Meeting the Challenges of Integrating Renewable Energy into Competitive Electricity Industries

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May 3, 2007

The AGO, REEEP and REIL wish to acknowledge that this report includes findings from the Integration of Renewables into Electricity Grids Experts Workshop hosted by the IEA in November 2006. This report does not however necessarily reflect the position of the IEA.

*The opinions and views offered by Commissioner Kelly are her own and not necessarily those of the United States, the Federal Energy Regulatory Commission, individual Commissioners or members of the Commission staff.

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Executive summary

Background

Growing concerns about energy security and climate change have heightened interest in harnessing renewable energy resources as a response to these critical issues. Electricity generated using these resources will in the most part be delivered to the point of use via large scale transmission and distribution systems. Consequently, the successful integration of renewable energy generation into large power systems has become fundamental to successfully addressing climate change and energy security concerns. This report arises from an IEA workshop held in Paris on 20 November 2006 to consider the challenges of integrating renewable energy resources into electricity industries.

The integration of renewable energy resources cannot be solved in isolation from the other challenges facing modern electricity industries. For example, price and technical performance are critical issues as well as energy security, environmental sustainability and end-use efficiency. Moreover, many countries are undertaking processes of electricity industry restructuring, which involve disaggregation of formerly vertically integrated monopoly supply utilities and the introduction of competition and enhanced end-user participation. The terms “de-regulation” and “liberalisation” suggest that rules are being removed. However, successful electricity industry restructuring requires the careful crafting of a set of institutions and rules that constitute an integrated decision-making framework that retains some centralised decision-making while decentralising other decision-making through purpose-designed markets and other commercial processes that create a competitive environment. Moreover, electricity industry restructuring processes should now be specifically designed and implemented to accommodate high levels of renewable energy penetration.

More broadly, these issues translate into sustainability challenges for the stationary energy sector and specifically the electricity industry to contribute to:

- Societal sustainability, through good industry governance processes that deliver reliable, affordable and sustainable electrical energy and in the process foster social cohesion and consensus and provide a benchmark for other sectors of the economy
- Economic sustainability by delivering economic efficiency, particularly dynamic efficiency in achieving rapid, effective and efficient innovation in the electricity industry
- Environmental sustainability, achieved via effective, market-compatible environmental regulation for local, regional & global impacts, particularly climate change.
- Technological sustainability, through rapid and effective innovation to a more sustainable set of technologies (a resource portfolio that is appropriate in this context), while not compromising energy security and affordability. Key technology options to be considered for a more sustainable resource portfolio include enhanced end-use efficiency and substitution for electricity by other energy vectors (fuel switching), responsive electricity

> demand, and low emission generation, including renewable energy, carbon capture & sequestration, and nuclear energy. The target portfolio must be technically effective as well as economically efficient and environmentally sound (Denny et al., 2007).

This document first of all considers this broader context before addressing the question of renewable energy integration per se. It begins with a summary of how a competitive electricity industry operates, which it is necessary to understand to successfully integrate high levels of renewable energy resources.

From a physical perspective, an electricity industry consists of a set of electricity generation, reversible energy storage and end-use equipment that is connected by a set of electrical network equipment, which may be continental in scope. Neither generation nor end-use equipment can operate in isolation. They must be connected so that electrical energy can flow continuously without interruption between them. The flow of electricity must also be of adequate quality (e.g. voltage magnitude, frequency and waveform purity).

The specific characteristics of renewable electricity generation often differ from those of the conventional power generators around which existing industries have been designed:

- The variable and non-storable nature of key renewable energy forms, such as wind and solar energy, leads to a need for accurate forecasting of resource availability and consequent electricity production as well as a need to define appropriate boundaries to autonomous decision-making by renewable energy generators for both operation and investment. For example, correlated production by wind farms may make it necessary to reduce wind farm output occasionally for system security reasons and it may be desirable to build wind farms in a dispersed rather than clustered pattern. The variable and non-storable nature of key renewable energy forms also increases the potential benefits of active end-user decision-making.
- High renewable energy penetrations in electricity industries may increase uncertainties during abnormal electricity industry operating conditions. It would be valuable to have mathematical models that could adequately predict industry behaviour with high renewable energy penetration.
- The small size of some renewable energy generator installations, such as photovoltaic systems, means an increase in the number of generator owners. Appropriate commercial contracts and technical requirements will be required for embedded generators.
- While still in the development phase, renewable energy technologies are experiencing ongoing improvements in technical performance but continue to require policy support. The challenge exists to provide financial support in a way that encourages the most cost efficient development of the technologies.
- The use of renewable energy in the context of autonomous single-users or small rural communities may raise community social, technical and financial resource questions, as well as technical challenges associated with remote locations and long equipment supply chains.

For these reasons, appropriate regulatory regimes and electricity market rules will need to be developed if high penetration of renewable energy is to be managed in a satisfactory manner. Such issues must be addressed, in a consistent manner, at all levels of decision-making from the high-level, long time-scale governance level to the technically specific, short term power system operating level. This in turn requires a rigorous, internally consistent multi-disciplinary approach to identification and solution of the research and development (R&D) tasks associated with restructuring the electricity industry to take into account sustainability and energy efficiency objectives. Satisfactory solution of these problems will require coordinated innovation and competitive processes throughout the industry. However, this can only take place if governments establish and maintain coherent decision-making frameworks for their electricity industries.

Electricity industries of multinational scope are directly impacted by World Trade Organization (WTO) rules, however the implications may change depending on whether the international transaction involved is regarded as a *good* or *commodity* on the one hand (e.g. bulk power trading between two vertically integrated utilities) or a *service* on the other (more likely to be the case in restructured electricity industries). This ambiguity should be removed.*

Electricity industries that are entirely within nations are also affected by WTO rules if questions arise about discrimination against equipment providers from other countries. An example would be technical rules for the connection of generators that could be deemed to discriminate against generator equipment providers from other countries.

Different WTO rules may apply depending on whether, and to what extent, grid access is set by government regulation, by a vertically integrated monopoly (and further whether such a monopoly is an organ of the state or not), by a former monopolist operating in a competitive generation market but still owning the transmission network, or by an Independent Market Operator, either a governmental, parastatal, or private regulated entity. Generally speaking, the more direct the involvement and control by government in setting the terms of access, the more fully WTO disciplines will apply. WTO rules do not address the allocation of costs for the infrastructure needed to trade electricity across jurisdictional boundaries or the sharing of responsibility between jurisdictions for externalities of such trade, such as breakdowns in the cross boundary grid, as happened dramatically in a significant part of North America in August 2003 (US-Canada Power System Outage Task Force, 2004).

Table 1 shows how a competitive electricity industry decision-making framework can be structured in terms of governance, commercial, technical and security regimes (Outhred, 2007).

One task of the governance regime is to specify and implement the other regimes and the interfaces between them that manage boundary issues. Because of its largely separable nature, the technical regime can be developed within a self-regulatory environment so long as overarching objectives are specified at the governance level, for example with respect to compliance with international standards. For a particular electricity industry, we should now review the ability of these various regimes to function effectively in the presence of high levels of renewable energy penetration that in turn, for non-storable renewable energy fluxes, implies new sources of uncertainty in the flow of energy through an electricity industry.

Risks and uncertainties in an electricity industry can be broadly characterised as questions of resource adequacy, which may be further characterised by location (due to network flow constraints) and by forecasting horizon (long-term investment risk versus short-term operational risk). Effective market-based responses to these problems require investors and operators to see commercial signals that reflect these uncertainties and allow the risks to be efficiently managed. Effective security management requires accurate forecasting and effective response strategies.

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*Robert L. Howse, Alene and Allan F. Smith Professor of Law, University of Michigan, contributed ideas to the trade aspects of this report.

Table 1: Governance, commercial, technical and security regimes for a competitive electricity industry

Governance Regime	*The set of formal institutions, legislation and policies that underpin the decision-making framework in which a competitive electricity industry operates.* The governance regime includes the formal regulatory arrangements for electricity industry participants, supplemented by the broader social context that influences the industry. The scope of an electricity industry is defined by the physical extent of the underlying transmission and distribution networks and may involve one or more national jurisdictions, for example in the European Union or North America.
Security Regime	*The task, assigned to one or more system operators, of maintaining the integrity of a local or industry-wide core of an electricity industry in the face of threats posed by plausible large disturbances.* The security regime typically has authority to restrict and, if necessary, override the commercial regime in defined circumstances and to a specified future horizon. For example, the security regime may have the power to direct participants to operate their components at specified levels and, under defined circumstances, to disconnect components. This is an example of the prioritisation of industry goals.
Commercial Regime	*The commercial arrangements for the competitive electricity industry.* These may include spot markets for electrical energy and ancillary service as well as associated derivative or capacity markets, and commercial interfaces between competitive industry participants, such as generators and end-users, and regulated industry participants, such as network service providers.
Technical Regime	*The integrated rules for component and system design and system operation that allow the various components of an electricity industry, when connected together, to function effectively as a single machine.* These rules are necessary for the industry to deliver a continuous flow of electrical energy of appropriate availability and quality from generation equipment to end-use equipment, tracking decision-maker targets, rejecting disturbances and degrading gracefully if equipment faults occur.

