16 Transitions in Energy Systems

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Executive Summary

This chapter examines the theme of transitions in energy systems. It assesses the literature that explores the genesis, growth, and management of transitions. This literature provides a multi-level framework for large-scale, transformative change in technology systems, involving a hierarchy of changes from experiments to niches to technology regimes.

The chapter also covers specific innovation systems and experiments in the energy sector that may have the potential for larger impact and could lead to new niches or technology regimes. These experiments include technology-driven innovations in generation and end-use; system-level innovations that could reconfigure existing systems; and business model innovations centered on energy service delivery. Experiments in generation include hybrid systems, where multiple primary energy sources help address issues such as intermittency. Experiments in end-use include technology options for the simultaneous delivery of multiple energy services, or energy and non-energy services. System-level experiments include innovations in storage, distributed generation, and the facilitation of energy efficiency by effectively monetizing savings in energy use.

In some of these experiments, technology can lead to changing relationships between actors or changing roles for actors; for example, the process of consumers becoming producers is seen in small-scale biogas projects. These changing relationships present both challenges and opportunities for influencing the transition process. The chapter also discusses policy and institutional issues that affect transitions. Finally, it is seen that although technological research, development, and innovation are important, a wide-scale, equitable, and accessible transformation to energy systems for sustainable development needs to be tackled as a socio-political issue.

16.1 Introduction

The energy sector is evolving rapidly. This evolution is shaped by the convergence of several factors, including the realization that energy is a key enabler for achieving development goals, such as the Millennium Development Goals (MDGs). Chapters 2 and 6 of this report review the link between economic growth and energy use, while the effects of energy system operation for human health and the local & global environment are reviewed in Chapters 3 and 4, respectively.

This evolution simultaneously poses a challenge and an opportunity. The challenge is to manage multiple goals and objectives, while the opportunity is to use this evolution to move society towards an energy future that promotes sustainability. The challenge is complicated by the fact that, in many countries, existing energy policy institutions were not designed for this task. Many countries have energy institutions designed for the liberalization and privatization of their energy systems in the 1990s. The challenge of investing and developing energy systems for sustainable development may require new institutional innovations (Helm, 2005; Smith, 2009).

Accomplishing the transition in energy systems will require an accelerating pace of technological change throughout the developed and developing world. Energy policies will need to facilitate this acceleration, while at the same time avoiding lock in to sub-optimal solutions. The variety of energy resources as well as end-use and supply-side technologies that may be available are assessed in earlier chapters of this assessment (Chapters 7–15). While these chapters have assessed the state of the energy system as it exists today, Chapter 17 describes possible pathways by which energy systems could be modified to simultaneously achieve multiple objectives, including environmental sustainability. In many ways, these pathways require transformative change in the energy system.

Transformative change and transitions therefore form the focus of this chapter, and the literature assessed is intended to reflect some of our learning and experience with large-scale transitions in energy systems and in other large, complex socio-economic systems; to provide insights into how transitions may be studied; and, more importantly, how they can be managed. We also review recent experiments and innovations in energy systems, which, if scaled up appropriately, could offer significant opportunities for transforming the energy system.

These experiments include approaches for generating electricity by combining different primary energy sources and approaches for the simultaneous delivery of multiple energy services. An emphasis on providing the energy services while reducing energy wastage (energy efficiency), demand-side management, and a supportive regulatory and policy environment is also encouraging innovations in business models, with energy service companies being a prime example. Finally, in many parts of the developing world, the challenge of achieving energy access goals more rapidly is leading to efforts aimed at supporting a new generation of energy-sector entrepreneurs. Taken individually, each of these trends might be seen as an isolated example, with little significance for the large-scale context. But taken together, and governed effectively, they offer a possibility of creating new transformation pathways for energy systems. In this way, the chapter serves to connect the assessment of the expectations from, and the current state of, the energy system (Clusters I and II) with the pathways to energy systems for sustainable development (Clusters III and IV).

The remainder of this chapter is structured as follows. Section 16.1 reviews literature on transitions and transition management that underpins the importance of considering ancillary and complementary factors while examining policy-driven or autonomous change. Several examples of experiments that may have the potential to influence future energy transitions are grouped into two broad categories. The first section (16.2) includes technology-driven experiments in electricity generation and end-use. Then Section 16.3 considers innovative systems experiments in overall energy system optimization, configuration, and operation. The final section (16.4) looks at a number of policy and institutional issues that may positively or negatively influence energy system transitions.

16.1.1 Transitions and Transition Management

A detailed historical perspective on the long-term evolution of energy systems is given in Chapter 1, including the way in which the industrial revolution changed the fabric of human society and our natural environment. Chapter 1 also discusses the characteristics of historical energy transitions, such as the change in resource use from traditional biomass to coal, oil, and gas. These long-term transformations were driven by both endogenous factors, such as the emergence of electricity after the invention of the dynamo by Michael Faraday, and by exogenous factors, such as the 1973 Oil Crisis. Endogenous technological change is a key element of these long-term transitions. A combination of historical analysis and new modeling techniques can help in identifying predictable patterns of technological change and innovation (Grubler et al., 1999) and thus improve the treatment of technology in models used to project trends in energy and economic and environmental futures.

16.1.1.1 Determinants and Drivers of Transitions

Transformations in energy systems are long-term change processes (decadal or longer) in technology, the economy, institutions, ecology, culture, behavior, and belief systems. They typically cover all aspects of energy systems, including resource extraction, conversion, and end-use. While these transitions are not deterministically caused by technology, technological change is a useful entry point through which long-term transitions may be analyzed and explained. In relation to the transport sector, for example, transitions have been explained as changes in the mode of transport, such as from sailing ships to steamships (Geels, 2002) and from horses to motorcars (Grubler et al., 1999).

A recent approach to understanding transitions is the "multi-level perspective" (Rip and Kemp, 1998; Geels, 2002; Geels and Schot, 2007; Markard and Truffer, 2008). Combining insights from evolutionary theory and the sociology of technology, this perspective conceptualizes major

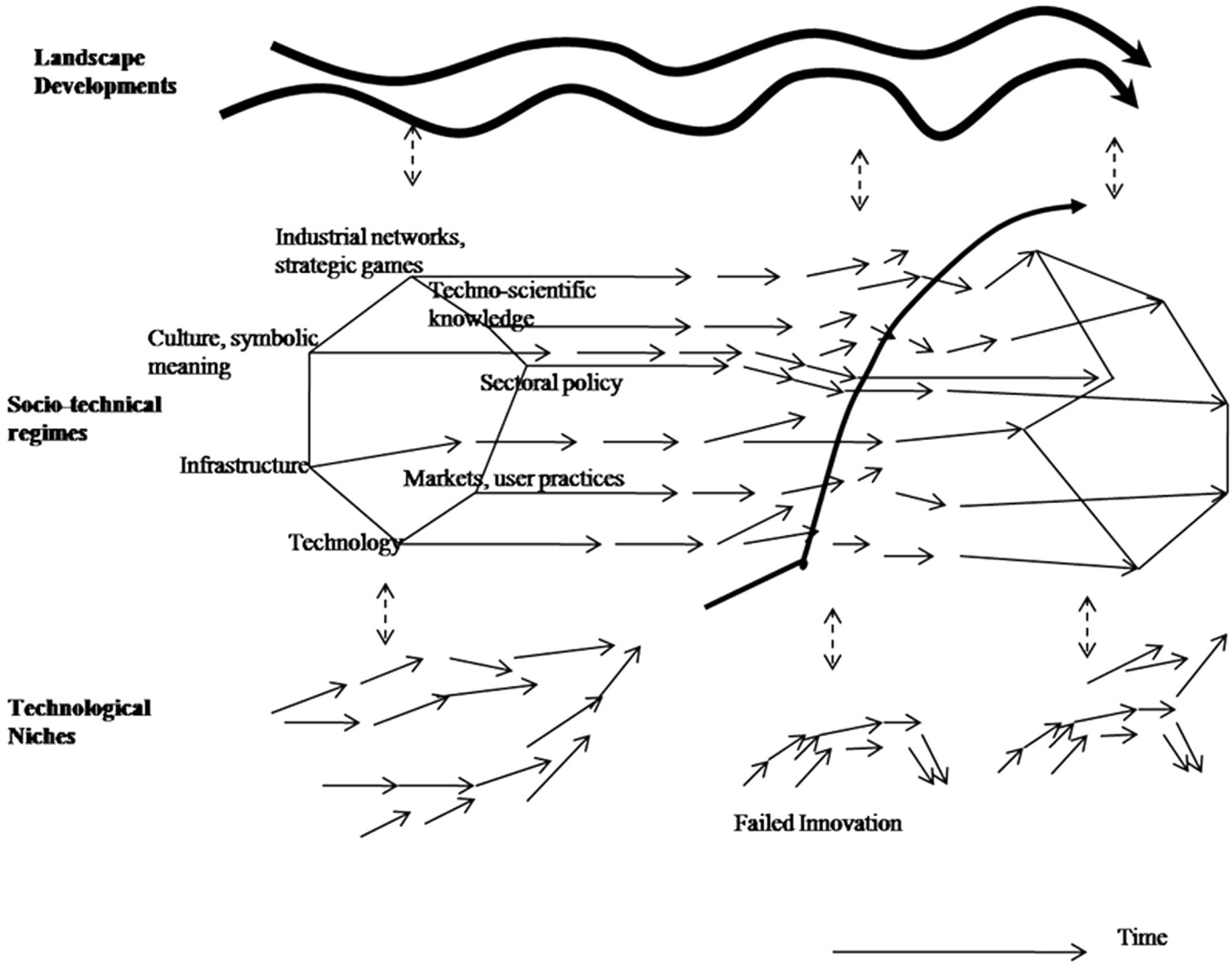


Figure 16.1 | A dynamic representation of the multi-level perspective on transitions. This perspective distinguishes between the micro-level of niches, the meso-level of socio-technical regimes, and the macro-level of landscapes. Innovations and experiments can only break through when there is sufficient pressure on the socio-technical regime. The small arrows at the bottom represent the niche innovations and experiments, which join together, become powerful (as in the thicker arrows), start influencing the socio-technical regimes, leading to major changes in technology, market, user practices, etc., and eventually become part of the landscape. Source: Geels, 2002.

transformative change as the product of interrelated processes at the three levels of niche, regime, and landscape. The framework emphasizes the incremental nature of innovation in socio-technical regimes. A niche is a network of similar projects carried out by innovating actors who seek to challenge the incumbent and dominant socio-technical practice (regime), such as a distributed generation using renewable energy versus a regime of centralized electricity generation. Regimes and niches develop in the context of a socio-technical landscape, which consists of both hard geographical features, such as resource availability and infrastructure, and "soft" elements, such as political conditions, societal trends, and economic fluctuations. The socio-technical landscape provides the exogenous environment for regime change and is a source of major selection pressures on prevailing regimes. Transitions, i.e., shifts from one stable socio-technical regime to another, occur when regimes are destabilized through landscape pressures, which in turn provide breakthrough opportunities for niche innovations. Figure 16.1 visualizes the multi-level model.

Similar frameworks have been developed by other authors. For example, Van Dijk (2000) defines the technological regime as a particular combination of opportunity, appropriateness, cumulativeness, conditions, and properties of the knowledge base that are common to specific activities of innovation and production and are shared by a population of firms undertaking those activities. Stier (1983) and Kathuria (1998) have used examples from product/process and system diffusion to describe changes in technologies and technology systems. Technology products or processes form part of technology systems, which in turn form part of technology regimes.

The transitions literature has advanced from an initial one-pathway conceptualization of transitions, in which niches grow and change regimes, to distinguishing between pathways, depending on different configurations and multi-level interactions (Smith et al., 2005; Geels and Schot, 2007), as summarized in Box 16.1.

Box 16.1 | Pathways that Represent and Characterize Transitions

1. Reorientation/transformation

This pathway is characterized by external pressure (from the landscape level or outsider social groups) and gradual adjustment and reorientation of existing regimes. Although external pressures create windows of opportunity for wider change, niche innovations are insufficiently developed to take advantage of them. Change is therefore enacted primarily by regime actors, who reorient existing development trajectories. Outside criticism from social movements and public opinion is important because it creates pressure on regime actors, especially when they spill over towards stricter environmental policies and changes in consumer preferences. Although regime actors respond to these pressures, the changes in their search heuristics, guiding principles, and research and development investments are modest. The result is a gradual change of direction in regime trajectories. New regimes thus grow from older ones through cumulative adjustments and reorientations. Regime actors survive, although some change may occur in social networks. Furthermore, regime actors may import external knowledge if the distance with regime knowledge is not too large. Such symbiotic niche innovations add to the regime, rather than disrupting the basic architecture.

