for LPG), depending on the size of the production plant and mode of further distribution (truck versus pipeline). Distribution of biogas for vehicles can be achieved using trucks with LNG-storage.

Small-scale storage of hydrogen can be achieved in 50 l, 200 bar steel cylinders. Composite-based hydrogen gas cylinders that can withstand pressures up to 700 bar have been developed and are now being installed in demonstration hydrogen vehicle fuelling stations. Hydrogen can also be stored at low pressures in stationary metal hydrides, but these are relatively costly and can only be justified for small volumes of hydrogen or if compact storage is needed. In integrated gas grids, it is probably more suitable to use low-pressure (12-16 bar) spherical containers that can store relatively large amounts (>30,000 m^3) of hydrogen (or methane) above ground (Sherif et al., 2005). However, for safety reasons, such storage will normally have to be situated far away from densely populated areas.

At the large-scale, hydrogen can be stored as a compressed gas or cryogenically in liquid form. However, this will come at a larger cost than biomethane storage due to the lower volumetric density and boiling temperature (-253ºC). In practice, about 15-20% of the energy content in the hydrogen is required to compress it from atmospheric pressure to 200-350 bar. Around 30-40% of total energy is required to store liquid cryogenic hydrogen (Riis et al., 2006). Natural underground options such as caverns or aquifers for large-scale, seasonal storage can be found in various parts of the world, but their viability must be evaluated on a case-by-case basis and safety needs attention.

8.2.3.4.2 Institutional options

System reliability, regulation, and standards for new gas carriers relate to RE gases. The reliability of gas grids, adequacy, and security of supply are influenced by a number of factors (McCarthy et al., 2006) such as:

- Is there enough gas supply to meet demand?
- Can the gas be delivered where and when it is needed?
- Is the gas system robust to disruptions due to natural or hostile acts?

Adequacy of supply can be influenced by the variability and seasonality of the RE resource. For example, biomass resources can be seasonal in their availability and quantities can vary from year to year. If hydrogen is made from variable RE sources the fluctuations of the primary energy supply must be considered. Designing a system to provide gas on demand may require storage of the primary feedstock (for example, baled straw or pelletized biomass) or storage of the produced energy carrier such as the high pressure storage of biomethane or hydrogen. Adequate capacity of the gas transmission and distribution systems can also be a concern.

The security of gas pipeline systems involves assuring a secure primary supply, and building robust networks that can withstand either natural or malicious physical events. In terms of security, biomethane or hydrogen networks are likely to be more secure than current transport-fuel networks because they can use many different primary sources rather than being wholly dependent on a single petroleum feedstock. Similarly, diverse local or regional RE resources for gas production offer more secure supply than imported natural gas. To enhance network security, gas pipeline networks often include some degree of redundancy (such as having multiple paths between supplier and user). Therefore a pipeline disruption in a single network cannot shut down the entire system. Assessing vulnerability to malicious attacks for an extensive pipeline system over thousands of kilometres is a daunting task, and may require technological solutions such as intelligent sensors that report back pipeline conditions via GPS technology to allow rapid location of problems and corrective action.

Feed-in regulations can enable the introduction of biomethane into a natural gas grid in a similar way to RE feeding into an electricity grid. After clean-up, well-established safety regulations and standards for natural gas pipeline systems and end-use appliances should also be applied to biomethane.

Hydrogen is widely used in the chemical and petroleum refining industries and safety procedures and regulations are already in place. Industrial hydrogen pipeline standards and regulations for on-road transport of liquid and compressed hydrogen have been established. However, there is a current lack of safety information on hydrogen components and systems used in a hydrogen fuel infrastructure, which poses a challenge to the commercialization of hydrogen energy technologies. Uniform international codes and standards are necessary to standardize technology and to gain the confidence of local, regional and national officials in the use of hydrogen and fuel cell technology, but these have not yet been developed.

Over the past few years, there have been concerted efforts in individual countries and internationally to develop consistent safety information on hydrogen and to harmonize existing codes and standards. For example, the United States Department of Energy maintains a variety of resources on hydrogen codes and standards, including a Hydrogen Safety Bibliographic Database and “Best Practices” website [TSU: Insert link as footnote or reference.]. Industry organizations such as the National Hydrogen Association and the US Fuel Cell Council provide information, and hold workshops on hydrogen safety. The International Energy Agency has a Hydrogen Implementing Agreement with a task focused on safety, codes and standards. The European Union through its HyWays project is working toward international standards. The International Partnership for a Hydrogen Economy addresses similar issues.

8.2.3.5 Benefits and costs of large scale penetration of RE into gas grids

Gas must be delivered at an acceptable cost to compete with other energy carriers for a particular application, such as heating or transport. The cost of a gas transmission pipeline exhibits strong economies of scale: to achieve low costs per unit of energy delivered, a high flow rate is desirable. The major cost of a pipeline is the pipe itself with installation costs, permits and rights of way and compressors also part of the overall investment.

Operational issues relating to gas grids are mainly influenced by gas pressure, quality, and safety and the operating cost of a gas grid is dependent on these parameters. In general, the handling costs associated with hydrogen storage will be higher than for other gases because of its volumetric energy density being about three times lower than methane.

A significant part of the extra investment cost for storing gas at high pressures is the extra cost for materials since thicker walls in pipelines and storage tanks are needed. From an operational point of view, increasing the gas pressure will result in increased running costs for the gas compressors, which also have to be serviced fairly frequently.

The cost of local distribution depends on the density of urban demand, with denser, more compact systems yielding a lower cost. When planning a new gas distribution network, it is common to plan for anticipated future expansion. If demand grows rapidly, increased pressure can provide additional gas flow. When additional new pipes must be installed, this is a costly option.

Since relatively large investments are required for building new gas grids, and their economic and environmental viability depends on the local RE and energy infrastructure (gas grids, electricity, heating/cooling networks), a clear policy on the end-use of the gas is required on a regional basis, particularly for RE-based gases, so that these energy carriers do not compete in the same markets.

Methane is already well-established for applications in heating, cooking, power generation, and transportation and cleaned biomethane is compatible with the existing natural gas system. Hence, there is a straightforward transition path for introducing RE into the existing supply chain using existing natural gas grids with the costs of transmission and distribution similar.

Biomethane should primarily be used in highly efficient industrial processes (with future possibilities for CCS (carbon dioxide capture and storage) and/or advanced CHP systems. Biomethane as a transport fuel will require additional systems and infrastructure. To avoid this, hydrogen should primarily be produced locally and used as a fuel for vehicles. In a larger hydrogen economy, the gas could be injected into the natural gas grid.

The outlook for RE-derived gaseous energy carriers depends on how quickly they can penetrate the energy system and how much can they ultimately contribute. Biomethane is limited by available supplies but, in some regions such as the EU, could provide a large resource by 2020, thereby replacing significant amounts of imported gas (Fig. 8.20).

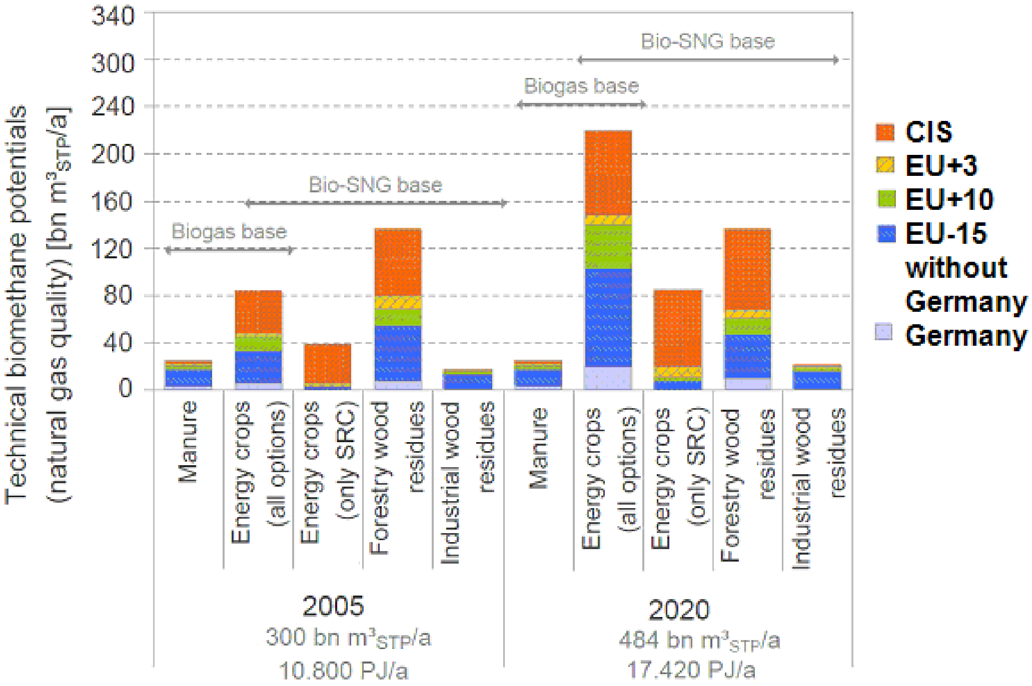


Figure 8.20: Technical potentials of biomethane at standard temperature and pressure (STP) in the EU-region in 2020 (Müller-Langer et al., 2009).

In order to blend RE gases into the gas grid, the gas source needs to be located near to the existing system to avoid high costs. For remote biogas plants it may be better to use the methane on-site to avoid the need for transmission. Similar considerations apply to syngas produced from biomass and hydrogen. Blending syngas into the natural gas system could be feasible, but may require changes to gas distribution and end-use equipment which is tuned for natural gas. “Town gas” city networks that currently employ fossil fuel-derived syngas may be good markets for biomass derived syngas.

The potential RE resource base for hydrogen is greater than for biogas or biomass-derived syngas. The rate limiting factors are more likely to be the capital and time involved in building a new hydrogen infrastructure. If hydrogen is used as a transport fuel, it would require several hundred billion dollars spent over four decades to fully develop a suitable infrastructure for refueling vehicles (NRC, 2008). Incorporating variable RE sources could add to the cost because of the added need for storage.

8.2.4 Liquid fuels

8.2.4.1 Characteristics of RE with respect to integration

Renewable-based liquid fuels are basically produced from biomass sources. Currently most biofuels are produced from sugar, carbohydrate and vegetable oil food crops. Alcohol fuels can replace gasoline in spark ignition engines, and biodiesel can be used in compression ignition engines (see Chapter 2). Biogas can also be combusted directly in internal combustion engines similar to those suitable for running on compressed natural gas (cng). Solid biomass (ligno-cellulosic) sources can be converted to “second generation” liquid fuels by means of biological processes such as enzymatic hydrolysis or by thermo-chemical processes to produce synthesis gas (mainly CO + H2) followed by the established Fischer-Tropsch conversion to produce a range of synthetic liquid fuels suitable for aviation, marine and other applications

If biomass is going to play an important role in the future, the demand for large amounts of traditional solid biomass used for cooking and heating is likely to be replaced by more convenient liquid fuels such as dimethyl ether (DME) or ethanol gels (IEA, 2008b). Most of the projected demand for liquid biofuels is for transport, though industrial demand for liquid fuels could be as bio-lubricants and methanol (for use in petro-chemical industries).

The type of fuel storage and delivery system will vary depending on properties of the biofuel and compatibility with the existing petroleum fuel system. Biofuels can take advantage of existing infrastructure components already used by the petroleum-based fuels for storage, blending, distribution and dispensing. Most biofuels have fairly similar properties to gasoline and diesel and can be blended in any proportion with these petroleum fuels. Biofuels are compatible with the petroleum storage and delivery infrastructure (NAS, 2009). Transition barriers would be low as these fuels could be introduced without costly modifications to existing petroleum storage and delivery systems. Fuels could be transported from bio-refineries via truck, barge, ship or pipeline to terminals and from there trucked to retail outlets. Storage and distribution costs should be similar for petroleum-based fuels. Bio-refineries are generally smaller in capacity than oil refineries, and could be located in different geographic regions where the resource exists (for example, in the United States bio-refineries are in the Mid-west or South-east whereas oil refineries are concentrated on the coasts). At high levels of biofuel use, various fuel transport routes and delivery modes from refinery to terminal might be preferred.

Integration issues are challenging for bio-ethanol. Replacing a substantial proportion of gasoline with blends or neat fuel would require investment in infrastructure including additional tanks and pumps at the service stations. Although the cost of delivery is a small fraction of the overall cost, the logistics and capital requirements for widespread expansion could present many hurdles if they are not well planned. Ethanol and ethanol/gasoline blends (gasohol) cannot be easily stored, transported and delivered in the existing petroleum infrastructure because of the incompatibility of materials and water absorption by ethanol in the pipelines. Ethanol tanks need to be double-layered to avoid condensation occurring. In addition, ethanol has only around two-thirds the volumetric energy density of gasoline, so larger storage systems, more rail cars or vessels, and larger capacity pipelines would be needed to store and transport the same amount of energy. This would increase the fuel storage and delivery cost.

8.2.4.2 Features and structure of liquid fuel supply systems

Ethanol is used today in several countries, as a transportation fuel additive or blend especially USA, France and Brazil or as a neat fuel (Brazil, Sweden). The structure of a biomass-to-liquid fuel system is well understood (Fig. 8.21).

Transportation of biomass feedstocks (sugar cane, corn grain, soybeans, straw etc.) to a biorefinery is by road over short distances or rail. Depending of the feedstock, transport costs vary considerably. For second generation biofuels, ligno-cellulosic materials can be transported at low energy densities to centralized biomass-processing plants. This bears a transport cost and can result in greenhouse-gas releases. In Brazil, ethanol is stored at the refineries where it is blended, but also at the production sites. Transport and storage costs play a critical role in the development of the cellulosic-ethanol industry (NAS, 2009). Due to the agricultural seasonality of many crops grown as feedstocks, storage of the biofuel produced is crucial to meet all-year-round demand.

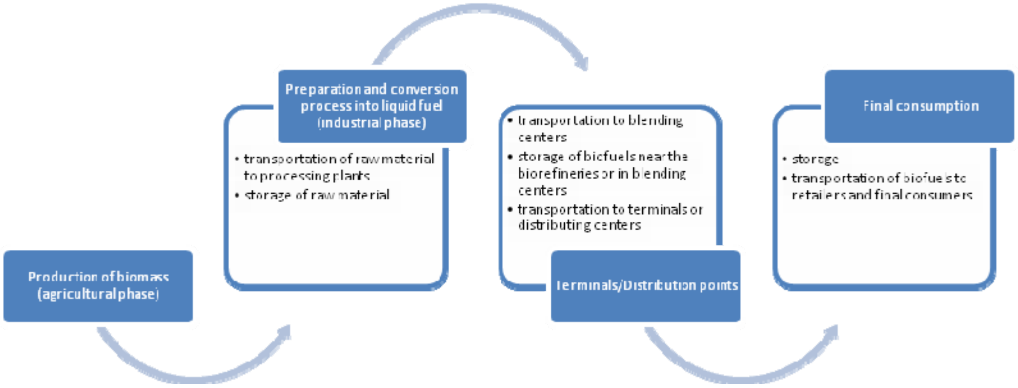


Figure 8.21: The typical biofuel process, blending and distribution system.

For short distances between plantations, bio-refineries, and blending centres, road transportation is usually the most cost effective transportation mode. In Brazil and USA ethanol has also been transported in pipelines also used to transport oil products. Pipelines can be cost effective when production is geographically concentrated otherwise road and rail transportation is preferable. Existing pipelines are not necessarily close to bio-refineries.

8.2.4.3 Challenges of integration

Decentralized biomass production, seasonality and agricultural locations not necessarily existing near oil refineries or distributing centres can impact on the logistics and storage of biofuels. Land use competition, fertilizer inputs and pesticide applications are concerns commonly raised.

Problems faced by sharing oil-product infrastructure (storage tanks, ducts, pipelines, trucks) with biofuels, especially ethanol, are water contamination and corrosion that can result in new materials needed to preserve the lifetime of equipment. Since oil pipelines are not air-tight, moisture can get in and increase the water content of the ethanol being transported. If the water content is above the technical specification, further distillation will be required. The affinity for water of ethanol and its solvent properties require use of a dedicated pipeline or significant cleanup of existing pipelines. Moisture does not represent a great problem with oil-products and can be easily drained off.

Covering ethanol storage vessels and where it is loaded can reduce condensation. “Sacrificial buffers” of neat ethanol can be sent down a pipeline ahead of the “primary” batches of an ethanol or gasohol shipment to absorb the moisture. The shot is then discarded or re-distilled. Ethanol can also dissolve and carry impurities that are present inside multi-product pipeline systems. These impurities are potentially harmful to internal combustion engines. Ethanol in high concentrations can also lead to accelerated stress corrosion cracking (SCC) in steel pipelines especially at weld joints or bends. These effects could be ameliorated by adding tank liners, selective post-weld heat treatment, and coating of internal critical zones (at pipeline weld points, for example) but these all increase costs. Ethanol may also degrade certain elastomers and polymers found in seals and valves in pipelines and terminals as well as some engines.

It would probably not be economic to retrofit existing multi-purpose pipelines. However, new pipelines could be constructed with ethanol-compatible polymers in valves, gaskets, and seals and be designed to minimize SCC (NAS, 2009). Phase separation during pipeline shipment can be avoided by first shipping hydrous ethanol which is then used directly by end-users or distilled, and then anhydrous ethanol which is later blended with gasoline.

8.2.4.4 Options to facilitate integration

8.2.4.4.1 Technical options

Biofuel technologies could evolve to produce biofuels that are more compatible with the existing petroleum infrastructure (Sims et al., 2008). Quality control procedures need to be implemented to ensure that biofuels meet all applicable product specifications (Hoekman & Kent, 2009). This will also facilitate the integration of biofuels into the liquid fuel supply system. Biodiesel is more prone to variation in its composition during storage due to the action of micro-organisms leading to rises in acidity and corrosion whereas ethanol is more stable.

As biofuels started to be traded internationally there was a need for international standards to be developed. Ethanol and biodiesel are in most cases blended into gasoline and diesel which in turn present regional differences depending on the types of predominant vehicle engines and local emission regulations. There are variations in current standards for regulating the quality of biodiesel on the market, though less variations for ethanol fuel since it is a single chemical compound whereas biodiesel varies with the feedstock. This translates to variations in the performance characteristics of each biofuel. A comparison was made of existing standards for biofuels (Anon. 2007) as used by the three main biofuel producing and consuming regions (US, Brazil and EU). The standards for biodiesel in Brazil and US reflect its main use as a blending component in conventional mineral diesel fuel, whilst the European biodiesel standard describes a product that can be used either as a stand-alone fuel or as a blending component. Bioethanol regulations differ with respect to the water content, but no technical specification constitutes an impediment to international trade.

8.2.4.4.2 Institutional aspects

Agencies in charge of regulating the oil-product markets could also include biofuels under their jurisdiction. Specifications and quality control at the production level as well as at the fuelling station or retail level could be put in place.

8.2.4.5 Benefits & costs of large scale penetration

The adaptation of existing transport, storage and dispensing equipment at fuelling stations is possible to handle biofuels and blends but would be expensive. To retrofit existing fuelling stations, underground storage-tank systems, pumps, and dispensers must be converted to be compatible with higher-ethanol blends. Issues relating to retrofitting of existing fuelling stations are similar to those associated with pipeline transport of ethanol and blends including phase separation, SCC, and contamination of incompatible materials found throughout conventional fuelling stations (NAS, 2009).

Ethanol terminals usually have one or more storage tanks ranging from 750,000 to 15 Ml capacity. New ethanol storage tanks cost around USD 0.15 /l [TSU: Needs to be presented in 2005 US$/l] capacity for small tanks to USD 0.05 /l[TSU: Needs to be presented in 2005 US$/l] for large tanks (Reynolds, 2000). It is sometimes possible to refurbish gasoline tanks for ethanol storage at lower costs. Collection terminals at ports and refineries often include equipment for blending ethanol (costing around $300,000[TSU: Needs to be presented in 2005 US$]), receiving shipments via rail, truck, boat or pipeline, and loading blended product onto road tankers. Upgrading an existing large gasoline terminal to handle ethanol blending can cost as much as USD 1 M[TSU: Needs to be presented in 2005 US$] (Reynolds, 2000).

In the US, the majority of ethanol is transported by rail as well as road tanker and barge (NCEP, 2007). At present no ethanol pipelines are in use. The choice of transportation mode used depends on the shipping distance, the volume of ethanol transported, and whether the product is accessible to water. Capacities and costs vary for ethanol storage and delivery equipment (Table 8.7). For reference, ethanol plants in the US produce 0.3-1.2 Ml /day; demand for 1 million cars using E10 would be about 0.4- 0.8 M l / day and terminals can hold 4-12 Ml.

Table 8.7: Equipment capacity for ethanol storage and long-distance transport (RFA, 2009).

	Capacity	**Cost (USD)** [TSU: Needs to be presented in 2005 US$]
Truck/trailer	25 m^3	USD 110,000 (USEPA, 2007) USD 125,000 (Reynolds, 2000)
Rail car	90 m^3	$90,000 (USEPA, 2007)
River barge	Several units @1,200 m^3/unit	USD 2M for 450,000l (USEPA, 2007)
Ocean barge/ship	3,000-30,000 m^3 (Reynolds, 2000)	
Pipeline (300 mm diameter)	12,000 m^3/day	USD 0.30-0.75 M/km
New terminal storage tank	3,000 m^3 6,000 m^3	USD 450,000 (Reynolds, 2000) USD 760,000 (Reynolds, 2000)
Retrofit gasoline storage tank	1,200 m^3	USD 20,000 (USEPA, 2007)
Blending equipment for terminal		USD 150,000-400,000 (Reynolds, 2000)
Total terminal refit	6,000 m^3 capacity	USD 1 M (Reynolds, 2000)
Ethanol production plant	230-950 m^3/day	
Ethanol terminal	600 m^3 (local)- 12,000 m^3 (regional)	

For short distances under 500 km carrying relatively small quantities of ethanol, road tanker transport is usually the most efficient and cost effective delivery mode (Reynolds, 2000). Tankers are often used to distribute ethanol from large regional terminals served by boat, barge or rail, to smaller local terminals that have insufficient storage to receive barge or rail deliveries.

Rail shipment is generally the most cost effective delivery method for medium and longer distance destinations incapable of receiving ethanol by ship (i.e. 500 to 3,000 km) (Reynolds, 2000). Because of the number of units and smaller unit volumes compared to barges, as well as the more labour intensive efforts for cargo unloading and inspection, rail shipments require more effort at the terminal level. Unit trains for ethanol (containing up to 75 railcars) are not used at present but they have been proposed as an alternative to pipeline development.

Barges are used for long distance transport when ethanol production plants have access to rivers or sea. In the US, ethanol barges travel down the Mississippi river from Midwestern ethanol plants to ports at the Gulf where ethanol is stored in terminals and transferred to ships for transport to overseas or national coastal destination terminals for blending.

Ethanol and blends are not currently shipped via pipeline in the US, except in a few proprietary short distance industry pipelines (Yacoub et al., 2007). Although pipelines would, in theory, be the most economical method of delivery, and trial pipeline shipments of ethanol have been successfully achieved, a number of technical and logistic challenges remain. Moreover, current ethanol demand volumes are considered too low to justify the cost and operational challenges (Reynolds, 2000). An average US passenger car might use 4-8 l /day of ethanol assuming it ran on 100% ethanol. This implies that a geographically localized fleet of 2 million dedicated ethanol vehicles (or 20 million vehicles using E10) would be needed to justify building an ethanol pipeline delivering 12 Ml /day of ethanol.

Storage and transport are relatively small costs for ethanol on a USD /l[TSU: Needs to be presented in 2005 US$] basis. According to Reynolds (2000), when transporting larger ethanol shipments over greater distances, the economics for waterway (barge and ship) and rail prevail over truck transport. Estimates for ethanol shipping cost varies from USD 0.005 to 0.01 /l[TSU: Needs to be presented in 2005 US$] for ship and ocean barge; USD 0.02 to $0.08 /l[TSU: Needs to be presented in 2005 US$] for barge; $0.01 to $0.35 /l for rail, and $0.01 to $0.02 /l[TSU: Needs to be presented in 2005 US$] for trucks used only for short distance transport.

In Brazil, depending on the origin of the biofuel, the costs of transporting ethanol from the producing regions to export ports is around USD 0.038 – 0.07 /l[TSU: Needs to be presented in 2005 US$], which also includes storage costs at the terminal (Scandiffio, 2008). Ethanol pipelines are being planned to connect main rural producing centres to coastal export ports with an expected cost ranging from USD 0.021-0.031 /l[TSU: Needs to be presented in 2005 US$] (CGEE, 2007).

8.2.4.6 Case studies

8.2.4.6.1 Brazilian ethanol

In Brazil almost all new vehicles sold are flex-fuel and capable of using bioethanol blends ranging from E20 to E95. The distribution system, retailing, and production of flex-fuel engines works smoothly without being too expensive. All gasoline sold has a content of 20-23% of anhydrous ethanol (by volume) and is used in Otto engine vehciles. Since 2003 the fleet of hybrid motor vehicles that can run on any mixture of ethanol and gasoline (Fig 8.22). Over the last 30 years a country-wide storage and distribution system was implemented and ethanol is available in practically all fuelling stations throughout the country. Ethanol prices to the consumer have declined steadily in Brazil and are competitive with gasoline prices (Fig. 8.23).

Implementation of the ethanol programme followed the strategy as outlined below.

- Large incentives to producers 1979-85
    - Subsidies for new distilleries, retrofits, upgrades, etc.
    - Government purchased all production at a given price.
    - Production grows from 0.6 to 11.6 bn litres per year.
- Subsidies given to ethanol consumers; national fixed pricing; country-wide distribution.
- Blends with gasoline and introduction of 100% ethanol-fuelled cars.
- Incentives (tax cuts) for ethanol cars especially taxis and government fleets.

- Gasoline taxed heavily (1979-85).
- Private sugar industry became interested in increased productivity.
- In the 1990s
  - deregulation and
  - priority for sugar and sugar exports.
- Internal market grows and flex-fuel vehicles introduced in 2003.