Key issues for the governance regime include:

- Coherence and consistency, particularly when the electricity industry spans more than one national or provincial jurisdiction (Commission of the European Communities, 2007; US-Canada Power System Outage Task Force, 2004; UCTE, 2006).
- Efficacy in delivering good industry outcomes, particularly where choices can be made between different implementations of electricity industry restructuring.
- Robustness, in the face of pressures that threaten the integrity of the governance regime
- Boundary issues and compatibility with other regimes, including, where appropriate, supra-national governance and formal regulatory bodies (op cit).
- Prioritising the multiple objectives that society sets for the electricity industry: - for example, security and integrity at a system level, reliability of supply to end-users, economic efficiency, environmental sustainability, industry and regional development and

social equity.

- Setting goals and designing and project managing the associated transition processes to integrate high levels of renewable energy resources. The transition process can be challenging given the need to rapidly and drastically reduce climate change emissions and the potentially disruptive nature of many renewable energy technologies.

Key issues for the security regime include:

- Coherence and consistency, particularly when more than one system operator is involved, noting that there are choices to be made between centralised and distributed control. Note also that in an electricity industry involving multiple jurisdictions, the geographical mappings of the jurisdictional boundaries may not match those of security-related flow constraints or even the franchise territories of system operators (op cit).
- Efficacy and scope of authority to intervene and independence from industry participants, in the face of pressures from industry participants who fear commercial losses.
- Adequacy of information to support sound decision-making: system visibility; forecasts of critical uncertain variables (e.g. demand, wind power production at appropriate levels of aggregation, etc.); contingency assessment
- Transparency in the development of grid codes, preferably by system operators without generation interests, and with equal consideration of the full range of generator types.
- The security regime should not act as a barrier to entry for new technologies, and should only intervene at high penetration levels of a "suspect" technology. TSO requirements for fault ride through capability of wind farms provide both good and bad examples of this.

Key issues for the commercial regime include:

- Effectiveness in commercially rewarding participant behaviour that is beneficial to overall economic efficiency (defined in a broad socio-economic sense), and in commercially penalising participant behaviour that is harmful to overall economic efficiency
- The unsuitability of bilateral trading regimes for electricity industries with high levels of stochastic renewable energy penetration –gross-pool style electricity trading arrangements are better able to manage the high levels of short-term uncertainty involved, as illustrated in (European Transmission Operators, 2007).
- Coherence in risk management from very short term operation (ancillary services, from seconds to minutes), to near term (energy spot market – which may range from 5 to 30 minutes ahead), to long term (derivative markets – which may range from hours to years ahead)
- Forecasting tools that support informed commercial decision-making
- Boundary issues and compatibility with other regimes

Key issues for the technical regime include:

- Technical requirements for system flexibility, predictability, variability (and intermittency); optimising the technical design and management of generation, network

- Evolution of technical requirements to facilitate and guide the development of emerging technologies, so that they function effectively as components of a single machine when integrated into conventional power systems.
- Technical challenges and benefits of distributed generation, intelligent grid control, and demand side management.
- Appropriate provisions for metering, communication and remote control.
- Investigating the scope for geographical and technological aggregation to manage variability.
- Boundary issues, including interconnection design operation & flow constraints, and compatibility with other decision-making regimes.

Renewable energy integration into competitive electricity industries

Distributed renewable energy resources are energy fluxes that are often geographically dispersed, in some cases storable to varying degrees within varying timescales, in other cases not storable at all. Forecasting is an important issue for all renewable energy resources, particularly those that are not storable, such as wind and solar energy. There may be different forecasting objectives may arise for security and commercial regimes unless they have been designed to be closely compatible.

Single user and small community electricity industries must use local renewable energy resources unless they can be transported to site (e.g. some biomass). It is even more important to involve end-users to a greater extent in design, planning and operating decisions in small electricity industries than it is in larger electricity industries.

Electricity industries with larger geographical scale can take advantage of any renewable energy resources within the reach of the associated transmission and distribution networks, subject to network losses and flow constraints that may be device-specific or determined by system security considerations. Larger electricity industries may also be better able to absorb variations in electricity output from renewable energy sources. Renewable energy generators that are located away from major load centres and existing generation (e.g. wind farms) may require network augmentation and possibly additional interconnectors to avoid flow constraints.

Electrical networks have been traditionally designed for unidirectional energy flows from large, remote power stations to urban centres. The use of dispersed, time varying renewable energy generators is more likely to result in bi-directional flow and may either ameliorate or exacerbate problems with voltage and fault management.

If we use the analogy of the electricity industry as a single machine, renewable energy generators become new component types for that machine. It follows that compatibility between new components and the pre-existing industry will be an important issue, particularly given the complexity of electricity industries. Both new and pre-existing components (e.g. networks) may have to adapt to provide the best industry outcome in the changed circumstances. Compatibility will be considered in governance, commercial, security and technical dimensions.

Technical issues

The technical issues associated with renewable energy compatibility relate to the ability of renewable energy equipment to function effectively as part of the electricity industry as it exists today. There may also be technical means at the system level to reduce the variability of the aggregated output from renewable energy generators. Renewable energy generators must meet engineering requirements with respect to voltage, frequency, waveform purity, be able to rapidly isolate faulty equipment from the rest of the industry and must have a reasonable ability to withstand abnormal system operating conditions (fault ride through). Depending on the context there may be additional technical requirements with respect to control over output level and the ability to actively contribute to voltage management. Technical requirements for individual generators can usually be effectively dealt with in connection rules. System-level issues are more likely to be the province of network service providers and system operators.

Security issues

Security issues can be regarded as an extension to technical issues from the component to the local or industry-wide level. They arise at both the transmission and distribution levels.

Transmission-level security issues can be industry-wide and are mostly related to the ability of renewable energy generators to:

- Ride-through disturbances emanating from the power system and thus avoid contributing to cascading outages.
- Reduce output if needed to avoid overloaded or insecure power system operation.
- Contribute to voltage and frequency control and to stabilising system operation following a disturbance.
- Behave in a manner that can be adequately predicted by mathematical models for use in power system simulation studies, and that can be adequately forecasted for system security assessment and for informing derivative markets.

Distribution-level security issues are local and mostly relate to the ability of renewable energy generators to:

- Contribute to voltage control in the vicinity of, and down stream from, the generator, while complying with islanding policy requirements.
- Contribute to managing distribution network flows in the vicinity of the generator.
- Avoid excessive fault levels while still contributing to fault identification and clearance.
- Avoid contributing to (or actively reduce) waveform distortion.
- Behave in a manner that can be adequately predicted by mathematical models for use in power system simulation studies, and that can be adequately forecasted for system security assessment and for informing derivative markets.

Some of these issues can be managed via connection guidelines and technical connection requirements. The latter includes obligations for the provision of operating data, an important resource for which appropriate provisions should be made. Mathematical models and forecasting remain open research questions.

Governance issues

Governance issues are addressed here in the sub-categories of institutions, legislation and policy.

Institutional issues include the development and implementation of:

- A robust security regime that can effectively manage the additional uncertainty associated with variable, non-storable renewable energy fluxes. This cannot be taken for granted, even in the absence of significant renewable energy penetration.
- An efficient commercial regime that can correctly value uncertain, time-varying renewable energy generation at both transmission and distribution levels with respect to both energy and ancillary services, as well as encourage compatible technologies such as reversible storage and flexible generation and demand.
- An effective regulatory regime that correctly manages the interface between renewable energy generators and regulated network service providers, with respect to technical and commercial terms for connection.
- Compatible institutional arrangements for other energy vectors, including the natural gas industry, to support the use of flexible gas-based generation to accommodate time varying renewable energy generation.

Legislative issues include:

- Internalisation of the increasing environmental costs associated with fossil fuel combustion.
- Internalisation of cost for security of supply.
- Non-discriminatory treatment of risks associated with different energy resources, particularly between renewable energy forms, fossil fuels and nuclear energy.