2. Reconfiguration

In this pathway, niche innovations are further developed when regimes face problems and external landscape pressures. In response, the regime adopts certain niche innovations into the system as add-ons or component substitutions. This leads to a gradual reconfiguration of the basic architecture and changes in some guiding principles, beliefs, and practices. In the reconfiguration pathway, the new regime also grows out of the old regime. But it differs from the transformation pathway insofar as the cumulative adoption of new components changes the regime's basic architecture substantially. The main interaction is between regime actors and niche actors, who develop and supply the new components and technologies. This is therefore a more radical transition than that of the transformation pathway.

3. Technological substitution

Here, landscape pressures produce problems and tensions in regimes, which create windows of opportunity for niche innovations. Niche innovations can use these windows when they have stabilized and gathered momentum. Diffusion of these new technologies usually takes the form of niche-accumulation, with innovations entering increasingly bigger markets and eventually replacing the existing regime. In this pathway newcomers (niche actors) compete with incumbent regime actors.

4. De-alignment and re-alignment

Major landscape changes lead to huge problems in the regime. The regime experiences major internal problems, collapses, erodes, and de-aligns. Regime actors lose faith in the system's future. The regime's destabilization creates uncertainty about dimensions on which to optimize innovation efforts. The sustained period of uncertainty is characterized by the coexistence of multiple niche innovations and widespread experimentation. Eventually, one option becomes dominant, leading to a major restructuring of the system (new actors, guiding principles, beliefs, and practices).

Source: Smith et al., 2005; Geels and Schot, 2007.

The multi-level perspective on transitions is still under active development and has raised some criticisms. In their review of current transitions research, Genus and Coles (2008) have identified limitations of this perspective that need to be addressed to improve the understanding of processes of innovation affecting the transformation. Few case studies presented in the literature systematically identify or analyze the meso-level socio-technical regimes said to be central to stability and change in socio-technical systems, not least with respect to the rules and routines acknowledged as key to the activities of groups in those regimes. There has also been a tendency to focus on successful technologies and

methodological issues concerning the multi-level perspective's functionality, and the poor record of historical case studies appears to have been undervalued. Moreover, there is a danger that some ideas implicit in this treatment of the perspective can seep into the policymaking domain, so that the reality of a neat, mechanistic model of transition could become the dominant interpretation of the perspective. Markard and Truffer (2008) suggest that the multi-level perspective approach is largely confined to the niche level in its analysis of emerging technologies. Frameworks for the analysis of transitions need to:

- consider more explicitly the innovation processes perceived at the micro-level of organizations (strategies, agency);
- take account of mutual dependencies between actors and institutions;
- develop consistent performance comparisons to recommend how to support the development of particular innovations; and
- facilitate systematic identification and assessment of the broad range of factors (e.g., events, developments, institutional effects, actor behavior) that influence innovation processes.

Fouquet (2010) attempts to analyze the role of economic drivers in past energy transitions in order to identify commonalities that may be useful in anticipating future transformations. The analysis proposes that the same micro-economic drivers that were important in the past, such as better and cheaper services, will be relevant in the future. In terms of policy findings, governments and regulatory agencies will have to protect niches rather than rely solely on consumers' willingness to pay for niche technologies. This would involve incentivizing the provision of ever cheaper services and highly valued additional attributes, and minimizing the problem of negative aspects of new technologies. The study further suggests that the periods of niche development, refinement, and large-scale adoption will probably spread over decades.

16.1.2 Managing Transitions

The emerging understanding of transitions and transformations have raised the possibility that they may be actively influenced or managed through policy and other interventions. For example, strategic niche management (SNM) conceptualizes innovation projects with novel technologies as sustainability experiments taking place in real-life contexts (Hoogma et al., 2002; Raven, 2005; Schot and Geels, 2008). SNM also emphasizes the critical role of social network dynamics, articulating expectations, learning processes, and clever niche regime interfaces. The perspective has been applied to a large number of case studies in the field of sustainability, such as sustainable transport (Hoogma et al., 2002), photovoltaic cells (Van Mierlo, 2002), sustainable food supply chains (Wiskerke, 2003; Smith, 2006), bioenergy technologies (Raven, 2005), biofuels (Van Eijck and Romijn, 2008; Van der Laak et al., 2007), wind turbines (Kemp et al., 2001; Healey, 2008), the hydrogen economy (Agnolucci and Ekins, 2007), and low-energy housing (Lovell, 2007; Smith, 2007).

Another part of the literature deals with specific social groups as niches for sustainable technologies, such as Non Governmental Organizations (NGOs), civil society, and social entrepreneurs (Verheul and Vergragt, 1995; Seyfang and Smith, 2007; Witkamp et al., 2011). More fundamentally, Hegger et al. (2007) and Monaghan (2009) suggest that rather than emphasizing technology, niche management could include experimentation with concepts and guiding principles. Ieromonachou et al. (2004) propose an adapted version of strategic niche management based on policy niches, rather than technological niches, to investigate urban road pricing schemes.

A similar method of conceptualizing the role of experiments is the Bounded Socio-Technical Experiment, in which the mapping and monitoring of the learning process can be conceptualized into four levels (Brown and Vergragt, 2008):

- problem solving using pre-determined objectives;
- problem definition in relation to the particular technology-societal problem coupling;
- dominant interpretive frames; and
- worldview, which denotes deeply held values with regard to the preferred social order.

A detailed case study by Brown and Vergragt (2008) of a zero-fossil-fuel residential building led them to conclude (though by no means generic) that the learning involved in bringing about system changes takes place at both the individual and team levels, that it mainly involves changes in problem definition, and that the process involved is just as important as the product obtained. However, a study of several green niches by Smith (2007) found that different actors drew different lessons from projects in niches, depending upon their institutional position and interests. Learning is important, but so too is translating lessons between actors operating in very different contexts. Low-carbon construction techniques that work for green builders may be less amenable to mainstream volume house-builders, for instance, who adopt only elements of the greener techniques. Policy has to support more effective translation processes between niche actors and those in the incumbent regime. Smith et al. (2005) have downplayed the role of niches as instruments in transition governance and introduced the concept of transition contexts to better understand how regimes might adapt to changing selection pressures, such as emerging sustainability preferences in society. They argue that governance must be understood as articulating selection pressures and coordinating and providing resources for adaptation.

The management of transformations could be considered as the transformation of complex adaptive systems (Kemp et al., 2007; Loorbach,

2007), where governance is a process of envisioning sustainable futures in a participatory manner, with front-runners in policy, industry, and society.

Another approach examines the functions of technological innovation systems. This approach conceptualizes transformative change towards sustainability as a process of fulfilling a set of different system functions that are developing and interacting over time. Change occurs through motors that produce either virtuous or vicious cycles, causing system growth or system collapse (Suurs, 2009). Governance advice following an analysis of the functioning of a specific technological innovation system often entails arguments to support certain system functions that are preventing further growth and breakthrough.

Since technology is an important element of transitions, the planning and coordination of research and development efforts may be relevant for guiding transitions. Shafiei et al. (2009) have developed a mathematical and conceptual model of energy research and development resource allocation with an explicit perspective of developing countries (in their case, Iran), which has been linked to a bottom-up energy-systems model and can help in determining the optimal allocation of research and development resources. A similar effort was produced for the United States energy system through a recent project involving several US national laboratories. This model, an open source, long-range Stochastic Lite Building Module, which is part of a larger economic model for the US energy system (the Stochastic Energy Modeling System), estimates the impact of different policies and consumer behavior on the market penetration of low-carbon building technologies (Stadler et al., 2009). The tool can be used, among other things, to simulate the impact of different levels of research and development funding for energy-related technologies. Recent work from the Lawrence Berkeley National Laboratory using the Stochastic Energy Modeling System assesses the impact of research and development levels for photovoltaic technology and solid-state lighting (Stadler et al., 2009). These models can also be helpful in getting at least an approximation of the expected duration of a major energy transition.

As the variety of technology options and combinations increases, there is a greater need for assessment, evaluation, and planning tools. Azevedo (2009) has developed a flexible and transparent, user-friendly tool that assesses the most cost effective way to provide residential end-use energy services (heating, cooling, clothes washer, dishwashers, hot water, cooking, clothes dryer, refrigerator, freezers, and lighting) from different fuels (natural gas, electricity, kerosene, wood, geothermal, coal, solar, distillate, and LPG). With this tool, known as the Regional Residential Energy Efficiency Model, simulations can be performed in any number of the following US census division regions: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain and Pacific. The model considers different energy and climate policy constraints.

Transition processes have been studied in the context of national policies. Marinova and Balaguer (2009) present a comparative study of photovoltaic industry growth in three countries – Australia, Germany, and Japan. While Australia has seen successes in sophisticated photovoltaic off-grid systems, it has not been able to achieve great success in the development of on-grid systems, due to the lack of market development and also because of a shortage of funding available to smaller or newer research groups emerging in the photovoltaic domain. In contrast, the growth in Germany and Japan has been more successful, because development took place in a more business-like and industrial environment. In Germany, the strong industrial environment in sophisticated manufacturing allowed the vertical integration of the photovoltaic industry from feedstock materials to module fabrication. In Japan, meanwhile, the existing and huge electronics industry served as a natural base for solar cell technology. In both these countries, the photovoltaic industry was directed towards on-grid applications and was well nurtured by subsidies that helped create markets and mainstream the technologies. These studies suggest the importance of considering energy, industrial, and technology policies in an integrated manner.

In the developing world, an important transition is the replacement of traditional non-commercial energy carriers by modern energy sources. A recent analysis of the household energy transition in India and China reported that, despite sharp differences in the absolute amount of energy used and penetration of electric infrastructure, the overall trends in energy use and the factors influencing a transition to modern energy in both nations are similar (Pachauri and Jiang, 2008). Compared with rural households, urban households in both nations consume a disproportionately large share of commercial energy and are much further along in the transformation to modern energy. However, total energy use in rural households exceeds that of urban households because of a continued dependence on inefficient solid fuels, which contributes to over 85% of rural household energy needs in both countries. It has been found that, in addition to urbanization, key drivers of the transition in both nations include income, energy prices, energy access, and local fuel availability. Similar trends have also been observed in other parts of the developing world.

The study of transitions is an active area of research, and may provide many useful insights into the way that emerging trends and options for meeting energy-related goals might be facilitated and accelerated into larger-scale system transitions. This will require careful identification, documentation, and analysis of experiments that may have a potential to enhance sustainability, and that may be replicable and scalable. Crucially, research also shows that opportunities for these experiments to influence wider changes may depend upon processes that destabilize the incumbent energy regime and its institutions, and it may be necessary to consider the creation of sustainable alternatives in tandem with tensions within prevailing energy systems (Smith, 2005; Smith et al., 2005; Geels and Schot, 2007).

16.2 Technology-Driven Innovations Experiments

Experiments play an important role in long-term, large-scale transitions, particularly where there is a supportive policy environment that allows for promising experiments to evolve into niches that could challenge incumbent regimes. The challenges of access, cost, security, environmental, and health concerns are pushing for new ideas and technologies to emerge in the energy sector, creating a range of possibilities. This section assesses emerging experiments that are largely driven by technology innovation. Three categories of experiments are considered. The first consists of experiments that combine multiple primary energy sources for electricity generation, to overcome problems such as intermittency, and to increase reliability and availability. The second considers multiple energy end uses that may be addressed together, while the third category addresses experiments in which energy and non-energy services are provided simultaneously.

16.2.1 Combining Different Primary Energy Sources

Renewable energy technologies are A key element of all energy system evolution pathways that meet the GEA normative goals for sustainability (see Chapter 17). However, renewable energy sources, such as biomass, wind, and solar, vary greatly in intensity and availability, both diurnally and seasonally. This intermittency is an important constraint to their use. Performance may be improved by connecting non-correlated, multiple sources together, to create a hybrid system. A hybrid system typically consists of two or more energy sources, together with power conditioning equipment and optional energy storage. There is increasing experience with the design and operation of such hybrid systems. Mohamed et al. (2004) have demonstrated that hybrid energy systems can significantly reduce the total lifecycle cost of stand-alone power supplies in many situations, whilst providing a more reliable supply of electricity through the combination of energy sources. An example of hybrids that combine multiple renewable energy technologies are solar-wind LED-based lighting systems that are being used extensively in China for street lighting (Liu and Wang, 2009).