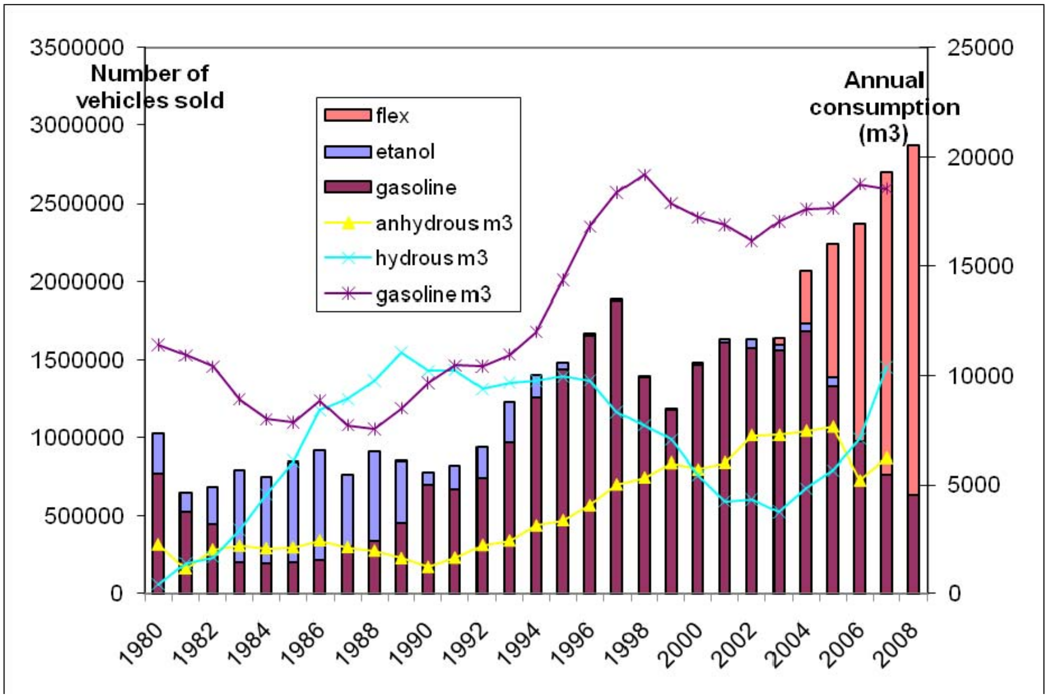


Figure 8.22: Light vehicle annual sales in Brazil and annual consumption of hydrous and anhydrous ethanol from 1980 to 2007 (ANFAVEA, 2009; MME, 2008).

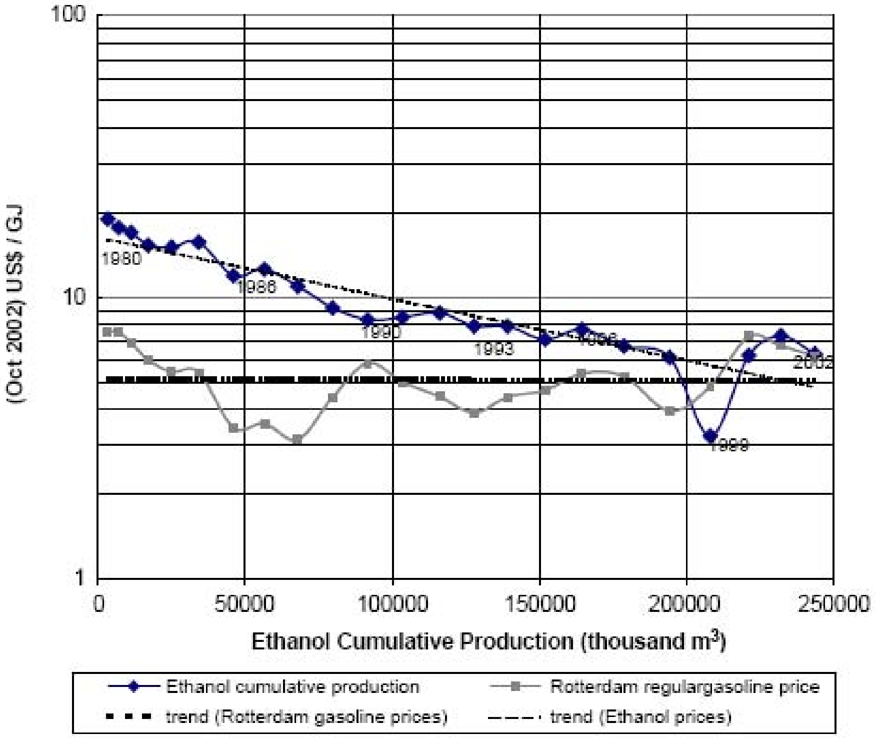


Figure 8.23: Global ethanol and gasoline prices (1980-2002) (Goldemberg et al., 2004a).

8.2.4.6.2 Biofuels for cooking in Malawi

The use of ethanol, DME and synthetic fuels (from Fischer Tropsh) for cooking are potential biofuel applications with wide global relevance. Combustion of biofuels for cooking will yield emissions of pollutants that are lower than emissions from cooking with solid fuels (Hutton et al., 2006; WHO, 2006; Goldemberg et al., 2004b). The example of sugar cane ethanol is well documented (Zuurbier and van de Vooren, 2008) with cost benefits of ethanol as a domestic fuel. A project is currently being carried in Madagascar and some experience has been gained in this field in Malawi.

The household sector in Malawi consumes 7.5 Mt of woody biomass which exceeds sustainable supplies by 3.7 Mt. The major cooking fuel is charcoal, followed by firewood, then electricity. Electricity is used for cooking in 11.5% of urban households and kerosene by 1.2%, mostly located in central and southern regions. Biomass fuels are the main source of cooking energy giving one of the highest health impact due to particulate emissions in the region. The World Health Organization (WHO, 2007) has evaluated the national burden of disease (that expresses the mortality and morbity of a given population) attributable to the risk from burning solid fuels in Malawi to be 5.2%.

Cost comparisons were carried out with other fuels based on current market prices, tax free prices and useful energy. When the most efficient ethanol stove is used (Fig. 8.24), ethanol is cheaper than LPG but it remains more expensive than charcoal or firewood which are indirectly subsidized. If taxes were to be lowered for ethanol while they are retained for kerosene, cooking with ethanol could become cheaper.

Figure 8.24: Clean Cook ethanol stove (source: Project Gaia, www.projectgaia.com)

An economic analysis conducted by WHO (Hutton et al., 2006) calculated that the returns from investing in household energy in 11 sub-regions (Table 8.8) would be positive if around 50% of the population in this African sub-region would switch from solid biomass to ethanol.

Table 8.8: Returns from investing in household energy assuming 50% of the African sub- region population cooking with solid biomass in 2005 switched to cooking with modern biofuels by 2015. [TSU: Needs to be presented in 2005 US$]

Cost items	Urban	Rural	Total
Annual value of health system cost savings (USD M)	10	16	26
Annual sickness time avoided (million work days)	26	43	69
Annual value of sickness time avoided (USD M)	55	91	146
Annual number of deaths averted (thousands)	39	57	96
Annual value of deaths averted (USD M)	552	810	1362
Annual value of patient cost savings (USD M)	0.8	1.3	2.1
Annual value of total health care cost savings (USD M)	11	18	29

(Hutton et al., 2006)

8.2.5 Autonomous systems

8.2.5.1 Characteristics

In order to be sustainable, an energy system needs to keep demand-supply balance in various time frames depending on the nature of the energy, as electricity, liquid fuel or gaseous fuel. When an electricity system is small, the difficulty of the demand-supply balance readily emerges so that the energy system has autonomy for the balancing (an autonomous system). The integration of several RE conversion technologies, energy storage options and energy use technologies in a small-scale energy system depends on the site specific availability of RE resources and the energy demand due to geology, climate, and lifestyle. This creates several types of autonomous systems as follows.

- *Autonomous power supply systems.* Different RE generators can meet a part of an autonomous power system demand to enhance the sustainability of the system in, for example, an off-grid island. Currently, it is usual that fossil fuel generators are also included for security, reliability and flexibility of system operation.
- *Autonomous power supply in a developing economy.* Single or mixed types of RE generation technologies can form a hybrid power supply system in a remote area for off-grid electrification. A stand-alone hybrid power supply can improve its performance with further integration of energy storage technologies to overcome RE variability.
- *Autonomous remote area fuel supply.* There is a possibility to produce gaseous or liquid fuels from biomass or hydrogen from electrolysis of RE electricity.
- *Autonomous buildings.* Urban houses and commercial buildings are less dependent on network energy supply through energy efficiency enhancement and utilization of RE technology. Rural buildings are more suitable to be autonomous due to the increased RE resource in the vicinity.
- *Specific utilization.* In areas where the provision of commercial energy is not economically available, RE is often beneficial for supplying energy services such as water desalination, water pumping, refrigeration and drying.

8.2.5.2 Options to facilitate integration and deploy autonomous systems

Autonomous power supply systems. An autonomous RE power system begins with the limited deployment of a single type of renewable power generation technology such as wind power that then develops into a comparatively large system. The capacity of the RE generation will increase with additional generation units of the same type, or, to enhance operational flexibility, by adding other types of RE generation technologies. Fossil fuel generation to maintain the desired supply reliability and flexibility of system operation could, in the future, be displaced by increased flexibility and the integration of energy storage technologies.

Autonomous power supply in developing economies. The balance between cost and quality of the power supply is critical when deploying autonomous power supplies in developing economies. The simplest type of remote area power supply is a direct current power supply from stand-alone PV panels to meet lighting, radio and television demands of one or more households. For the increased cost of adding a battery, power becomes available during the night. Where a wind resource is available, a hybrid wind/solar system may have benefits.

Technically, energy storage technologies can enhance the performance of small-scale power supplies. However, it is usually an expensive technology so capital and operational costs should be carefully evaluated along with the desired reliability.

Autonomous remote area fuel supply. Fuel supply from biomass is either at the large-scale from agriculture, plantation forests, or food and fibre processing industries and used for vehicle fuel, electricity generation or heat for industry, or at the small-scale when social activities provide self-supply of fuel for domestic lighting, cooking, and heating in a household or small community.

8.2.5.2.1 Technical options

For an autonomous RE system, energy storage and energy utilization technologies are essential.

Energy storage technology. These are more important in autonomous energy systems than in electricity network integration due to the variability of several RE technologies and strict demand-supply balancing of small-scale systems. Among the energy storage technologies suitable for power systems (see section 8.2) the following are applicable to autonomous energy systems:

- pumped hydro storage (PHS) - small scale and including sea water pumped storage;
- compressed air energy storage (CAES);
- flywheel energy storage;
- batteries (lead acid, lithium ion, Redox flow etc.);
- ultra capacitor;
- hydrogen (from electrolysis).

Many simulation analyses, demonstration tests and commercial operations on the application of energy storage technologies to an autonomous system have been reported. These include demonstrations of PHS + wind integration in Canary Islands (Bueno et al., 2004) and PV + wind + hydrogen storage in Greece (Ipsakis et al., 2008). Liquid fuels produced from biomass energy are comparatively easy to store in a tank or container as are gaseous fuels under pressure.

Energy utilization technology. Autonomous RE systems have the possibility to enhance value or performance when integrated with special energy utilization technologies such as a solar still; humidification-dehumidification; membrane distillation; reverse osmosis or electro-dialysis for desalination (Mathioulakis et al., 2007); water pumping consisting of PV arrays and an AC or DC motor (Delgado et al., 2007); solar-powered adsorption refrigerator (Lemmini et al., 2008); and multi-seeds oil press (Mpagalile et al., 2005).

Autonomous building. Zero-emission energy buildings generate as much energy as they consume through energy efficiency technologies and on-site power generation. The Net-Zero Energy Commercial Building Initiative of the USDOE aims to achieve marketable net-zero energy commercial buildings by 2025 (US DOE, 2008d). Low-rise buildings have good potential to become autonomous buildings through the combination of air-tight structure, high heat insulation, energy efficient air conditioning, lighting, ventilation and water heating, and high utilization of RE technologies (see section 8.2.5.7). New technologies such as building-integrated photovoltaics (BIPV) (Bloem et al., 2008), distributed energy systems (IEA, 2009b) and off-grid operation (Dalton et al., 2008) are available.

8.2.5.3 Benefits and costs of RE integration design

In autonomous energy systems the electricity generated should be competitive with traditional energy supplies but is usually more expensive than that from a network. Integration of different kinds of RE may improve the economy and reliability of the supply (Skretas et al., 2007). The viability of autonomous energy systems should be evaluated including the possible sustainability constraints of fossil fuel supply in the future, and current technology innovation and cost reduction (Nema et al., 2009).

For remote off-grid areas, it is widely recognized that electrification can contribute to rural development through increased productivity per person; enhancement of social and business services such as school, markets, drinking water and irrigation; decreases in poverty; and improvements in education, gender, health and environmental issues (Goldemberg, 2000; Johansson, 2005; Takada et al., 2006; Takada et al., 2007). Other than for electric power, the use of biomass-based autonomous remote-area energy supplies, where biomass resources or organic wastes are substantial, is inevitable to supply basic services of cooking, lighting and small-scale power generation.

In an autonomous building where more technologies can be integrated to provide various services, there is more room to enhance the performance of the system. In China, extensive solar energy utilization in the building industry brings great environmental and economic benefits using solar water heater systems (Li et al., 2007). Some Japanese house suppliers, such as Misawa Home Co. Ltd. sell net-zero energy houses which are 100% electrified but compensate for their power consumption by the power generated from PV on the roof. The urban autonomous building can increase its benefit with special functions such as having a green value, and non-interruptable power service (Shimizu Construction Co., Ltd.).

As in off-grid circumstances, autonomous energy to supply telecommunication facilities is economically feasible in both developed and developing countries. Solar water pumping is at the commercial stage in many developed countries, but is not often employed in developing countries where it is needed such as the Algerian Sahara (Bouzidi et al., 2009).

8.2.5.3.1 Constraints on the rate and extent of deployment

Technological constraints and planning tools. The role of RE technologies changes from a niche to a major role in autonomous energy systems. Hence the need for system integration will increase. For each type of autonomous system, appropriate planning methodologies should be established (Giatrakos et al., 2009). In the utilization of RE technologies, the variable feature and the variety of possible technologies makes planning more difficult. To instigate planning methodology, reliable databases should be established through the best use of research, demonstration, and commercial experiences that reflect various combinations of technologies, specific site conditions, and life styles (Amigun et al., 2008; Himri et al.,2008). In the case of biomass, sustainability criteria should be included (Igarashi, 2009).

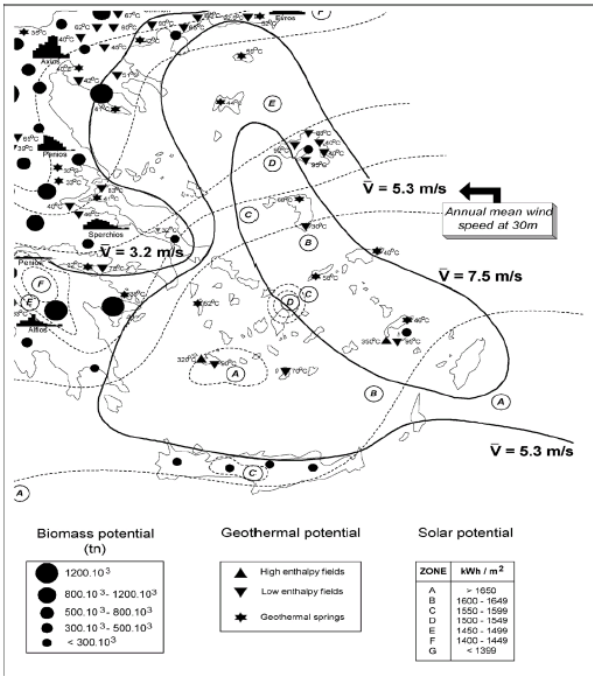
Institutional and social constraints. Autonomous RE systems feature variations of technical specifications. Major constraints can arise from the difficulty of appropriate planning, designing, construction and maintenance which lead to capital and operational cost increases and disclaimers after a failure. In order to avoid these factors, establishing standardization and certification of the products, integrating planning tools, developing a database and capacity building are important (Kaldellis et al, 2009) together with local capacity building and market establishment for low capital and operation cost (Meah et al., 2008).

Implementation and operation. Generally, RE technology is capital-cost-intensive as compared with fossil fuel conversion technology that is operation-cost-intensive. Accordingly, even if an integrated system is economically feasible, there is a need for an appropriate financial scheme for the dissemination of autonomous RE systems to remove the barrier of large capital costs. Local operation and maintenance resources can be secured through appropriate capacity building programmes.

8.2.5.4 Case studies

8.2.5.4.1 Aegean Islands (Greece)

Generators of 848 MW and 800 MW produced 2750 GWh and 2200 GWh electricity in Crete and in the other Aegean Archipelago islands in 2005. The islands, excluding Crete, can be categorized by the size of their generation capacity: very small(<1 MW); small (>1 - <9MW); medium (>9 - <20MW); medium/large (>20 -<50MW) and large (>50MW). Generation capacity consists of steam turbines, combined-cycle units, diesel units, gas-turbine units and a limited amount of wind power.



ZONE	kWh / m²
A	> 1650
B	1600 - 1649
C	1550 - 1599
D	1500 - 1549
E	1450 - 1499
F	1400 - 1449
G	< 1399

Figure 8.25: RE potential in the Aegean Archipelago region (Kaldellis et al., 2009).

In the area, despite abundant wind, solar and geothermal resources (Fig.8.25), and other RE resources available, the power demand increase has been met mainly by fossil fuel generation and only limited amounts of wind power. The limitation is due to the costs of RE and also to deterioration of the power supply quality due to the poor load-following capability of the autonomous power system without there being sufficient controllable generation resources.

In a small capacity, autonomous power system, the load and additional supply fluctuations from the variable RE generation can cause serious difficulties of the demand-supply balance control of the system. Due to these difficulties, the penetration of RE in the area is less than 15% energy production and 30% generating capacity. In order to overcome the obstacles for RE integration, there are alternatives being practiced. Improvements in the characteristics of generation units such as wind turbines and solar PV panels can decrease their generation when necessary to improve the demand-supply balance. Diversification of RE sources through the deployment of different kind of generation can reduce the total fluctuation of RE generation and the total cost including energy storage.

In the short term, energy storage systems can affect the short cycle, demand/supply balance control. In the future, after the costs of energy storage technologies have been reduced, they can take over the function to smooth the daily demand-supply balance. Energy storage technologies will be selected in accordance with the energy demand, charge-discharge capacity needed, and natural conditions of the site. A techno-economic comparison of energy storage systems was provided for very small, medium and large island autonomous power systems (Kaldellis et al., 2009)

Power system inter-connection by submarine cables is a promising technical option. Deployment depends on an economic evaluation of the option. The connection between islands and the main power system can change the situation totally (Hatziargyriou, 2007).

8.2.5.4.2 Seawater desalination in a rural area of Baja California, Mexico

Baja California Sur, Mexico is an arid sparsely populated costal state where underground aquifers are over-exploited due to population growth, agricultural demands and booming tourism. There are around 70 desalination plants using fossil fuel electricity and plans to construct more.

After several demonstration plants, the current most successful solar desalination system consists of a PV array, battery bank, and seawater reverse osmosis (PFSWRO). The system can produce 19 m^3/day of freshwater with a total dissolved solids content of less than 250 ppm and consuming as little as 2.6 kWh/m^3 of water (Contreras, 2007).

Small-scale desalination using PV is an attractive water supply option for small remote communities. The two major issues of the PFSWRO are an energy recovery device for small processes and integration of battery banks to enable the smooth operation for 24 hours. There is room to identify the balance between smooth operation and cost reduction through the optimized integration of battery banks. In the future, further integration of the desalination plant and rural electrification will be beneficial for water and energy supplies to remote rural communities, by adopting the best available process technology of desalination.

8.2.5.4.3 The Renewable Energy House, Brussels, Belgium.

The concept of refurbishing this 140 year-old office building and meeting facilities of approximately 2,800 m² aimed to reduce the annual energy consumption for heating, ventilation and air conditioning by 50% compared to a reference building, and to cover energy demand for heating and cooling by 100% RE sources. Key elements of the renewable heating and cooling system are two biomass wood pellet boilers (85 kW + 15 kW); 60 m² solar thermal collectors (30m² evacuated tube collectors, 30 m² flat plate collectors); four geothermal energy loops (115 m deep) exploited by a 24 kW ground source heat pump in winter and used as a ‘cooling tower’ by the thermally driven cooling machine in summer; and a thermally driven absorption cooling machine (35 kW cooling capacity at 7-12°C).

In winter, the heating system mainly relies on the biomass pellet boilers and the geothermal system. The solar system and the biomass boilers heat the same storage tank, while in winter the geothermal system operates on a separate circuit. The solar contribution in winter is low but when available, contributes to the reduction of pellet consumption. The core of the cooling system for summer operation is the thermally-driven absorption cooling machine, which is powered from relatively low temperature solar heat (85°C) and a small amount of electrical power for the control and pumping circuits (Fig. 8.26). Since solar radiation and cooling demands coincide, the solar thermal system provides most of the heat required for cooling. The solar system is backed up on cloudy days by the biomass boiler. The geothermal borehole loops absorb the excess low-grade excess heat from the cooling machine, thus serving as a seasonal heat storage system which is used during winter operation (EREC, 2008).

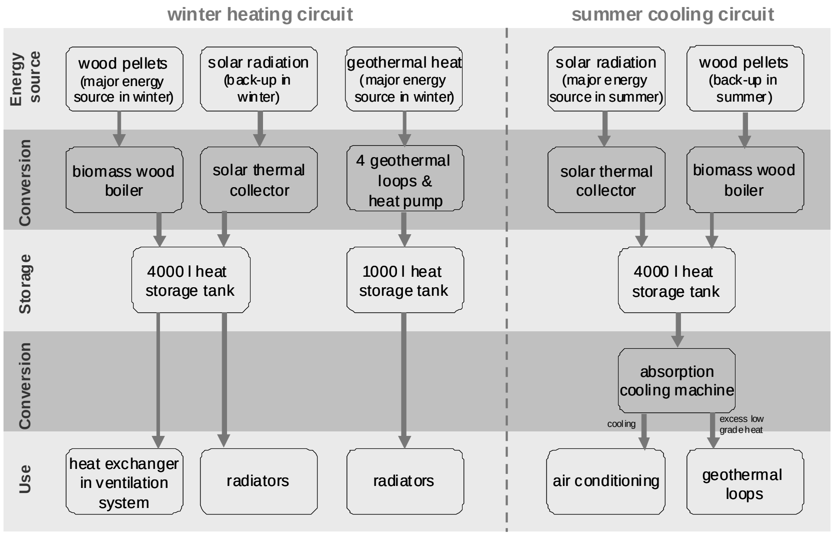


Figure 8.26: Renewable heating and cooling system in an autonomus office building (EREC, 2008).

8.2.5.4.4 Wind/hydrogen demonstration system at Utsira, Norway

An autonomous wind/hydrogen energy demonstration system located on the island of Utsira, Norway was officially launched by Norsk Hydro (now StatoilHydro) and Enercon in July 2004. The main components of the installed system are a wind turbine (rated 600 kW, but cut-off set at 300 kW), water electrolyzer for hydrogen (10 Nm^3/h), hydrogen gas storage (2400 Nm^3 at 200 bar), hydrogen engine (55 kW), and a PEM fuel cell (10 kW) (Nakken et al., 2006). The system gives 2-3 days of full energy autonomy for 10 households on the island, and is the first of its kind in the world.

Operational experience and data has been collected from the plant for the past 4-5 years. The specific energy consumption for the overall hydrogen production system (including electrolyzer, compressor, inverter, transformer, and auxiliary power) at nominal operating conditions was about 6.5 kWh/Nm^3, equivalent to an efficiency of about 45% (based on LHV). The efficiency of the hydrogen engine generator system was about 25% at nominal operating conditions. Hence, the overall efficiency of the hydrogen storage system (AC-electricity to hydrogen to AC-electricity) was only about 10%. If the hydrogen engine had been replaced by a new 50 kW PEM fuel cell (the 10 kW fuel cell at Utsira did not operate properly), the overall hydrogen storage efficiency would be likely to increase to about 16-18%. If the electrolyzer had been replaced by a more efficient unit (e.g. a PEM electrolyzer or a more advanced alkaline electrolyzer), the overall efficiency would have increased to about 20%. Overall, the low hydrogen storage efficiency illustrates the challenge with up-scaled hydrogen energy storage systems.

Nevertheless, the system at Utsira has demonstrated that it is possible to supply remote area communities with wind power using hydrogen as the energy storage medium. The project has also demonstrated that further technical improvements and cost reductions need to be made before wind/hydrogen-systems can compete with existing commercial solutions, for example wind/diesel hybrid power systems. Several areas for improvements have been identified. In general, the overall wind energy utilization must be increased (at Utsira only 20% of the wind energy is utilized). This can best be achieved by installing more suitable and efficient load-following electrolyzers that allow for continuous and dynamic operation. Surplus wind energy should also be used to meet local heating demands, both at the plant and in the households. In addition, the hydrogen could be utilized (and possibly the oxygen) in other local applications, e.g. as a fuel for local light-weight vehicles and boats.

More compact hydrogen storage systems and more robust and less costly fuel cell systems need to be developed before wind/hydrogen-systems can be technically and economically viable.

8.3 Strategic elements for transition pathways

For each of the transport, buildings, industry, and primary production sectors, in order to gain greater RE deployment, strategic elements and non-technical issues need to be better understood. Preparing transition pathways will enable a smooth integration of renewables to occur with the conventional energy systems. Multi-benefits for the energy end-users should be the ultimate aim.