Policy issues associated with renewable energy compatibility can be characterised as:

- Support for appropriate innovation in renewable energy technologies in a manner that enhances compatibility.
- Support for the installation of renewable energy technologies in appropriate locations and at an appropriate rate, with the objective of avoiding unnecessary costs. This involves a broad range of policy issues including planning processes, payment mechanisms and the establishment of a level playing field for renewable energy technologies in subsidy terms.
- Design of forecasting regimes for renewable energy fluxes (both primary energy and associated electricity production), with appropriate specification of industry-level and generator-specific roles and accountabilities.
- Strengthening and interconnection of transmission networks to enable electricity industries to take advantage of geographical diversity and to increase their capacity to absorb variable output from renewable energy generators.
- Compatible infrastructure development and restructuring of other energy industries such as natural gas, to accommodate the variable output from renewable energy generators.
- Development of market-pull strategies to complement technology-push policies, in a manner that minimises the costs of renewable energy integration.

Commercial issues

The commercial issues associated with compatibility can be split into financial and legal aspects:

- Financial support for investment in appropriate renewable energy generation (type, location, timing) while avoiding inefficient subsidy.
- Development and implementation of commercial regimes at both transmission and distribution levels that can accommodate renewable energy generation on a "level playing field" with respect to traditional generating technologies and that encourage investment in complementary technologies such as reversible energy storage, responsive generation and responsive demand.
- Development and implementation of commercial regimes that correctly specify and allocate risks associated with renewable energy technology and encourage and facilitate efficient (physical and/or financial) risk management by either renewable energy generator owners themselves or by other appropriate parties.

Research and development issues for the integration of renewable energy into the electricity industry

An important outcome from the workshop was that we need a carefully crafted response to the complex set of challenges facing modern electricity industries, with or without high penetrations of renewable energy, which takes account of both the interconnected, multi-disciplinary nature of the challenges and the specific circumstances that a particular industry faces. This can be achieved by considering each electricity industry as defined by its physical scope, from single dwelling to continental scale, with varying degrees of renewable energy penetration, and with varying degrees of ability (robustness, flexibility) to absorb this penetration, and developing a coordinated and coherent strategy that is tailored to its circumstances. This strategy should take into account the decision-making framework and the specific institutions and as well as the physics of the particular industry concerned. It may require the involvement of governments, regulators, manufacturers, research institutions, financiers and electricity industry participants.

The intention of research and development (R&D) specifically targeted at renewable energy is to support effective innovation by improving the performance and reducing the financial and other costs associated with a particular renewable energy technology. The workshop felt that this should continue because further technical progress appears possible for all renewable energy technologies.

Considerable R&D has already been undertaken on the integration of renewable energy. Wind energy integration has received particular attention because it is the first renewable energy form that exploits a non-storable energy flux to reach high levels of penetration. However, there are still unresolved issues for wind energy integration, particularly in the area of forecasting and in the general enhancement of electricity industry decision-making frameworks to accommodate renewable energy.

Priorities for R&D on the integration of renewable energy

The discussions at the workshop and the studies reviewed in the literature reveal a consistent list of R&D priorities:

- Data collection and analysis to support better understanding of the impacts in practice (which may be context-specific) of high levels of renewable energy (notably wind energy) penetration.

- Enhanced forecasting techniques that can predict not only the behaviour of individual renewable energy generators but also the behaviour of groups of generators aggregated in ways that are appropriate in a particular electricity industry context (e.g. security and commercial regimes). Such forecasting techniques should pay special attention to unusual, extreme behaviour because of its importance to security assessment – differential behaviour may be important as well as summated behaviour.
- Further refinement of electricity industry restructuring to provide appropriate commercial signals (cash flow and legal obligations), effective in both operation and investment timescales, for diversity, flexibility and controllability in renewable energy generation, as well as flexibility and controllability in non-renewable energy generation, reversible storage and end-use energy services (supported by compatible gas industry restructuring).
- Further refinement of electricity industry restructuring with respect to developing short-term and long-term resource adequacy and security management strategies that are consistent with high levels of renewable energy penetration.
- Further refinement of electricity industry restructuring with respect to the provision, management and pricing of network services.

Technical regime related R&D for the integration of renewable energy

Rapid progress is being made on resolving the underlying technical issues associated with renewable energy integration for relatively mature technologies such as wind generators. However, there is now an increasing need for a multidisciplinary and multi-party approach to R&D to address interactions between commercial, economic, environmental, policy, regulatory and technical issues.

For example, manufacturers of renewable generators often design them for remote monitoring, functional upgrade and control, to facilitate field deployment of large numbers of generating units. Such generators could often provide security regime functionality to contribute to voltage and frequency control, respond to system operator start-up or curtailment directives and provide on-line data collection, analysis (including forecasts) and data transmission to a system and/or market operator. Without clear commercial signals as to the value to the industry of such functions, they may not be provided.

Similarly, the development of satisfactory mathematical simulation models requires cooperation between manufacturers, generator owners, network service providers and system operators. While progress is being made in a general sense, there will always be context-specific issues that must be addressed by the particular parties concerned.

Specific requirements for technical R&D include the design and demonstration of:

- Distributed resource systems consisting of embedded generators and possibly reversible storage and flexible demand that can contribute to efficient use of distribution network assets through the management of energy flows and quality and availability of supply attributes.

- Communication and control systems that enable distributed systems to function effectively and have interoperability with distribution network data acquisition and control systems.
- Advanced metering and information technologies that can measure and communicate the time-varying value of interval energy and ancillary service contributions by end-users and distributed resources.
- Control and optimisation technologies for industrial, commercial and residential end-use equipment that can facilitate flexible end-user response to time-varying prices and security management protocols.
- Improved power electronic devices that have lower life-cycle costs and can withstand higher voltages, currents, switching frequencies and power densities.
- Compact, high capacity and cost-effective reversible energy storage technologies.
- Modelling tools that can support the design and performance analysis of distributed resource systems.

Governance regime related R&D for the integration of renewable energy

There are several high-level policy R&D requirements:

- *Further refine our understanding of the innovation processes associated with renewable energy generation*. This should consider both the development of individual technologies and their successful uptake, and their deployment and integration into large and small electricity industries in both developed and developing countries.
- *Review and enhance policies for the restructuring of electricity and gas industries to accommodate high levels of renewable energy penetration.* This should include consideration of the ways in which responsibilities and accountabilities are shared between the different categories of decision-makers with respect to forecasting and the management of resource adequacy and security from the short-term to the long-term future. Institutional arrangements should be reviewed as well as the detailed design of the security and commercial regimes.
- Review and enhance policies to incorporate the costs of environmental impacts in general and in with respect to those associated with fossil fuel combustion in particular. This should include careful consideration of the roles of tradeable environmental instruments, environmental taxes and direct physical constraints on emissions.

Security regime related R&D for the integration of renewable energy

- *Review and refine the design of security regimes for their compatibility with renewable energy resources.* Important issues include forecasting, risk identification and categorisation and the management of volatile network flows and voltage profiles in the presence of fluctuating renewable energy generation.

Commercial regime related R&D for the integration of renewable energy

- *Review and refine the design of markets for ancillary services, energy, network services and derivatives and/or capacity for their compatibility with renewable energy resources.* Renewable energy resources introduce greater variability in energy flows that can test the ability of commercial arrangements to deliver economically efficient outcomes.

- *Review and refine the design of network service contracts for their compatibility with renewable energy resources.* Renewable energy resources are often distributed in a different geographic pattern to the primary energy resources that have been used traditionally. Their varying outputs also increase the variability of network flows and voltage profiles. There may be additional costs involved with these characteristics and renewable energy generators may be able to contribute to their management in some cases.

Definitions of key terms

Electricity industry: *Physical perspective* – the set of equipment connected to an electrically connected set of electricity transmissions and distribution networks, that combined, with input flows of primary energy, together implement an energy conversion process from a suite of primary energy forms to a suite of end-use energy forms. Engineers often use the term *power system* to describe the supply-side of an electricity industry from a physical perspective. *Governance perspective* – the scope of the set of government policies and regulatory activities that impact on the flow of electrical energy through an electricity industry as defined from a physical perspective. This may involve one or more governments at the provincial and/or national level. *Commercial perspective* – the commercial relationships between the set of organizations that together own and operate all the equipment that implements the electricity industry energy conversion chain, from primary energy resources to end-use equipment. New entrants may join, and existing participants exit, this set at any time.