Sometimes, for reasons of resource availability, landscape, climate, or investment difficulties, it is not possible or feasible to harness more than one source of renewable energy. In such situations, conventional fossil fuels could be used to supplement the electricity generated through renewable options. For example, hybrid dual-fuel engine pumps using biogas obtained from community biogas plants are often the least expensive option for pumping irrigation water. The unit cost is further reduced for large-capacity biogas plants, reflecting the effect of an economy of scale in their capital cost, in comparison to pumps operating on-grid electricity, wind power, solar photovoltaic, and stand-alone biogas plants (Purohit, 2007). Similarly, Shaahid and El-Amin (2009) have discussed the techno-economic feasibility of using a hybrid solar photovoltaic-diesel battery power generation system for off-grid supply to Saudi Arabia's remote, unelectrified villages. Another approach to issues of variability and intermittency is the addition of storage or coproduction of another energy carrier, such as hydrogen. Energy storage technologies and related issues are covered in Section 16.3.1, while Chapter 15 examines the generation, storage, and use of hydrogen as a future energy carrier.

Hybridization may offer not only greater reliability, but also optimize the utilization of various energy resources. To maximize revenue from such systems, the optimum configuration will depend on resource availability, the capital and fuel input prices, and the prices of electricity generation from different sources (Dufo-López et al., 2009).

One interesting review by Paska et al. (2009) lists various hybrid combinations that are commercially available (see also Chapter 11), in development, or, at least, plausible (Figure 16.2). Potentially, hybrid energy systems are proving capable of adding reliability and quality to the existing power generation system, particularly as renewable energy systems seem to offer distinct, technology-specific advantages. This approach can be extremely useful in addressing region-specific power issues.

It is clear that most technologies mentioned above have been demonstrated successfully at the research and development stage, and even in small-scale application. To achieve an economy of scale, appropriate policy and enabling environment interventions may be needed.

Research into hybrid systems has focused mostly on the actual design and operation of generation technologies. However, constructing even a pilot plant or innovative, experimental system to evaluate the economic feasibility for each new location where a hybrid or renewable energy system is being proposed can be very cumbersome and capital intensive and can lead to disinterest among decision makers. In such situations, the use of mathematical modeling and simulation techniques may be an attractive alternative for assessing techno-economic feasibility. For example, Deshmukh and Deshmukh (2008) have produced mathematical models of hybrid solar and wind energy systems, including a diesel generator and a battery.

16.2.2 Addressing Multiple End-uses

The idea of hybridization could also be used to address multiple energy end-uses. The most common example is the use of heat produced during electricity generation for thermal applications or the use of waste heat for electricity production, i.e., cogeneration, or combined heat and power (CHP).

Low temperature heat produced by heat engines has very few applications, because most applications require heat at high temperature.

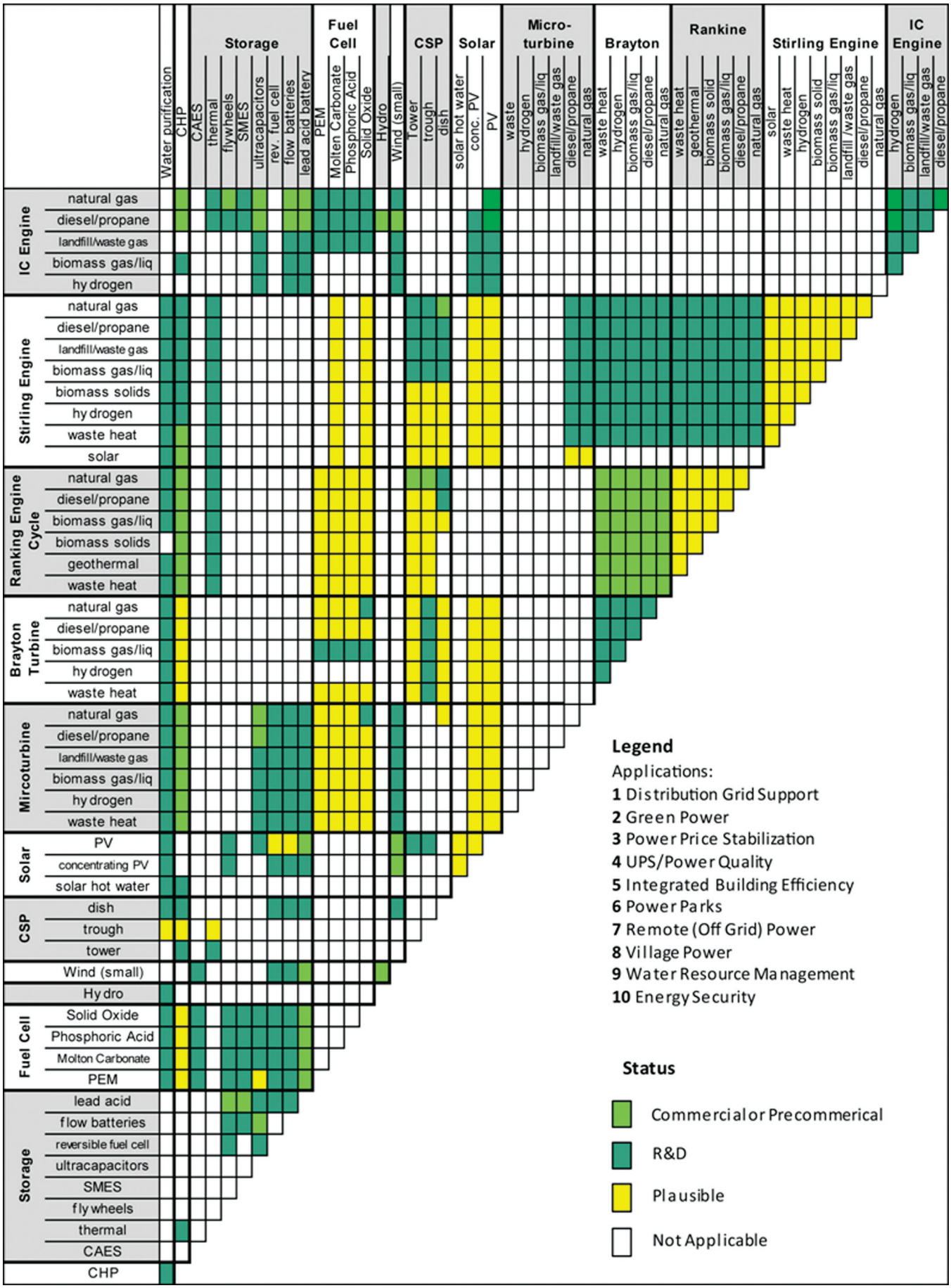


Figure 16.2 | Matrix showing overview of commercialized, research and development stage, and plausible combinations of hybrid technologies, including storage. Source: Paska et al., 2009.

However, if this heat can be harnessed to produce electricity on-site, which is technically possible, a CHP system is obtained. This category of micro-CHP system is generating much interest (Laughton, 1996; Hinnells, 2008). Such systems can operate in homes or small commercial buildings and are driven by heat-demand, delivering electricity as the by-product. Micro-CHPs have the added advantage of being able to run on renewable energy sources, such as wood, biomass, and solar thermal systems, as well as on fossil fuels. Gas turbines are used in most small systems because of their high efficiency, small size, clean combustion, durability, and low maintenance requirements. Natural gas is normally used to provide heat in a boiler or furnace by combustion, and the waste heat (usually from the waste gas stream) is used to generate electricity from a dynamo (generator). Marbe et al. (2004) show the economic advantage of cooperation between an industry and an energy company when a biofuel CHP plant delivers both process stream and district heating. District heating systems transfer and distribute heat from one or more centralized heating plants or CHP plants to individual homes, institutions, and industrial consumers for space heating and industrial processes. In Europe many heating systems are old and need upgrades and maintenance. The general development in the electricity sector towards distributed generation may have two advantages for the cogenerated heat. On the one hand, the generated heat is produced closer to the consumer, thereby reducing the losses. On the other hand, the system gets more dispersed with widespread smaller producers. As in the electricity sector, there will be a strong future need for making the distribution system more intelligent, with closer links between producer and end-user. One further development of district heating systems toward higher levels of sustainability is to combine the systems with solar heating systems and storage facilities, allowing a higher degree of overall optimization of the total system.

The district heating system might, in summer, be used for heat-driven cooling systems. Heat-driven cooling machines might also be used to offset part of the need for electricity for air- conditioning and thus reduce the peak load of electricity in the world's hot regions. A more direct way of district cooling is to develop specially piped chilled water circulating inside the cooling systems to end-use customers. Presently, the integration of district cooling and heating systems is used in the Finnish cities of Helsinki, Turku, and Lahti (Finnish Energy Industries, 2004). District cooling also makes it possible to prolong the utilization period of the maximum load in CHP plants.

Another interesting approach for the simultaneous delivery of heat and electricity is the use of fuel cells based on natural gas, where household needs for electricity and space heating could be met simultaneously. Brown et al (2007) describe micro-CHP using fuel cells in Japan. Simultaneous production of heat and electricity by hybrid solar photovoltaic and thermal systems could reach higher rates of solar energy conversion than stand-alone solar photovoltaic systems. Evaluation of relative payback time periods for both the systems demonstrate that the hybrid systems are cheaper (Kalogirou and Tripanagnostopoulos, 2006). End-use hybrids could also include systems where two different thermal end-uses are provided simultaneously without the intermediate production of electricity. For example, Rane and Dasgupta (2003) report a Multi-utility Vapor Compression System that simultaneously produces hot and cold water streams for different end-use applications, such as bathing and air-conditioning.

16.2.3 Delivering Energy and Non-energy Services

New opportunities may arise from the possibility of combining the delivery of energy services with non-energy services. One example that has attracted much recent attention is that of plug-in hybrid vehicles (PHEV), which create interesting possibilities around the combination of transport and electricity. Other examples include the use of waste heat for desalination of water for domestic and industrial use, the integration of waste management with electricity production, and more generally, the concept of energyplexes, where multiple energy carriers and other byproducts may be produced simultaneously.

The PHEV contains an internal combustion engine as well as batteries that can be recharged by connecting a plug to an electrical power source. It therefore shares characteristics with both traditional hybrid electric vehicles (HEVs), having an electric motor and an internal combustion engine, and battery electric vehicles (BEVs), also having a plug to connect to the electric grid. Depending on the vehicle control design, a PHEV can be driven solely on electricity until the storage battery charge is depleted, after which the vehicle can be operated as a traditional HEV powered primarily from petroleum (Bradley and Frank, 2009). This gives users the advantages of driving on electricity as with a BEV, without the limitation of a shorter range.

Benefits of the PHEV include reduced carbon emissions, economic operating costs, and more efficient use of existing electric system capacity (EPRI, 2007; Shiau et al., 2009). Even when the production of the vehicle's storage battery is included, the life cycle amount in gCO_2-eq/km of a PHEV are below that of a conventional hybrid vehicle, when the PHEV is charged with electricity that has about 650–750 gCO_2-eq/kWh (Samaras and Meisterling, 2008). Other benefits include fewer fill ups at service stations, the convenience of home recharging, opportunities to provide emergency backup power in the home, and vehicle to grid applications. Disadvantages include a battery pack with increased size and cost, the requirement of public and home electrical outlets, potentially increased peak electrical loads, and increased pollution in some areas from increased electricity production from coal, although overall pollution declines (Simpson, 2006; EPRI, 2007). The availability of a distributed system of PHEVs may create the opportunity for large-scale storage and integration of variable renewable energy in the future (Kempton and Tomic, 2005).

The user cost, fuel use, and greenhouse gas emissions of PHEVs also depend critically on the size of the battery and the distance traveled. Further efficiency can be added to PHEVs by using newer batteries, such as closed-system regenerative fuel cells, instead of the regular battery. The regenerative fuel cell uses the conversion of water into its

Box 16.2 | The Future of Solid-state Lighting for General Illumination

The International Energy Agency has estimated that worldwide lighting is responsible for emissions of approximately 1900 $MtCO_2$/year, with 80% of these emissions being associated with electricity generation, and 20% from the 1% of global lighting that is produced by the direct combustion of paraffin and oil lamps used (IEA, 2006). Dramatically improved lighting system efficiency, together with electrification, could make a large contribution to controlling global CO_2 emissions. The most widely used technology, the incandescent bulb, converts only between 1% and 5% of the electricity into usable light. To address and overcome such inefficiency and concerns for the environment, energy security, and affordability, legislatures and regulators in the European Union (EU), Australia, Brazil, Canada, Ireland, Italy, New Zealand, the United States, and Venezuela have all recently moved to implement a mandatory phase-out of most standard incandescent bulbs over the coming decade. Most remaining countries in the EU are likely to adopt similar policies. Solid-state lighting uses technology based on a light-emitting diode, which has the potential to achieve such objectives.

Monochromatic LEDs have seen a very sharp increase in efficacy over a very short period of time when compared with other lighting technologies. Today, red and green LED efficacies are as good as, or better than, fluorescent and high intensity discharge technologies. Commercialized white solid-state lighting is expected to reach those levels in just the next few years, and still is far from reaching theoretical limits that have already constrained future improvements in incandescent and fluorescent lamps.