In the IPCC 4th Assessment Report -Mitigation (IPCC, 2007) the economic potentials for each of the sectors were analysed in detail: transport (chapter 5); residential and commercial buildings (chapter 6); industry (chapter 7); and agriculture (chapter 8) linked with forestry (chapter 9) (Fig. 8.27). The substitution of fossil fuels by RE sources was included in the energy supply sector (chapter 4), together with fuel switching, nuclear power and CCS (carbon dioxide capture and storage). Around half of the economic potential from energy supply in 2030, assuming carbon prices up to USD 100 /tCO_2-eq[TSU: Needs to be presented in 2005 US$/$tCO_2$-eq], was as a result of the share of renewable electricity in the generation mix reaching between 26% and 34% of the total from the present 18%. In the transport sector, fuel savings in all vehicle types accounted for most of the mitigation potential in 2030, with biofuels projected to increase from a 3% share of total transport fuel use in the baseline to 5-10%. For a carbon price range between USD 20 and 100 /tCO_2-eq[TSU: Needs to be presented in 2005 US$], a mitigation potential of 0.6 – 1.0 $GtCO_2$-eq would result, subject to future oil prices and the success of technologies to utilise cellulosic biomass (IEA, 2008a). In the building sector, most of the potential came from savings in heating fuel and electricity due to improved efficiency, with 0.1 – 0.3 $GtCO_2$-eq coming from solar installations. RE provided limited potential in the industry sector, other than from increased biomass use in the food processing and pulp and paper industries, concentrating solar thermal systems to provide process heat, and solar drying. The agriculture, forestry and waste sectors supplied the biomass used across all sectors including their own, but used little other RE themselves.

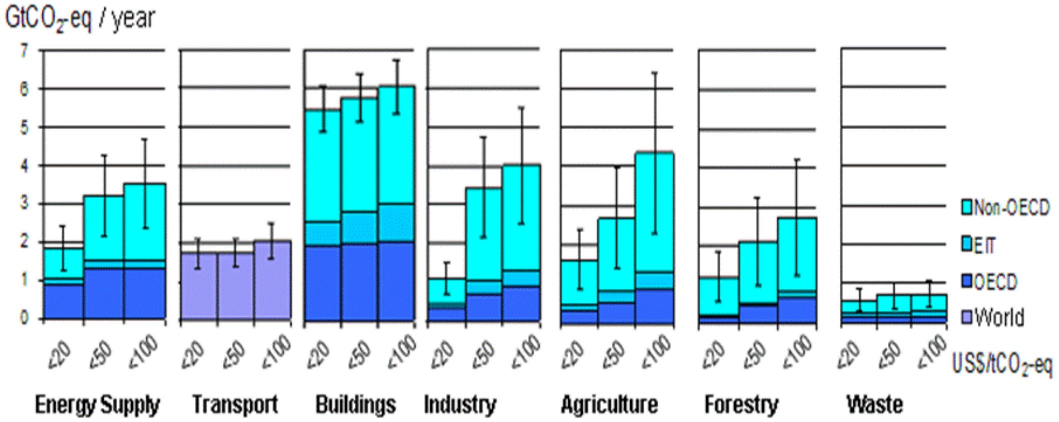


Figure 8.27: Estimated economic, mitigation potential ranges for energy supply and end-use sectors, above the assumed baseline for different regions as a function of the carbon price in 2030 and based on end-use allocations of emissions including from electricity generation.

The IPCC 4th Assessment Report was based mainly on data collected from 2004 or before as published in the latest literature at the time of writing. Since then, RE technology developments have continued to evolve and there has been increased deployment due to improved costcompetitiveness, more supporting policies, and increased public concern at the threats of energy security and climate change. In the following sections, for each of the transport, buildings, industry and primary production sectors, the current status of RE use, possible pathways to enhance its increased adoption, the transition issues yet to be overcome, and future trends, are discussed. Regional variations are included, particularly for the building sector where deploying RE technologies is vastly different in mega-cities with commercial high-rise buildings and apartments than in small towns of mainly individual dwellings; in wealthy suburbs than in poor urban areas; in established districts than in new sub-divisions; and in farming and fishing communities in OECD countries than in small village settlements in developing countries that have limited access to energy services.

8.3.1 Transport

8.3.1.1 Sector status and strategies

Significant fractions of global primary energy use (19%), GHG emissions (27%)[6], and air pollutant emissions (5-70%, depending on the pollutant and region) come from the direct combustion of fossil fuels for transportation (IEA, 2009a). Although improved energy efficiency in buildings or low-carbon electricity generation might offer lower cost ways of reducing carbon emissions in the near term (McKinsey, 2008; IEA, 2008b; Lutsey, 2008), improving the efficiency of, and decarbonising, the transport sector will be critically important to achieving long-term, deep cuts in carbon emissions required for climate stabilization (IEA, 2009e).

Energy supply security is also a serious concern for the transport sector. Demand for mobility is growing rapidly with the number of vehicles projected to triple by 2050 (IEA, 2008e). About 97% of transport fuels currently come from petroleum, a large fraction of which is imported. To meet future goals for energy supply security and GHG reduction, oil use will need to be radically reduced over a period of several decades. Light duty vehicles (LDVs) account for over half of transport energy use worldwide, with heavy duty vehicles (HDVs) 24%, aviation 11%, shipping 10%, and rail 3% (IEA, 2009e).

There are three approaches to reducing transport-related energy use and emissions.

- Reduction of travel demand or vehicle miles travelled. This might be achieved by encouraging greater use of car-pooling, cycling and walking, combining trips or tele-commuting. In addition, city and regional “smart growth” practices could reduce GHG emissions as much as 25% by planning our cities with denser population so that people do not have to travel as far to work, shop and socialize (Johnston, 2007; Pew Climate Center, 2007).

- Shifting to more efficient modes of transport, such as from LDVs to mass transit (bus or rail), or from trucks to rail or ships. On a passenger-km basis, the transport modes with the lowest GHG intensity are rail, bus and 2-wheelers, the highest being LDVs and aviation. For freight, the lowest GHG intensity mode on a tonne-km basis, is shipping, followed by rail, and then, by at least an order of magnitude greater, LDVs and air (IEA, 2009e). Further reductions could be achieved by adopting more energy efficient vehicles including reducing vehicle weight, streamlining, and improved deigns of engines, transmissions and drive trains, including hybridization. These can often pay for themselves relatively quickly. The introduction of battery and fuel cell electric vehicles could potentially pay for themselves over the vehicle lifetime, given sufficient vehicle cost reductions in the longer term depending on prevailing carbon and liquid fossil fuel prices. Consumer acceptance of

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[6] 27% in 2005 on a well-to-wheel basis, (IEA, 2008e)

high efficiency drive trains and lighter cars will depend on a host of factors including fuel price, advancements in materials and safety. In the heavy duty freight movement sub-sector and in aviation, there is also promise of significant efficiency improvements.

- Replacing petroleum-based fuels with low or zero carbon alternative fuels. These include renewably produced biofuels, and electricity or hydrogen produced from low carbon sources such as renewables, fossil energy with CCS, or nuclear power. Alternative fuels have had limited success thus far in most countries – the total number of alternative-fuelled vehicles is currently less than 1% of the global fleet. Exceptions include Brazil, where around 50% of transport fuel (by energy content) is ethanol derived from sugar cane, Sweden, where imported ethanol is being encouraged, India, Pakistan and Argentina, where compressed natural gas (CNG) is widely used, and the United States where ethanol derived from corn is currently blended with gasoline up to 10% by volume in some regions, and accounts for 3% of US transport energy use (USDOE, 2009). However, the context for alternative fuels is rapidly changing and a host of policy initiatives in Europe, North America and Asia are driving toward lower carbon fuels and zero-emission vehicles.

Recent scenario studies (IEA, 2008e; NRC, 2008; Yang et al., 2009) strongly suggest that a combination of approaches (reduction in vehicle miles travelled (VMT), higher efficiency and low carbon fuels) will be needed to accomplish 50-80% reductions in GHG emissions by 2050 (compared to current rates) while meeting growing demand and diversifying primary supply. In IEA (2008e) scenarios, vehicles become about twice as efficient by 2050, and in the 50% GHG reduction by 2050 “Blue Map” scenario (Fig. 8.28), conventional gasoline automobiles are largely replaced by battery electric vehicles (EVs) or hydrogen fuel cell vehicles (HFCVs) while biofuels are used extensively in the heavy duty, air and marine sections. GHG reductions come from a mix of improved efficiency (which accounts for at least half of the reductions) and alternative fuels. In these scenarios, biofuels, electricity and hydrogen make up 25-50% of the total transport fuel use in 2050.

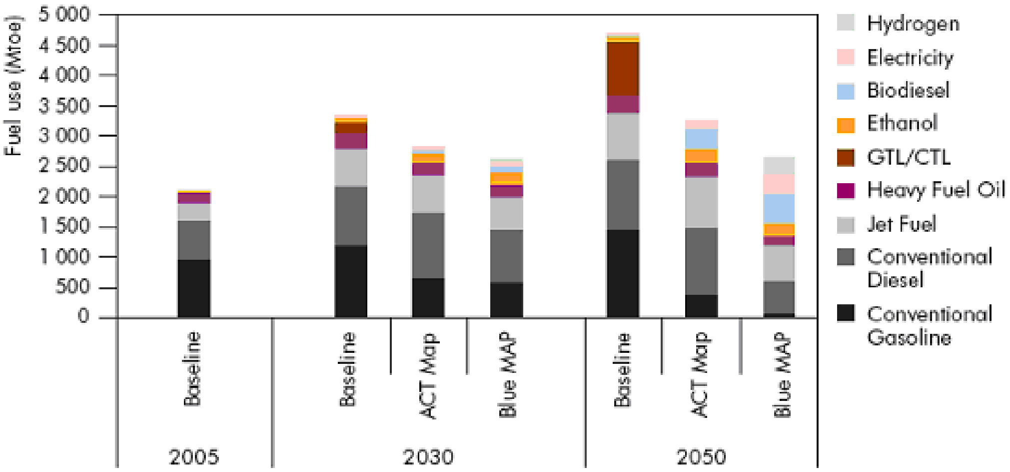
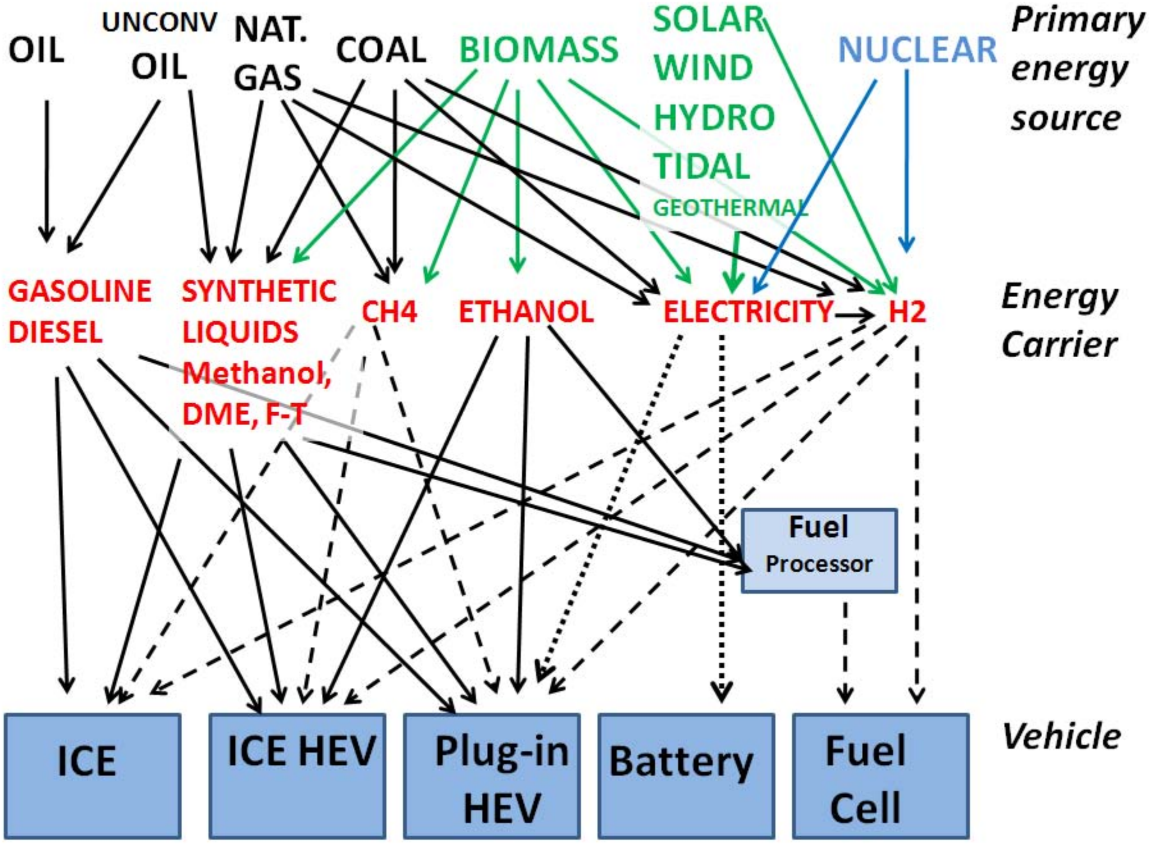


Figure 8.28: Projected mix of global transport fuels in 2005, 2030 and 2050 according to IEA scenarios (Source: IEA, 2008e).

The potential exists to make a transition to the transport sector using large quantities of RE. In this section, renewable fuel and vehicle pathways are reviewed within the larger context of future vehicles and fuels, and transition issues and future trends discussed.

8.3.1.2 Renewable fuels and light-duty vehicle pathways

A variety of more efficient vehicles, and alternative fuels, including liquified petroleum gas (LPG), CNG, ethanol, methanol, electricity and hydrogen have been proposed to address climate change and energy security concerns. Possible fuel/vehicle pathways begin with the primary energy source, conversion to an energy carrier (or fuel), and use in a vehicle "engine" (Fig. 8.29).



F-T= Fischer-Tropsch process. HEV=hybrid electric vehicle.

Figure 8.29: Possible fuel/vehicle pathways, from primary energy sources (top), through energy carrying fuels (red) to vehicle options (bottom) showing renewable resources (green).

Primary energy use and GHG emissions vary with different fuel/vehicle options. Well-to-wheels (WTW) analyses (Wang et al., 2008; CONCAWE, 2007; Bandivekar et al., 2009; Maclean, 2004) account for all the emissions associated with primary resource extraction, processing and transport, conversion to a useful fuel, distribution and dispensing, and vehicle use, although land use change impacts from biofuel feedstock production are often not included (see Chapter 2). Air quality and energy security are other important considerations for future transport pathways and sustainability issues such as land-use, water and materials requirements may impose constraints. New vehicle technologies could require large amounts of scarce or hard to access mineral resources: current automotive fuel cells require platinum and advanced, lightweight batteries require lithium. Composite sustainability indices for fuels have been developed (Zah et al., 2008) that include a variety of attributes in addition to GHG emissions.

8.3.1.2.1 Status and prospects - vehicle technology

A variety of alternative vehicle drive trains could use renewable-based fuels. These include advanced internal combustion engine (ICE) vehicles using spark-ignition or compression-ignition engines, EVs, HEVs, plug-in hybrids (PHEVs) and HFCVs. Several recent studies have assessed the performance, technical status and cost of different vehicle types (Heywood, 2000; Kromer and Heywood, 2007; Bandivedakar et al., 2008; CONCAWE, 2007; Plotkin and Singh, 2009; IEA, 2009e). A series of simulations of current and future (up to 2035) vehicle technologies estimated vehicle fuel economy and cost (Table 8.9).

Table 8.9: Attributes of light duty vehicles out to 2035 (Bandivadekar et al., 2008; Kromer and Heywood, 2007).

Vehicle type	**Status**	**Projected average fuel consumption in 2035** (litres gasoline equivalent / 100 km)	**Added retail price (from mass production) compared with 2035 gasoline ICE models** (USD 2007)	**Fuel options**	**Range** (km)	**Refuelling time**	**Infrastructure availability/ compatibility**
Spark ignition – ICE gasoline	Commercial	8.9 (2008) 5.5 (2035)	USD 2000 more than current model	Gasoline	500+	2-4 minutes	Baseline
	Commercial	Similar to gasoline (CONCAWE, 2009)	100-200 (EFC, 2009)	Ethanol (E85)	500+	2-4 minutes	Regional ethanol availability; blending possible with gasoline; separate storage and dispenser required.
	Commercial, in limited production	Similar to gasoline (CONCAWE, 2009)	1000-2000	Methane (CNG) or propane (LPG)	400	5 minutes	Available in some urban areas; bio-methane could be blended with CNG.
Spark ignition-ICE hybrid	Commercial	3.1	2500	Gasoline or liquid biofuels	700+	2-4 minutes	Same as baseline
Compression ignition-ICE diesel	Commercial	4.7	1700	Diesel biodiesel, or synthetic diesel	500+	2-4 minutes	Biodiesel widely available, though less than gasoline.
Spark ignition-ICE plug-in hybrid	Demonstration (commercial planned for 2010-2011).	2.2	5900	Gasoline (and/or liquid biofuels) and electricity. Battery cost, performance, safety issues.	500+ 50 on electric only	2-4 minutes for gasoline; 2-6 hours for battery charging	Common for gasoline; home charging possible; very limited public charging available to date.
Battery electric (EV)	Demonstration (limited commercial use as local fleet vehicles + 2-wheelers)	1.7	14,400	Electricity from a variety of RE sources. Battery cost, performance, safety issues.	200-300	2-6 hours for domestic charging; 10-15 minutes for public fast charge	Home charging possible; very limited public charging available to date.
Fuel cell –	Demonstration	2.3	5300	High purity hydrogen from	500+	3-5 minutes	Limited hydrogen fuelling networks in

hydrogen	(commercial around 2015-2020)			a variety of sources (from natural gas, biomass, electricity). Lifetime and cost; H_2 infrastructure; storage; safety issues.			Europe, Iceland and N. America with 100 stations worldwide. H_2 storage requirements and volumes will be a challenge at the service station forecourt.

Two-wheel motor-bikes and scooters are large and fast-growing vehicle segments in the developing world. They have significant potential for fuel efficiency improvement and GHG reduction through greater electrification. Electrification of bikes and scooters in China is already taking place on a large scale with 20 million annual sales in 2007 (ICCT, 2009).

Many ICE vehicles already use liquid biofuels whereas only a small fraction of ICE vehicles have been adapted to run on gaseous biofuels or renewable hydrogen. Hybrid electric drive trains have been introduced for gasoline vehicles and could be easily adapted in the near term to use biofuels. Most of the existing fleet of gasoline and diesel ICE vehicles can only operate on relatively low concentration blends of biofuels up to 10% by volume of ethanol or 5% biodiesel, (although Brazil gasoline is blended with up to 25% ethanol) to avoid adverse effects on the vehicle operation.

Plug-in hybrid vehicles are still under development, spurred by recent policy initiatives worldwide, and several companies have announced plans to commercialize them within the next few years. Costs and lifetime of present battery technology are the main barriers to both plug-in hybrids and battery electric cars. Hydrogen fuel cell vehicles have been demonstrated, but are not likely to be commercialized until at least 2015-2020 due to barriers of fuel cell durability, cost, and on-board hydrogen storage. The timing for commercializing each technology is discussed further under transition issues (8.3.1.4).

8.3.1.2.2 Status and prospects -liquid biofuels

Biomass can be converted to liquid fuels using many different routes (see section 8.2.4 and Chapter 2). "First generation" processes are commercially available today and advanced processes aiming to convert non-food cellulosic materials and algae are under development (Fig. 8.30).

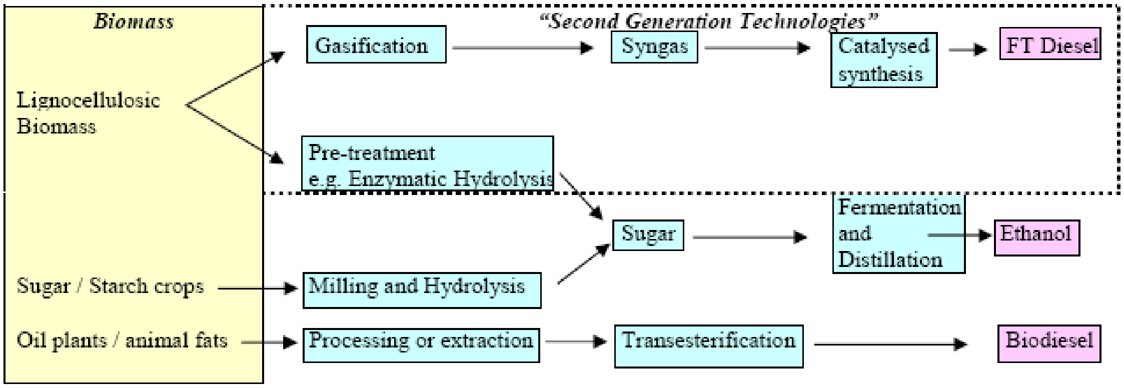


Figure 8.30: Examples of liquid biofuel production pathways (Doornbosch and Steenblik, 2007).

Conversion of biomass to biofuels entails energy losses. The IEA (2008e) estimated up to 29 EJ of advanced liquid biofuels could be produced each year by 2050, accounting for about 25% of the total transport fuel supply. Conversely, CONCAWE (2007), estimated a lower penetration displacing less than 15% of road fuels. Other routes such as electricity or hydrogen production can displace more petroleum (CONCAWE, 2007).

Incremental costs of many biofuels are higher than gasoline and diesel, Depending on the biofuel pathway, 2nd generation biofuels would add USD 0.15 to 0.45 /l[TSU: Needs to be presented in 2005 US$] gasoline equivalent assuming the crude oil price to be USD 60/bbl[TSU: Needs to be presented in 2005 US$] (IEA, 2009e) and USD -0.10 to +0.25 cents if oil was at USD120/bbl[TSU: Needs to be presented in 2005 US$].

8.3.1.2.3 Status and prospects – hydrogen/fuel cells

Hydrogen is a versatile energy carrier that can be produced by high temperature chemical processing of hydrocarbons (such as fossil fuels or biomass) or via electrolysis using electricity to "split" water into hydrogen and oxygen (Fig. 8.31). Today, industrial grade hydrogen (< 99.99% pure) is produced in large quantities primarily from fossil fuels for oil refining and chemical applications (National Hydrogen Association, 2009). Hydrogen can be produced regionally in industrial plants or locally at vehicle refuelling stations or buildings. Well-to-wheels GHG emissions vary for different fuel/vehicle pathways but both RE and hydrogen pathways offer reductions (Table 8.10).

In the United States a mix of low carbon resources including natural gas, coal (with carbon sequestration), biomass and wind power could supply ample hydrogen for vehicles (NRC, 2008). The primary resources required to provide sufficient fuel for 100 million passenger vehicles from various gasoline and hydrogen pathways have been assessed (Fig. 8.32). For example, enough hydrogen could be produced from wind-powered electrolysis to fuel 100 million fuel cell cars in the United States, using about 13% of the technically available wind resource. However, the combined inefficiencies of making the hydrogen via electrolysis then converting it back into electricity on a vehicle via a fuel cell lose more than half of the original RE inputs. Electricity is used more efficiently in a battery-electric or plug-in hybrid vehicle.

Hydrogen production and delivery pathways have a significant impact on the cost to the consumer. In addition, compared to industrial uses, fuel cell grade hydrogen needs to be extremely pure (> 99.999%) and must generally be compressed to 35 to 70 MPa before dispensing. Hydrogen at the pump might cost USD 3 - 4 /kg[7][TSU: Needs to be presented in 2005 US$] excluding taxes with higher costs near-term (NRC, 2008). Given the potential higher economy of fuel cell vehicles, the fuel cost per kilometre could become competitive with gasoline vehicles in the future.

Hydrogen distribution to consumers will require development of a new storage and delivery infrastructure (see section 8.3.1.4).

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[7] 1 kilogram of hydrogen has a similar energy content to 1 US gallon or 3.78 litres of gasoline

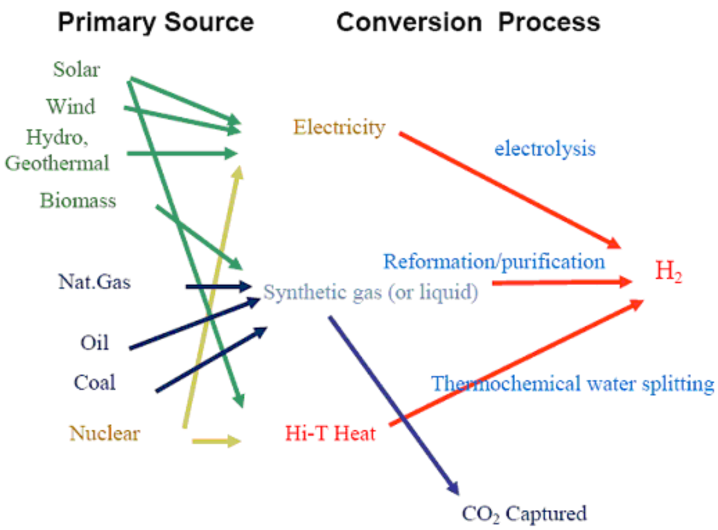

Figure 8.31: Some possible hydrogen production pathways.

Table 8.10: Well-to-wheel greenhouse gas emissions for light duty vehicles in 2010 using fossil fuels and biomass as feedstocks (CONCAWE, 2007).