Electricity market: a market is a form of organized commercial activity, with at least some rules. Electricity markets may have very complex rules because they need to capture at least some of the complexity of a physical electricity industry. Electricity markets are commonly divided into two types – “energy-only” or “gross-pool” markets and “energy plus capacity” or “net-pool” markets.

Power system: An engineering term for the supply-side of an electricity industry, focussing on the physical behaviour of the equipment.

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Meeting the Challenges of Integrating Renewable Energy into Competitive Electricity Industries

A report arising from the IEA workshop held on 20 November 2006 on scoping priority tasks

1. Introduction: the renewable energy integration challenge

Growing concerns about climate change and energy security have heightened interest in harnessing renewable energy resources as a response to these critical issues (Ackerman 2006; Bauer and Mastrandrea, 2006; Energy Watch Group 2006 & 2007; Galvin Electricity Initiative, 2006; Hansen, 2005; IPCC, 2007; Stern, 2006). The most important renewable energy resources are bioenergy, hydro, geothermal, wind, solar and (in the future) ocean energy systems (IEA, 2006). Electricity generated using these resources will, in the most part, be delivered to the point of end-use via large scale transmission and distribution systems. Consequently, the successful integration of renewable energy generation into large power systems has become fundamental to successfully addressing climate change and energy security concerns.

However, modern electricity industries now face a range of challenges. For example, a recent scenario analysis by the Galvin Electricity Initiative of US electric energy services in 2025 reached the following general conclusions:

> *"We concluded that three very robust drivers for the evolution of electric energy services cross-cut all of these scenarios. The first is an intensified focus on energy efficiency and domestic energy resources in the face of global competition for oil and natural gas. The second cross-cutting driver is increasing requirements for power quality and reliability. The third universal driver is the additional pressure on electricity prices and generation sources that will result from an increasing consensus regarding the impact of electricity production from fossil fuels on the environment."* (Galvin Electricity Initiative, 2006)

Thus we need to consider the integration of renewable energy within the broader set of challenges facing modern electricity industries, where price and technical performance are critical issues as well as energy security, environmental sustainability and enhanced end-use efficiency (e.g. Doherty et al, 2006; Kushler et al, 2006). Therefore, this document first considers this broader context before addressing the question of renewable energy integration. It begins with a review of how the electricity industry operates and the ongoing process of electricity industry restructuring.

2. The electricity industry & its associated decision-making processes

The electricity industry implements an energy conversion chain that aims to deliver a continuous energy flow from primary to end-use energy forms via electrical energy, in the process delivering end-use energy services to end-users. In return, cash flows from end-users to the supply side of the industry and, ideally, provides an appropriate return on investment to investors in supply-side equipment.

The electricity industry is in competition with other conversion chains such as natural gas, as illustrated in Figure 1. The close relationship between the electricity and gas industries implies that the interactions between them need to be carefully considered – in both physical and decision-making terms.

An electricity industry consists of a set of electricity generation, reversible energy storage and end-use equipment that is connected by a set of electrical network equipment. The electricity generation (or power station) equipment has the capacity to convert a primary energy flux into an electrical energy flux and (in some cases) to maintain a voltage waveform at its point of connection. End-use equipment has the capacity to convert an electrical energy flux into an end-use energy flux, in the process providing an end-use energy service. However, neither generation nor end-use equipment can operate in isolation, particularly as they are usually at different geographical locations. Electricity transmission and distribution networks provide current paths so that electrical energy can flow between the generation and end-use equipment to complete the energy conversion chain.

The geographical scope of an electricity industry is defined by the area spanned by the connected set of network equipment, which can range in size from a local, autonomous single generator-user industry (in which case there is no network equipment), through a small community-scale industry to a multi-national continental-scale industry. Owners of generation, storage and end-use equipment participate in the same electricity industry if they are connected to the same network.

The services provided by networks include important contributions to maintaining the continuity and quality (e.g. voltage magnitude, frequency and waveform purity) of the electrical energy flows. To be more precise, generator and network services maintain voltages at the points of connection to end-use equipment, allowing that equipment to extract electrical energy flows from the network. Generators in turn match their injected flows of electrical energy to the flows of electrical energy extracted by end-use equipment plus the flows of energy losses in network equipment.

Reversible intermediate energy storage equipment (which may not be present at significant scale) can provide a chronological arbitrage function at a particular location by extracting energy flows at some times and reinjecting it (minus losses) at others. Reversible intermediate storage may be a cost-effective way to manage temporal mismatches between primary and end-use energy fluxes or temporary electrical energy flow constraints.

By contrast, network equipment provides connectivity (current paths) between generation and end-use equipment at different locations, which can be considered to be a form of spatial arbitrage and can take advantage of diversity between varying generator injection and/or end-use equipment off-take flows of electrical energy.

Because electrical energy travels at the speed of light through the network, an electricity industry operates physically much like a single machine. However, multiple decision-makers are involved in designing, building, modifying and operating this machine, even at the single-user scale, once the roles of equipment providers, household members, the local community and governments are taken into account. Millions of decision-makers are involved in an electricity industry of continental scale.

The present state of an electricity industry is a result of accumulated decision-making about that industry to date. Present and future decision-making determines its future evolution. Decision-makers in an electricity industry may be grouped as follows (Figures 1-4, 12):

- *Governance decision-makers:* typically led directly or indirectly by national governments, these decision-makers design the electricity industry structure, institutional and regulatory arrangements and objectives and the overall decision-making framework within which industry-specific decision-makers function. They respond to inputs from the broader society as well as from the electricity industry itself. Large electricity industries may cross national boundaries, in which case multiple governments will be involved and questions of international trade law must also be considered. Under WTO rules, the implications may then depend on whether *commodities* or *services* are deemed to be involved, which may in turn depend on the design of the electricity trading rules (Howe and Heckman, 1996).

- *Regulators:* With delegated authority from government and as part of the governance regime, regulators may determine priorities for industry goals and objectives (e.g. reliability versus cost), the rules and objectives for the competitive and regulated participant decision-making regime and monitor compliance by industry participants with rules and objectives. They usually also determine the revenue that regulated industry participants are allowed to earn. Their decision-making may be influenced by factors other than the formal criteria in their founding legislation.
- *Competitive industry participants:* in a restructured electricity industry, these decision-makers typically include large generators, and may include end-users and some providers of network services. In theory but not necessarily in practice, their decisions are primarily influenced by price signals in one or more electricity-related markets. For example, their decisions may be influenced by factors outside the electricity industry context. They may also engage in meta-level activities such as attempting to exercise market power or influence the evolution of industry rules.
- *Regulated industry participants:* these decision-makers typically include most transmission and distribution network service providers (TNSP & DNSP) and may include some end-users and small generators. Their decision-making is constrained in various ways by the regulatory regime in which they operate and, as a result, they may try to influence the nature of the regulatory regime.
- *System and market operators:* these decision-makers are critical to achieving an appropriate and sustainable balance between the engineering decision-making regime required to keep the electricity industry machine functioning effectively and the commercial decision-making regime required to achieve economically efficient operating and investment decisions. System operators must exercise judgement, for example within the security regime, in which their task is to defend the integrity of the core of the electricity industry for which they are responsible against large disturbances. Security management can impact on the outcomes achieved by competitive and regulated industry participants. Because of asymmetries in their accountabilities, system operators may take a risk-averse approach to security management.

In the traditional model of regulated monopoly electricity supply, the following simplifying assumptions were taken at the governance level:

- End-users were allowed to make autonomous decisions about the use of their equipment, constrained only by the occasional failure of electricity supply availability (blackouts).
- Ownership and management of the supply-side of the electricity industry was delegated to a monopoly institution, which was replaced by a set of interconnected monopolies as the industry scope was enlarged by interconnections between neighbouring regulated monopoly supply systems. In return for a regulated return on assets the monopoly had an *obligation to supply* end-users regardless of their decisions.

Several features of the traditional electricity industry contributed to the success of this industry structure during much of the 20th century:

- the use of readily available and relatively cheap storable primary energy forms (such as fossil fuels or storage hydro),
- significant economies of scale in steam-cycle generation technology, in network service

provision and in institutional arrangements,

- the physical ability of a large electricity network (within its secure operating envelope) to exploit diversity between the stochastic energy fluxes associated with individual items of generation and end-use equipment, and to tolerate failures of individual items of electricity supply equipment without loss of supply,
- The relatively small amount of electrical energy required to meet what were regarded as essential residential loads, coupled with a relatively high tolerance of low availability and quality of supply by residential end-users.