Solid-state lighting shows great promise as a source of efficient, affordable, color-balanced white light. Azevedo et al. (2009) have shown that, assuming market discount rates, white solid-state lighting already has a lower annualized cost than incandescent bulbs. The annualized cost for white solid-state lighting will be lower than that of the most efficient fluorescent bulbs by the end of this decade. However, much of the literature suggests that households do not make their decisions in terms of simple expected economic value. Assuming higher discount rates on consumer decision-making will delay the adoption of solid-state lighting technology. Successful consumer adoption will depend on, among other things, the availability of solid-state lighting products providing high color quality, high efficiency, and a low up-front cost.

Sources: IEA, 2006; Azevedo et al., 2009.

components, hydrogen and oxygen gases, whose recombination (again, to produce water) generates energy. The gasoline consumption of the vehicle can be reduced by over 80%, whilst reducing the operating cost of the vehicle by about US$200/year by 2010 and US$500/year if less expensive air-cooled engines are used in plug-in fuel cell hybrid electric vehicles (PFCHEV) (Suppes, 2006). A further advantage is found in solar chargers to recharge these plug-in hybrid vehicle systems during the day, when most people are at work (Birnie, 2009). Parking lots can thus become large solar recharging stations for commuters.

The use of low-energy lighting can also provide co-benefits (Box 16.2).

Another interesting example is the use of industrial waste heat, generated in a power plant or a chemical plant, to desalinize water from the sea and make it potable. Desalinization is a highly energy-intensive process, where seawater is distilled by heat from coal- or oil-fired boilers. Multi-stage flash distillation currently accounts for over 85% of the world's desalinized water, while the rest uses mostly membrane-based reverse osmosis process (Water Technology, 2009). The heat currently generated by fossil fuels dedicated solely to desalinization units can alternatively come from waste heat from power plants. Chacartegui et al. (2009) examine one example. Their research, taking a thermal power plant in Spain as a case study, shows that desalinization is actually the most efficient and most economically and technically feasible option of cogeneration that can be obtained from a power plant. This is because the waste heat from the power plant is at a temperature that is too low for most other options, such as residential and district heating/cooling and oil-refining. The desalinization unit can be installed with minor configuration changes, such as increasing the plant's condenser pressure and installing a heat exchanger at the top of the stack.

Mahmoudi et al. (2008) have assessed the feasibility of using hybrid (wind and solar) energy conversion systems to meet the energy needs to power a seawater greenhouse.[1] Examination of the data collected confirms that it is technically feasible to take advantage of renewable energy to run the seawater greenhouse and produce freshwater without the back-up support of fossil fuel energy sources. An attempt to scale-up these concepts in practice is the Sahara Forest Project, a collaborative effort of the Jordanian and Norwegian governments. The project, targeted to commence in 2015, attempts to simultaneously provide water for a greenhouse for growing crops, desalination for drinking water, and solar thermal for electricity

1 Seawater Greenhouse: The seawater greenhouse is a method of cultivation adopted in arid coastal areas that provides desalination, cooling, and humidification in an integrated system. Its purpose is to provide a sustainable means of agriculture where scarcity of fresh-water and expense of desalination make agriculture unviable (Davies et. al, 2004).

production and is a good example of an integrated system that attempts to generate energy and non-energy co-benefits.

Waste-to-energy projects are gaining popularity in the developing as well as the developed world. These experiments and niches offer the opportunity of generating electricity and heat as well as assisting in waste management, thus generating non-energy related co-benefits. A recent experiment in India illustrates the interaction of social, technological, economic, and policy-related aspects around electricity generation using cattle-waste as a primary fuel (Patankar et al., 2010). This experiment represents local technology adaptation of bio-methanation and electricity generation technologies prevalent in other applications, and independent plant management as success parameters to ensure waste collection and energy throughput. In addition to electricity generation, the experiment contributes to waste management and greenhouse gas mitigation.

Solid waste management offers opportunities to simultaneously meet waste management, climate mitigation, and electricity generation objectives. Landfills are the primary mode of disposal for municipal solid waste in developing countries. Methane emissions from landfills, occurring as a result of the natural decomposition of waste, are estimated to account for between 3% and 19% of anthropogenic emissions globally (Mor et al., 2006). The landfill gas generated can be extracted from the landfills through a gas recovery system. Once collected, this gas can be utilized for electricity generation or used as an alternative vehicle or industrial fuel such as in Sweden (Lantz et al., 2007). Municipal solid waste could also be converted into refuse-derived fuel, for use in electricity production or other industrial applications as a substitute for coal or traditional biomass. This conversion helps in higher and constant heating value; homogeneity of physical-chemical composition; ease of storage, handling, and transportation; lower pollutant emissions; and a reduced excess air requirement during combustion. While the production and sale of refuse-derived fuel alone might not be economically viable, there are benefits associated with regard to waste management and the reduction of pressure on landfills. The economics may improve further if the refuse-derived fuel is used for downstream electricity production, as that offers additional opportunities for incentivization (Caputo and Pelagagge, 2002a; 2002b).

Another promising alternative is the development and deployment of integrated energy conversion and end-use systems. In energy conversion, these integrated systems are also known as energyplexes. They are highly efficient and incorporate advanced technologies that may have fuel flexibility and allow for various combinations of electricity, liquid fuels, hydrogen, chemicals, and/or heat. Yamashita and Barreto (2005) have explored three co-production strategies based on coal gasification, namely hydrogen and electricity, Fischer-Tropsch (F-T) liquids and electricity, and methanol and electricity. Using these examples, they have highlighted the important role that integrated energy systems and enabling poly-generation strategies may play in long-term global energy supply systems. Specifically, emphasis has been laid on the role of synthesis gas (or syngas) as a key energy carrier for a multi-fuel, multi-product system based on carbonaceous feedstocks. Since syngas can be obtained not only from natural gas but also from solid energy carriers such as coal and biomass, this allows for its conversion into higher quality, cleaner, and more flexible energy carriers. Because syngas production systems are similar, or at least compatible to some extent, this could facilitate the introduction of multi-fuel systems, provided that technical issues over the quality and variety of feedstocks can be overcome. Hu et al. (2011) have attempted a techno-economic evaluation of coal-based polygeneration systems. China is abundant in coal reserves but deficient in oil and gas, which poses a challenge of utilizing the fossil fuels efficiently and cleanly. Polygeneration system technologies for chemical and power coproduction are therefore becoming more important. When compared with conventional synthetic fuel production systems and power generation technologies, with system integration, the polygeneration technology can achieve a trade-off between primary installed capital cost and fuel savings. That can effectively reduce the cost penalty for CO_2 avoidance. The polygeneration system, without shift reaction and the adoption of a partial recycle scheme, can achieve the optimal primary cost saving of over 10%. Another novel technique proposes the synthetic utilization of coal and natural gas through a combined cycle process of dual fuel-reforming. In this technique, the thermal heat released from burning coal is absorbed by the reforming reaction and transformed into chemical energy of the syngas (Han et al., 2007). Since the chemical energy of natural gas and coal is used more efficiently, the net thermal efficiency of coal to power can reach from 43.5% to 46.3%, which is almost equal to the efficiency of the integrated gasification combined cycle. Sensitivity analysis shows that the performance of the new cycle can be improved further to about 50%. Further, the net specific investments of coal to power, and the operating cost of the new combined cycle, are also lower than the integrated gasification combined cycle.

16.3 Experiments and Niches in System Configuration and Operation

Technological change and innovation is also creating opportunities for improvements in overall system operation. For example, the smart grid is an umbrella term used for a range of technologies to enhance system operation and performance and perhaps transform the grid from a centrally controlled entity to several self-controlled sub-networks (Hamidi et al., 2010). The array of technologies observed in today's smart grid ranges from smart metering to simulating business models with variations in configuration and operation. The improvements in computer communications and networks enhance the ability to optimize generation, demand management, and integration of renewable energy resources (Rahman, 2009).

Amongst the range of experiments related to system configuration and operation, four emerging ideas seem to have significant transformational potential for the future. These include energy storage, distributed generation, micro-grids, and business models around energy service delivery.

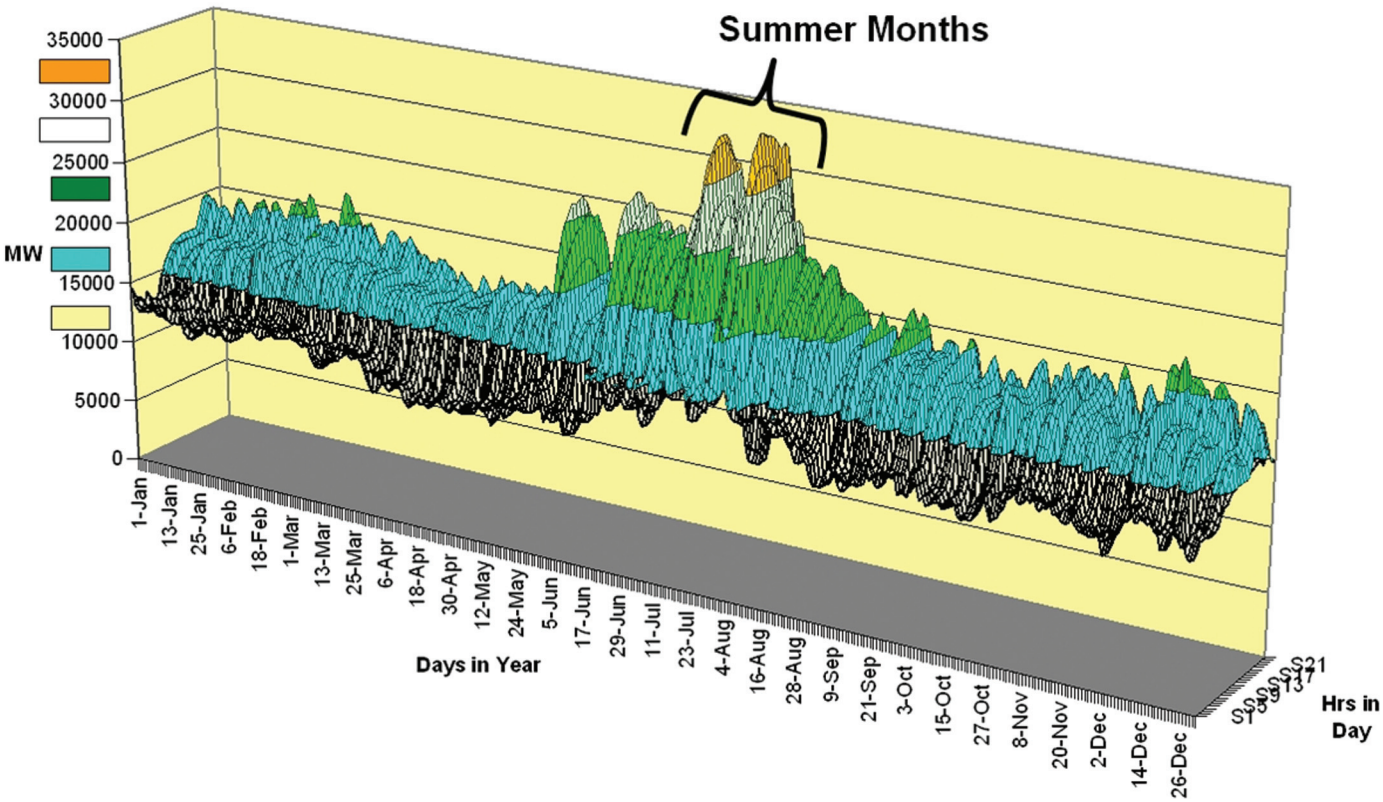


Figure 16.3 | Variability in daily system load curves for NY (using 2006 load data from NYISO). Source: Walawalkar, 2008.

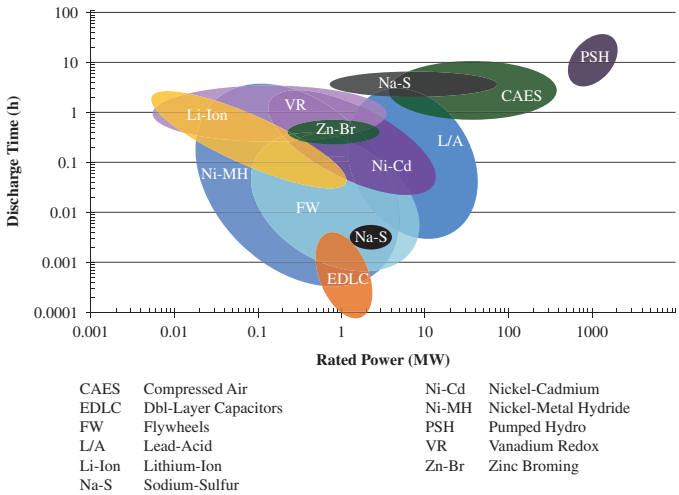
16.3.1 Energy Storage

Although the present electric grid operates effectively without storage, cost-effective ways of storing electrical energy can help make the grid more efficient and reliable. The amount of load in most electrical grids changes from hour to hour and from day to day (Figure 16.3). In most regions, system operators typically try to meet this demand by using least-cost economic dispatch, based on available generation and transmission. Electric energy storage (EES) can be used to accumulate excess electricity generated at off-peak hours and discharge it at peak hours, thus reducing the need for peak generation and reducing the strain on transmission networks. EES can also provide critically important ancillary services such as grid frequency regulation, voltage support, and operating reserves, thereby enhancing grid stability and reliability.