	GHG emissions (gCO_2/km)	**GHG emissions relative to current gasoline ICE vehicles**
Fossil-derived fuels		
Conventional - gasoline SI-ICE vehicle	160- 170	-
Hybrid - gasoline SI / electric vehicle	125-150	-12 to -22%
Conventional - diesel CI-ICE vehicle	145-155	-9%
Hybrid - diesel CI / electric vehicle	110-140	-18% to -31%
Coal-to-liquids via F-T /CI-ICE vehicle	325 to 380	+103 to 124%
Coal-to-H_2 /fuel cell vehicle	250 to 350	+56 to +106%
CNG SI-ICE vehicle	120-140	-18% to -25%
Gas-to-liquids via F-T / CI-ICE vehicle	160 - 175	0 to 3%
Gas-to-H_2 /fuel cell vehicle	70-90	-47 to -56%
H_2 from gasified biomass /fuel cell vehicle	10-15	-91% to -94%
H_2 from RE electrolysis /fuel cell vehicle	0	-100%
Biofuels		
Ethanol - sugar cane / SI-ICE vehicle	20 - 39	-83 to -88%
Ethanol –wood / SI-ICE vehicle	35 – 60	-65% to -78%
Ethanol – straw / SI-ICE vehicle	15-65	-62% to -91%
Bio-diesel /CI-ICE vehicle	25-125	-27% to -84%
Biogas - dry animal manure /SI-ICE vehicle	0 - 5	-97% to -100%
Biogas - liquid manure /SI-ICE vehicle	-175 - -125	-174% to -206%
Biogas – municipal solid waste /SI-ICE veh.	25-35	-79% to -84%
DME - waste wood / CI-ICE vehicle	0 - 10	-94% to -100%
DME - farmed wood /CI-ICE vehicle	10-20	-99% to -94%
F-T diesel - waste wood /CI_ICEV	0 - 10	-94% to -100%
F-T diesel - farmed wood CI_ICEV	10-20	-99% to -94%

SI= spark ignition. CI=compression ignition. F-T = Fischer-Tropsch process.

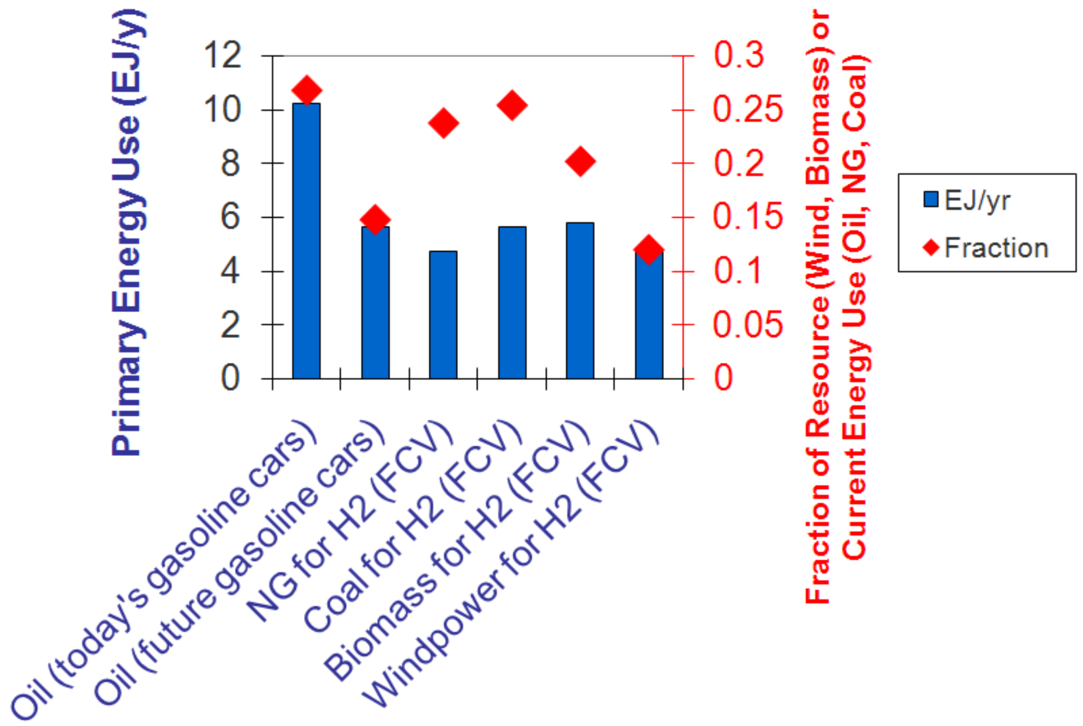

Figure 8.32: Primary energy resources required to fuel 100 million gasoline or hydrogen-fuelled vehicles, also shown as the fraction of the current US annual fossil fuel use or the projected RE resource demand (Ogden and Yang, 2009).

8.3.1.2.4 Status and prospects – electric and hybrid vehicles

While electricity generation from primary energy sources is typically only 30%-55% efficient, electric vehicle (EV) drive chains are relatively efficient and battery charging is an efficient way to store primary renewable electricity. Combined EV drive train and battery charge/discharge efficiencies (plug-to-wheels) are in the order of 60%-75%.

The GHG emissions and environmental benefits of EVs depend on the marginal grid mix and the source of electricity used for vehicle charging. For example, the current US grid being 54% dependent on coal, WTW emissions from EVs would not be much of an improvement over efficient gasoline vehicles (Fig. 8.33.). Various studies have developed scenarios for decarbonising the grid over the next few decades that would give reduced WTW emissions for EVs and PHEVs (EPRI/NRDC, 2007; IEA 2008e). With large fractions of renewable electricity, WTW emissions for EVs could be very small. An integration issue is the timing of vehicle recharging when variable renewable electricity is available. An electricity cost/infrastructure issue is timing of vehicle recharging during off-peak periods (typically, middle of the night).

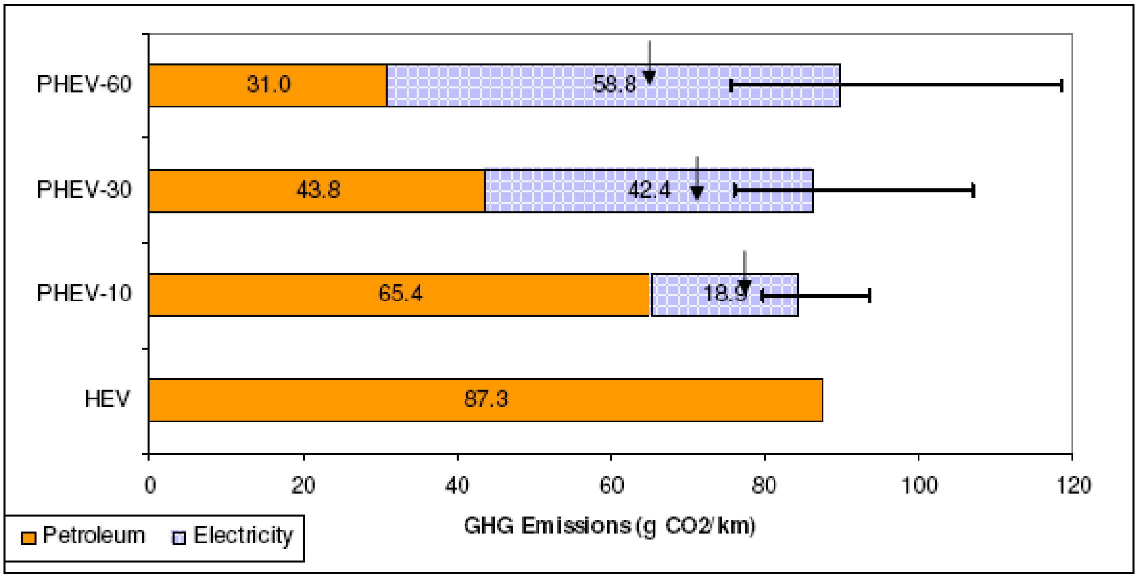

Figure 8.33: Well-to-wheels GHG emissions for gasoline-fuelled hybrids (HEV) and plug-in hybrids (PHEV) showing the various all-electric range.

Notes: PHEV-10 corresponds to an all-electric range of about 30 km and PHEV-60, around 100 km. Horizontal bars indicate the emission range when using electricity from natural gas to coal-fired generation.
Vertical arrows indicate emissions from a partially decarbonized grid similar to that in California today (Kromer and Heywood, 2007).

8.3.1.3 Comparison of alternative fuel/vehicle pathways

Fuel economy and incremental costs of alternative-fuelled vehicles have been compared (Figs. 8.34 and 8.35). Since each study employed different criteria for vehicle design and assumptions about technology status, the results shown have been normalised to those for an advanced, gasoline ICE vehicle (as was defined in each study). (Not all vehicle/fuel pathways were covered in all studies.) The relative efficiency of different vehicle types varied among the studies, especially for less mature technologies, although the overall findings are consistent. Several trends are apparent.

- There is significant scope to improve fuel economy relative to an advanced gasoline vehicle by adopting new drive trains.
- Hybrid vehicles and adoption of electric drives give increasing efficiency.
- Hybrids can improve fuel economy by 15-70%.
- Fuel cell vehicles are 2 to 2.5 times as efficient as gasoline ICE vehicles.
- Battery electric vehicles are 2.7 to 3.5 times as efficient.
- On a total WTW fuel cycle basis, these relative efficiency improvements for HFCVs and EVs are generally less when electricity generation and hydrogen production losses are included.
- There is more uncertainty in the fuel economy and cost projections for EVs and HFCVs which are still far from commercialization.
- In general, the higher the fuel economy the higher the vehicle price.

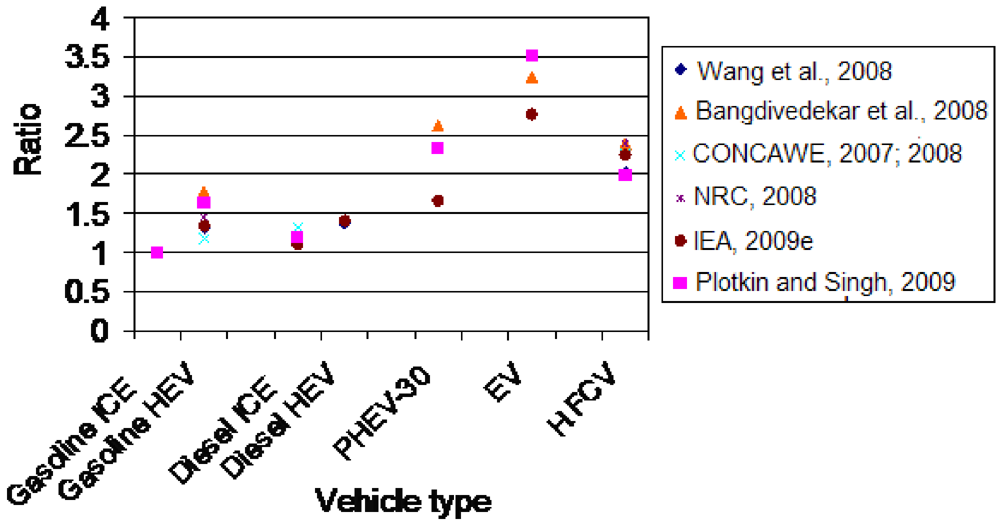

Figure 8.34: Relative fuel economy of future alternative fuelled light duty vehicles compared to advanced spark ignition, gasoline-fuelled, ICE vehicle based on various studies. (Well-to-tank inefficiencies such as electric power generation and hydrogen production not included).

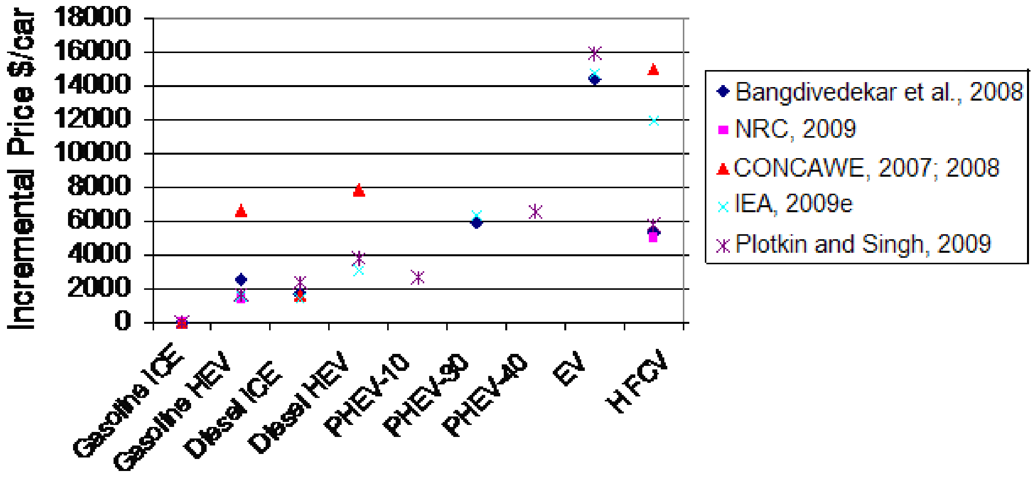

Figure 8.35: Incremental retail price for alternative light duty vehicles compared to an advanced gasoline SI-ICEV.

Notes: Bangdivedekar et al, 2008 vehicles were projections for 2035 technology.
NRC, 2009 is for a mature technology with learned-out costs post 2025.
CONCAWE 2007 and 2008 is for 2010+ technology.
IEA, 2009e and Splotkin and Singh, 2009 were 2030 technology projections.

8.3.1.4 Transition issues

To meet future goals for transportation energy security and GHG emissions reduction, the transport sector will need to be fundamentally transformed. Historically, major changes in transport systems such as building canals and railroads, paving highways, and adoption of gasoline cars, have taken many decades to complete. Transitions in the transport sector take a long time for several reasons.

- Passenger vehicles have a relatively long lifetime (15 years average in the US). Even if a new technology rapidly moves to 100% of new vehicle sales, it would take a minimum of 15 years for the vehicle stock to “turn over”. In practice, adoption of new vehicle technologies occurs much more slowly and can take 25 to 60 years for an innovation to be used in 35% of the on-road fleet (Kromer and Heywood, 2007). For example, research into gasoline HEVs in the 1970s and 1980s, led to a decision to commercialize in 1993 with the first vehicle becoming available for sale in 1997. HEVs still represent only about 1% of new car sales and less than 0.5% of the worldwide fleet.This slow turnover rate is also true for relatively modest technology changes such as the adoption of automatic transmissions or fuel injection. The timeframe for new technologies relying on electric batteries, fuel cells, or advanced biofuels could be even longer since they all need further RD&D investment before they can be commercialized.

- Changing a fuel supply infrastructure, especially if switching on a massive scale from liquids to gaseous fuels or electrons, will require both time and a significant amount of capital. This will take many decades to complete (IEA. 2009e; Splotkin and Singh, 2009). Developing new supply chains for renewables and replacing existing fossil fuel and electricity plants will take time. Such paradigm shifts will require close co-ordination among fuel suppliers, vehicle manufacturers and policy makers.

- Each fuel/vehicle pathway faces its own transition challenges which can vary with region. Transition challenges in terms of technology readiness (of fuel and vehicles) include infrastructure compatibility, consumer acceptance (for example, limited range or long recharging times for batteries), primary resources available for fuel production, GHG emissions, cost, and other environmental and sustainability issues (such as air pollutant emissions, and water, land and materials use).

8.3.1.4.1 Transition issues for biofuels

Second generation biofuels should give much lower WTW GHG emissions than petroleum derived fuels, but these technologies are still perhaps 10 years from market introduction (IEA, 2008a). An advantage of liquid biofuels is their relative compatibility with the existing liquid fuel infrastructure. Biofuels can be blended with petroleum-derived fuels, though typically cannot be shipped in existing fuel pipelines (section 8.2.4) and have limits on the concentrations that can be blended. Although ethanol would likely need its own distribution and storage systems, this would be less of a radical change than supply chain changes needed to provide either electricity, hydrogen, or even CNG where such a network is not yet in place. Biomethane could be purified and used in the existing natural gas system.

Biofuels are generally compatible with ICE vehicle technologies. They can be blended with petroleum products and most ICE vehicles can be run on blends or even on pure biofuels. Millions of vehicles with flex-fuel engines that can run on 100% gasoline up to 100% ethanol, have been sold around the world. Biodiesel blends can also be used with current compression ignition engine technologies, but limits depend on the triglyceride feedstocks used and ambient temperatures.

Since liquid biofuels blended in limited amounts are much like gasoline or diesel in terms of vehicle performance and refueling time, they can be relatively “transparent” to the consumer. Fuel cost may therefore be the main factor determining consumer acceptance. In Brazil for example, flex-fuel vehicle users can select the fuel based on price. Reduced range and reduced fuel economy with ethanol and, to a lesser extent, biodiesel, can also be a factor in consumer acceptance.

Primary resource availability is a serious issue for biofuels. Recent studies (IEA, 2009e; Splotkin and Singh, 2009) have assessed the national or global potential for biofuels to displace petroleum products. They found that environmental and land-use concerns would limit biofuel production to 20-25% of total transport energy demand. Given that certain transport sub-sectors such as aviation and marine require liquid fuels, it may be that biofuels will be used primarily for these applications, whilst electric drive train vehicles (EVs, HEVs, PHEVs, or HFCVs), if successfully developed and cost effective, might come to dominate the light duty sector.

8.3.1.4.2 Transition issues for hydrogen

Hydrogen produced from fossil fuels is used in oil refining to upgrade heavier crude slates and to hydro-treat petroleum products to remove nitrogen and sulphur impurities. In addition, hydrogen contributes to the energy content of petroleum-derived fuels. Hydrogen-rich synthesis gases (produced by thermal gasification of coal or heavy oil) have been used for electric generation. Hydrogen production currently consumes around 2% (USDOE, 2009) of global primary energy, and is growing rapidly. If all this hydrogen were further purified and then used in fuel cell cars, it could supply about 150 million, about 20% of the world fleet. While most hydrogen is produced and used in oil-refineries or chemical plants, some 5-10% is delivered to distant users by truck or pipeline. In the United States, this “merchant hydrogen” delivery system carries enough energy each year to fuel several million cars (but would first need purification). In the near term, excess hydrogen capacity from refineries and industrial hydrogen plants could fuel up to 100,000 cars in California alone (Ritchey, 2007).

Hydrogen has the potential to tap vast new energy resources to provide transport with zero or near-zero emissions. If hydrogen made from natural gas, the most common method today, is used in an efficient fuel cell car, GHG emissions would be about half those emitted from the tailpipes of today’s conventional gasoline cars and somewhat less than those from a gasoline HEVs. To fully realize the benefits of a hydrogen economy, a transition to cost-effective, zero emission, fuel supply pathways is needed.

Hydrogen from renewable sources has near-term cost barriers rather than technical feasibility or resource availability issues. In the longer term, biomass and wind hydrogen could compete with gasoline (NRC, 2008). In the very long-term, advanced renewable pathways employing direct conversion in photo-electro-chemical or photo-biological systems could become practical for production of hydrogen or other fuels.[8]

RE and other low carbon technologies will likely be used first to make electricity, a development that could help enable zero-carbon hydrogen that might be co-produced with electricity in energy complexes. Hydrogen should be seen in the context of a broader transition to low-carbon sources across the energy system, though it is likely that low-carbon hydrogen from renewables would cost more than hydrogen from natural gas. Public policy will be needed to assure that low carbon sources are used for hydrogen.

Although hydrogen can be burned in an ICE vehicle, more efficient HFCVs are seen as holding greater promise. Most of the world’s major automakers have developed prototype fuel cell cars, and several hundred of these vehicles are being demonstrated in North America, Europe and Asia. HFCVs are currently very costly, in part because they are not yet mass produced and fuel cell lifetimes are not yet adequate. It is projected that the costs of HFCVs will fall with further improvements from R&D, economies-of-scale from mass production, and learning by doing (NAS, 2008).

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[8] Hydrogen from nuclear energy has other challenges including cost (for electrolytic hydrogen), technical feasibility (for thermo-chemical water splitting systems powered by nuclear heat) and public acceptance. Nuclear hydrogen would have the same waste and proliferation issues as nuclear power.
Large-scale production of hydrogen from fossil fuels with CCS can offer near-zero emissions at poetentitally modest C prices, assuming suitable C disposal sites are nearby. Establishing the viability and acceptance of CCS is crucial for long-term use of hydrogen from fossil resources, especially coal.

HFCVs could match current gasoline vehicles in terms of vehicle performance and refueling time, and could be "transparent" to the consumer, in most respects. The maximum range of present-day fuel cell cars of about 500 km is acceptable so fuel availability and high cost of both vehicle and fuel remain the factors determining consumer acceptance.

Unlike electricity, natural gas, gasoline and biofuels, hydrogen is not widely distributed to consumers today. Bringing hydrogen to large numbers of vehicles would require building a new refuelling infrastructure that will be a decades-long process. The first steps to provide hydrogen to test fleets and demonstrate refuelling technologies in mini-networks are in place in Iceland and being planned through projects like the California Hydrogen Highways Network, the HyWays and Norway's projects in Europe. System level learning from these programmes is valuable and necessary, including development of safety codes and standards. When in the future hydrogen vehicles are mass-marketed, hydrogen will have to make a major leap to a commercial fuel available at perhaps 5% of refuelling stations (or an equivalent number of sites) and must be offered at a competitive price. The cost of hydrogen dispensing stations is likely to be higher than current gasoline or diesel stations due to the equipment, energy and safety measures needed to generate (or transport if the hydrogen is made off-site), compress, handle, and store the high purity hydrogen (350-700 bar) needed for fuel cell vehicle refuelling. Whether stored as a liquid or compressed, the energy density of hydrogen is 5-12 times less than oil-products. On-site storage equipment will therefore make up a significant portion of total station costs.

Recent studies (NRC 2008; Greene et al., 2007; Gronich, 2007; Lin et al., 2006; Gielen, 2005) indicate the costs to "buy-down" fuel cell vehicles to market clearing levels (through technological learning and mass production) and to build the associated infrastructure might cost tens of billions of dollars, spent over the course of one to two decades. The majority of the cost would be associated with early hydrogen vehicles, with a lesser amount needed for early infrastructure. It is almost certain that government policy will be needed to bring these technologies to cost-competitive levels.

Ancillary benefits could be important for hydrogen. Since hydrogen vehicles have zero tailpipe emissions, WTW air pollutant emissions can be lower than comparable advanced ICE vehicles including hybrids (Ogden et al., 2004; CONCAWE 2007; Jacobson and Collela 2007; Wang and Ogden, 2008). Zero-emission vehicle regulations are a motivation for hydrogen vehicles. Sustainability issues include the added demand for platinum for fuel cell manufacture.

8.3.1.4.3 Transition issues for electricity

For renewable electricity to serve large transport markets, several innovations must occur such as development of low cost supply available at the time of recharging EVs. With night-time off-peak recharging, new capacity would not be needed and there may be a good temporal match with wind or hydropower resources, although not necessarily to solar. Energy storage may also be needed to balance vehicle electric demand with renewable sources. Conversely, for distributed energy systems, the EVs become an integral part of the system and provide "vehicle to grid" storage (IEA, 2009b).

Home recharging would require new equipment. a recent study estimated that in-home electric vehicle charging systems capable of an overnight recharge might cost $800-2100 per charger (USDOE, 2008c). However, the distribution grid could need upgrading to handle the added load. To manage the significant new demand, "smart grid" technologies could be the solution.

EVs currently have limited use as neighbourhood and fleet vehicles including from small go-cart vehicles to pick-ups and buses. There are also a limited numbers of passenger EVs still operating from the original models sold by GM, Toyota, Honda and others in the 1990s and early 2000s.

Commercialization of EVs and PHEVs is planned over the next few years (CARB, 2007). The main transition issue is to bring down the cost and improve the performance of advanced batteries. Today's lithium batteries cost 3-5 times the goal needed to compete with gasoline vehicles on a lifecycle cost basis. Battery lifetimes for advanced lithium battery technologies are perhaps 3 years, when 10 years is required for automotive applications.

Consumer acceptance is a key issue as well. One of the attractions of electricity is that vehicles could be recharged at home, avoiding trips to the gasoline station. However, for typical residential power levels, charging a battery would take several hours, unlike the quick fill possible with liquid or gaseous fuels. Even at fast charge outlets that might bring batteries to near full charge in 10-15 minutes, recharging would take more time than refilling a gasoline car. Moreover, an EVis likely to have a shorter range than a gasoline car, 200-300 km versus 500 km. While this range is adequate for 80% of car trips, these factors may make long distance travel less attractive with an EV. This could be overcome by owners of small commuter EVs using rental or community-owned vehicles for longer journeys (IEA, 2009b).

The added vehicle cost for PHEVs, while still significant, is less than for an EV and there are no range limitations. One strategy is to introduce PHEVs initially while developing and scaling up battery technologies. This would lead to more cost-competitive EVs. However, regular ICE hybrids will always be cheaper to manufacture than PHEVs due to the smaller battery. Advances in battery technologies would make them more competitive. Incentives such as low electricity prices relative to gasoline, carbon charges and first-cost subsidies would be needed to make PHEVs a viable option. Availability of materials for advanced batteries, notably lithium, may be a future concern. EVs have the added ancillary benefit of zero tailpipe emissions, which can reduce urban air pollution. However, if the electricity is produced from an uncontrolled source (such as coal plants without proper scrubbers), one source of pollution might simply substitute for another.

8.3.1.5 Comparisons and future trends

Transition issues vary for biofuels, hydrogen and electric vehicles (Table 8.11). No one option is seen to a clear "winner", and all will take several decades to implement at the large scale.