3. Electricity industry restructuring and its effects

Towards the end of the twentieth century many countries sought to reduce direct government involvement in, and to increase the economic efficiency of, their electricity industries through a change in industry decision-making arrangements, often described as electricity industry restructuring. To date, electricity industry restructuring has mainly consisted of disaggregating generation, network and retailing functions and introducing competition into generation and retailing via formally designed markets. This has had the effect of decentralising decision-making among many more supply-side decision-makers than was previously the case but has yet to have much impact on the demand-side of the industry, which already involved decentralised decision-making, albeit largely decoupled from the supply side of the industry due to government policies and, in particular, economically inefficient, predetermined cost-recovery tariffs.

The terms “de-regulation” and “liberalisation” suggest that rules are being removed. However, successful electricity industry restructuring requires the careful crafting of a set of institutions and rules that constitute an integrated decision-making framework that retains some centralised decision-making while decentralising other decision-making through purpose-designed markets and other commercial processes that create a competitive environment. Moreover, electricity industry restructuring processes should now be specifically designed and implemented to accommodate high levels of renewable energy penetration.

Restructuring is intended to deliver economic efficiencies but it has had mixed success. The Australian experience has been more successful than most, with average real prices falling by 19% since the early 1990’s while investment has continued and supply reliability and security have been maintained despite growing electricity demand (Productivity Commission, 2005; NEMMCO, 2006a). However, the Australian restructuring process is still incomplete (e.g. ERIG, 2006) and doubts remain, for example about price and service outcomes for small end-users (EWON, 2006). Increasing use of air-conditioners in summer heat waves is now driving additional network investment with associated upward pressure on network costs and prices.

In some other countries, there are greater doubts about the success of electricity industry restructuring, particularly with respect to cost outcomes for end-users (Johnston, 2006a & 2006b) and the ability of competitive generation sectors to achieve timely investment in new generating capacity (IEA, 2002b; IEA 2003a; NERC, 2006).

Introducing a significant number of renewable energy resources into electricity industries at this time adds new challenges to restructuring in addition to the particular challenges associated with renewable energy resources themselves. There are a number of reasons for this:

- The variable, non-storable nature of key renewable energy forms such as wind and solar energy, leads to a need for accurate forecasting and a need to define appropriate boundaries to autonomous decision-making by renewable energy generators for both operation and investment. It also increases the potential benefits of active end-user decision-making.

- The novel nature of some renewable energy generator technologies, such as wind turbines and photovoltaic systems, leads to uncertainties in their technical performance, particularly during abnormal power system operating conditions when power system security may be at risk. It also leads to challenges in developing mathematical models that can adequately predict power system behaviour with high renewable energy penetration.
- The small size of some renewable energy generator installations, such as photovoltaic systems, leads to a rapid increase in the number of supply-side decision-makers and a need to develop appropriate commercial contracts and technical requirements for generator connection to distribution networks (e.g. BCSE, 2004), in contrast to the more mature arrangement for generators connected to transmission networks.
- While still in the development phase, renewable energy technologies will continue to require policy support. The challenge exists to provide financial support in a way that encourages the most cost efficient development of the technologies (e.g. Carbon Trust, 2006, Huber et al., 2004; Watt and Outhred, 2000).
- The use of renewable energy in the context of autonomous single-users or small rural communities may raise community social, technical and financial resource questions, as well technical challenges associated with remote locations and long equipment supply chains (e.g. Retnanestri et al., 2005).

For these reasons, the regulatory framework and market rules for a restructured electricity industry may have to evolve to accommodate high levels of renewable energy penetration. To achieve effective outcomes, these issues must be addressed in a consistent manner, at all levels of decision-making from the high-level, long time-scale governance level to the technically specific, short term power system operating level (Figures 3, 12). This in turn requires a rigorous, internally consistent multi-disciplinary approach to identification and solution of the R&D tasks associated with restructuring the electricity industry to take into account sustainability and energy efficiency objectives.

3.1 Risk management in the electricity industry

Because electrical energy travels at the speed of light through the network, an electricity industry operates physically much like a single machine, albeit dispersed over a geographical area that may be continental in scope and with multiple decision-makers determining its evolution. The electricity industry faces continuing threats to its ability to maintain the continuous flow of end-use services from local to system-wide phenomena. In other words, the electricity industry machine is at continuous risk of breaking down in various ways. These threats may arise as the unintended consequences of participant decisions as well as from physical phenomena. This is illustrated in Figures 2 & 4.

Many end-use services delivered by the electricity industry have achieved the status of essential services in modern human society, implying a need for both high probability of availability and low cost of provision. However, a number of industry trends are now stretching the feasibility and affordability of this interpretation:

- Expectations for very high levels of availability and quality of electrical energy delivered at the point of connection to end-user premises.

- Increasing use of end-use equipment such as air-conditioners that can exhibit highly correlated (and thus expensive to supply) demand for electrical energy under certain conditions.
- The massive size and complexity of continental-scale electricity industries that, while usually robust, may be vulnerable to complex, cascading failure modes (Pourbeik et al., 2006).
- Restrictions in the operation of hydro and thermal power stations and network equipment compared to previous experience due to climate change.
- Operating constraints on fossil fuel power stations due to their environmental impacts and/or primary resource availability constraints.
- Increasing interest in the use of non-storable, stochastic renewable energy resources such as wind and solar energy.

Thus, climate change, energy security and essential service concerns have led to new priorities for the industry and the objective of an electricity industry may now be stated as follows:

> *The objective of an electricity industry is to deliver end-use flows of energy services to acceptable levels of risk in a manner that is technically, economically, socially and environmentally sustainable.*

Traditionally treated as a matter for the supply side of the industry, risk management must now be undertaken in a coherent manner by all industry participants including end-users. This is because informed end-users, preferably supported by energy service advisors (Outhred and MacGill, 2006a) are most aware of the consequences of loss of supply to their premises and thus best placed to assess cost-effective levels of risk for their particular end-use energy services. By entering into appropriate derivative contracts with their local network service provider and (separately) with their energy market operator or retailer, the (insurance) values that end-users place on receiving supply in the future and avoiding blackouts, can be translated into assured cash flows to their network service provide and generators on the other side of the energy market..

The set of risk management problems can be broadly characterised as resource adequacy questions (Yang, 2006), which may be further characterised by both location and future projection horizon (e.g. short-term operational risks versus long-term investment risks). Satisfactory solution of these problems will require coordinated innovation and competitive processes throughout the industry to deliver acceptable outcomes (European Commission, 2006a). Decision-making should be led by end-users with end-use efficiency enhancements and renewable energy forms being important options to consider (European Commission, 2006b). However, this can only take place if governments establish and maintain coherent decision-making frameworks for their electricity industries.

4. Decision-making for a restructured electricity industry

Figures 3 & 12 show a decentralised decision-making framework for an electricity industry. Note that the decision-makers are linked and that none are fully autonomous. One important task of restructuring is to recognise and, where possible, formalise those linkages in a manner that correctly delegates decision-making authority and accountability, while providing appropriate interfaces between decision-making regimes.

Some important linkages can be set out as follows:

- Governance decisions overlap in the temporal dimension with the investment decisions of competitive participants and regulated participants (network service providers or NSPs).
- The investment and operating decisions of regulated network service providers (NSPs) in providing spatial arbitrage, interact with competitive participant (generator or end-user) investment decisions in both spatial and temporal dimensions.
- The operating decisions of system operators interact with those of competitive and regulated participants.
- Depending on market design, decisions by market operators may interact with operating and investment decisions of competitive and regulated participants, for example in determining capacity obligations.

Moreover, all decision-makers can influence the outcome with respect to the delivery of end-use energy services, because risks to end-use services arise from all stages in the energy conversion chain as illustrated in Figure 4. Advanced metering at end-user points of connection, which can record the energy produced or consumed in each market interval (e.g. 30 minutes) as well as important indicators of availability and quality of supply, is critical to assign accountability in a decentralised decision-making context, particularly if end-users are to be active participants (e.g. FERC staff, 2006).

For the purposes of analysis, it is often useful to consider separately those decision-makers lying outside the industry per se (governance, regulation and society generally) from direct industry participants (generators, network service providers, end-users and retailers/suppliers) and system and market operators, while recognising the links between the various categories.

This is because industry participants are more focussed on industry issues in their decision-making whereas governance and regulatory decision-making is, to a greater extent, informed by, and responsive to, broader societal issues. Given the overlapping time-scales in decision-making, there is little room for error or instability in policy and governance arrangements. This has implications for policy and governance research, which should aim to identify and redress any shortcomings of proposed policies or market designs prior to their implementation. Experimental economics can assist with the assessments of this type (e.g. Outhred and Kaye, 1996a).