Unlike other energy forms, electricity cannot be easily stored in large quantities. Without storage, there is little flexibility in managing electricity production and delivery. Likewise, intermittent renewable energy resources such as solar and wind are constrained in their ability to practically enter the bulk electricity market and keep pace with its continuously changing demands (see Chapter 11). Advanced storage technologies promise to change the nature of electricity markets by providing much greater operational and financial flexibility and enabling carriers to resolve system transients and bottlenecks. The accelerated development and implementation of more cost-effective, higher capacity storage options, including batteries, flywheels, super-capacitors, hydrogen, and super-conducting systems, is the critical issue underlying further diffusion. Today, most of these bulk storage options are relatively unproven, and their value proposition is complex and poorly understood.

For example, the lead acid battery is the most used for large energy storage as well as all types of stationary applications (Perrin et al., 2005). However, advanced batteries being developed for large- scale applications include nickel cadmium, sodium sulfur, sodium nickel chloride, lithium ion, and zinc bromine. Advanced batteries are moving towards commercialization[2], although they remain too expensive for large-scale electricity carrier and storage system application. However, significant cost reductions are expected as modular design and factory assembly become the norm and production volumes increase substantially. Particularly notable from a strategic perspective is the lithium ion battery, being targeted for electric vehicle applications, and the sodium sulfur battery, with the latter being used in Japan for more than 200 MW of energy storage installations (Baker, 2008). The total worldwide market for energy storage products was estimated at around US$26 billion in 2005 (Frost and Sullivan, 2006). About 59% of this market came from

2 A recent commercial-scale deployment of Na-S batteries is a project in Texas, US, where a 4 MW Na-S was energized to the grid in March 2010, with the objective of providing transmission backup in the event of a transmission line outage, along with additional benefits of improvement in power quality. For more information, see ETT, 2011.



CAES	Compressed Air	Ni-Cd	Nickel-Cadmium
EDLC	Dbl-Layer Capacitors	Ni-MH	Nickel-Metal Hydride
FW	Flywheels	PSH	Pumped Hydro
L/A	Lead-Acid	VR	Vanadium Redox
Li-Ion	Lithium-Ion	Zn-Br	Zinc Broming
Na-S	Sodium-Sulfur		

Figure 16.4 | Energy storage system ratings (rated power vs. discharge time) for installed systems (November 2008). Source: Roberts, 2009. © Energy Storage Association.

sales of automotive starting batteries. Another 27% of the total market was concentrated in portable electronics, while motive power (batteries for, e.g., forklifts, golf carts, and electric vehicles) constitutes about 6.6%. Only about 6% of the market, or around US$1.5 billion, came from stationary power products (Frost and Sullivan, 2006). Most of these sales were for backup power applications, such as UPS systems, substation and generating plant backup batteries, and telecom backup batteries. The market for energy storage in utility applications, other than their use as backup batteries, is relatively small. EES technologies can be grouped as electrochemical and non-electrochemical EES technologies. The most common EES technologies are:

- Electrochemical EES
- Lead Acid Battery
- Sodium-Sulfur Battery
- Flow Batteries
- Vanadium Redox Battery
- Zinc Bromine Battery
- Nickel Cadmium Battery
- Nickel Metal Hydride Battery
- Lithium Ion Battery
- Non-Electrochemical EES
- Pumped Storage Hydroelectric
- Compressed Air Energy Storage
- Flywheel
- Ultra-Capacitor
- Superconducting Magnetic Energy Storage (SMES)

The EES technologies listed above and shown in Figure 16.4 are described in detail in EPRI (2003; 2004) and Gyuk et al. (2005). In general, large-scale applications of energy storage have been limited to the utility industry. Utility-scale projects based on storage technologies other than pumped hydroelectric storage have been built, though they have not become common. Existing US facilities include one Compressed Air Energy Storage system, several plants based on lead-acid batteries, one based on nickel-cadmium batteries, and recent installations of sodium sulfur batteries. There are also recent installations of lithium ion batteries and flywheels for frequency regulation in regions where there are spate markets for frequency regulation through Independent System Operators/Regional Transmission Organizations (ISO/RTOs). In all, some 2.5% of the total electric power delivered in the US passes through energy storage, largely pumped hydroelectric. The percentages are somewhat larger in Europe and Japan, at 10% and 15%, respectively (EPRI, 2003). The most widespread form of electricity storage used for utility scale applications is pumped hydroelectric storage, with over 90 GW of installed capacity throughout the world. According to the US Energy Information Administration, the United States had 150 pumped storage plants with a total nameplate capacity of 19.5 GW in 2005 (US EIA, 2005).

There are technical as well as market barriers for the wide-scale integration of energy storage for wholesale market applications. At present, most energy storage technologies have higher capital costs than peaking power alternatives, such as gas turbines. While capital costs are falling somewhat due to technology improvements, significant manufacturing economies of scale have not yet been realized (EPRI, 2003; 2004).

In the longer term, the introduction of energy storage can potentially resolve the renewable energy intermittency challenge. The type of storage under consideration ranges from advanced stationary batteries to other emerging technologies, such as electrochemical capacitors, thermal storage using ice, pumped hydro technology, and compressed air energy storage (Roberts, 2009). The advanced compressed air energy storage system essentially uses the concept of compressing air and storing it during off-peak hours when energy prices are very low and running a turbine with the released air to produce electricity when needed. Because the compressed air is blended with the input fuel in the turbine, it produces much more power than conventional stand-alone gas turbines. Such systems have already been installed in places like Handorf, Germany, and McIntosh, AL, United States. Locations considered ideal for these systems are underground geological formations, such as mines, salt caverns, or depleted gas wells. The largest of these, with a capacity of 800 MW, was proposed to be installed in the United States as of August 2009 (Roberts, 2009). While these systems have mostly been built on the principle of using energy from a conventional electricity grid, they can also be designed as a hybrid to use renewables like wind energy (from turbines) to compress the air.

16.3.2 Decentralization of Power: Distributed Generation

The provision of electricity remains a major challenge in many developing countries. The typical policy response has been to mount aggressive and large-scale rural electrification schemes. Advances in technology and the possibilities provided by hybrid systems may make it more attractive technically and economically to provide these modern energy

services through distributed, off-grid generation options. Recent studies have tried to make explicit the trade-offs and choices between these two modes for electrification and energy service delivery.

Distributed generation is the concept of having decentralized, small generating units that may or may not be connected to the main grid, but are usually located close to the point of end-use (Bayod-Rújula, 2009). Distributed systems may be connected to the grid, or they may operate independently. They are generally not centrally controlled and, with few exceptions at the present time, are not dispatchable; that is, they cannot be switched on and off according to the needs of the grid unless they incorporate suitable grid support technologies, such as energy conversion and storage (Larsen and Peterson, 2005).

Distributed generation provides consumers with opportunities to gain benefits, such as a degree of energy independence, opportunities for local control to improve security of supply, financial optimization, equal or better power quality, and a cleaner environment. It also offers a possibility of including millions of small suppliers, providing a high proportion of renewable energy sources. With distributed generation, homes and businesses could produce their own electric power and heat using various technologies or a mixture thereof. Excess power would be sold to the grid, and consumers could obtain from the grid any power that they did not generate themselves.

Distributed generation is often described as 'integrated' and 'decentralized' to distinguish it from traditional centralized systems, in which power is generated at large, centrally located, and centrally controlled plants. Electricity is presently the dominating medium of exchange in distributed generation, although heat from, for example, combined heat and power (CHP) plants also plays an important role in district heating and other kinds of energy supply. In the long run, energy carriers such as hydrogen and biofuels are expected to contribute very significantly to the energy exchange in distributed generation. Regardless of size, fuel, or technology, the central issue in distributed generation is the large-scale integration of decentralized energy resources.

The generating technologies and energy sources behind distributed generation include wind, solar, micro-hydro, biomass, geothermal energy, and wave or tidal power. These share several attributes:

- energy resources that are geographically dispersed and unevenly distributed;
- energy resources that are typically intermittent, varying by the hour or the season, and not available on demand (some technologies, such as fuel cells and micro turbines, are not intermittent);
- energy that is typically produced as electricity, rather than some other energy carrier that is easier to store; exceptions include biomass and hydropower based on reservoirs; and
- in electricity-driven technologies, heat may be a by-product; in the same way, electricity may be a by-product in heat-driven technologies.

These characteristics, and the inflexibility of most renewable energy technologies, pose important constraints on and requirements to energy systems based on distributed generation. As the share of renewables grows, energy systems (and their necessary support technologies) will face increasing challenges to their operation and future development, affecting both the supply and demand side. Information and Control Technology will be very important to the successful integration of these renewable energy options.

The perceived benefits of distributed power systems include increased reliability of service, improved power quality, the ability to defer investment in extending the grid, and greater energy efficiency, e.g., through better use of waste heat. Of these drivers, reliability of service is one of the most important. Increasingly, consumers need uninterrupted power supplies, yet many existing grids cannot operate without occasional blackouts. Finally, the redundancy offered by a distributed generation network, with its intertwined multitude of generators, converters, and connections, will certainly enhance the security of the power system to deal with acts of terrorism.

Distributed generation based on a high proportion of renewable energy will depend on a number of support technologies that include energy storage and load management to deal with the fluctuating power and intermittency from renewable sources such as wind turbines. Once the concept is fully developed, distributed generation, in addition to the obvious benefit of providing a cleaner environment, has the advantage in that it is easy to add generating capacity as required, using local energy resources. The cost of such expansion is predictable over the life cycle of the generating plant, regardless of price fluctuations and shortages that may affect fossil fuels in the future.

Of the various barriers to a robust implementation of distributed power, key factors include the need for reliable interconnections between distributed generation systems and the grid, and the quality assurance that includes the testing and certification of distributed generation systems and components. Developing standards, procedures, and techniques for the design, testing, and certification of distributed generation systems is relatively new, but it can draw on experiences developed in the wind industry over the last two decades for both systems and projects. Other pacing issues include the lack of experience in understanding how various distributed generation systems interact when a variety of designs are broadly deployed, and the increasing complexity of physical and cyber security issues as the number of electric system participants grows. Proper availability and provision of skills for the maintenance and repair of such systems is also an issue.

New electricity pricing and electricity supplier business structures will be needed in many jurisdictions to remove the reduced bulk electricity sales

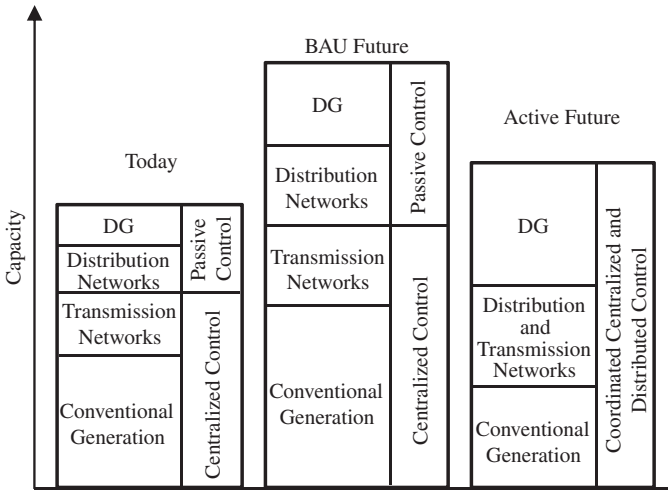


Figure 16.5 | Passive vs. active management of distribution networks. Note: BAU = Business As Usual. Source: Cossent et al., 2009.

disincentives that monopoly electricity suppliers now experience when they encounter user-sited distributed generation. These can be replaced with incentives that encourage distributed generation investments that achieve widely accepted societal benefits such as carbon reduction. The use of a more distributed power generation system will be an important element in protecting consumers against power interruptions and blackouts, whether these are caused by technical faults, natural disasters, or terrorism. Figure 16.5 proposes a Coordinated Centralized Control Mechanism for better control of grids that use distributed generation (Cossent et al., 2009).