Table 8.11: Transition issues for biofuels, hydrogen and electricity

	Biofuels	Hydrogen	Electricity
Technology Status			Limited current use of EVs.
Vehicles	Millions of flex-fuel vehicles using ethanol	Demo HFCVs. Commercial: 2015-20	Demonstration PHEVs. Commericial EVs: 2015-2020 Commercial PHEVs:2010-15.
Fuel production	1st generation:Ethanol from sugar and starch crops, biomethane, biodiesel. 2nd generation: ethanol/diesel/green fuels from cellulosic biomass, biowastes, bio-oils and algae - after at least 2015	Fossil H_2 commercial for large-scale industrial applications. Not competitive as transport fuel. Renewable H_2 often more costly.	Commercial power. Renewable electricity can be more costly, but can compete with retail power prices if generated in buildings.
Cost (vs. gasoline vehicles)			>USD 5900 (2035) (PHEVs)
Vehicle price (USD)	Similar	>USD 5300 (2035)	>USD 14,400 (2035) (EVs).
Fuel cost (USD /km)	Competes with gasoline at USD 0.15-0.45/l	Competes with gasoline at USD 0.50-0.75/l (mature H_2 infrastructure). Renewable H_2 at least 2-3x more expensive.	Competes with gasoline at if using renewable electricity at USD 0.10-0.18/kWh.
Compatibility with existing	Partly compatible with	New H_2 infrastructure	Widespread electric

infrastructure	existing petroleum distribution system.	needed. Infrastructure deployment must be coordinated with vehicle market growth.	infrastructure in place. Need to add in-home and public chargers, renewable generation sources, upgrade transmission and distribution.
Consumer acceptance	Fuel cost; alcohol vehicles have shorter range than gasoline. Potential cost impact on food crops and land use.	Vehicle and fuel cost. Availability in early markets.	Vehicle initial cost. Electricity cost of charging on-peak. Limited range unless PHEV. Modest to long recharge time, but home recharging possible.
Primary resources (potential in 2050)	Sugar, starch crops. Cellulosic crops; forest, agricultural and MSW. Algae and other biological oils.	Fossil fuels. Nuclear. All renewables- hence potential renewable resource base is large.	Fossil fuels. Nuclear. All renewables – hence potential renewable resource base is large.
GHG emissions	Depends on feedstock, pathway and land use issues. Low for fuels from wastes, residues. Near-term can be high for corn ethanol. 2nd generation biofuels lower.	Depends on H_2 production mix. Compared to future hybrid gasoline ICE vehicle. WTW GHG emissions for HFCV using H_2 from gas are slightly more to slightly less depending on assumptions. WTW GHG emissions can approach zero for renewable pathways.	Depends on grid mix On current US grid mix EVs, and PHEVs have WTW GHG emissions similar to gasoline hybrid. With larger fraction of renewable electricity, WTW emissions are lower.
Petroleum consumption	Low	Very low	Very low
Environmental and sustainability issues			
Air pollution	Similar to gasoline.	Zero emission vehicle.	Zero emission vehicle.
Water use	More than gasoline depending on feedstock and irrigation.	Potentially very low but depends on pathway.	Potentially very low but depends on pathway.
Land use	Might compete with food-for cropland.	Depends on pathway.	Depends on pathway.
Materials use		Platinum in fuel cells.	Lithium in batteries.

Note: Costs quoted do not always include payback on the incremental first vehicle costs.

8.3.1.6 Low emission propulsion and renewable options in other transport sectors

8.3.1.6.1 Heavy duty vehicles

Globally, most HDVs consist of freight trucks and long-haul tractor-trailers which account for about 24% of transport-related energy use and a similar fraction of GHGs (IEA, 2009e). Other HDVs include buses and off-highway vehicles such as agriculture and construction equipment. As was the case for LDVs, there are several strategies to reduce fuel consumption and GHG emissions by:

- further increasing vehicle efficiency, perhaps up to 30-40% by 2030 (IEA, 2009e). This can be achieved through more advanced engines, exhaust gas energy recovery (via advanced turbo-charging or turbo-compounding), hybrid vehicles (which may include either electric or hydraulic motors), light-weighting, tyres with lower rolling resistance, improved truck-trailer integration for better aerodynamics, more efficient driving behaviour, speed reduction, and use of more efficient auxiliary power units (APUs) decoupled from the powertrain;

- streamlining operational logistics to freight handling and routing efficiency by GPS routing technology, optimized automatic gear shifting, avoiding empty return trips etc.; and
- partially switching to lower carbon fuels.

Today, about 85% of freight-truck fuel is diesel, with the remainder being gasoline. Integrating biofuels into the fuel mix would be the most straight forward renewable option. The IEA (2008e) expects 2nd generation biofuels to become a more significant blend component in diesel fuel for trucks, possibly reaching as high as 20-30% by 2050. Due to range and resulting energy storage requirements for long-haul HDVs, use of other lower carbon alternatives such as CNG, LPG, compressed biogas, hydrogen (for either fuel cells or ICEs), or electricity (including EVs and trolley buses) would likely be limited to urban or short-haul HDVs. LNG might however be an option for freight transport. Another potential use of low carbon H2 or electricity might be to power APUs that could consist of on-board fuel cells or batteries, although neither of these options is yet cost effective.

The reduction of fuel consumption and GHG emissions in HDVs may be more difficult than for LDVs due to slower vehicle turnover, faster growth in vehicle kilometres travelled (VKT), little or no discretionary freight movement, and inherent economic drivers that continuously aim to minimize life cycle HDV costs. Because many HDVs are purchased for fleet operations, there could be an opportunity to integrate alternative fuels and vehicles by providing fleet-wide support for new fueling infrastructure, technology maintenance and, if needed, driver training. According to the IEA's baseline scenario (IEA, 2008e), HDV energy use by 2050, even with improved energy efficiency in the order of 20%, is projected to increase by 50% as the quantity of freight worldwide moved by trucking doubles. Most of this growth will occur in non-OECD countries.

8.3.1.6.2 Aviation

Aviation energy demand accounted for about 11% of all transport energy in 2006 and could double or triple by 2050 (IEA, 2009e). Rapid growth of aviation is mainly driven by the increase of air traffic volumes for both passenger and freight traffic and the fact that aviation boasts the highest energy and GHG intensity of all transport modes. Efficiency improvements can play an important role in reducing aviation energy use by up to 30-50% in future aircraft (IEA, 2009e). These include improved aerodynamics, airframe weight reduction, higher engine efficiency, and improvements in operation and air traffic control management to give higher load factors and better routing, and more efficient ground operations at airports (including more gate electrification and towing by low carbon fueled vehicles) (TRB, 2009). Although reductions in energy intensity (energy use per passenger kilometre) can be substantial, they will not sufficiently decouple fuel demand growth from activity growth to avoid large increases in fuel use since about 90% of fuel use and GHG emissions occur in flight, mostly at cruising altitude (TRB, 2009). Slow fleet turnover, every 30 years on average (TRB, 2009; IEA, 2009e), will further delay the penetration of advanced aircraft designs.

Aircraft will continue to rely mainly on liquid fuels due to the need for high energy density fuels in order to minimize fuel weight and volume, and minimize drag in the process. In addition, due to safety, the fuels need to meet much more stringent requirements than for other transport modes, particularly thermal stability to assure fuel integrity at high temperatures, low temperature properties to avoid freezing or gelling at low temperatures, specific viscosity, surface tension, ignition properties and compatibility with aircraft materials. Compared to other transport sectors, aviation has less potential for fuel switching due to these special fuel requirements. In terms of renewables, various aircraft have already flown demonstration test flights using various biofuel blends, but significantly more processing is needed than for road fuels to ensure that stringent aviation fuel specifications are met. IEA (2008e) scenarios range from a few percent to up to 30% biofuel use in aviation by 2050.

Liquid hydrogen is another long-term option, but faces significant hurdles due to its low volume density, fundamental changes need in aircraft design due to the need for cryogenic storage, and distribution infrastructure hurdles at airports. The most likely alternative, albeit not necessarily lower carbon aviation fuels, are synthetic jet fuels (from natural gas, coal or biomass) since they have similar characteristics to conventional jet fuel.

8.3.1.6.3 Maritime

Marine transport, the most efficient mode for moving freight, currently consumes about 9% of total transport fuel, 90% of which is used by international shipping (IEA, 2009e). Ships rely mainly on heavy fuel (“bunker”) oil (HFO), but lighter marine diesel oil is also used. HFO accounts for nearly 80% of all marine fuels. Unlike in other transport sectors, except perhaps rail, the negative radiative forcing of HFO combustion by-products, mainly sulphates that create aerosols, may actually mitigate the GHG impact from shipping. However, future regulations will require lower sulphur marine fuels. An expected doubling to tripling of shipping transport by2050 coupled with ever more stringent air quality regulations aimed at reducing particulate emissions through cleaner fuels, will lead to greater GHG emissions from this sector.

Due to a fragmented industry where ship ownership and operation can occur in different countries, as well as slow fleet turnover (typical ship replacement occurs about every 30 years), energy efficiency across the shipping industry has not improved at the same rate as in the HDV and aviation sectors. Hence, there exist significant opportunities to reduce fuel consumption through a range of technical and operational efficiency measures (IEA, 2009a; TRB, 2009) such as improvements in:

- vessel design (e.g., larger, lighter, more hydro-dynamic vessels, reduced ballast operation, lower drag hull coatings);
- engine efficiency (e.g., diesel-electric drives, waste heat recovery, engine derating);
- propulsion systems (e.g., optimized propeller design and operation, use of sails or kites);
- APUs; and
- operation (e.g., speed reduction, routing optimization, better fleet utilization).

These measures could potentially reduce energy intensity by as much as 50-70% for certain ship types (IEA, 2009e).

The key application of renewables in marine transport would be through the use of biofuels. Existing ships could run on a range of fuels, including blends of lower quality, lower cost, biocrudes. Engines would probably need to be modified, similar to HDV road vehicles, to operate on high fraction (80-100%) biofuel mixtures. Other renewables and low-carbon options could include the use of on-deck hybrid solar PV and micro-wind systems to generate auxiliary power, solar thermal systems to generate hot water or space heating or cooling, and electric APU motors plugged in while at port to a renewable grid source. Other limited low carbon options include LNG-powered tankers which are already in limited use today, expanded use of nuclear-powered vessels, and possibly all-electric ships (using future bulk energy storage systems or nuclear propulsion as for submarines) (TRB, 2009; IEA, 2009e).

8.3.1.6.4 Rail

Although rail transport accounts for only a small fraction (~2% in 2005) of global transport energy use, by 2050 rail freight volume is expected to increase by up to 50% with most of this growth occuring in non-OECD countries (IEA, 2009e). Rail moves more freight but uses an order of magnitude less energy than trucking due to its much higher efficiency (IEA, 2009e). Rail transport is primarily powered by diesel fuel being almost 90% in 2005 (IEA, 2009e), with the balance of the rail network mostly electrified. Growth in high-speed electric rail technology continues rapidly in Europe, Japan and elsewhere. As with shipping, the use of high sulphur fuels has helped to mitigate net GHG emissions (due to negative radiative forcing effect of sulphates), but this trend has other negative environmental consequences and will likely decrease with stricter clean fuel regulations.

Options for improving rail energy efficiency include upgrading locomotives to more efficient diesel engines and APUs as well as hybrids, reducing the empty weight of the rolling stock, increasing the maximum train size through longer trains, higher load factors, and double-stacked containers, and operational improvements such as driver training, optimized logistics, reduced idling (IEA, 2009e; TRB, 2009). Efficiency increases of up to 20-25% are possible.

The two primary pathways for RE penetration in rail transport are through increased use of biodiesel and renewable “green” diesel (from around 2-20% in IEA (2009e) 2050 scenarios) and a shift towards electrification. Compared to their diesel counterparts, all-electric locomotives can improve life cycle efficiency by up to 15%, (or less if compared to a diesel hybrid-electric drive system), but also further reduce GHG emissions as electricity generation switches to renewables and/or nuclear power. Although the use of hydrogen fuel cells may be limited due to range, energy storage, and cost issues, the challenges for fuel cells on locomotives appear to be fewer than for passenger HFCVs. Compared with light duty vehicles, a rail system system provides more room for H2 storage, provides economies of scale for larger fuel cell systems, and uses the electric traction motors already in diesel-electric locomotives.

8.3.1.7 Future trends

Perhaps the most important single trend facing transportation is the projected explosive growth of numbers of vehicles worldwide. This is expected to triple by 2050 from 700 million vehicles today to 2 billion. (IEA, 2008e). Meeting this demand while achieving a low carbon, secure energy supply will require strong policy initiatives, rapid technological change, and monetary incentives or the willingness of customers to pay additional costs. There is scope for renewable transport fuel use to grow significantly over the next several decades, playing a major role in this transition.

In the future, a wider diversity of transport fuels and vehicle types is likely. These could vary by geographic region and transport sub-sector. For applications such as air and marine, liquid fuels are probably the only practical option. In the light duty sector, increased use of electric drive train technologies has already begun, beginning with hybrids, plug-in hybrids and leading to electric battery and hydrogen fuel cell cars (IEA, 2008e). Historically, the electric sector and the transport sector have been completely separate, but through electric-drive vehicles, they are likely to interact in new ways through charging battery vehicles or “vehicle to grid” electricity supply (McCarthy et al., 2008).

Ancillary environmental concerns and energy security are important motivations for new transport systems. Sustainability issues such as land-use, water use and materials requirements may impose constraints on the use of alternative fuels or vehicle designs. Understanding these issues will be necessary is a low carbon future transport system is to be achieved.

Meeting future goals for GHG emissions and energy security will mean displacing today’s ICE vehicles, planes, trains and ships with higher efficiency, lower emission models (including electric-drive trains) and ultimately adopting new, low- or zero- carbon fuels that can be produced cleanly and efficiently from diverse primary sources. There is considerable uncertainty in the various technology pathways, and the need for further RD&D investment is needed for key technologies including batteries, fuel cells, hydrogen storage, and renewable and other zero-carbon production methods for biofuels, hydrogen and electricity. Given these uncertainties and the long timeline for change, it is important to maintain a portfolio approach that includes behavioural changes (to reduce vehicle km travelled or km flown), more efficient vehicles, and a variety of low-carbon fuels. This approach will recognize that customers will ultimately make the vehicle purchase decisions, and that different technology/fuel options will fit their varying situations. Recent studies (IEA 2008e; IEA, 2009e) see a major role for renewable transportation fuels in meeting societal goals for transportation, assuming that strict carbon limits are put in place.

8.3.2 Buildings and households

- The basic energy services that people need may be summarised as below:
- cooking – 95% of staple foods must be cooked (DFID, 2002);
- heating – of space in colder climates, or water e.g. for washing or purification;
- cooling – of space in hotter areas and that is growing in demand;
- lighting – household, commercial building and street lighting;
- refrigeration – of food and perishable items including medicines;
- communications and entertainment – including TVs, radio, phone, internet and computers;
- mobility – transport of people and products;
- social services – including water pumping and purification; health (vaccine refrigeration, sterilization, lighting of operations, transport to clinics); education (time saving, lighting for night study);
- productive uses – producing other goods and services for consumption as well as sale for income generation such as agriculture, agro-processing, industry/enterprises etc.

These energy services are met by using a number of energy carriers including electricity and heat in appliances (such as cook stoves, light bulbs, motors, boilers, mills) as well as fuels.

- Solid fuels are extracted and either used directly from nature in the form of biomass, coal or uranium, or can be transformed into other more convenient energy carriers such as charcoal, pellets, briquettes and coke.
- Liquid fuels (section 8.2.4) are usually refined from fossil fuels, oil-containing plants, sugar and carbohydrate crops or other forms of biomass.
- Gaseous fuels (section 8.2.3) such as natural gas or biogas produced from decomposition of natural matter can be combusted directly to produce heat and power.

Energy carriers are converted into energy services in a variety of ways. Although it is possible to use different types of energy for the same use, it is also possible to utilize specific characteristics of the vectors which make them more or less suitable for meeting the specific requirements of the energy service provided (Table 8.12).

Table 8.12: Energy carriers and their suitability for providing basic energy needs.

	Solid (wood, charcoal)	**Liquid**	**Gas**	**Mechanical power**	**Electricity**
Cooking	XXX	XX	XXX		XX
Heating	XXX	XXX	XXX		XX
Cooling					XXX
Lighting	X	XX	XX		XXX
Refrigeration	X	XX	XX		XXX
Communication/ entertainment					XXX
Mobility	X	XXX	X	XX	X
Social services				XX	XXX
Productive uses	XX	XX	XX	XXX	XXX

X – Possible but not usually preferable. XX – Applicable but limited. XXX – Most suitable.

For household and commercial building sub-sectors, energy vectors and energy service delivery systems vary depending on the local characteristics of a region and its wealth. Residential and commercial building owners and managers use energy to provide comfort for those working or living there through space heating, ventilation and cooling as well as for lighting, water heating, and powering other gas and electrical appliances. Energy for cooking, water heating and waste treatment is deemed to be a basic human requirement, although for many millions of people living in developing countries, these services are not readily available.

The present use of fossil fuels to provide heating and cooling can be replaced economically in many regions by RE systems using modern biomass and enclosed stoves, geothermal ground source heat pumps, or solar thermal and solar sorption systems (IEA, 2007a). The total global demand for renewable heating (excluding traditional biomass at around 45 EJ/year) is around 3.5-4.5 EJ/year. Policies to encourage the greater deployment of RE heating/cooling systems are limited but several successful national and municipal approaches have been described (IEA, 2007a). Full details of the potential for energy efficiency and RE in the building sector were provided in Chapter 6 of the IPCC 4th Assessment Report – Mitigation (www.ipcc.ch) [TSU: Should rather be cited as a formal reference in the reference list].

8.3.2.1 Urban settlements in developed countries

8.3.2.1.1 Characteristics of urban energy supply/demand (including efficiency)

In OECD and other major economies, most buildings in urban environments are connected to electricity, water, and sewage distribution schemes. Others have natural gas supplied for heating and cooking that is more convenient for residents than using coal, biomass or oil-products to provide these services.

RE has low energy density by comparison with fossil fuels and conversion technologies can be comparatively expensive. Its integration in buildings is expanding in order to give residents quality of life at the same time as realizing low carbon and secure energy supplies (IEA, 2009b). RE deployment is often combined with the enhancement of energy efficiency in a building through technologies, management and energy conservation via behavioural change.

8.3.2.1.2 Challenges caused by integration into urban supply system

Efforts to improve energy efficiency and utilize carbon-free energy sources are largely dependent on the motivation of building owners, inhabitants and customers. Institutional and financial measures such as energy auditing, labelling, subsidies, regulations, incentives and charge systems can lead to increased deployment.

The features and conditions of energy demand in an existing or new building differ with location and from one building design to another. Therefore the technologies and pathways discussed in this section are, of necessity, generic. In reality, effective and efficient methods and products are being developed to apply to buildings under a variety of situations.

The transition from a fossil-fuel based, centralized urban space into a more distributed and RE system will need to revise drastically how urban space has been occupied. The location of public spaces and services in the urban environment has been planned around the design and construction of houses, apartments, commercial buildings and public facilities. The required changes in land and resource use to better accommodate RE technologies in parallel with the use of the existing energy supply is one of the major structural changes that will shape the integration of renewables into the energy system.

The greater deployment of RE such as solar systems and small wind turbines in an urban environment may require more use of roof and wall surface areas in city buildings (IEA, 2009a). This will impact on the orientation and height of buildings to gain better access to solar light and wind. Local seasonal storage of excess heat using ground source heat pumps and access to surface ground water may need to be considered. The local application of combined heat and power from biomass, solatr thermal or geothermal systems is an important spatial option for some cities requiring adaptation of the electricity grid and/or heat/cold distribution grid.

Technological advances are required in order to speed up the integration of RE into the built environment, including energy storage technologies, real time meters, demand-side management and more efficient systems that also have benefits for the power supply system (see section 8.2.1). New technologies will need to be accompanied by new and progressive energy regulations and incentives to obtain more rapid dissemination of them (IEA, 2008c).

The opportunity is available for buildings to become energy suppliers rather than energy consumers if distributed RE generation systems could be used internally to produce sufficient heat and power to meet local demands (IEA, 2009b). Appliances in buildings could also contribute to the demand-supply balance of the system through demand response and energy storage technologies (including through the use of electric cars).

Many commercial or residential buildings are leased to the users, leading to the owner/tenant conundrum. Investing in energy efficiency or RE by the building owner usually benefits the tenants more than the investor, so that return on investment often has to be recouped through higher rents. Relatively high capital investments by building owners and long payback periods for solar water heaters, ground source heat pumps, new cook stoves etc. can be a constraint, possibly to be overcome by government grants, utility leasing arrangements, or micro-financing. Several examples exist of successful government policies and entrepreneurial initiatives that can be replicated elsewhere.

The present market of around USD 1.7 bn /yr[TSU: Needs to be presented in 2005 US$] for building integrated PV systems could be hindered over the next few years by lack of standardisation, low production volumes and competition from PV panels applied to buildings as retrofits (Lux, 2009). Retrofits can now encompass a broader class of building-mounted PV and include some traditional roof-integrated PV systems.

8.3.2.1.3 Options to facilitate integration into urban supply systems

New building designs for both domestic and commercial use in both hot and cold regions have demonstrated that imported energy for cooling/heating can be minimised by careful design, adequate insulation and thermal sinks. Building codes are steadily being improved to encourage the uptake of such technologies, with the hope that by around 2050 most new buildings will need little if any heating or cooling based on imported energy systems.

Existing buildings can often be retrofitted to significantly reduce their energy demand for heating and cooling using energy efficient technologies such as triple glazing, cavity wall and ceiling insulation, shading, and white painted roofs. In OECD countries many building designs demonstrate these passive solar concepts well, but they remain a minority due to slow stock turnover. The lower the energy demand that the inhabitants of a building require to meet comfort standards as well as communication, cleaning, cooking and entertainment activities, then the more likely that RE can be employed to meet those demands.

RE supply

Solar photovoltaic generation technologies and solar thermal water heating and space heating are the most promising and active RE supply technologies for buildings because of the universal availability of the solar resource and the maturity of technology. PV technologies are also good for street lighting in combination with high efficiency lamps, because, with a deployment of a small battery, it does not need connection to a power distribution which leads to the reduction of capital and operational costs. The fundamentals of solar thermal technologies are well understood, but even though the technologies are mature, there are several possible improvements to the supply chain including new materials, products and adaptive designing.

Solar thermal and solar PV technologies can be integrated into building designs as components (such as roof tiles, wall facades, windows, balcony rails etc). Innovative architects are beginning to incorporate such concepts into their designs but the technologies have not yet moved into the mainstream. Integration of PV panels into buildings during construction can replace the look and function of traditional building materials for roofs, window overhangs, and walls. They can be sold as single units and integrated into buildings to improve the aesthetics and system reliability while reducing costs and utility transmission losses.

Development of small wind turbines with low noise and little vibration can make roof-mounting more acceptable to building inhabitants and neighbours, though flickering may remain an issue in some situations.

Combined heat and power (CHP) generation technology can run on solid, liquid or gaseous fuels, not only from fossil fuel sources but also from RE sources at medium and small scales (Liu et al., 2009). The heat can be used for water heating and/or space heating for residential or commercial buildings or sold to nearby industries. CHP has a possibility to use electrolysis H2 (see section 8.2.3) or other solid or gaseous fuels produced from biomass feedstocks. CHP combustion/steam generation engines, gas turbines, micro-gas turbines and other conversion technologies are available at large (50MWe) and small (5 kWe) scales and research including fuel cells and small/micro scale CHPs is on-going (Leilei et al., 2009).

Efficiency and passive renewable energy integration

Air heating and conditioning is one of the largest energy uses in buildings, both in high latitudes for heating and low latitudes for cooling. An air-tight, well insulated building can provide a high efficiency for air heating and cooling. Various kinds of building materials and construction methods are available including plasterboard, upgraded windows, and ventilated rain screen system of external insulation. In the future, technologies such as vacuum insulation panels, multi-foil insulation, insulation paint, vacuum glazing, and triple glazed windows could be used to enable a house to need very limited or zero space heating except on the coldest days.At the other extreme, in order to avoid over-heating, curtain and automatic shading systems are currently available, and new technologies such as electro-chromic glazing thermo-chromic system will be applicable in the future.

Substantial progress of high performance heat pump air conditioners/heaters utilising atmospheric or ground heat has been made. For air-tight buildings of single-residential, multi-residential, or commercial usage, high energy demands for continual ventilation can be reduced through appropriate selection and hybridization of photovoltaic generation, solar chimneys, wind cowls etc. (Antvorskov, 2007).

Water heating is also a major energy demand in buildings for which RE can be applied through the deployment of solar water heating, biomass, heat pumps or CHP systems (IEA, 2007a). Cooking is also a major energy use for residential buildings. Like water heating, there is room for greater efficiency in heat generation, cooking style and new appliance designs such as microwave ovens. For lighting, electricity is the usual energy source to give quality and low energy consumption. Lighting technologies continue to be developed, from incandescent lamps, to fluorescent lamps, compact fluorescent lamps, and recently to light-emitting diodes (LED). The theoretical conversion efficiency of electricity to light is much higher than that of current technologies which also produce much heat. Therefore innovative technologies continue to be sought by active R&D. More efficient technologies are also under development for various appliances used in residential and commercial buildings (Fig. 8.36) including liquid crystal display (LCD) screens, high thermal insulation refrigerator and energy reduction when in stand-by power mode. Smart appliances that use low energy and operate automatically at off-peak times for use with future intelligent electricity networks (IEA, 2009b), are reaching the market.

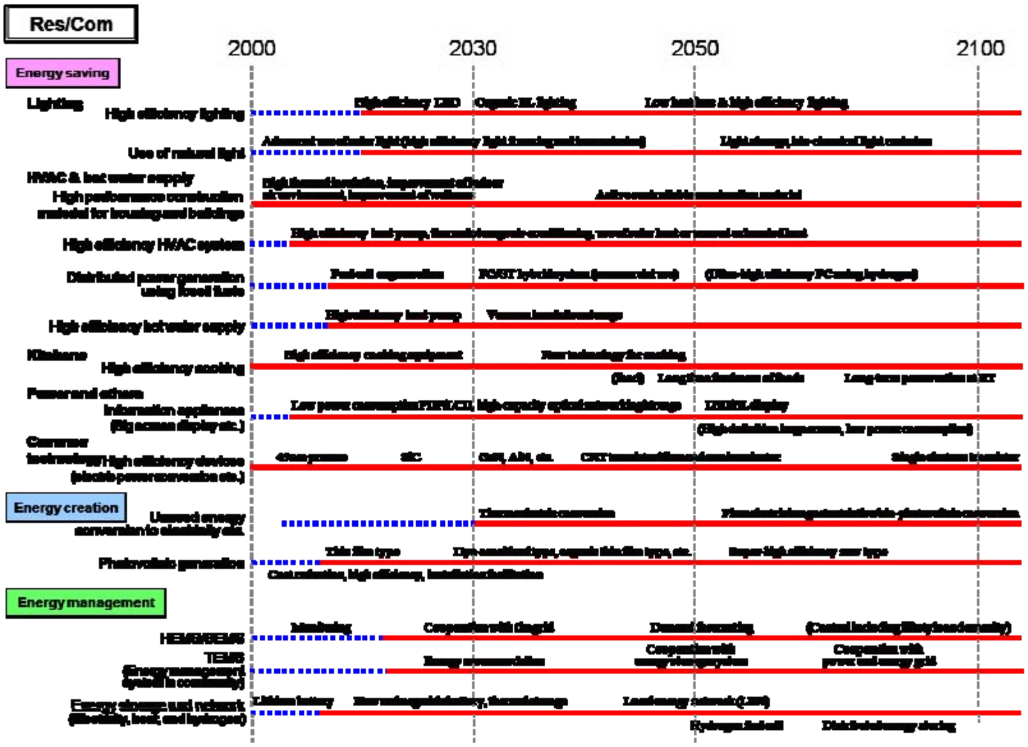

Figure 8.36: Technology development in future energy saving technologies for residential and commercial buildings (METI, 2005).