Within an electricity industry, a formal framework is required to manage the linkages between industry participants, system operators and market operators (Outhred, 1993; Outhred and Kaye, 1996b; Outhred, 2007, Thorncraft et al., 2007). This is due to the overlapping time-scales in decision-making and the inevitable boundary issues between decision-making regimes. It will be illustrated by reference to the implementation in the Australian National Electricity Rules (AEMC, 2006a).

A key issue to note at this point is that a market representation of an electricity industry will always be incomplete, leading to a situation where responsibility for decision-making to manage risks to energy service flow must be shared, and should be closely coordinated between centralised reliability target setting and system operation (jointly described here as the security regime (Wang & Morrison, 2006)), competitive, decentralised participant decision-making (described here as the commercial regime) and governance and policy making (described here as the governance regime). Finally, decision-makers rarely control the behaviour of an electricity industry directly. Rather, they set targets for automatic control systems that determine the operation of one or more items of equipment. The industry as a whole operates in a semi-autonomous manner in response to the way in which the various items of equipment and their control systems interact. A successful outcome is achieved through engineering rules and studies, which will be described here as the technical regime. The four regimes are shown in Table 6.

Table 6. Governance, commercial, technical and security regimes for a restructured electricity industry

Governance Regime	*The set of formal institutions, legislation and policies that provide the framework in which a competitive electricity industry operates.* This includes the formal regulatory arrangements for electricity industry participants, supplemented by the broader social context that influences the industry. The scope of an electricity industry is defined by the physical extent of the underlying transmission and distribution networks and may involve one or more national jurisdictions, for example in the European Union or North America.
Security Regime	*The task, assigned to one or more system operators, of maintaining the integrity of a local or industry-wide core of an electricity industry in the face of threats posed by plausible large disturbances.* The security regime typically has authority to restrict and, if necessary, override the commercial regime in defined circumstances and to a specified future horizon. For example, the security regime may have the power to direct participants to operate their components at specified levels and, under defined circumstances, to disconnect components (including involuntary load-shedding). This is an example of the prioritisation of industry goals.
Commercial Regime	*The commercial arrangements for the competitive electricity industry.* These may include spot markets for electrical energy and ancillary service as well as associated derivative or capacity markets, and commercial interfaces between competitive industry participants, such as generators and end-users, and regulated industry participants, such as network service providers.
Technical Regime	*The integrated rules for component and system design and system operation that allow the various components of an electricity industry, when connected together, to function effectively as a single machine.* These rules are necessary for the industry to deliver a continuous flow of electrical energy of appropriate availability and quality from generation equipment to end-use equipment, tracking decision-maker targets, rejecting disturbances and degrading gracefully if equipment faults occur.

Key issues for the governance regime include:

- Coherence and consistency, particularly when the electricity industry spans more than one national or provincial jurisdiction (Commission of the European Communities, 2007; US-Canada Power System Outage Task Force, 2004; UCTE, 2006).
- Efficacy in delivering good industry outcomes, particularly where choices can be made between different implementations of electricity industry restructuring.
- Robustness, in the face of pressures that threaten the integrity of the governance regime
- Boundary issues and compatibility with other regimes, including, where appropriate, supra-national governance and formal regulatory bodies (op cit).
- Prioritising the multiple objectives that society sets for the electricity industry: - for example,

security and integrity at a system level, reliability of supply to end-users, economic efficiency, environmental sustainability, industry and regional development and social equity.

- Setting goals and designing and managing the associated transition processes to integrate high levels of renewable energy resources. The transition process can be challenging given the need to rapidly and drastically reduce climate change emissions and the potentially disruptive nature of many renewable energy technologies.

Key issues for the security regime include:

- Coherence and consistency, particularly when more than one system operator is involved, noting that there are choices to be made between centralised and distributed control. Note also that in an electricity industry involving multiple jurisdictions, the geographical mappings of the jurisdictional boundaries may not match those of security-related flow constraints or even the franchise territories of system operators (op cit).
- Efficacy and scope of authority to intervene and independence from industry participants, in the face of pressures from industry participants who fear commercial losses.
- Adequacy of information to support sound decision-making: system visibility; forecasts of critical uncertain variables (e.g. demand, wind power production at appropriate levels of aggregation, etc.); contingency assessment.
- Transparency in the development of grid codes, preferably by system operators without generation interests, and with equal consideration of the full range of generator types.
- The security regime should not act as a barrier to entry for new technologies, and should only intervene at high penetration levels of a "suspect" technology. TSO requirements for fault ride through capability of wind farms provide both good and bad examples of this.

Key issues for the commercial regime include:

- Effectiveness in commercially rewarding participant behaviour that is beneficial to overall economic efficiency (defined in a broad socio-economic sense), and in commercially penalising participant behaviour that is harmful to overall economic efficiency.
- The unsuitability of bilateral trading regimes for electricity industries with high levels of stochastic renewable energy penetration – gross-pool style electricity trading arrangements are better able to manage the high levels of short-term uncertainty involved, as illustrated in (European Transmission Operators, 2007).
- Coherence in risk management from very short term operation (ancillary services, from seconds to minutes), to near term (energy spot market – which may range from 5 to 30 minutes ahead), to long term (derivative markets – which may range from hours to years ahead).
- Forecasting tools that support informed commercial decision-making.
- Boundary issues and compatibility with other regimes.

Key issues for the technical regime include:

- Technical requirements for system flexibility, predictability, variability (and intermittency); optimising the technical design and management of generation, network and end-use equipment, system interconnection, reversible energy storage and power quality.

- Evolution of technical requirements to facilitate and guide the development of emerging technologies, so that they function effectively as components of a single machine when integrated into conventional power systems.
- Technical challenges and benefits of distributed generation, intelligent grid control, and demand side management.
- Appropriate provisions for metering, communication and remote control.
- Investigating the scope for geographical and technological aggregation to manage variability.
- Boundary issues, including interconnection design operation & flow constraints, and compatibility with other decision-making regimes.

It is a task of the governance regime to establish an effective security regime (World Energy Council, 2006) as well as an effective commercial regime and the boundaries between them. The technical regime can be developed within a self-regulatory environment so long as overarching objectives are specified at the governance level, for example with respect to compliance with international standards.

The objective of the industry-wide security regime (Wang & Morrison, 2006) is to manage significant threats to continuing delivery of energy services identifiable within the operations horizon (typically to one year), by preventing system operation from moving outside secure operating limits (Wang and Morrison, 2006) and by maintaining the integrity of the core of the power system if a major disturbance does occur. By contrast the objective of a local, distribution-level security regime is to manage threats to the adequacy of availability and quality of supply within a particular distribution network.

The interface between the industry-wide security and commercial regimes is illustrated in Figure 5, where nodal markets refer to nodal spot and derivative markets for electrical energy and ancillary services, noting that in practice, nodal markets are implemented at some level of spatial aggregation (Outhred and Kaye, 1996b). Network access refers those parts of the network (distribution and part of transmission) that are not modelled in the set of the nodal markets (in which the network provides an arbitrage function).

Within the operating envelope defined by security limits, the commercial regime can be used to find the most economically efficient operating state. Figure 6 illustrates this partition of roles. Figure 6 is based on the security & commercial regimes used in the Australian National Electricity Market (NEM). In this model, spot prices for electrical energy and ancillary services are set at five-minute intervals by means of a security-constrained dispatch, in which the spot market can only solve within secure operating limits that the system operator sets for each five-minute interval to reflect evolving transmission-level security threats (AEMC, 2006a). Figure 7 shows the spot and derivative energy markets and the frequency-related ancillary service markets in the NEM commercial regime.

The Australian NEM is a wholesale electricity market, in which few end-users participate directly. At present, most end-users buy electricity from electricity retailers on retail contracts, which typically include predetermined tariffs, albeit sometimes with time-of-use features. This approach doesn’t fully integrate end-users into the NEM risk management framework, nor does it provide efficient pricing for distributed resources, which include embedded generators connected to the distribution network, demand responsiveness, enhanced end-use efficiency, fuel switching and other measures. Some renewable energy generators qualify as embedded generators.