Distributed generation appears to be a more promising approach where grid connectivity does not exist. In such regions, distributed generation offers an alternative to grid extension. One such case study identifies niche areas in India where renewable energy-based decentralized generation options can be financially more attractive than grid extension for providing electricity (Nouni et al., 2008). They estimated the cost of delivering electricity in remote areas, considering the cost of electricity generation, and also the cost of its transmission and distribution in the country, where about 70% of the population live in rural areas (see Chapter 24).

Nouni et al. (2008) also analyze the relative contributions of different factors to the levelized unit cost of electricity. At any location receiving electricity through the grid, the delivered cost of electricity consists of three components: (a) cost of generating electricity at the bus bar of the centralized plant; (b) cost of transmitting electricity through the transmission network; and (c) cost of distribution. For electricity generated from coal thermal power plants, the delivered cost of electricity in remote areas located in the distance range of 5–25 km was found to vary from INR[3] 3.18–231.14/kWh (US_{2005}\$0.073–5.32/kWh), depending on the peak electrical load up to 100 kW and on the load factor (Nouni et al., 2008). The paper concluded that all renewable energy-based decentralized electricity supply options (such as micro-hydro, dual-fuel-biomass gasifier systems, small wind electric generators, and photovoltaics) could be more financially attractive than grid extension in providing access to electricity in remote villages.

A similar study in Cameroon (Nfah and Ngundam, 2009) uses software simulation to examine the breakeven distances for grid extension compared to distributed generation using hybrid systems. Pico-hydro and photovoltaic hybrid systems incorporating a biogas generator were simulated for remote villages in Cameroon based on a load of 73 kWh/day and 8.3 kW peak. For a single wire grid extension cost of €5000/km (US_{2005}\$6329/km), operation and maintenance costs of €125/km (US_{2005}\$158/km) per annum, and a grid power price of €0.10/kWh, the breakeven grid extension distances were 12.9 km for pico-hydro/biogas/battery systems and 15.2 km for photovoltaic, biogas, and battery systems, respectively.[4]

By giving more emphasis to distributed generation, the United Kingdom can potentially reduce its energy losses in the transmission and distribution system of electricity. Including the waste heat generated during electricity production, this currently amounts to about 65% of the energy input (Allen et al., 2008). However, technical barriers still cause significant impediments to their growth. These include grid integration, planning permission, and licensing issues, because the main grid is designed for large-capacity centralized power generation (Sauter and Watson, 2007). Financial and economic barriers also exist, notably including the poor performance of the Low Carbon Buildings Programme grant given directly to home owners to encourage distributed generation using renewables. For instance, according to the UK Department of Trade and Industry, a domestic solar photovoltaic installation in 2006 could cost up to £10,400 (US_{2005}\$19,259),[5] and it could supply about 51% of the average annual electricity demand of the house. However, the maximum available Low Carbon Buildings Programme grant for this is £2500 (US_{2005}\$4630), which is too little to make the distributed generation system an economic option (Allen et al., 2008). Wolfe (2008) has also described the Low Carbon Buildings Programme grants as too limited in nature to cause a significant surge in distributed generation. A general lack of monitoring and information on distributed generation also prevents a faster growth of successful commercialization of these new systems.

Nevertheless, many European Union countries have managed to achieve appreciable distributed generation contributions using renewable energies in their electricity supply. Figure 16.6 shows the percentage

3 US\$1.00 = INR45.80 (October 20, 2006)

4 US\$1.00 = €0.71 (July 01, 2009)

5 US\$1.00 = £0.54 (July 01, 2006)

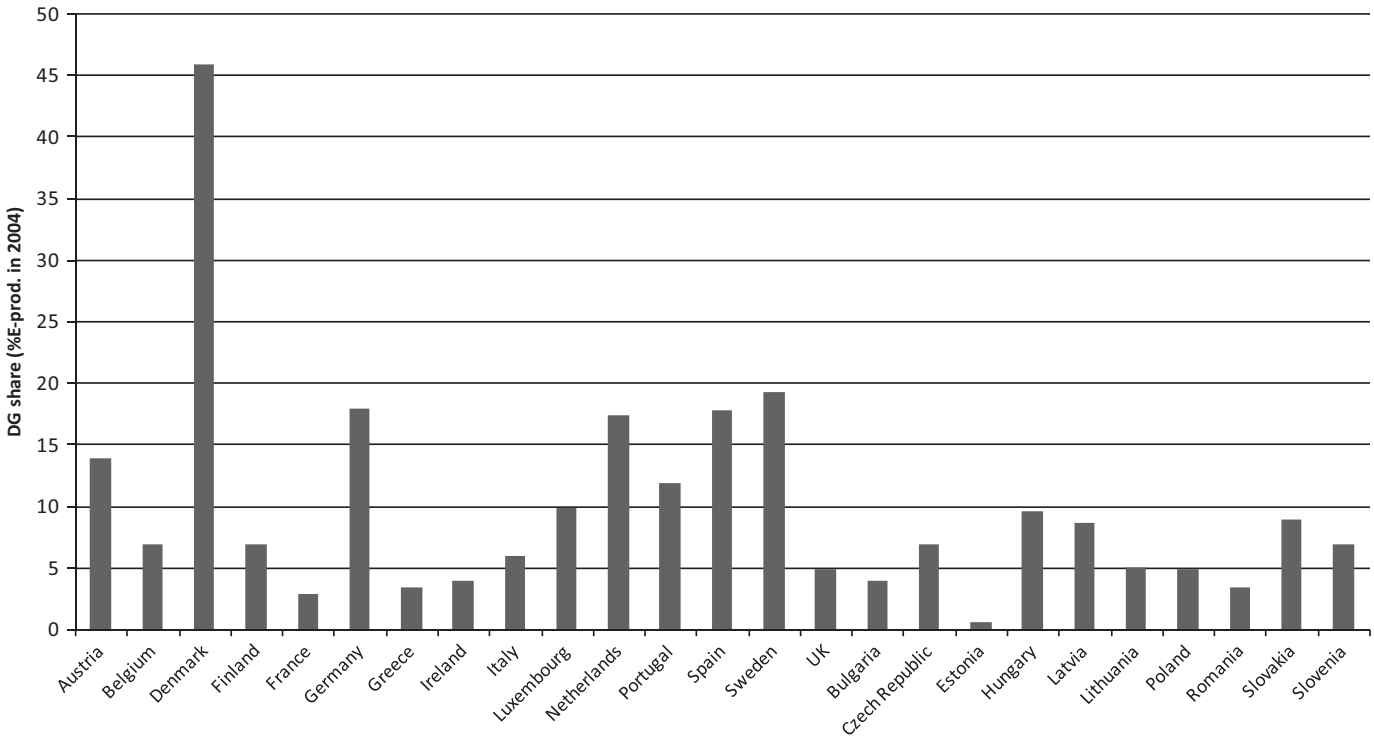


Figure 16.6 | Distributed generation shares in total electricity production in 25 EU countries (2004). Source: Cossent et al., 2009.

contribution of distributed generation in each EU member's total electricity generation in 2004 (Cossent et al., 2009). Denmark scores the highest, with over 45% of its electricity coming from distributed generation resources. It is interesting to note that historical circumstances, next to favorable policies, have played a critical role in the success of distributed generation in Denmark, particularly the role of the cooperative movement in the Danish power industry (van der Vleuten and Raven, 2006).

16.3.3 Aggregating the Distributed Energy Resources (DERs): The Micro-grid

Distributed generation has many benefits and, although it is commercially stable, its growth has been rather slow. DERs can be much more economic if they are realized as a micro-grid. A micro-grid is systems architecture: an aggregate of DERs in a small power network that can provide electric power and often heating and cooling to a small group of closely located customers (King, 2006). This combines the advantages of DERs with those of the micro-grid, the latter being aggregated demand, increased reliability, and an ability to share the capital costs.

Intelligently interconnected buildings and distributed electricity generation are the most critical elements of the micro-grid architecture. It is also becoming feasible to incorporate mobile electricity storage in the form of plug-in electric vehicles (PHEVs). Micro-grids will enable an electricity delivery network strategy where transportation can become an efficient energy supply source, particularly during high cost, peak demand periods. The essential enabling policy step to realizing the full benefits of distributed generation, micro-grids, and PHEVs is time-of-use electricity pricing, which incentivizes consumers to be efficient and to take advantage of the resulting savings.

The interface between the micro-grids and the wider electricity distribution network is through a well-defined and controlled interface utilizing smart grid technologies. The micro-grid is designed and operated to best serve the needs of its customers, ensuring a precise quantity and quality of electricity supply that most efficiently and cost-effectively meets the needs of those customers at all times. In effect, the micro-grid acts as a local electricity refinery, raising the reliability, efficiency, and quality of the bulk electricity supply system.

Although there are a variety of potential micro-grid ownership and operation alternatives, micro-grids intrinsically lend themselves to local cooperative ventures where consumers may also be suppliers (Sauter and Watson, 2007). Metering and billing arrangements are agreed upon locally to reflect the market needs for power within each micro-grid. Micro-grids can also take full advantage of current commercial energy storage technology to accommodate rapid fluctuations in electricity demand or supply.

Micro-grid development in the United States has taken a somewhat different path than similar efforts in Japan and Europe. In the United

States, the emphasis has been on compensating for the relatively poor reliability and power quality provided by the nation's bulk electricity supply system. This is in contrast to Europe and Japan, where the emphasis has been on incorporating clean distributed electricity generation. Micro-grid development efforts in the United States have been led by the Consortium for Electricity Reliability Solutions and, more recently, by the California Energy Commission and the Galvin Electricity Initiative. Prototype micro-grid demonstrations include the Fort Bragg military base in North Carolina, the Beach Cities Micro-grid project in San Diego, CA, and the Illinois Institute of Technology campus in Chicago (GalvinPower, 2010). General Electric is also developing a Micro-grid Energy Management framework to provide a unified control, protection, and energy management platform. Unfortunately, micro-grids are still not defined in most US states' regulatory laws and are usually subject to case-by-case interpretation of regulatory laws for the main power grids, their suppliers, and their customers (King, 2006). Steps such as formalizing the definition and legal rights of micro-grids, adopting formalized procedures for their interconnection with the main grid, and formalizing the responsibilities of the micro-grid owner would greatly help to encourage this new power architecture, along with the great scope for innovation and creativity that it potentially has.

In the European Union, several major research efforts have been devoted to distributed generation micro-grids. These include a consortium led by the National Technical University of Athens, along with utilities, equipment suppliers, and research teams from many EU countries. Demonstration sites include Kythnos Island, Greece, and Mannheim-Wallstadt, Germany. Japan is also a leader in micro-grid demonstration projects. These generally serve the purpose of ensuring that the fluctuating power of distributed renewable energy resources does not degrade Japan's outstanding electricity reliability and power quality. These projects are demonstrating the technical feasibility of micro-grids incorporating renewable energy, while providing multiple levels of power quality and reliability with constant bulk electricity delivery system inflows.

16.3.4 Business Models for Energy Service Delivery

Optimization across demand and supply has created the possibility of new business models centered on the energy service companies (ESCOs). ESCOs are private or public companies that can provide the technical, commercial, and financial services needed for energy efficiency projects. ESCOs may assume a variety of risks, including project performance risk (technical risks associated with the project), arrange financing for the project, and, depending on their reach and agreement with the client, may also take customer credit risk (financial risks). This is done through a performance contract between the ESCO and customer. Two popular models of ESCO operation are:

- *Shared saving contracts*: the ESCO finances the project either from its own fund or by borrowing from a third party. Thus, the ESCO assumes the performance as well as the credit risk.

- *Guaranteed savings contracts*: the customer finances the project by borrowing funds from a third party. Finance is usually arranged by an ESCO, but the loan contract is between the bank and the customer. The ESCO takes only the performance risk by guaranteeing the savings.

In general, the services provided in the two models above are characterized in Table 16.1.

ESCO models may be evaluated with regard to their business sustainability and viability, attractiveness to entrepreneurs, technology linkages and requirements, and the enabling environment required. At the level of firms or in the public systems (buildings, water pumping, street-lighting), the role of ESCOs has proven to be successful at various levels. ESCOs provide multiple services related to the diagnostics of existing energy-use patterns and the implementation of identified technical interventions, including technical, operation, and maintenance services.

Different levels of success characterize the maturity of the ESCO industry in North America and Europe, compared to the evolving ESCO industry in Asia and Africa. ESCOs are still at a nascent stage in developing countries. Painuly et al. (2003) describe a number of barriers to ESCOs in developing countries, including market barriers, institutional barriers, financing barriers, and knowledge and information barriers. They suggest that market development through the active involvement of governments as a customer, information provider, and policymaker is required to promote ESCOs. Local financing markets need to be boosted through the development of special energy efficiency financing windows in appropriate financial institutions such as banks. Skills for energy efficiency project appraisal and for the development of financial products to execute energy efficiency projects also need to be developed. In some cases, specialized energy funds and guarantee funds may be needed to kick-start the investment in energy efficiency projects.