Energy management technology

Energy management awareness consists of measurement and monitoring of energy use and the interior environment (Wei, 2009), followed by decisions to control energy demand. The energy manager of a building should be responsible for multiple objectives including comfort, cost, energy efficiency, environmental impacts and the integration of RE. In commercial buildings, various building energy management systems, including advanced controls, have been developed to balance the multiple objectives (Dounis et al., 2009). Some monitoring has been deployed in multi-family buildings and many R&D projects are being conducted to produce “Home Energy Management” standard technologies for monitoring, control and actuators (interfacing to appliances).

Advanced electricity meters with bi-directional communication capability and related information infrastructure technology are expected to be widely deployed to gain the benefits of demand response in combination with interfacing technology for appliances, distributed generation and energy storage (NETL, 2008).The set of these technologies has become known as a “smart” or “intelligent” grid.

Assessing, planning and designing technology

The 4th IPCC Assessment Report concluded that buildings represented the largest and most cost-effective sector for GHG mitigation efforts. Greater integration of RE into the built environment is directly dependent on how urban planning, architectural design, engineering and technology will be able to be better integrated. Realizing RE and energy efficiency integration of buildings can be achieved using a combination of technologies. Accordingly, tools and methods to assess and support strategic decisions for planning new building construction and retrofits are useful (Doukas et al., 2008). For the subsequent stages of planning and design, other kinds of methods are necessary to project a strategy to reality for which there are several proposed tools including computer simulations (Larsen, 2008; Dimoudi et al., 2009).

Policies and regulations

Regardless of the type of renewables, policies including building codes and minimum air emission standards can encourage rapid deployment of technologies in new and existing buildings. These are needed to help overcome barriers including education and training of engineers, architects and installers. City planning regulations may need modification to encourage rather than hinder deployment (IEA, 2009b). For example, regulations to protect the solar envelope for PV and solar thermal installations and prevent shading from newly planted trees and new buildings need to be developed along with easing the process to obtain a resource or building consent within pre-determined guidelines.

8.3.2.1.4 Case studies

A study “Energy efficiency in buildings – transforming the market” (WBCSD, 2009) includes case studies of single-family homes in France, multi-family homes in China, and an office in Japan. The study depicts the pathway for each market as follows.

Single-family homes in France. The energy consumption of single-family homes is dominated by space heating being around two thirds of the total (Fig. 8.37). These buildings offer great potential for energy efficiency by reducing space heating needs through insulation, air tightness and more efficient equipment, and by improvements in domestic hot water and lighting. Solar PV and solar thermal are the major RE sources.

Figure 8.37: Shifts in building stock energy classes and impacts of energy saving measures in single family homes in France (WBCSD, 2009).

Multi-family housing in China[TSU: Case study on China in a section on ‘Urban settlements in developed countries? – Better in 8.3.2.2 case study]. Most housing in urban areas is multi-family apartment buildings where over 90% of the population in most cities live. The major energy reduction potential is in space heating consumption, water heating and lighting (Fig 8.38). Solar thermal is the major RE source utilized. Sub-metering, apartment-level controls within the building, and charging of individual apartments are emphasized.

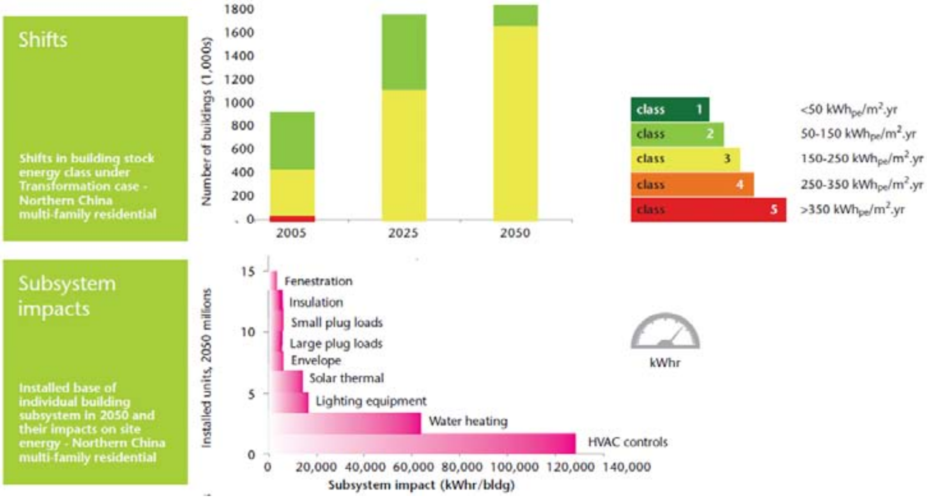

Figure 8.38: Shifts in building stock energy classes and impacts of energy saving measures in multi-family houses in China (WBCSD, 2009).

Office buildings in Japan. Heating and cooling equipment have the highest potential to curb energy demand in office buildings followed by lighting (Fig. 8.39). PV is the major RE source used, especially for low-rise buildings.

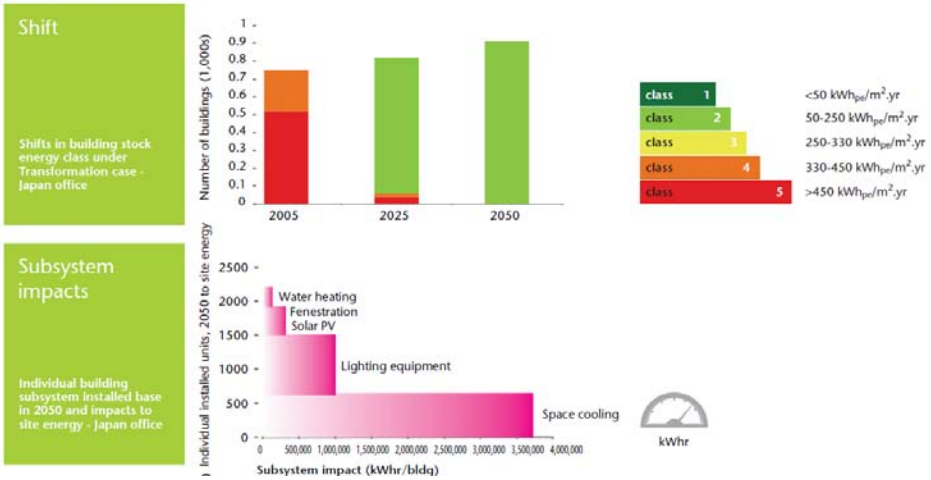

Figure 8.39: Shifts in building stock energy classes and impacts of energy saving measures in office buildings in Japan (WBCSD, 2009).

Urban residential and commercial buildings are expected to contribute to improve the demand-supply balance of energy networks which is subject to the additional fluctuation of “variable” RE generation outputs. Distributed energy management technology for buildings is now under development incorporating latest IT technologies to effectively control domestic peak demands and use energy storage equipment and distributed generation systems in or around buildings. When controls are made in harmonization with central energy management using an incentive or control signal, the improvement can be maximized. More variable RE can then be accommodated flexibly and economically in the energy system. Buildings that have been passive energy consumers could become energy producers and managers become co-operators of an energy network (USDOE, 2008c).

Assuming a low stock turnover of buildings of around 1% per year in developed countries, retrofitting of existing buildings will play a significant role for energy efficiency and RE integration (Ravetz, 2008; Roberts, 2008). Among many activities to pursue optimum retrofitting to gain 100% energy supply for heating, cooling & electricity, the “Renewable Energy House” in Bruxelles is a good example (see section 8.1.5 and EREC, 2008). Another example of retrofitting is residential buildings in China’s northern region where exterior windows, roofs, and heating system were retrofitted and the importance of metering of energy use and management is based on actual data (Zhao et al., 2009).

8.3.2.2 Urban settlements in developing countries

8.3.2.2.1 Characteristics

As far as urban poor in developing countries are concerned, particularly in the Sub-Saharan continent, the urban energy consumption pattern depends on the non-rational use of biomass, particularly from forest resources located close to urban consumption centres. The inefficiency of the whole supply chain, together with indoor air pollution problems, affect a large proportion of the urban population, particularly women who still rely on wood energy for their basic cooking and heating needs.

Many urban areas are experiencing a rapid transition from wood to charcoal which is impacting negatively on deforestation, given the low energy conversion efficiency of traditional kilns used in the carbonization process.

8.3.2.2.2 Challenges and options

The major challenge is to reverse this consumption pattern by providing access to modern energy services while increasing the share of renewables. In some urban areas, grid electricity is available although limited to basic needs. It is therefore unlikely that decentralized renewables will secure significant penetration in the next two decades. During the 1980s, solar water heaters were considered as a good RE option in some urban areas of developing countries including China that now has over 50% of the global installed capacity. A market niche for solar water heaters remains, particularly in the service sector such as hotels and lodges as well as middle and high income households. Regulations and incentives could be necessary in many regions to reach a critical mass and gain a large dissemination of solar water heaters.

The introduction of liquid or gaseous RE fuels replacing solid biomass for cooking could play a critical role in improving the health of billions of people. The scale of biofuel production needed to meet cooking energy needs is far smaller than that for meeting transport fuel needs (see sections 8.2.4 and 8.3.1).

A further challenge is to ensure that woody biomass as used extensively by urban and rural populations in developing countries is supplied from sustainably produced forests. Many forests close to urban areas have already been depleted or have disappeared. For instance, in Senegal charcoal for use in urban areas is supplied from forests in excess of 400 km away, leading not only to high prices but also to relatively high GHG emissions as a result of inefficient carbonisation technologies and inefficient transport vehicles.

Fuel switching is an option and in some regions LPG has displaced charcoal. However, this is a costly option and only a few countries have achieved a significant penetration. LPG is not affordable for the majority of poor people and if subsidised, is also a high burden on a state budget. Its use benefits mainly middle and high income people as well as businesses. Replacing LPG by DME (di-methyl ether) produced from biomass, shows good potential (see Chapter 2).

Biomass will remain a valuable fuel in many urban centres in poor developing countries. To ensure the sustainability of forest resources a holistic approach encompassing supply (plantations, natural forest management) and demand (fuel switching, efficient equipment such as improved stoves and kilns) is required (Fig. 8.40). This approach could be accompanied by fiscal policies (for instance differential taxation) to provide financial incentives for woody biomass supplied only from sustainable sources.

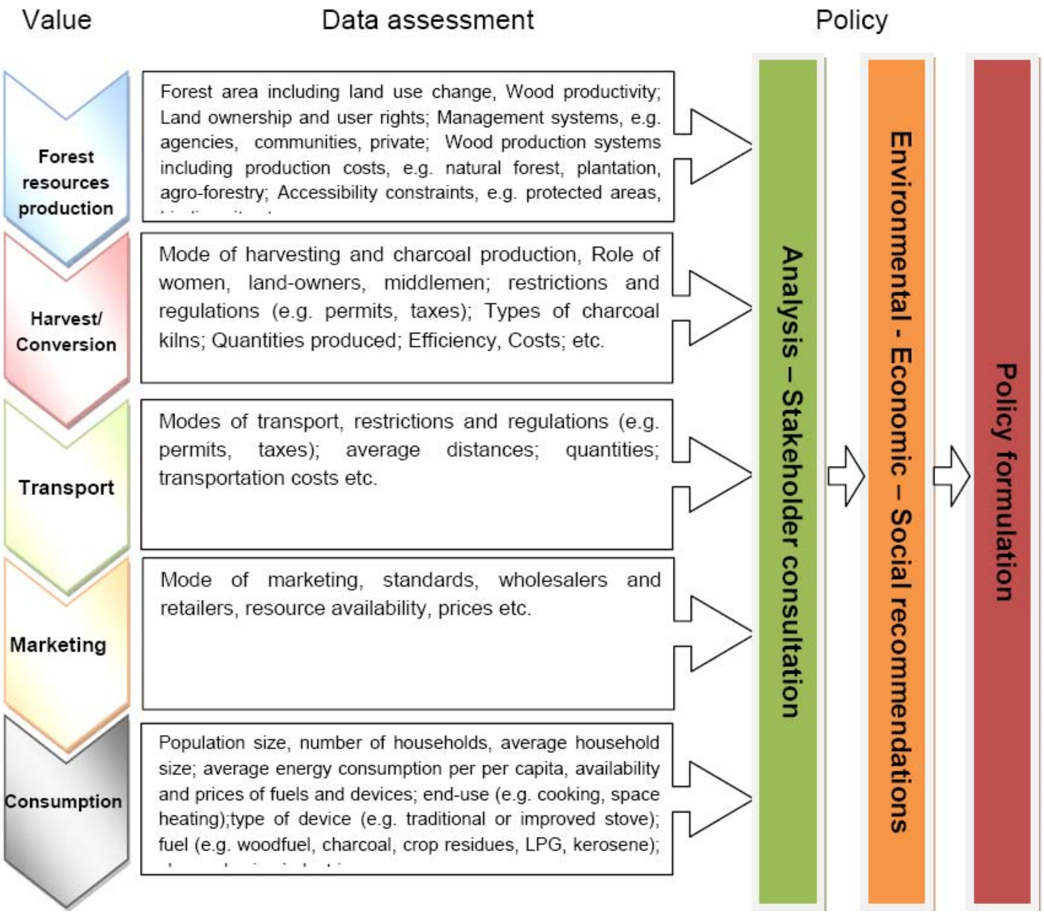

Figure 8.40: A holistic approach using chain analysis of biomass supplied for energy purposes. (Khennas et al., 2009).

8.3.2.2.3 Case Study - Peri urban settlements in Brazil

The fast urbanization process in many developing countries has created peri-urban areas near to central metropolitan areas. In Brazil for example, all major cities have a large fraction of their population settled in peri-urban areas and about one third of all municipalities have population living in peri-urban areas (IBGE, 2008). These areas frequently lack proper infrastructure and basic services and most of the urban-poor households are concentrate there. Woodfuel continues to dominate household energy use but there is an increased use of multiple fuels including mixing woodfuel with charcoal, kerosene and some LPG.

Housing patterns are, for the most part, quite precarious and constructions are fragile and often very temporary. These areas frequently lack basic urban infrastructure such as waterworks, sanitation and adequate electricity distribution. This can provide an opportunity to create new RE technologies. Energy planning in these areas will need to take place against a background of complexity and change. Depending on the type of settlement, a combination of small-scale technologies available for rural communities and urban dwellings could be employed. These include treadle and wind pumps, solar pumps, improved stoves, biodiesel as a fuel for stationary engines, solar water heaters, wind turbines, biomass gasifiers and solar PV systems.

Access to energy services is not necessarily the main problem of the majority of the urban and peri-urban poor, but rather the ability to afford the services. Therefore, the greater penetration of RE technologies in the peri-urban areas will need to be accompanied by comprehensive energy policies and tariffs as to enable these households to make use of RE.

Access to modern energy services is a challenge for many local governments and energy utilities. Brazil's electricity utilities for example have invested about USD 80 M annually in low-income energy efficiency programmes, about half of their compulsory investments in end-use programms under current regulations. A number of particular and complex issues still need to be tackled including the inefficacy of enforcing legal regulations, the need to develop more creative and technical solutions to treat theft and fraud in services, and the economic situation of such populations living in an urban setting.

In Brazil low-income energy efficiency and solar water heating programmes have been promoted. A number of programmes have replaced inefficient light bulbs and refrigerators, improved local distribution networks and and maintained individual connections (including re-wiring of domestic installations). Modern and state-of-the-art technologies are being used in peri-urban areas, including remote metering, real-time demand monitoring of households, more efficient transformers, new cabling systems and materials (ICA, 2009a). These regions are leap-frogging to new technologies.

A pilot case study in one "favela" in São Paulo reported the reduction of household electricity consumption from 250 kWh/month to 151 kWh/month and an internal rate of return on investment of 276% with a payback of only 1.36 years. The financial analysis assumed a reduction in commercial and technical losses and increased revenues for the utilities with reduced arrears and non-payments (ICA, 2009b).

8.3.2.3 Rural settlements in developed countries

8.3.2.3.1 Characteristics of rural energy supply/demand

The energy consumption pattern in rural developed countries does not differ a great deal from urban areas. Modern forms of energy such as electricity, natural gas, LPG and coal are the main sources, however there is scope for more RE, particularly sustainably produced biomass for space heating.

8.3.2.3.2 Challenges of integration of RE into rural supply systems

Renewable local energy resources are not only tapped to meet the local demand but also the surplus contributes to meeting the national demand. Financial, institutional and lack of awareness are among key barriers to reaching this objective. Although financing might be available for some schemes, up front investment is still a hindrance to mobilising RE on a large scale. Institutional barriers, such as obtaining planning permission, often increase delays in implementing RE schemes, thus raising the transaction costs of integration.

8.3.2.3.3 Options to facilitate the integration of RE

In rural regions there are good opportunities for local RE resources to be developed to meet local demand and, in some cases, to generate surplus electricity that can be delivered to the grid. Advanced bioenergy technologies for CHP systems can have a significant impact on the energy supply. In Sweden and the USA, as a result of increased biomass demand, the rate of afforestation has increased (Mabee and Saddler, 2007). The following case study illustrates opportunities for the deployment of renewables in rural developed countries.

8.3.2.3.4 Case study

[TSU: Missing case study title (for consistency with other case studies) – e.g. RE installations in rural England]

Cornwall is a rural peninsula in the south-west region of England, which is leading the way on partnerships for the delivery of energy initiatives. Because of its peripheral location, the region has limited access to natural gas pipelines but has sufficient RE resources in the form of solar, wind, marine, small hydro and biomass, to meet the county's demand. In 2004, the Cornwall Sustainable Energy Partnership (CSEP) published the UK's first sub-regional sustainable energy strategy and action plan (EC, 2004). The strategy's 32 point action plan aimed to support the use of natural resources, deliver local, national and international RE targets, incorporate greater energy efficiency and RE in buildings, and reduce carbon emissions (CSEP, 2004). CSEP's Energy in Buildings Group is the lead delivery partnership for this local area agreement (LAA).

Two years after the CSEP began, the installed capacity of RE measures in domestic and community buildings tripled, and there has been a 6-fold increase in the number of RE measures installed in domestic and community buildings in Cornwall. As part of the LAA delivery plan, CSEP has been providing free technical and funding advice to developers, architects, housing associations, community groups etc. It has facilitated micro-generation installations in a number of social and private sector housing developments. The strategy commits the partnership to doubling Cornwall's current renewable electricity generating capacity to achieve a sub-regional target of at least 93 MW by 2010.

8.3.2.4 Rural settlements in developing countries

8.3.2.4.1 Characteristics of rural energy supply/demand

Rural households rely on traditional biomass (mainly crop residues, fuelwood and charcoal) for their basic energy needs for cooking ands heating. In 2005, there were 570 millions stoves used in rural areas of which 220 million were improved stove designs (REN21, 2006). Unlike urban areas, the biomass can be collected locally, generally by women from nearby woodlands and savannah lands. Although the time devoted to this task has been increasing in some regions as local resources become diminished in a non-sustainable fashion, the illusion of a free commodity coupled with severe poverty make it difficult to substitute firewood with modern energy or even to improve energy efficiency for cooking. Providing local plantations to harvest more sustainably is one solution but not always easy to accomplish due to land ownership and other social issues.

Lighting demands can be met by kerosene lamps, torches and candles, all of which are expensive options. Only a tiny fraction of rural households having access to modern energy services is a major constraint to eradicating poverty, and meeting the Millennium Development Goals by improving health, education, social and economic development. In sub-Saharan Africa for example, and many other developing countries, traditional biomass accounts for more than 75 % of cooking fuels. Resulting environmental impact and strategies vary depending on the regions and whether it is a rural, urban or peri-urban context.

8.3.2.4.2 Challenges of integration into rural supply system

Around 2.4 billion energy poor people rely on traditional biomass fuels for cooking and heating, including 89 per cent of the population of sub-Saharan Africa, and another 1.6 billion people who do not have access to electricity mainly in rural areas (Vijay et al, 2005). The key challenge for rural communities is to move up the energy ladder (Fig. 8.41).

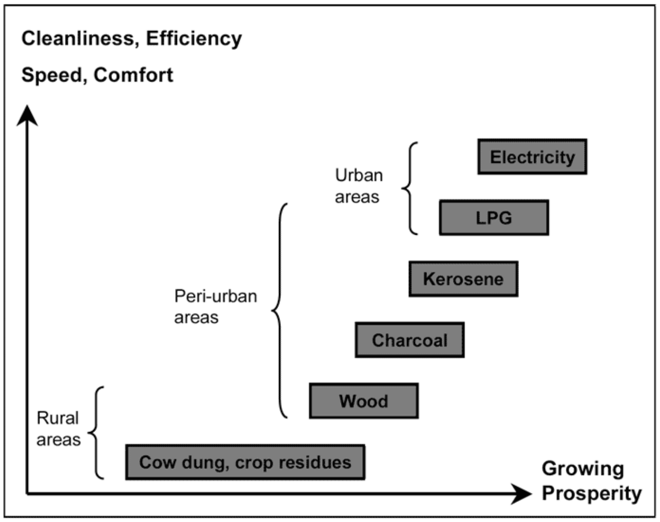

Figure 8.41: The "energy ladder" indicates how growing prosperity results from improved energy quality and availability. (Mahamane et al., 2009).

Some of the energy poor in peri-urban urbans may achieve sufficient funding for purchasing electricity from the grid in the next 20 years in some regions as extension of the distribution network reaches more peri-urban people currently without access to modern energy services. However, energy consumption might remain limited to basic needs such as lighting, ventilation and communication (including radio, television and mobile phone recharging). The energy poor in rural areas may better utilize local RE technologies as the least cost option available if innovative finance mechanisms can be put in place.

8.3.2.4.3 Options to facilitate RE integration

Although rural income is generally lower than urban income, there could be a market for RE for wealthier rural people, entrepreneurs and social institutions (churches, mosques). For example solar PV, micro-hydro power, and biogas could be developed locally on a sustainable basis to service rural communities, institutions and businesses who can afford to invest in such appropriate technologies. For the majority of rural people however, innovative and affordable delivery mechanisms need to be developed such as concessions coupled with subsidies and public private partnerships to increase energy access.

8.3.2.4.4 Case study: RE in the Democratic Republic of Congo

The Congo Basin is the second largest tropical rainforest area in the world after the Amazon. The level of deforestation in absolute values is particularly high, particularly so in the Democratic Republic of Congo (DR Congo) which is the largest country and the most populated of the Congo Basin (Table 8.13). Paradoxically despite the large hydro potential in the region, the rural electrification rate is extremely low at less than 1% (Fig. 8.42). The prospects to develop the micro- and mini- hydro potential of the region are therefore high which would dramatically increase the rural electrification rate and ultimately improve the livelihood of the energy poor rural people. In DR Congo alone, some 325 hydro schemes have been identified for which preliminary data have been gathered (Knennas et al., 2009). The implementation of such a programme will dramatically increase the supply of RE for rural people in meeting energy needs for education, health and income generating activities. It may also contribute to limiting deforestation around villages.

Table 8.13: Deforestation and degradation rate of the forests in the Congo Basin.

	Forest area (1000 ha)	**Deforestation (%/year)**	**Degradation (%/year)**
Cameroon	19 639	0.19	0.02
Equatorial Guinea	1 900	0.42	0.52
Gabon	22 069	0.12	0.09
Central African Republic	6 250	0.07	0.02
Republic of the Congo	22 263	0.03	0.01
DR Congo	108 359	0.26[9]	0.15
Total Congo Basin	**180 480**	**0.19**	**0.10**

(Etat des Forêts, 2006).

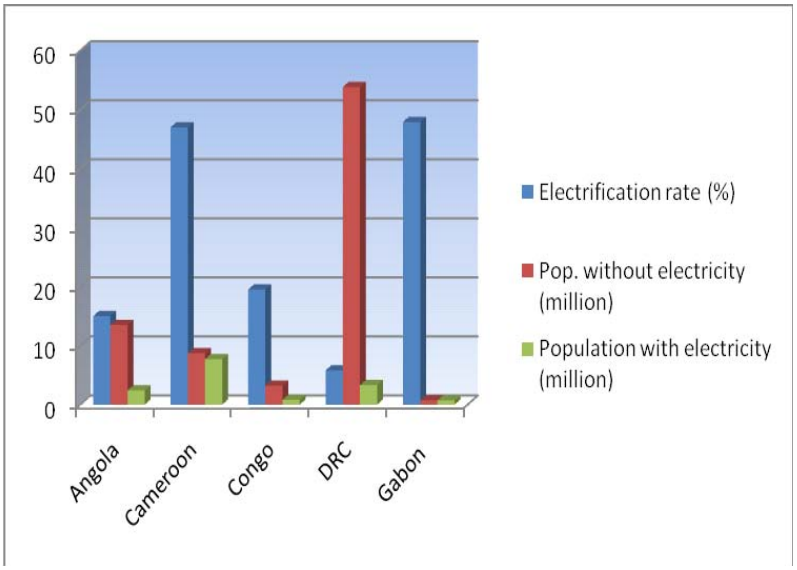

Figure 8.42: Electricity access in selected countries of the Congo Basin in 2005 (adapted from IEA, 2006).