Figure 8 shows a possible future industry structure that would more fully integrate end-users and distributed resources into the Australian NEM risk management framework (Outhred & MacGill, 2006b). Note that in Figure 8, DR stands for distributed resources, ESCO stands for energy Service Company and AMI for Automatic Metering Interface. In this proposed model, end-users and DR providers would participate directly in both the commercial and security regimes of the NEM, assisted by ESCOs with relevant expertise. This structure would require advanced spot and derivative market designs, such as those discussed in Outhred (2006a).

5. Implications of the rules of the World Trade Organization (WTO)

Electricity industries of multinational scope are directly impacted by WTO rules, however the implications may change depending on whether the international transaction involved is regarded as a *good* or *commodity* on the one hand (e.g. bulk power trading between two vertically integrated utilities) or a *service* on the other (more likely to be the case in restructured electricity industries). This ambiguity should be removed.

Electricity industries that are entirely within nations are also affected by WTO rules if questions arise about discrimination against equipment providers from other countries. An example would be technical rules for the connection of generators that could be deemed to discriminate against generator equipment providers from other countries. Different WTO rules may apply depending on whether, and to what extent, grid access is set by government regulation, by a vertically integrated monopoly (and further whether such a monopoly is an organ of the state or not), by a former monopolist operating in a competitive generation market that stills owns the transmission network, or by an Independent Market Operator, either a governmental, parastatal, or private regulated entity. Generally speaking, the more direct the involvement and control by government in setting the terms of access, the more fully WTO disciplines will apply.

A further issue is that of the application of WTO rules to the management of interconnection issues between national and sub-national electricity systems by regional or transnational "grids" or by regulatory cooperation mechanisms such as the Reliability Councils in North America. Such bodies are not themselves bound to follow WTO rules. However, where they create technical standards the states that participate in them have a best efforts obligation to ensure that the standardization process is consistent with certain kinds of due process or good governance norms (the TBT code of good practice).

A final general consideration about the nature of WTO obligations is that they contain few requirements to take positive measures to assure network access (as opposed to negative constraints, on discriminatory conduct for instance); thus, nothing in the WTO rules would require a government to make investments in transmission infrastructure that may be required to permit trade or increases in trade across national boundaries. Along similar lines, apart from what is implied in non-discrimination obligations, WTO rules do not address the allocation of costs for the infrastructure needed to trade electricity across jurisdictional boundaries or the sharing of responsibility between jurisdictions for externalities of such trade (such as breakdowns in the cross boundary grid, as happened dramatically in a significant part of North America in August 2003).

In sum, there may be both public and private decisions that affect grid access for international trade in electricity where WTO disciplines do not operate even though the decisions themselves may have very important, even crucial implications for trade.

We now proceed to provide an overview of the main WTO provisions, both on trade in goods and trade in services, which may entail disciplines on grid access conditions.

5.1 Trade in Goods

Non-Discrmination

The most important disciplines here are those of non-discrimination, as they apply broadly to internal laws, rules and regulations that "affect" trade in goods; these are contained in the General Agreement on Tariffs and Trade (GATT.) This has been interpreted in very wide fashion to include any such measures that influence the competitive relationship between domestic and like imported products (National Treatment, Article III of GATT)) or between imported products originating from different WTO Members (the Most-Favoured Nation obligation, Article I of GATT).

These provisions go beyond prohibiting intentional discrimination to applying to circumstances which may include certain non-intentional discriminatory effects. However, precisely how far beyond (i.e. the meaning of *de facto* discrimination) is not entirely clear from the case law. For example, suppose a jurisdiction, as a condition for grid access, imposes on a market actor the requirement that a certain percentage of the electricity it feeds into the system originate from renewable sources but excludes hydroelectricity from the definition of renewable generation. Does this discriminate against an exporting WTO Member that has a comparative advantage in hydroelectric generation, even though there is nothing explicit in the measure that singles out for disadvantaged treatment imports from that jurisdiction?

A key concept in National Treatment is that of "like product." Regulatory distinctions drawn between products that are not "like" will not attract discipline under the National Treatment obligation; thus if a government creates grid access conditions that are favorable to renewable over other sources of power, but without any regard to whether the power is from a domestic or foreign source, no National Treatment issues will arise if renewably generated electricity is not a "like" product to electricity generated from fossil fuels. Conversely, if a government seeks to disadvantage renewable energy in terms of grid access, this will also be permissible if the electricity generated from renewable sources is unlike energy generated from non-renewable sources. Considerations to be taken into account in this analysis include physical properties, consumer habits and tastes, end uses and customs classification, with very subsidiary emphasis on the last factor.

State Trading Enterprises

By virtue of the GATT provision on monopolies and state trading enterprises (Article XVII of the GATT), WTO Members are required to ensure that public and private entities that fall under these categories comply with the National Treatment obligation. The relevant definition of state trading enterprise is "governmental and non-governmental enterprises, including marketing boards, which have been granted exclusive or special rights or privileges, including statutory or constitutional powers, in the exercise of which they influence through their purchase or sales the level or direction of imports or exports." (WTO, 1994)

Article XVII also contains an obligation that the covered entities make purchase and sale decisions based on commercial considerations and afford an adequate opportunity for foreign goods to compete. In the *Canada-Wheat Board* case, The Appellate Body of the WTO has interpreted these additional obligations as largely a gloss on the general non-discrimination obligation of National Treatment, and *not* as an independent discipline on anti-competitive behavior. Thus a monopoly can take advantage of its market power as monopolist and an incumbent of its dominant position while still acting in accordance with commercial considerations. The non-commercial considerations boil down to considerations that relate to the foreign origin of goods. This narrow interpretation of "commercial considerations" is probably appropriate; if "commercial considerations" were interpreted very broadly Article XVII would effectively disallow decisions of state trading entities based on non-discriminatory legitimate public policy goals (some of these decisions might be covered by exceptions in the GATT as described below though not all). "Commercial considerations" must surely include decisions that are based on the suitability of goods purchased in light of the policy objectives that the state is imposing on the enterprises.

An additional provision of the GATT that may be relevant to electricity-related international trade transactions is Article XI, which disallows prohibitions and restrictions on imports and exports. This provision would normally require a government to permit electricity to be traded across the border as a commodity, without imposing limits on the amount of exports or imports, subject to certain exceptions to be discussed below.

Exceptions to rules in the GATT

In the case of the GATT, the evaluation of the legality of an internal policy entails not only a consideration of whether the policy is consistent with the non-discrimination requirements in Articles I and III (MFN and National Treatment) but also whether, even if inconsistent, it can nevertheless be justified under the *General Exceptions* provision (Article XX.). This provision "saves" measures that would otherwise be GATT-illegal if they serve certain defined public policy objectives, which include the protection of human life and health (XX(b)) and the "conservation of exhaustible natural resources."(Article XX(g)).

As interpreted in WTO jurisprudence, the chapeau or preambular paragraph of Article XX requires that measures maintained under Article XX be applied in an objective, transparent, non-arbitrary and non-protectionist manner. Also, Article XX(j) of the GATT provides an exception for measures "essential to the acquisition or distribution of products in general or local short supply." Finally the National Security Exception in Article XXI of the GATT provides, in part that "Nothing in this Agreement shall be construed…to prevent any contracting party from taking any action which it considers necessary for the protection of its essential security interests … taken in time of war or other emergency in international relations."

Several of these exceptions may apply to justify otherwise GATT-inconsistent measures that affect grid access in relation to international trade; grid security and reliability for example have important affects on human life and health as well as national security. At the same time, the conservation of exhaustible natural resources might be relevant to justifying otherwise GATT inconsistent grid access conditions that favor renewable sources of energy; those necessary to ensure the security and reliability of the grid in light of concerns about the intermittency of renewable sources or possible serious negative externalities such as harmonics, ripples or other technical conditions that induce the propagation of 'dirty power' throughout the grid.

5.2 Technical Barriers to Trade Agreement (TBT)

The TBT Agreement imposes obligations with respect to some internal measures in addition to those in the GATT. Mandatory technical regulations are treated differently from standards of a voluntary nature that are not imposed through law. Mandatory technical regulations are defined very broadly to include documents that prescribe the characteristics of products as well as their related process and production methods. Mandatory regulations may include regulations imposed by a quasi- or non-governmental Independent Market Operator where it is acting under state control or direction or delegated governmental authority.

Most notable in the TBT are the obligation that technical regulations have international standards as a basis, where such standards exist and are not ineffective or inappropriate to attain the legitimate policy objective. In addition, technical regulations must not create unnecessary obstacles to trade, i.e. they must be the least trade restrictive available to achieve the legitimate, non-protectionist policy objective in question. As already noted in the case of non-mandatory standards, which may be promulgated by non-governmental entities, governments are required to make efforts to ensure that these abide by a Code of Good Practice contained in the TBT.