ESCOs have a much longer history and a richer knowledge base in developed countries. Vine (2005) reports that, based on an international

Table 16.1 | Two models of energy service companies.

	Energy auditing	Project structuring	Project financing	Implementation	M&V	Stake in perpetual savings
Guaranteed savings	Yes	Yes	No	Yes	Yes	Limited
Shared savings	Yes	Yes	Yes	Yes	Yes	High

survey, the total amount of ESCO activity outside the United States in 2001 was between US$560 million and US$620 million. This is approximately half to one-third of the ESCO revenues in the United States for 2001.

Goldman et al. (2005) present a detailed empirical analysis of project data and market trends in the United States. They estimate that industry investment for energy efficiency related services reached US$2 billion in 2000, following a decade of strong growth. ESCO activity is concentrated in states with high economic activity and strong policy support. Typical projects save 150–200 MJ/m^2/year and are cost-effective, with median benefit to cost ratios of 1:6 and 2:1 for institutional and private sector projects, respectively. The median simple payback time is seven years among institutional customers; three years is typical in the private sector. They conclude that appropriate policy support, both financial and non-financial, can jump-start a viable private sector energy efficiency services industry that targets large institutional and commercial or industrial customers.

The ESCO market is quite diverse. Historically ESCOs were distinguished from other energy efficiency providers by their use of performance contracting as a core business activity. Increasingly, however, ESCOs are moving away from performance contracting, instead installing energy efficiency projects on a design/build or fee-for-service basis and offering additional services such as energy consulting and information services. Other ESCOs also provide performance-based services beyond the traditional shared savings and guaranteed savings mechanisms, such as build/own/operate contracts for major energy facilities at customer sites. Some ESCOs have pursued new business opportunities in restructured electricity and natural gas markets, combining commodity procurement with energy price risk management and energy efficiency services in a single, bundled product.

Although the ESCO concept has been working well globally, there are challenges facing ESCOs in developing countries, including:

- the creditworthiness (technical and financial) of ESCOs;
- the availability and acceptability of well-drafted energy service contracts and/or agreements;
- arranging finances for the implementation of projects (both equity and loans) for successful demonstration projects;
- performance guarantees: users want the ESCO to indemnify them if promised energy savings do not materialize;
- a lack of minimum performance standards; and
- a lack of clear measurement and verification protocols.

Box 16.3 describes a specific ESCO case study from India (Kalra and Shekhar, 2006).

Box 16.3 | Case Study of an ESCO with Nasik Municipal Corporation, India

A specific example of an ESCO in India is the experience of Nasik Municipal Corporation (NMC). In 2003, ICICI Bank financed an ESCO project implemented, following a tender process, by Sahastratronic Controls Private Limited (SCPL) for NMC in the city of Nasik, Maharashtra. The NMC project, based on shared savings, had SCPL as the borrower work to upgrade the existing street lighting facilities on NMC's premises. The contract was for SCPL to supply 460 energy-saving devices, which represented almost half of NMC's total requirement. Under the Energy Services Agreement, SCPL was required to invest in establishing energy efficiency measures, namely Street Light Controllers, including capital assets, and maintain the same for five years.

ICICI Bank provided financial assistance of INR8.3 million ($US_{2005}$$190,900) in two installments (INR4.5 million and INR3.8 million [$US_{2005}$$103,500 and $US_{2005}$$87,400]) to meet part of the project's cost, from a INR20.0 million ($US_{2005}$$460,000) Line of Credit facility sanctioned to the ESCO through USAID's ECO Programme. Repayments were secured by a direct payment mechanism to NMC through an escrow arrangement. Energy audit studies had estimated an energy savings potential of at least INR7.5 million per year ($US_{2005}$$172,500). SCPL had guaranteed a minimum 25% in energy savings. A large part of the saving was supposed to be shared with SCPL as compensation for their establishment and maintenance of the energy saving devices. The first phase, which consisted of 361 panels with a total load of 4000 kVA, was commissioned in December 2004. Subsequent to the successful implementation of this project, NMC awarded the second contract to the ESCO for 125 panels for which ICICI Bank sanctioned a term loan of INR3.8 million ($US_{2005}$$87,400).

NMC draws about 5000 kW of energy per hour in a 12-hour day, throughout the year for its street lighting application. This amounts to an energy bill of about INR5.5 million per month ($US_{2005}$$126,500) payable to the Maharashtra State Electricity Board (at a tariff of INR3 per kWh), for an annual expenditure of around INR65 million ($US_{2005}$$1,495,000) on street lighting alone. The SCPL area had an actual load of 2700 kW. On this basis, the monthly energy bill payable to the Maharashtra State Electricity Board was about INR35

million ($US_{2005}$$805,000). On the basis of 25% assured savings, the savings for this area was estimated to be 0.25 x 35.0 = INR8.8 million ($US_{2005}$$202,400). In line with this, the NMC project has realized energy savings of about INR11 million ($US_{2005}$$253,000) on a total load of 4000 kVA in one year, with a capital investment of INR12 million ($US_{2005}$$276,000). The average savings per year have worked out at 31% with peak savings on some sub-sections as high as 44%. SCPL has so far received INR7.8 million ($US_{2005}$$179,400) as its share of savings, while NMC's share was INR3.2 million ($US_{2005}$$73,600).

Impact

The project was the first of its kind in India. It has served as a model for other ULBs, municipalities, and government organizations to follow. Successful execution of the project and timely repayments to the bank has not only convinced other banks to lend to similar ESCOs but has also encouraged other municipal corporations to undertake similar street lighting projects.

16.4 Policy and Institutional Issues

The previous sections (Section 16.3 and 16.4) enumerate several emerging experiments both with regard to technological innovations as well as changes in systemic configuration and business models. Many of the experiments can become niches, provided they are suitably nurtured and supported. One of the key factors influencing the scaling up of niches to larger regimes is the existing policy environment. Energy transitions are as much affected by policy and institutional issues as they are by technological and systemic ones. Subsequent chapters (see Chapters 22 – 25) in this Assessment cover energy policies and related policies for innovation and capacity-building. This section focuses on the role of policies in facilitating and guiding transitions.

16.4.1 Role of Policy in Transition Management

To appreciate the role of policy in energy transitions, it is important to note that only very few historical regime transitions were explicitly directed by collective, socially deliberated, long-term goals like sustainability (Smith and Stirling, 2010). Nevertheless, there have been historical studies that trace the emergence of new regimes back to originating niches, and they do inspire ideas for sustainability transitions. Transition management focuses on facilitating an evolution of sustainable regimes from green niches. This should include helping green niches by putting incumbent regimes under significant pressure to reach sustainability targets through policy building, and thereby favoring the environment for these niches, although these are often underplayed in transition policy recommendations (Smith and Stirling, 2010).

Niches, by their very nature, provide protective settings that are less susceptible to prevailing market pressures. Radical innovations pertaining to those niches that carry systemic implications typically need this kind of space to develop, improve, and get much needed support. Transition management puts this niche-based, evolutionary view of change within an iterative, four-stage cyclical governance framework (Smith and Stirling, 2010):

1. *Problem structuring and goal envisioning*: In this step, the development of a shared vision for attaining sustainability goals by multi-stakeholder transition arenas is often facilitated by a government department. Practical visions are formed from the sustainability goals by scenario-building techniques, and these visions then provide a basis and a direction for subsequent government policies.

2. *Transformation pathways and experiments*: Pathways toward transition visions are identified by the participants using back-casting methods, which provide a framework for the development of the niche experiments. Successful pre-development of those niches is followed by a period of take-off and acceleration, before culminating in stabilization within a more sustainable regime.

3. *Learning and adaptation*: This step provides the essential links between long-term goals, socio-technical pathways, and short-term actions in niche experiments. Lessons are learnt for both the improvement of the niche and the institutional reforms. Understanding the institutional constraints and opportunities for the sustainable practices is central to the niche experiments.

4. *Institutionalization*: Institutionalization is often given the least consideration in transition management literature, despite the fact that it is the most important factor in transition management. Institutionalization involves the mobilization of serious selection pressures against the incumbent regime, and the redirection of vast institutional, economic, and political commitments into promising niches along certain feasible pathways. This is the point at which serious commitments are needed, to the extent that the incumbent regime suffers and is undermined as a result. This step is difficult politically as well as economically.

A promising approach for transformative change appears to be strategic niche management, which suggests that such transformative

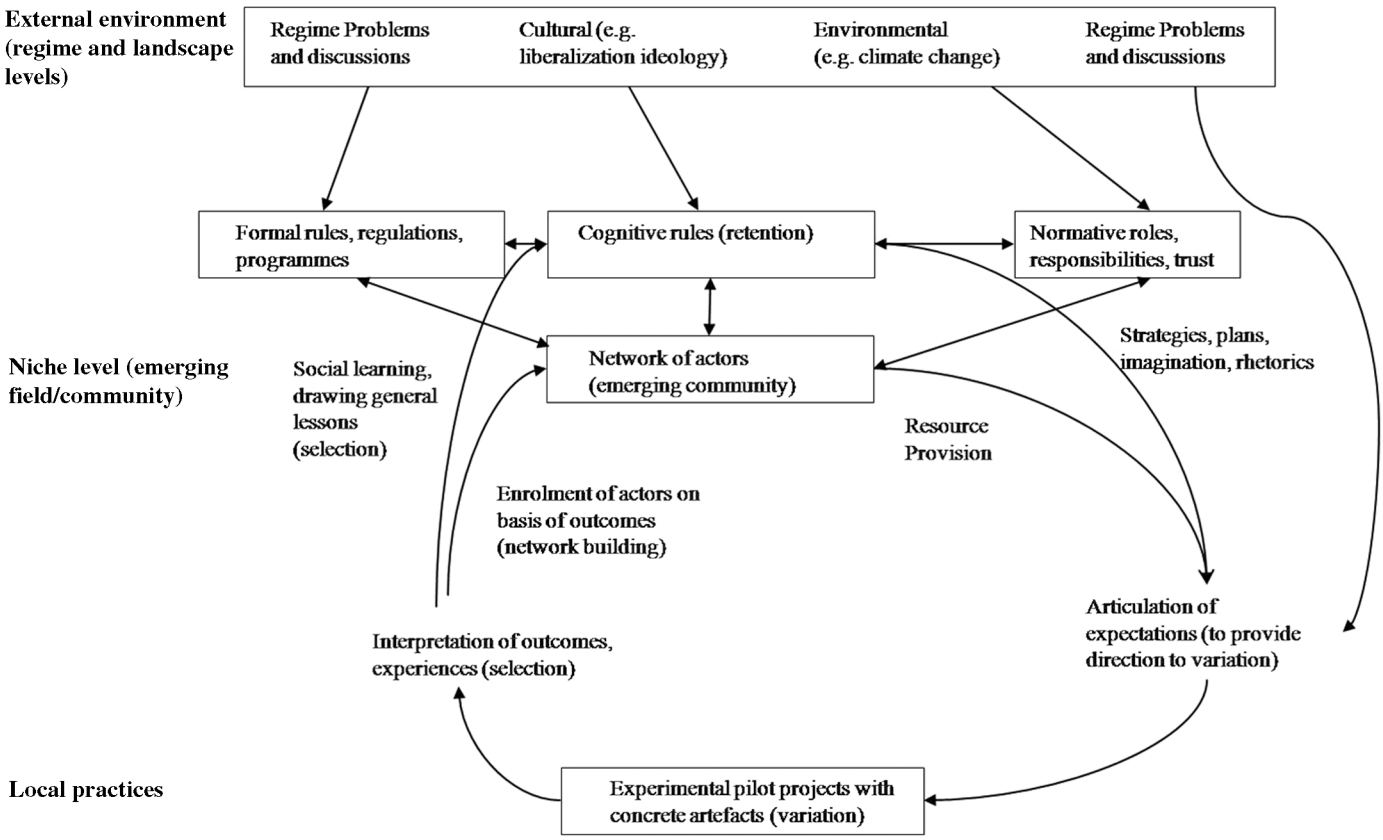


Figure 16.7 | Dynamics in socio-cognitive technology evolution. Source: Raven and Geels, 2010.

change could be facilitated by the creation of technological niches, i.e., protected spaces that allow experimentation with the co-evolution of technology, user practices, and regulatory structures (Geels and Schot, 2007). While the understanding of the evolution of a technological niche to a regime shifts, the following three internal niche processes have been distinguished (Elzen et al., 1996):

- The articulation of expectations and visions provides direction to the learning processes.
- The building of social networks becomes important for developing a constituency behind the new technology and facilitating interactions with relevant stakeholders.
- To facilitate alignments between variation and selection and create "configurations that work," the projects and experiments in technological niches should provide learning processes on dimensions such as:
    - Technical aspects and design specifications
    - Market and user preferences
    - Cultural and symbolic meaning
    - Infrastructure and maintenance network
    - Industry and production networks
    - Regulation and government policy
    - Societal and environmental effects

A further broader, more recent view of the role of niches in regime shift has led to the principle of multi-level perspective, which distinguishes three analytical levels. The niches form the micro-level, where the novelties emerge; the socio-technical regime forms the meso-level, which accounts for the stability of existing large-scale systems; and the socio-technical landscape depicts the macro-level, an exogenous environment beyond the direct influence of the niche and regime actors (Figure 16.7).