8.3.3 Industry

8.3.3.1 Introduction

Manufacturing industries account for about one-third of global energy use although the share differs markedly between individual countries. The industrial sector is highly diverse, ranging from very large, energy-intensive basic material industries to small and medium sized enterprises with light manufacturing. Perhaps 85% of industrial sector energy use is by energy-intensive industries: iron and steel, non-ferrous metals, chemicals and fertilizers, petroleum refining, minerals, and pulp and paper (Bernstein et al., 2007). The production of these industrial goods has grown strongly in the past 30-40 years and is projected to continue growing.

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[9] FAO, 2003 estimates that in DRC about 532,000 hectares (or 0.4%) of forest are cleared annually.

The sources of industry CO_2 emissions are direct and indirect use of fossil fuels, non-energy uses of fossil fuels in chemicals processing and production, and non-fossil sources such as CO_2 from calcium carbonate ($CaCO3$) in cement manufacturing. In most countries CO_2 accounts for more than 90% of industrial GHG emissions (IPCC, 2007). Other industry GHG gases include nitrous oxide ($N20$), HFC-23, perfluorocarbons (PFCs) and sulphur hexafluoride ($SF6$). Direct and indirect CO_2 emissions in 2006 were 7.2 and 3.4 gigatonnes (Gt) respectively, together being equivalent to almost 40% of world energy and process CO_2 emissions (IEA, 2009a).

Carbon dioxide emissions from industry can be reduced in several ways:

- energy efficiency measures reduce internal energy use and will in some cases release energy sources generated on-site available for export (as waste heat, electricity and fuels);
- materials recycling eliminates the energy-intensive primary conversion steps for many materials;
- energy input and feedstock substitution can reduce the use of fossil fuels;
- carbon dioxide capture and storage (CCS) of both fossil and renewable biomass origin can reduce emissions to the atmosphere.

All these measures are relevant for the integration of RE into present and future energy systems. In addition industry could provide demand-response facilities that could achieve greater prominence in future electricity supply systems.

The current direct use of RE in industry is dominated by biomass in the pulp and paper, sugar and ethanol industries where biomass by-products are important sources of co-generated heat and electricity mainly used for the process. Biomass is also an important fuel for many SMEs such as brick-making, notably in developing countries. There is a growing interest in utilising waste and by-products for energy in, for example, the food industry through anaerobic digestion for biogas production. Waste and wastewater policies are important drivers for biogas production (Lantz et al., 2007). Thus, industry is not only a potential user of RE but also a potential supplier as a co-product.

There are no severe technical restrictions to the increased direct and indirect use of RE in industry in the future. Indirect emissions, mainly from electricity consumption, can be reduced by decarbonisation of the power sector. The share of electricity in industrial energy use is expected to increase (IEA, 2009a). Hydrogen is also a potential future energy and feedstock input to industry (section 8.2.3). The direct use of fossil fuels can be replaced by energy carriers such as electricity from renewable sources and solar thermal heat, as well as gaseous, liquid and solid fuels from biomass, albeit subject to resource limitations. CCS can be important in future low-carbon energy systems and is also relevant to consider in the context of integrating RE in industry.

8.3.3.2 Energy-intensive industries

The largest contributions of CO_2 emissions in 2006 came from iron and steel (29%), cement (25%) and chemicals and petrochemicals (17%) (IEA, 2009a). The pulp and paper industry accounted for only about 2% of industrial CO_2 emissions but uses large amounts of biomass for process energy.

Iron and steel. Production of iron and steel involves ore preparation, coke making, and iron making in blast furnaces and basic oxygen furnaces to reduce the iron ore to iron. Primary energy inputs are 13 to 14 GJ/t from coal. Natural gas for direct reduction of iron-ore is also an established technology. Using electric-arc furnaces to recycle scrap steel, these energy-intensive steps can be by-passed and primary energy use reduced to around 4 to 6 GJ/t. However, the amount of scrap steel is limited and the increasing demand for primary steel is mainly met from iron ore. Electricity, used in the electric-arc furnace, can facilitate emission reductions through decarbonisation of electricity supply whereas replacing coal for coke-making with renewable biomass fuels may be more challenging, although charcoal is used for steel-making in some countries.

Biomass, in the form of charcoal, was for a long time the main energy source for the iron and steel industry until coal and coke took over in the 1800s. During the production of charcoal, roughly one third of the wood energy content is converted to charcoal, the rest being released as gases but higher efficiencies are attainable (Rossilo-Calle et al., 2000). Charcoal can provide the reducing agent in the production of iron in blast furnaces but coke has the advantage of higher heating value, purity and mechanical strength. Present day steel mills mostly rely entirely on fossil fuels and electricity and charcoal has not been able to compete, the exception being a few blast furnaces in Brazil. A few other steel mill blast furnaces have used sorted plastic waste to complement coke.

Options for increasing the use of RE in the iron and steel industry in the near term include substituting coal and coke with charcoal, subject to resource constraints, and switching to renewable electricity in electric-arc furnaces. Switching to renewable methane is also an option. Research on electricity and hydrogen-based processes for reducing iron shows potential in the long term but it is likely that CCS linked with coke combustion will be a less expensive option.

Cement. Production of cement involves extraction and grinding of limestone and heating to temperatures well above 950°C. Decomposition of calcium carbonate into calcium oxide takes place in a rotary kiln, driving off CO_2 in the process of producing the cement clinker. CO_2 emissions from this reaction account for slightly more than half of the total direct emissions with the remainder coming from combustion of fossil fuels. Hence, even a complete switch to RE fuels would only reduce emissions by less than half.

The cement process is not particularly sensitive to the type of fuel but sufficiently high flame-temperatures are needed to heat the materials. Different types of waste, including used tyres, wood and plastics are already co-combusted in cement kilns. A variety of biomass-derived fuels can be used to displace fossil fuels. Large reductions of CO_2 emissions from carbonate-based feedstock are not possible without CCS, but emissions could also be reduced by using non-carbonate based feedstock.

Chemicals and petrochemicals. This sector is large and highly diverse. High volume chemical manufacture of olefins and aromatics, methanol, and ammonia, account for more than 70% of total energy use in this sector (IEA, 2008e). The main feedstocks are oil, natural gas and coal, for providing the building blocks of products as well as for energy. Chemicals such as ethanol and methanol may be considered both as fuels and as platform chemicals for products.

Steam-cracking is a key process step in the production of olefins and aromatics and various biomass fuels and waste could be used for steam production. Methanol production is mostly based on natural gas but it can also be produced from biomass or by reacting CO_2 with hydrogen of renewable origin.

The potential for shifting to renewable feedstocks in the chemicals sector is large. Many of the first man-made chemicals were derived from biomass through, for example, using ethanol as a platform chemical, before the shift was made to petrochemistry. A shift back to bio-based chemicals involves four principal approaches:

- thermo-chemical conversion of biomass for the production of a range of chemicals, including methanol;
- naturally occurring polymers and other compounds can be extracted by various means;
- feedstock can be converted using industrial biotechnology processes such as fermentation or enzymatic conversions; and

- green biotechnology and plant breeding can be used to modify crops in non-food production.

Ammonia production in the fertilizer industry is an energy-intensive process which involves reacting hydrogen and nitrogen at high pressure. The energy embedded in fertilizer consumption represents about 1% of global energy demand (Ramirez and Worrell, 2006). The nitrogen is obtained from air and the source of hydrogen is typically natural gas but also coal gasification, refinery gases and heavy oil products. Ammonia production gives a CO_2-rich stream and lends itself to CCS. Hydrogen from RE sources could also be used for the reaction and other nitrogen fixation processes are possible, including biological nitrogen fixation.

Forestry. The forest industry, including harvesting operations, saw mills, pulp and paper mills, and wood processing industries, handles large amounts of biomass. Residues and by-products to provide energy for internal use as well as for export are occurring all along the value chain. The internal use of biomass energy as a by-product means that the CO_2 intensity of the energy intensive pulp and paper industry is relatively low.

There are many different pulping processes but the two main routes are mechanical and chemical. With electricity-intensive mechanical pulping, wood chips are processed in large grinders and nearly all the wood ends up in the pulp which is used for paper such as newsprint. Heat is recovered from the mechanical pulping process and the steam produced is used for drying the paper and other processes. Chemical pulping is used to produce stronger high quality fibres and involves dissolving the lignin in a chemical cooking process. About half of the wood ends up in the spent pulping liquor that is concentrated in evaporators. The resulting black liquor is combusted in chemical recovery boilers and the bark component can also be combusted in separate boilers. The high pressure steam produced is used for CHP generation, enough to meet all the steam and electricity needs of a modern pulp mill.

Continuous incremental improvements in energy end-use efficiency, higher steam pressure in boilers, condensing steam turbines, etc., are reducing the need for purchased energy in the pulp and paper industry and can free up a portion of fuels, heat and electricity for export. Changing from the traditional recovery boiler to black liquor gasification in chemical pulping would increase the efficiency of energy recovery and facilitate higher electricity-to-heat ratios in the CHP system or the use of syngas for fuels production (See Box). [TSU: **Box 8.1:** Principles of power balancing in the system? Or is there to be another box inserted here?] The main options for direct integration of RE is to replace fossil fuels in boilers, produce biogas from wastewater with high organic content, and switch from oil and gas to biomass, such as using bark powder in lime kilns that produce calcium oxide for the preparation of pulping liquor.

Overall, possible pathways for increased use of RE vary between different industrial sub-sectors. Biomass can replace fossil fuels in boilers, kilns and furnaces and there are alternatives for replacing petrochemicals through switching to bio-based chemicals and materials. However, due to the scale of operations, access to sufficient volumes of biomass may be a constraint. Direct use of solar technologies is constrained for the same reason. For many energy-intensive processes the main option is indirect integration of RE through switching to electricity and hydrogen. Electricity is also the main energy input for producing aluminium using the electro-chemical Hall-Héroult process. Assuming that CCS becomes an important element in future energy systems this will also be an option for energy-intensive industries, irrespective of whether the fuels used are of fossil or renewable origin.

The broad range of options for producing carbon neutral electricity and its versatility of use implies that electro-thermal processes could become more important in the future for replacing fuels in low (<200°C) and medium (200-400°C) temperature processes including drying, heating, curing, and melting. Plasma technologies can deliver heat at several thousand degrees Celsius and replace fuels in high temperature applications. Electro-thermal processes include heat pumps, electric boilers, electric ovens, resistive heating, electric arcs, plasma, induction, radio frequency and micro-waves, infrared and ultraviolet radiation, laser and electron beams. These technologies are presently used where they offer distinct advantages (such as primary energy savings, higher productivity or product quality), or where there are no viable alternatives (such as for electric-arc furnaces and aluminium smelters). However, deployment has been limited since direct combustion of fossil fuels is generally less expensive than electricity. However, relative prices may change considerably under climate policies placing a value on carbon emissions.

Energy-intensive industries are typically capital intensive and the resulting long capital asset cycles constitute one of the main transition issues in this sector. Low profit margins are common in energy-intensive industries and management focus is usually on cutting costs and sweating assets rather than on making investments and taking risks with new technologies. In existing plants, retrofit options may be constrained in various ways. Green-field investments mainly take place in developing countries where enabling energy and climate policies are less common than in developed countries. However, energy-intensive industries are also generally given favourable treatment in developed countries that have ambitious climate policies since they are subject to international competition and resulting risks of carbon leakage. Exemptions from energy and carbon tax, or free allocation of emission permits in trading schemes, are prevalent. But industries using biomass, such as the pulp and paper industry, can also respond to RE policy by exporting fuels, heat and electricity. Sectoral approaches are considered in international climate policy in order to reduce carbon leakage risks and facilitate technology transfer.

8.3.3.2.1 Case study: Black liquor gasification for bio-DME production

Black liquor gasification as an alternative to chemical recovery boilers is a technology that has been subject to R&D for more than 20 years and has also been demonstrated in a few pilot plants. The syngas produced (mainly CO and H2) can be used with high efficiency in combined cycles for CHP or for the production of biofuels via the Fischer-Tropsch process (section 8.2.4). A pilot plant for producing DME (di-methyl ether) is expected to begin production in Piteå, Sweden, in July 2010 with a capacity of about 4t/day. The plant, with financial support from the Swedish Government and the European Commission, involves companies Chemrec, Haldor Topsoe, Volvo, Preem, Total, Delphi and ETC. Compared to gasification of solid biomass, one advantage of black liquor is that it is easier to feed to a pressurised gasifier. Depending on the overall plant energy balance and layout there are often process integration advantages and potential for significant increases in energy efficiency. Energy which is tapped off for liquid or gaseous biofuels production (including DME) can be compensated for by using lower quality biomass for meeting pulp and paper process energy demands. In addition to DME production, the project also involves four filling stations and 14 DME trucks to study the viability of bio-DME as a fuel for heavy trucks.

8.3.3.2.2 Case study: Demand response in industry

Industrial peak load shifting as a form of load management is an important measure to facilitate a greater uptake of variable RE generation in power systems (section 8.2.1). It can also reduce the need for high marginal cost generation, offer low cost system balancing and decrease grid reinforcement investment. The concept is already widely used to secure enough reserve- and peaking-capacity in many countries and is expected to become more important in future. Existing programmes have mainly focused on industrial users that can shed relatively large loads through rescheduling, machinery interruption, thermal energy storage, cool stores, reducing demand response times, interruptible electric boilers, etc. Typically, industries are contracted to reduce or shut down load, sometimes remotely by the transmission system operator, according to pre-defined rules and against various means of financial compensation. For industry, reduced production and risks of process equipment failure associated with demand response are important considerations. Estimates of the potential depend on the level of industrial manageable power demand. According to one study the potential for demand response in the energy-intensive industries of Finland is 1280 MW, equivalent to 9% of total peak demand (Torriti, 2009).

8.3.3.3 Other non-energy intensive industry

In addition to increased use of biomass derived fuels and residues for heat and CHP production there are four main opportunities for integrating RE in non-energy intensive industries:

- indirect use of RE through increased use of electricity including electro-thermal processes;
- indirect use through co-location with biomass-based industries that generate waste heat at suitable temperatures;
- direct use of solar thermal energy for process heat and steam demands; and
- direct use of geothermal for process heat and steam demands.

Other RE sources may also find industrial applications.

Non-energy intensive industries, although numerous, account for a smaller share of total energy use than energy-itensive industries but, are more flexible and offer greater opportunities for the integration of RE. They include food processing, textiles, light manufacturing of appliances and electronics, automotive assembly plants, wood processing, etc. Much of the energy demand in these industries is for installations similar to energy use in commercial buildings such as lighting, space heating, cooling and ventilation and office equipment. Most industrial heating and cooling demands are for moderate temperature ranges which facilitate the application of solar thermal energy, geothermal energy and solar-powered cooling systems with absorption chillers (Schnitzer et al., 2007; IEA, 2007a). Solar thermal collector capacity in operation world wide in 2007 was almost 150 GW but less than 1% is in industrial applications (IEA-SHC, 2009).

Process energy use is typically for low and medium temperature heating, cooling, washing, cooking pumping and air-handling, coating, drying and dehydration, curing, grinding, preheating, concentration, pasteurization and sterilization, some chemical reactions and space heating. In addition, a range of mechanical operations use electric motors and compressed air to power tools and other equipment. Plants range in size from very small enterprises to large-scale assembly plants and sugar mills.

Many companies use hot water and steam for processes at temperatures between 50 and 120°C. When fossil fuels are used, installations that provide the heat are mostly run at temperatures between 120 and 180°C to enable the use of smaller heat exchangers and heating networks, since heat exchanger areas can be smaller with higher temperatures in process heat supply. Solar energy will therefore possibly focus more on engineering designs for operating at lower temperatures in order to optimise the whole system. For temperatures < 80°C, thermal collectors are on the market, but there is limited experience for applications that require temperatures up to 250°C. Such higher temperatures are possible using heat pumps or, in appropriate areas, concentrating solar thermal systems

Industrial electro-technologies can save primary energy by using electricity. Industrial CO_2 emissions can be reduced even if there are no primary energy savings, assuming electricity from RE or nuclear resources replaces or saves fossil fuel-based thermal generation. Examples include freeze concentration instead of the thermal process of evaporation; dielectric heating (radio frequency and microwave heating) for drying; polymerisation; and powder coatings with infra-red ovens for curing instead of solvent-based coatings and conventional convection ovens (Eurelectric, 2004). Other advantages include quick process start up, better process control, and higher productivity (EPRI, 2009). The conventional wisdom that high quality (high exergy) electricity should not be used for low quality (low exergy) thermal applications may be challenged in a future decarbonised electricity system.

RE is most widely used in the food and fibre processing industries where on-site biomass residues are commonly used to meet internal energy needs, exported for use elsewhere, or constitute a waste disposal problem. Bio-based industries often provide opportunity for utilising residues that are normally left after harvest of the feedstock or generated on-site during processing. For cane-based sugar production, the mills can be self-sufficient in energy from using the waste bagasse as fuel. Historically bagasse (the fibre remaining after crushing sugar cane for juice extraction), was combusted inefficiently to dispose of it whilst producing just enough heat and power for use on-site. Advanced CHP technologies can make electricity available for export.

In other food and fibre processing industries, wastewater with high organic content could be used for biogas production but currently is poorly utilized. In many developing countries, substantial amounts of crop residues in the form of husks, straw and shells from nuts, coffee, coconuts, rice, etc. could be used for heat and power generation. These residues are low cost and often used as fuel to supply heat for local industries together with fuelwood and charcoal. In developed countries, waste policies are an important factor driving the increased utilisation of biomass residues for energy.

Bio-based industries such as pulp and paper and the sugar/ethanol industries, as well as other process industries, generate waste heat that can be used in other industries and in district heating systems. Industrial ecology and symbiosis are relatively new concepts used to denote such inter-firm exchanges of energy, water, by-products etc. although these are not new phenomena. Greenhouses and fish-farming are also potential users of low-grade heat. An inventory of the Swedish forest industry found several examples of such inter-firm exchanges, typically between different entities within the same company group (Wolf and Petersson, 2007). The potential for increased indirect use of RE in sucxh innovative way is difficult to estimate.

Dehydration of agricultural and other products is an important application of solar energy. In many developing countries the traditional method of dehydration in open air may result in food contamination, nutritional deterioration and large product losses. Solar dryer technologies that improve product quality and reduce drying times have been demonstrated. Examples include a solar tunnel dryer for hot chilli (Hossain and Bala, 2007) and a solar dryer with thermal storage and biomass backup heater for pineapple (Madhlopa and Ngwalo, 2007).

Geothermal energy could meet many process heat demands in industry at temperatures, or elevated by heat pumps to higher temperatures. Almost 500 MW of geothermal capacity, equivalent to about 4 % of worldwide direct applications of geothermal energy, is currently used for industrial process heat (Lund, 2005). Current utilisation is only about 10 PJ with applications in dairies, laundries, leather tanning, beverages, and a paper mill in New Zealand. The potential is very large (see Chapter 4) and high capacity factors relative to solar thermal energy make it an attractive alternative for industry.

The potential for increasing the direct use of RE in industry is poorly understood due to the complexity and diversity of industry and various geographical and climatatic conditions. Aggregate mitigation cost estimates cannot be made for similar reasons. Improved utilisation of processing residues in biomass-based industries and substituting for fossil fuels offer near-term opportunities. Solar thermal technologies are promising but further development of collectors, thermal storage, back-up systems and process adaptation and integration is needed. Increased use of energy carriers such as electricity and natural gas, that are clean and convenient at the point of end-use, is a general trend in industry. Indirect integration using electricity generated from RE sources and facilitated through electro-technologies, may have the largest impact both in the near and long-term. Direct use of RE in industry has difficulty competing at present due to the relatively low fossil fuel prices and low- or zero-energy and carbon taxes for industry. RE support policies in different countries tend to focus more on the transport and building sectors than on industry and consequently potentials are relatively un-charted.

8.3.3.3.1 Case study: Sugar industry and CHP

Limited grid access and low prices offered by monopoly-buyers of electricity and independent power producers have provided disincentives for many industries to increase overall energy efficiency and electricity-to-heat ratios in CHP production. Process electricity consumption in sugar and sugar/ethanol mills for example is typically in the range of USD 0.20-0.30/ kWh per tonne of fresh cane. Most mills have been designed to be self-sufficient in heat and electricity using mainly bagasse as a fuel in low pressure boilers. With high pressure boilers and condensing extraction steam turbines, more than 100 kWh/t can be produced for export. However sugar/ethanol mills provide opportunity for integrating a much higher level of biomass for energy in industry. The sugarcane tops and leaves are normally burned before harvest or left in the field after harvest. These could also be collected and brought to the mill to increase the potential export of electricity to more than 150 kWh/t. This could be further increased to over 300 kWh/t using gasification technology and combined cycles or supercritical steam cycles (Larson et al., 2001). Integrating the utilisation of biomass residues with sugar/ethanol mills and feedstock logistics offer cost and other advantages over separate handling and conversion of the residues.

8.3.3.3.2 Case Study: Solar industrial process heat for industry

There is good potential to use solar heat for industrial processes. In 2003, the net industrial heat demand in Europe was estimated to be 8.7 EJ and the electricity demand was 4.4 EJ (Werner, 2006). Heat demands were estimated in 2003 at low, medium and high temperature levels for several industries in EU 25 plus four accession countries, and three European Free Trade Association countries (Fig. 43). (The figure was created from German industry experiences that were applied to the IEA database for the target area). Industrial process heat accounted for around 28% of total primary energy consumption with more than half of this demand for temperatures below 400°C. This could be a suitable application for solar thermal energy (Vannoni et al., 2008).

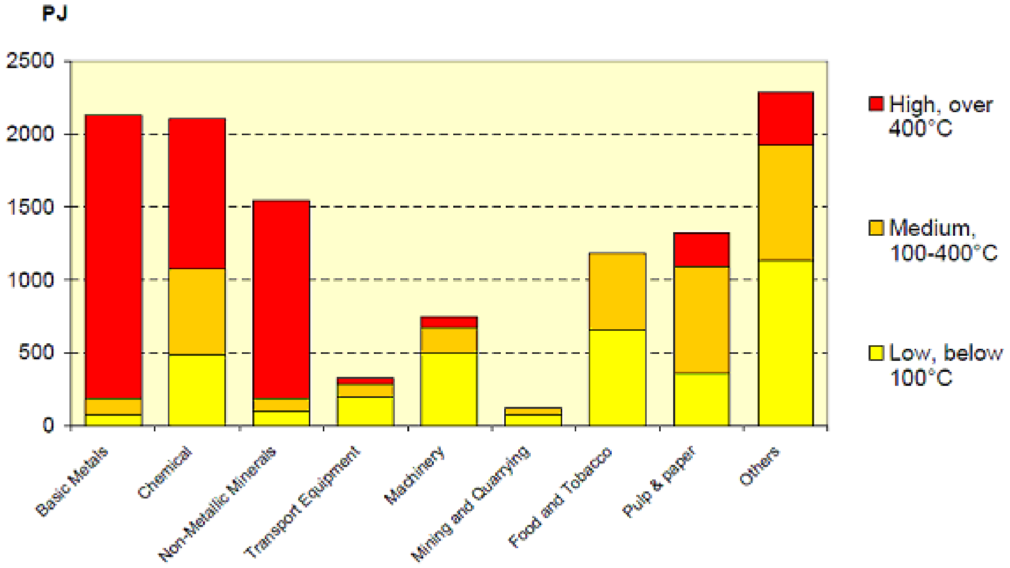

Figure 8.43: Industrial heat demands by temperature quality and by manufacturing sector for 32 European countries. (Werner, 2006).

Solar thermal energy technologies can be used to supply industrial heat including parabolic trough collectors (PTC) that can produce steam directly in the collector. A pilot plant installed at the production facilities of ALANOD[10] in Ennepetal, Germany in February 2007, the P3 project, aims to demonstrate direct steam generation in small parabolic trough collectors for industrial applications (Hennecke et al., 2008). The principal options for the integration of solar steam (Fig. 8.44) are:

- solar augmentation of the drying process;
- direct solar steam supply to individual consumers in the new production line; and
- solar steam integration into the existing steam distribution network. In this configuration the solar steam can feed directly into the production line by means of an over-pressure valve (>4 bar). The feed water to the solar steam generator is provided from the industrial steam system. Condensate from the solar system can be returned by the condensate line of the existing system. The feed water pump for the solar field is controlled by temperature measurement in the steam drum that is operated at a constant pressure of about 4.3 bar.

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[10] One of the products of this aluminium anodizing plant is MiroSun™, an aluminium based mirror also used as reflector material in the SOLITEM PTC 1800 parabolic trough collector.

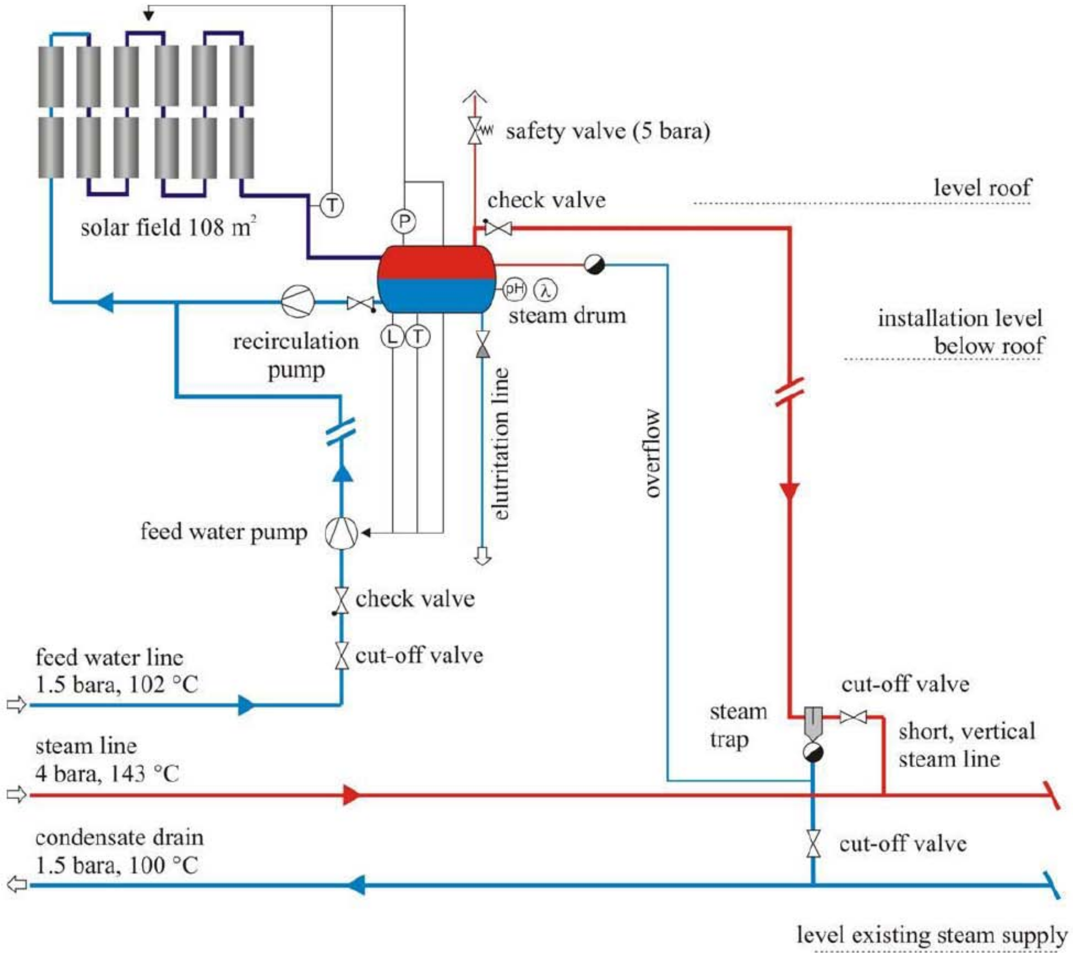

Figure 8.44: Layout of a direct solar steam integration system to be integrated at the ALANOD factory, Ennepetal, Germany (Hennecke et al., 2008).

8.3.3.3.3 Case Study: Ocean energy desalination

Desalination to produce fresh water is a growing industrial process. The two main process options are thermal (distillation) and membrane. RE-driven desalination systems are conceivable including stand-alone systems using variable RE sources since the product, potable water, can be stored cheaply (Koroneos et al., 2007). The National Institute of Ocean Technology, India, has developed a low temperature thermal desalination (LTTD) process and demonstrated it in the Lakshadweep islands. Low temperature evaporation of surface water at reduced pressure generates vapour which is condensed using deep sea-water at 12°C from 400 m water depth. After successful demonstration three more plants are now being built. The impact on the life and health of the islanders is remarkable as stomach disorders and various ailments related to dietary salt excess have been reduced. A barge-mounted offshore LTTD plant has also been demonstrated. Next development steps include the integration of an ocean thermal energy conversion module to power the LTTD plant to eliminate the need for purchased diesel or electricity (IEA-OES, 2008).

8.3.4 Agriculture, forestry and fishing

There has been a long and complex relationship between primary production, energy inputs and land use. Subsistence farming and fishing, as still practised in many regions of the world in order to feed billions of people living in rural areas, rely largely on human energy (as manual labour) and animal power. Biomass from crop residues and fuelwood, often scavenged from long distances, remains an essential energy source for cooking and heating applications (section 8.3.1.2). Conversely, industrialised agriculture, forest and fishing industries depend on significant energy inputs over and above the natural energy resource obtained from the sun. Intensive production of livestock, fish, crops and trees is widely practised in many countries to provide food and fibre products for consumption by city-dwellers. Energy inputs are mainly fossil fuels that are either combusted:

- directly for heating, drying and to power boats, tractors and machinery, or
- indirectly to manufacture fertilisers and agri-chemicals, construct buildings and fences, as well as to generate electricity for water pumping, lighting, cooling and operating fixed equipment.

For some food products such as potatoes, the energy inputs can exceed the food energy value of the harvested crop (as shown by a negative energy ratio of energy output/energy input) (Haj Seyed Hadi, 2006). However, there are variations depending on the boundaries used and assumptions made and a positive energy ratio for potatoes has also been reported in Iran (Mohamaddi et al., 2008).

Typically in OECD countries, energy demand for the agriculture sector is around 5% of total consumer energy. Energy efficiency measures are being implemented in various farm and forest activities including tractor operation, milking shed power demands, cool store refrigeration, greenhouse heating etc. Future opportunities exist to reduce fertiliser and agri-chemical inputs by using precision farming application methods based on GPS techniques (USDA, 2009), improved manufacturing techniques and organic farming systems.

Primary industries can also provide a number of biomass energy carriers such as crop residues, animal manures, forest residues, meat wastes, fish wastes and energy crops. These can be used for a range of applications including liquid biofuels.[11] Landowners also have access to RE resources including wind, solar radiation, potential energy in rivers and streams and geothermal heat. Their availability varies with different farm enterprises depending on land use, terrain and location (Table 8.14). Wherever land is farmed, wind turbines could also be constructed on suitable sites and solar systems installed on farm buildings or directly on the ground to provide power, heat for drying crops, or irrigation water pumping. Ground source heat pumps could also be installed to meet low-grade heat demands.

Currently land use and land use change accounts for around 30% of total greenhouse gas emissions. A small amount arising from fossil fuel energy inputs but most coming from deforestation, methane from ruminant digestion and paddy fields, and nitrous oxides from wastes and nitrogenous fertiliser use. Competition for land use to provide food, fibre, animal feed, recreation, biodiversity conservation forests, as well as energy crops is growing. Water use constraints, sustainable production and energy developments including biofuel production are under close scrutiny (Wilton Park, 2008).

Rich multi-national corporate organisations and food importing countries such as Saudi Arabia, South Korea, Kuwait and Qatar have negotiated investments with governments of poor countries for between 15 to 20 M ha of land from 2006 to 2009. Their aim is to grow, manage and export food such as wheat, rice and maize, but also to produce crops for biofuel exports (von Braun and Meinzen-Dick, 2009). Deals being quoted include China securing the right to grow palm oil for biofuel on 2.8M ha in the Democratic Republic of the Congo and also negotiating 2M ha in Zambia,

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[11] Note this section covers only on-farm and in-forest production and processing activities including harvest and post-harvest operations up to the farm gate. Food and fibre processing operations are covered in the Industry section 8.3.3.

South Korea investing in Madagascar, and Sun Biofuels UK, a private company, growing jatropha plantations for biodiesel oil in Ethiopia and Mozambique. Investments can either cause exploitation of the existing rural communities (Kugulman and Levenstein, 2009) or provide benefits when the advantages are equally shared, such as Brazilian sugar ethanol companies investing in Ghana (Renewable Energy World, 2008).

A code of good conduct to share benefits, abide by national trade policies and respect customary rights of the family farm unit is being considered.

8.3.4.1 Status and strategies

Large regional differences occur in primary production around the world due to climate, seasons, weather patterns, terrain, soil types, precipitation, cultural practices, land use history and ownership, and farm management using intensive or extensive methods (subsistence farming, versus low input (organic) farming, versus high input, industrialised farming). The classification of land ared and use by country or region can be found at the UN Food and Agriculture Organisation's web site faostat.fao.org. [TSU: URLs are to be cited only in footnotes or reference list.]

The integration of land use with the development of RE projects for electricity generation is well established. There are many examples of wind farms constructed on pasture and crop lands in areas with good mean annual wind speeds that have resulted from identification of the economic benefits from multi-purpose land use to the landowner. Only 2 to 3% of the total land area needs to be taken out of agricultural production for access roads, turbine foundations and control centre buildings. Installations can range from privately-owned, micro-scale (1 – 100 kW) plants that solely meet local individual or village demand, up to corporate–owned, large-scale (100s MW) where the power generated can be exported off the property to provide a return on the investment. Similar opportunities exist for small and large hydropower projects (although social disbenefits for local residents can also exist – see Chapter 9). Proximity to the load or to a nearby transmission grid, in order to avoid construction of costly power lines over long distances, can affect the economic viability of a project.

Hydropower projects are limited by local waterway characteristics. Having a high head is usually more efficient than a high flow. However low head turbines have been developed for run-of-waterway applications (using low weirs rather than high dams with water storage potential) including operation in low gradient water distribution channels to power the irrigation pumps (EECA, 2008).

Table 8.14: Primary production from industrial scale enterprises showing energy demand, energy use intensity (GJ/ha of land or buildings), RE resources available and potential for energy export across the farm boundary.

Type of enterprise	Direct energy inputs	Energy use intensity	Potential renewable energy resource	Energy export potential
Dairying	Electricity for milking facility, pumping of water and manure, refrigeration. Diesel for tractor. Diesel or electricity for irrigation.	High. Medium. High if for irrigation.	Manure for biogas. Heat from milk cooling. Solar water heating. Solar PV.	Limited as most used on-site.
Pastoral grazing animals (e.g. sheep, beef, deer, goat, llama)	Electricity for shearing. Diesel.	Very low but higher if irrigated. Low or medium if some pasture conserved.	Hill sites for wind turbines. Hydro power options. Solar systems on buildings. Green crops for biogas.	Wind power. Biogas CHP (combined heat and power).
Beef-lot, intensive production	Electricity for lighting, cooling, water pumping. Diesel for tractor.	Medium. High for harvesting feed.	Manure for biogas CHP. Solar PV and/or thermal if roof space available.	Limited as used on-site.
Pigs	Electricity for lighting, heating, cleaning.	High if housed indoors. Medium if kept outdoors.	Manure for biogas. Solar systems if roof space available.	Limited as used on-site.
Poultry	Electricity for lighting, heating, cleaning.	High if housed indoors, but low if free-ranging.	Combustion of litter for CHP. Solar systems.	High. Several multi-MW power plants already operating in UK, US.
Arable (e.g. cereals, maize, rapeseed, soyabean, cotton, rice, sugarcane, cassava, etc.).	Diesel. Electricity for storage facilities, conveyor motors, irrigation. Gas or LPG for drying.	Very high for machinery. Medium if rainfed. High if irrigated. Low and seasonal.	Crop residues for heat, power and possibly biofuels. Energy crops. Hydro power where streams suitable.	High where energy crops are purpose-grown.
Vegetables large scale (onions, potatoes, carrots, etc.)	Diesel. Electricity for grading, conveying irrigation, cooling.	High for machinery. Medium if rainfed. High if irrigated and for post-harvest chillers.	Dry residues for combustion. Wet residues for biogas.	Limited if used on site.
Market garden vegetables small scale	Diesel for machinery. Electricity for washing, grading.	Medium. Low for post-harvest.	Some residues and rejects for biogas.	Low.

Type of enterprise	**Direct energy inputs**	**Energy use intensity**	**Potential renewable energy resource**	**Energy export potential**
(mixture)		Medium if cool-stores.		
Nursery cropping	Diesel for machinery Heat for protected houses.	Low. Medium.	Some residues and rejects for combustion.	Low.
Greenhouse production	Electricity for ventilation, lighting and heating (or gas, oil or biomass).	High where heated. Medium if unheated.	Some residues and rejects for combustion.	Low.
Orchard (pip fruit, olives, bananas, pineapple)	Diesel for machinery. Electricity for grading, drip irrigation, cool-store etc.	Medium. Medium if irrigated and post-harvest storage.	Prunings for heat. Reject fruit for biogas.	Low.
Forest plantation crops (pine, spruce, eucalyptus, palm oil, etc)	Diesel for planting, pruning and harvesting.	Low.	Forest residues. Short rotation forest crops. Oil palm bunches.	High – large volumes of biomass for CHP or possibly biofuels.
Fishing – large trawlers off-shore	Marine diesel/fuel oil. Electricity for refrigeration.	High.	(Reject fish dumped at sea).	None.
Fish farm – near-shore or on-shore.	Diesel for boats for servicing. Electricity for refrigeration.	Low Medium if facilities off-shore. Medium.	Residues for biogas and oil. Ocean energy.	Low. Electricity from ocean energy possible in future.
Fishing – small boats near-shore.	Diesel/gasoline. Electricity for ice or refrigeration.	Low. Low.	Residues for biogas and oil.	Low.

Solar thermal systems have been commonly used for water heating, especially in dairy milking sheds, as well as for the drying of fruit and vegetables. Post-harvest chilling of fresh products using solar sorption technologies (Fan et al., 2007) remains in the development stage, but the technology holds good promise for air-conditioning, refrigeration, ice making and congelation of food products especially for hot regions.

Geothermal heat from natural hot water or steam near the Earth's surface has been used for various thermal applications in limited locations where the resource exists including for heating greenhouses and fish and prawn farming (Lund, 2002). Ground source heat pumps could have widespread use with applications for fruit and vegetable desiccation, heating animal livestock houses and drying timber, although the technology would not compete with simpler outdoor solar drying in sunny regions.

Biomass resources are commonly used to meet local agricultural and rural community energy demands. Although many examples exist, developing a project can be challenging in terms of securing biomass feedstock for the long term, ensuring it is sustainably produced, storing it for all-year-round use with minimal losses, transporting it cost-effectively due to its relatively low energy density compared with fossil fuels, recycling nutrients and obtaining planning consents. Guidelines to assist project developers and city planners have therefore been produced (IEA, 2007b).

Anaerobic digestion of animal manures, food and fibre processing wastes, or green crops to produce biogas is a well understood technology (Chapter 2). Fish processing residues can also be utilised, but tend to be dried and ground for animal feed. Chicken litter, with a major component of sawdust or shavings, is often better used for direct combustion. On-farm use of biogas for heat or CHP, using gas engines, is common practice. A less common application is as a transport fuel similar to compressed natural gas (cng). Gas storage is costly, so matching supply with demand is a challenge for the system designer. Larger community scale plants have been successfully developed in Denmark, India, Indonesia and elsewhere. The odourless, digested solid residues can be used for soil conditioning and nutrient replenishment.

Dry crop residues such as rice husks, coconut shells are easily stored and commonly combusted at the small scale for heat generation or at a larger scale for CHP. Bagasse (fibrous residues from sugarcane) is around 50% moisture content (wet basis). So to avoid a major disposal problem it has traditionally been combusted inefficiently to provide just sufficient heat and power to supply the refinery, though with high levels of air pollutants. Partly resulting from the privatisation of the electricity industry in many countries, a number of sugar plant owners have now invested in very efficient CHP plants that generate around 5 to 10 times more power for export. Partly drying the bagasse with available heat to give more efficient combustion, and with reduced air pollutant emissions, could be warranted (Shanmukharadhya and Sudhakar, 2007).

Bagasse, husks, nut shells, etc. are produced at the processing plant, and therefore, in effect, are delivered free-on-site. Cereal straw or forest residues have to be collected and transported as a separate operation following the harvest of the primary product (grain or timber). Due to the additional costs involved, techniques for integrated harvesting of co-products have been developed such as whole crop harvesting with later separation, or whole tree extraction to a landing where the tree is processed into various products. Although used mainly for heat and power production at present, with the possible advent of 2nd generation liquid biofuels from ligno-cellulosic feedstocks (IEA, 2008a), competition for this limited biomass resource could result in some regions. As a result, purpose-grown energy cropping has been proposed as a source of ligno-cellulose.

8.3.4.2 Pathways for renewable energy adoption

Much land under cultivation could simultaneously be used for RE production. Market drivers for RE power generation on rural land and waterways include electrification of rural areas, energy security and the avoidance of transmission line capacity upgrading where loads are increasing.

Many sites in Europe and elsewhere that used to house water mills could be utilised today for run-of-river micro-hydro power generation schemes. Fish farms may be able to utilise local waves or ocean currents for power generation opportunities in the future. In many cases much of the RE potential would be best utilised on the property to displace imported energy needed to run the enterprise (Table 8.14).

Little surplus land is available for bringing into cultivation in most countries and further deforestation is not an acceptable option. Therefore to meet the growing demands for primary products including biomass, increasing productivity of existing arable, pastoral and plantation forest lands by improving management and selecting higher yielding varieties is one option. (Changing diets to eat less animal products is another). Through these actions, average yields of staple crops have continued to increase over the past few decades (Fig. 8.45) though with variations between regions. This trend could continue over the next few decades, with genetically modified crops possibly having a positive influence. Conversely, global warming trends have possibly already offset some of the productivity gains expected from technological advances (Lobell and Field, 2006).

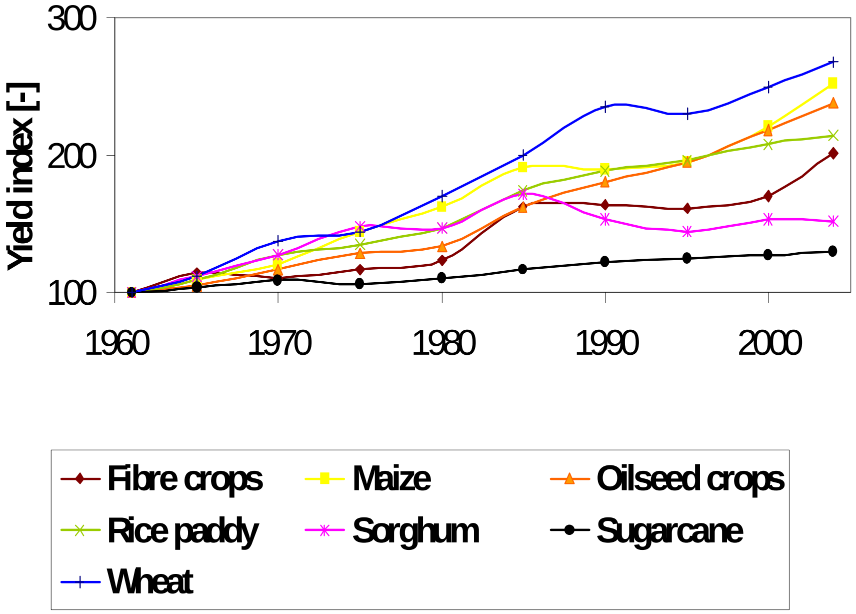

Figure 8.45: Increased productivity per hectare for a range of crops over the past few decades compared with base year 1962 (FAO, 2009).

8.3.4.3 Transition issues

The primary production sector is making a slow transition to reducing its dependence on energy inputs as well as to better using its naturally endowed, RE sources. Multi-uses of land for agriculture and energy purposes is becoming common, such as wind turbines constructed on grazing land, on-farm biogas plants, and crops grown to provide liquid biofuels and co-food products. The technologies are largely mature. However, based on the huge amount of RE resources available on farms and plantation lands, the share of the total potential being utilised at present is miniscule.

Barriers to greater deployment include high capital costs, lack of available financing, remoteness from energy demand (including access to electricity and gas grids), competition for land use, transport constraints, water supply limitations, and lack of skills and knowledge by landowners.

8.3.4.4 Future trends

RE is likely to be used to a greater degree by the global agricultural sector in the future to supply energy demands for primary production and post-harvest operations at both the large and small scales using a wide range of conversion technologies. The integration of RE with food and fibre production on the same land can provide a co-revenue stream for land owners. This will encourage steps towards sustainable development to be made in developing countries since the affordable supply of useful energy services is a critical component.

Distributed energy systems based on RE technologies are beginning to gain further traction in cities (IEA, 2009b) and also have large potential in rural areas. This concept, being developed for uptake in OECD countries, could be applied to produce mini-power distribution grids in rural communities in developing countries where electricity services are not yet available.

A future opportunity for the agricultural sector is the concept of carbon sequestration in the soil as “bio-char”. When produced via gasification or pyrolysis using the controlled oxygen combustion of sustainably produced biomass, incorporation of the residual char into arable soils is claimed to enhance future plant growth and the carbon is removed from the atmosphere. Further RD&D is required to assess soil suitability, impacts on crops yields, methods of pulverisation and integration but the future integration potential, once proven, could be significant (Lehmann, 2007).

8.3.4.5 Case study. Distributed generation in a rural community

There are promising opportunities for rural communities to benefit by capturing and using local RE systems and exporting excess power to the grid. Distributed energy can provide climate change mitigation benefits, lead to sustainable development in developing countries, as well as give increased security of supply. A small demonstration project at Totara Valley, New Zealand aims to:

- demonstrate a decision making methodology for rural communities whereby the local energy resources can be easily identified and utilised to meet local demands for heat and power in order to provide economic and social benefits;
- identify new business opportunities for power supply companies and circumvent the commercial conundrum of having to supply the more remote customers for limited commercial gain; and
- solve the technical problems of supplying heat and power to multi-users from several small generation sites within a given locality using RE resources wherever feasible.

Electricity meters at strategic locations measured demands of the appliances used in the woolsheds, houses, workshops, freezer sheds etc. (Murray et al., 2002) and enabled a series of electricity profiles to be produced showing both seasonal and daily variations (Figure 8.46) and identifying opportunities for energy efficiency improvements, solar water heaters and heat pumps. The wind speed and direction (together with the solar radiation resources) were monitored to develop a method of showing seasonal and daily variations.

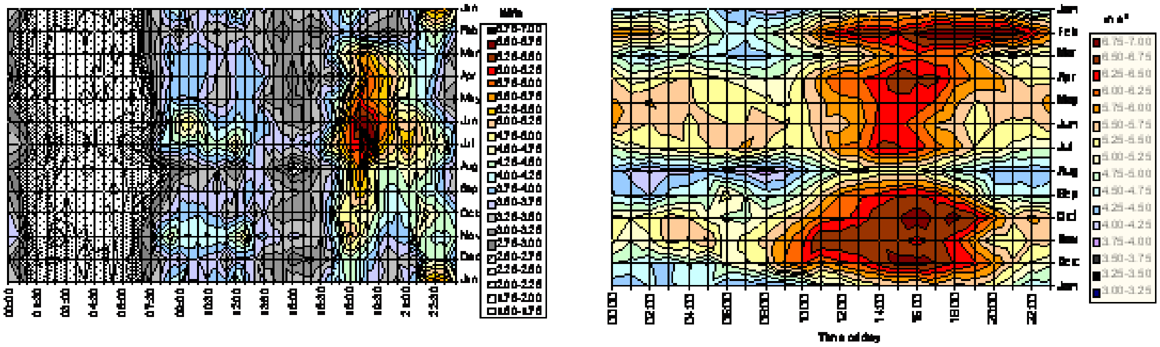

Figure 8.46: Average seasonal and daily electricity demand for the Totara Valley community households in kWh consumption per 30 minute period with annual and daily wind data showing a reasonable match with the demand. [TSU: Source?]

A 2.2kW wind turbine was installed on the best hill site, but due to the cost of 1.5km of copper cabling being around USD 13,000 TSU: Needs to be presented in 2005 US$] it is used to power an electrolyser (Sudol, 2009). The hydrogen produced is piped down to a fuel cell with losses of only around 1%. The pipe is used as an energy storage system for when the wind does not blow. A 1kW Pelton micro-hydro turbine was installed. Since wind and solar are variable and intermittent, and not all properties have a reliable stream with micro-hydro potential, matching power supply with continually varying demand is difficult and often requires some form of storage. Several options exist to provide good quality and reliable power supply systems to a rural community.

- Each building could have its own independent generation system often combining wind and solar with 3 or 4 day battery storage and a small gasoline generator as back-up.
- The community could be independent with several sources of small-scale generation, possibly located on more than one property and with a mini-grid to connect all the generation plants and to supply all the buildings. This could require battery storage or diesel generation back-up for when the demand exceeded the supply. At Totara Valley a biodiesel-generator is controlled remotely by the line company when extra capacity is needed. Water heaters and cool stores on the farms provide load demand control as well.
- If already connected to a grid, the community could continue to use mains power in the usual way, but with the risk of ever increasing fixed supply charges to cover maintenance costs and eventual replacement of the lines and poles should they go down in a storm.
- The grid could be used as a "battery" for when demand exceeds supply from the power generated on site. This could be attractive to a distribution company when a line is reaching its maximum transmitting capacity. An expensive upgrade could be avoided by installing this embedded generation.

A line company could therefore have a strong business interest in becoming a joint venture partner in such a scheme, possibly to purchase and lease the power generation equipment to the community members. A related study from the line company perspective (Jayamaha, 2006), modelled different scales of communities (Figure 8.47).

Suitable controls and metering systems will need to be developed to integrate various generation technologies between users and the local grid and to enable metering of both imported and exported power to be achieved (Gardiner et al., 2008).

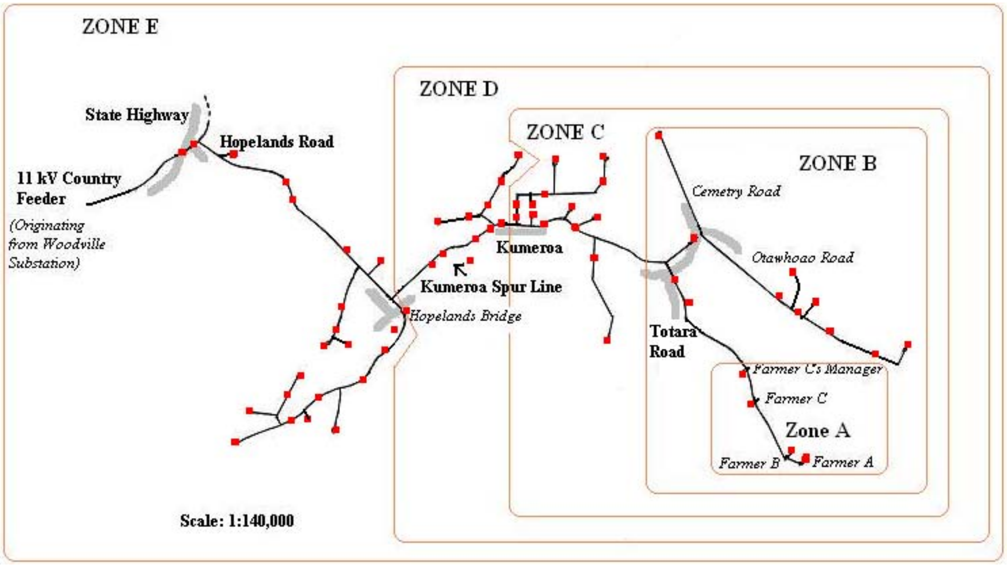

Figure 8.47: The power distribution feeder reaching Totara Valley (Zone A) is the end of the line. Larger community scales using their local RE resources (Zones A, B, C, D or E) could show greater economic benefits. (Farm and other building clusters with power loads are shown as red squares).

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