The manner in which transitions occur in the real world is a function of the dynamics between the three levels, as well as of internal niche interactions. The attributes that influence the transitions change depending upon the niche's setup and location. The following sections attempt to analyze transitions in practice which have occurred at different settings and scale.

16.4.2 Creating Policy Environment for Transitions

Overall, transition management incorporates goal-directing processes into socio-technical transformations. This approach is attracting increasing interest in many countries' environmental policies, such as

in the Netherlands and Finland. The European Commission is funding research into transition foresight under its seventh framework program. Think tanks in the United Kingdom and elsewhere are advocating the approach. The Austrian Program on Technologies for Sustainable Development promotes the so-called Energy Regions, which can be considered niche spaces for experimentation within a larger systemic perspective (Smith and Stirling, 2010).

The Swiss Energy program offers an interesting case study. It has been highlighted by Geels et al. (2008) as a systems-transformation approach to energy policy for sustainability. Switzerland's energy policy is characterized by strong vertical policy linkages, including both top-down initiatives and bottom-up engagement. The top-down initiatives include the Federal Energy Act 1998 and the CO_2 Act 2000, which encourage environmentally friendly energy sources and the reduction of CO_2 emissions. The bottom-up engagement is facilitated by the Swiss tradition of decentralization of power, so that the cantons (the provincial units) have a great say in decisions pertaining to energy matters and in their implementation. Furthermore, there is an emphasis on using voluntary measures to enhance cooperation between the state and industry. Lastly, the Swiss tradition of direct democracy empowers people to influence the local, cantonal, and federal policies by referendums and initiatives. Because of these vertical linkages, the Swiss energy policy is characterized by a combination of regulatory instruments and process-based implementation. The Swiss Energy program has focused on five key areas: modernization of buildings, renewable energy, energy-efficient appliances, efficient use of waste heat, and energy-efficient, low-emission transportation. Overall, Geels et al. (2008) believe that the Swiss Energy program should be considered a success, because without it, Swiss CO_2 emissions would have been about 2.8 $MtCO_2$ higher than present day levels, and fossil fuel consumption, about 8% higher. The key message here is how the strong vertical policy linkages have been utilized as an instrument to bring about a significant transition.

Nykvist and Whitmarsh (2008) provide a comparative analysis of sustainable transport-related policies in two countries, the United Kingdom and Sweden. In Sweden particularly, where the major historical focus of transport policy was on safety, a remarkable change is seen in the way it has embraced sustainability goals. Swedish policies, such as a law in operation since 2006 that requires filling stations above a certain size to supply biofuels, highlight the government's efforts to reduce dependence on traditional fuels. In the United Kingdom, there is graduated vehicle excise duty and a company car tax, which reduces the tax in line with carbon emissions. The governments of both countries have also been exploring the options of creating a modal shift from cars to public transport systems and car pools or car clubs. A decrease in the registration for driving licenses can also be possibly linked to an overall societal change of moving from private to public modes of transport. The authors note that there are several reasons for the emergence of such policies. Key amongst the determining factors are landscape pressures – including environmental (e.g., climate change), economic (e.g., oil prices, automotive and Information and Communication Technoloy markets), and cultural (value/behavior change) factors – which in turn have an impact on policies at the national and European level. At the niche level, there is interest in exploiting opportunities arising from these trends, e.g., among agricultural and emerging biofuel industries. Networks are starting to emerge in some areas (e.g., biofuels), supported by a favorable policy system. Regime actors are also beginning to respond to landscape pressures and exploit technological opportunities and new markets (e.g., biofuels, HEVs, and small, fuel-efficient cars).

Van der Laak et al. (2007) have studied three recent experiments on biofuels in the Netherlands in order to develop policy guidelines. The strategic niche management approach has been used to explain the success and failures of the three projects, and thereby develop key policy pointers. The guidelines have been categorized into three broad areas: shaping expectations, network building, and learning processes. Their analysis suggests that sustainable technologies often lack a clear advantage for individual entrepreneurs or users (e.g., financial gains), because advantages are at the wider level of society (e.g., reduction of greenhouse gases). Nevertheless, in particular situations (niche markets, local benefits, and ideological arguments) there might be local entrepreneurs willing to nurture and develop a technology that is potentially sustainable. These bottom-up initiatives are important, because they can trigger a process of increasing societal awareness, enable the emergence of local demand, and benefit from wider diffusion. Also, additional (unanticipated) advantages may prove to be viable. Issues such as new job creation, reinforcing local economies, and visual improvements to the countryside may render first generation biofuels socially and economically attractive, despite their limited potential for reducing greenhouse gas emissions.

16.4.3 Examples of Sectoral Transitions

16.4.3.1 Rural Energy Sector

Rural communities across the globe rely on cheap and inefficient fuels, such as traditional biomass. With rapid population growth and the absence of reliable alternatives to traditional fuels, these communities face a grave situation. Renewable energy options or other modern energy technologies are almost non-existent, either due to their high cost implications or because they are unreliable. Field experience has shown that energy, such as electricity, should be employed in enterprises that employ local people or add value to local resources (Bastakoti, 2003).

The energy sector and, in particular, energy service delivery could be an important source of new economic opportunities, including livelihood options. Many hybrid systems described in this chapter offer opportunities for new enterprises based around more sustainable energy solutions, and create the possibility of achieving energy, developmental, and economic goals. Innovation support programs of national governments and multilateral institutions may be used to target energy related sectors. Decentralization of power can be a possible solution to the problem of introducing clean energy technologies to rural areas of developing

nations. Distributed generation provides consumers with opportunities to gain a number of benefits, such as a degree of energy independence, opportunities for local control to improve security of supply, financial optimization, equal or better power quality, and a cleaner environment.

The *Uttam Urja* project was developed by TERI (2009) as a field project for dissemination of photovoltaic lighting technologies in rural India. The project developed a novel business model that promoted the delivery and management of energy services through the development of a local entrepreneurial chain. By customizing the financial assistance, providing affordable quality products teamed with good after-sales service through local energy service networks, this model has been able to function and sustain effectively without any foreign aid (financial/technical) (Rehman et al., 2010).

Another example is the African Rural Energy Enterprise Development (AREED) which demonstrates a partnership based model that accomplishes multiple objectives: new venture creation, support to small and medium enterprises, and energy service delivery (AREED, 2009; see also Chapter 25). An entrepreneur and an energy business are at the heart of the REED (the UNEP Rural Energy Enterprise Development) model, which seeks to tap and support the entrepreneurial spirit and help create sustainable energy businesses through appropriate financing, business development, technology support, and enabling government policies. Following the successful examples of AREED model, the REED approach has been applied in Yunnan province and neighboring areas of western China. China Rural Energy Enterprise Development (CREED) functions through coupling Enterprise Development Services (EDS) with closely targeted start-up financial for entrepreneurs, enabling them to deliver cleaner and higher quality energy services through new business ventures. CREED also offers support for consumer credit and income-generation loans through Green Village Credit. It creates strong links with local government agencies, NGOs and financial institutions active in the areas of energy, environmental protection, consumer credit, and income generation. Through these links, CREED aims to influence broader energy and development shifts underway in China, and redirect existing sources of finance and support to sustainable energy activities.

In general, the rural poor are willing and able to pay for energy services if they have appropriate financing options and are able to meet the first costs of access and/or of the appliance (Rehman et al., 2010).

16.4.3.2 Transport Sector

Delhi and Mumbai are the economic hubs of urban India. As a result of fast-paced economic development, the cities have seen a substantial increase in transport infrastructure and services. The existing transport technological regime, characterized by the use of low-efficiency fuel, was pressurized by public interest groups to improve local air quality. This triggered the development of institutions involved in clean technologies in the transport sector. These institutions analyzed various technological innovations to achieve the goal of better air quality, and consequently improved health conditions.

An increased awareness and concern over the deteriorating air quality was demonstrated through Public Interest Litigations and NGO movements. This resulted in actions taken at the policy level to address the issue. The transport authorizing bodies issued specific directives which resulted in phasing out older vehicles that depended on inefficient fuel. These directives were further supported through court interventions. These legal directives acted as a market pull for technology developers and service providers.

The transition in the transport sector for the two cities is characterized by both top-down initiatives and bottom-up engagement. The top-down approach includes the transport authority directives and court judgments. The bottom-up approach involves NGOs and citizen groups, who expressed their concerns through Public Interest Litigations, plus the interest shown by public and private organizations to develop ancillary infrastructure to support the transition. This is an example of an established technology regime that is supported by infrastructure, finance, and user interest, with clearly defined roles for policymakers and regulators.

The co-benefits associated with the change in the technological regime provided a major impetus to the entire transition phase. The concerns of citizens led technology and service providers, policymakers, and the judiciary to mobilize the implementation process rapidly. Although fuel switching in the transport sector is a micro-change, it has triggered the use of natural gas in the industrial and domestic sectors. Therefore, through the application of a supporting policy structure, a micro-change can be successfully converted into a large-scale technological regime (Patankar and Patwardhan, 2006).

16.4.3.3 Small and Medium Enterprises Sector

For governments and manufacturing companies, global warming, rising energy prices, and increasing customer awareness have pushed energy efficient manufacturing to the top of the agenda (Bunse et al., 2010). Energy management is the judicious and effective use of energy to maximize profits, to enhance competition through organizational measures and optimization of energy efficiency in the process. Realizing the importance of energy efficiency, many developing countries have initiated policy and regulatory mechanisms focusing exclusively on conservation of energy. These policies are a mix of both obligating and voluntary approaches (Lindhqvist, 2001).

Lack of financial and technical assistance is the most prominent hindrance in the adoption of energy efficient technologies in small to medium enterprises (SMEs). Most of the existing conservation policies provide some form of incentives to the existing industries, to motivate them to adapt efficient and clean technologies. This may be in the form of soft loans and/or tax incentives. Long-term, low interest funding

from international institutions like the World Bank and GEF can be utilized by countries to establish a separate dedicated financial institution with equity participation from the government to address the financial issues. One such example is the Pollution Control and Abatement Fund, a US$5 million fund established in Sri Lanka to provide financial assistance to financially viable industrial enterprises towards waste minimization, resource recovery, pollution control, and abatement.

The scheme has two components: (a) Technical assistance and (b) Credit component. The loan can be obtained from any of the six participating credit institutions. Loan disbursement is affected only after obtaining the Environmental Protection Licence. Under the Technical Assistance component, reimbursement up to 75% of cost towards cost of consultancy services for the investigation of waste minimization, preparation of designs, selection, supervision, installation, and operation of the equipment is affected. Under the Credit Component, finance up to a maximum amount of US$128,000 per industry at zero real rate of interest is provided. Maximum repayment period will be seven years including a maximum of one year of grace period. Security needed for the loan is a mortgage over the project assets. For projects that involve investment for modernization entailing a financial return in addition to the desired environmental effects, a loan amount of 50% of such costs would be provided and for all other cases it could be 100%. This loan could be used for purchase of equipment or phasing out of hazardous substances. Over 75 industries have benefited from this scheme (Thiruchelvam et al, 2003).

Demonstration projects in energy intensive sub-sectors undertaken as a part of government led initiatives can also act as an example of successful implementation of EE activities.

For example in India, The Energy Research Institute (TERI) has been involved in improvising the foundry segment of the SMEs. Energy efficient divided blast cupola (DBC), developed by the British Cast Iron Research Association (BCIRA), has been promoted by TERI. The implementation of these DBCs has improvised the profitability through reduced fuel costs. Further, it also delivers molten metal at higher temperatures and substantially reduces other (silicon and manganese) losses, thereby further reducing production costs (Patel et al., 2009).

For SMEs, energy is usually a small portion of the total production cost and therefore receives relatively little attention. Barriers to the introduction of energy management in SMEs are lack of innovation, information availability, and expertise of entrepreneurs. Further absence or lack of data on benchmarks, good practices, and standards makes comparative analysis difficult (Kannan and Boie, 2003).

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