5.3 General Agreement on Trade in Services (GATS)

The scope and structure of GATS obligations is significantly different than in the case of the GATT. The Agreement applies to measures affecting trade in services, defined as the supply of services by the service suppliers of one WTO Member to the consumers of another WTO Member, through any of four "modes" of delivery:

- *Mode 1* refers to a situation where neither the supplier nor the buyer of the service crosses the border in order to effect the transaction: supply of electricity across the border, to the extent that this is a service (see above), falls within mode 1 in many cases.
- *Mode 2* entails the consumer going to the jurisdiction of the supplier in order to consume the services (e.g. tourism).
- *Mode 3* involves the supplier establishing a commercial presence in the jurisdiction where the consumers of the service reside (and this mode may have important implications for the energy sector as well as *Mode 1*).
- *Mode 4* involves the entry of personnel of the service supplier into the jurisdiction where the consumers reside in order to deliver the service.

There are some general obligations in the GATS that apply to all services supplied from one WTO Member's providers to consumers of another Member in any of these modes of delivery, including Most Favored Nation treatment and transparency. However, many of the most important obligations apply only in respect of sectors where individual WTO Members have made commitments in their "schedules", and this includes National Treatment (Article XVII) and the rough GATS equivalent of GATT Article XI (Quantitative Restrictions), namely GATS Article XVI (Market Access) and Article. VI (Domestic Regulation—very roughly equivalent to the TBT in respect of goods).

These obligations are subject to a set of general exceptions that are similar to those Articles XX and XXI of the GATT, as discussed above. Further complicating the structure of obligations in GATS is the possibility for WTO Members to use their "schedules" to limit or qualify obligations such as National Treatment in scheduled sectors, and these limitations may apply across the board, or to only one particular mode of delivery for a particular service sector. It will be appreciated that when the GATS was being negotiated in the late 80s and early 90s, de-monopolization of electricity utilities and unbundling of functions had barely begun. In the circumstances, it is understandable that there were few specific commitments that bear upon the services entailed in the provision of electricity.

Moreover, as Zarilli notes, there is no clear and precise classification that would facilitate the scheduling of specific commitments on energy services in GATS: "The WTO "Services Sectoral

Classification List" (document TN-GNS/W/120) does not include a separate comprehensive entry for energy services. The United Nations Provisional Central Product Classification (UNCPC) also does not list energy services as a separate category." As she goes on to observe, Annex 1 in the CPC does provide a list of energy related services that might fall under various classifications, ranging from consulting to construction to transportation services, and there are a few energy related sub-classifications in the WTO scheduling document. Interpreting whether an activity that is not explicitly scheduled is nevertheless included within a classification or sub-classification in a Member's schedule is a complex exercise, which may include resort to materials such as negotiating history; see the US-Gambling Appellate Body report.

A provision of the GATS that may be particularly relevant to grid access issues and that goes beyond the provisions on state trading enterprises in the GATT is Article VIII on Monopolies and Exclusive Service Providers. Here there are some disciplines on anti-competitive behavior by such entities, including: "2. Where a Member's monopoly supplier competes, either directly or through an affiliated company, in the supply of a service outside the scope of its monopoly rights and which is subject to that Member's specific commitments, the Member shall ensure that such a supplier does not abuse its monopoly position to act in its territory in a manner inconsistent with such commitments."

5.4 Examples of Grid Access Issues Related to Trade in Renewable Energy Goods and Services

Mandatory standards (technical regulations within the meaning of WTO law as discussed above) are of vital importance to national grids and standards for electrical equipment have a long history. There are important legitimate reasons to impose technical requirements that burden producers of renewable energy, including reliability and security of the grid. For the purpose of this paper reliability is not the ability of renewable sources of supply such as wind and solar to supply electricity on demand but, amongst other things, the ability to provide clean power when connected to the grid through all phases of operation from minimum to maximum rated load, to meet standards for low voltage ride-through (the ability of a wind farm to stay connected to the grid and not affect grid stability during a low voltage event), to be able to work with reasonable gate closure times and to provide facilities that can be effectively managed by the grid operator in conjunction with other energy sources. It would be very unusual if these were explicitly discriminatory against imported renewable energy.

Gate time issues are very relevant to renewable intermittent power sources but, again, that is an issue for the grid operator and for international harmonization - here it is an issue of renewables v. traditional methods of managing the grid. The main question would be whether there is de facto discrimination-i.e. Are technical requirements written in such a way as to favor domestic producers? Here the most pertinent WTO discipline is the requirement that technical regulations be based on international standards and that they not constitute "unnecessary obstacles to trade." On the matter of international standards, generally these do not currently exist with respect to interconnection to the grid of renewable sources. The barriers to trade between jurisdictions within the US, for example, created by many diverse and inconsistent requirements in different US states has led the US Federal Energy Regulatory Commission to promulgate federal standards (with respect to interconnection of wind generation sources to the grid, for instance.)

Some traditional grid management approaches may disadvantage renewable energy but it may be possible to introduce alternative approaches that achieve the goals in question while being less restrictive of trade in electricity generated from renewable sources. For instance, a FERC study on wind power and the grid notes: "Transmission services that allow for the unique operational characteristics of wind energy such as conditional firm, curtailable firm, priority nonfirm, and hourly firm may offer wind generators increased certainty for gaining access to the transmission grid. Measures can also be taken to reduce the impact of imbalance penalties and innovative methods can be developed to allow wind resources to contribute to regional reserve requirements and capacity markets." Adopting such alternative approaches where feasible is required by the TBT obligation that technical regulations not constitute an "unnecessary obstacle" to trade.

The need for standards is no less for international grids and as such transnational grids grow and develop, national grids or portions of national grids wishing to interconnect with the new international grids will have to meet international standards of reliability, quality, manageability etc. Furthermore, this implies that equipment hooked to national grids will also have to meet international standards particularly where such equipment will effect stability and reliability. These considerations will automatically extend to facilities producing renewable energy. Indeed, the current emphasis on interconnecting grids internationally should naturally lead to the creation of international standards. The TBT Agreement requirement that international standards be used as "a basis" for technical regulations where they exist and are effective and appropriate ensures that international standards are widely used once they have been promulgated. The meaning of "international standard" is however not defined in the TBT Agreement; but presumably these are standards from international standardization bodies, which the TBT Agreement defines as organizations that are open to participation by the standardization bodies of all WTO Members. This would seem to mean that standards developed by entities responsible for regional grids (as opposed to the IIEE for instance) would not be deemed "international" for purposes of TBT requirements." and procedures to establish compliance with those regulations ("conformity assessment" in WTO language, under the TBT Agreement) may result in "unnecessary obstacles to trade," within the meaning of TBT or may constitute even if they do not distinguish on their face imports from domestic production, de facto discrimination, depending on the nature and scale of the disparate negative impact on imports.

Compliance

Compliance with national/regional/local regulations (and in many jurisdictions such as Denmark all three will be involved) can be a lengthy, costly and burdensome process. This is why the European commission requires that member states streamline access procedures for grid connection of distributed generation. A lack of such streamlining can add significantly to the time it takes to build a project as well as the cost. Conversely, streamlined procedures - and even better - procedures that are similar or identical between various jurisdictions - will allow renewable energy producers to maximize resources and the potential for profitability.

Jurisdictions that make the strongest efforts in this direction will advantage their own renewable energy companies, conversely complex and cumbersome local procedures with many local idiosyncrasies while hampering all will tend to disadvantage foreign entrants to the local industry the most. Whether in a given case this extra disadvantage amounts to de facto discrimination under the National Treatment obligation would require a very careful inquiry into the facts of each situation and the nature and scale of the disproportionately disadvantageous affect on foreign market actors.

At the same time, the conformity assessment provisions of the TBT Agreement provide: "5.1.2

conformity assessment procedures are not prepared, adopted or applied with a view to or with the effect of creating unnecessary obstacles to international trade. This means, *inter alia*, that conformity assessment procedures shall not be more strict or be applied more strictly than is necessary to give the importing Member adequate confidence that products conform with the applicable technical regulations or standards, taking account of the risks non-conformity would create. Further, the TBT Agreement provides that "Members shall ensure that 5.2.1 conformity assessment procedures are undertaken and completed as expeditiously as possible and in a no less favourable order for products originating in the territories of other Members than for like domestic products;. . ." Further, the TBT Agreement contains provisions concerning transparency and notification of technical regulations.

Idiosyncratic local regulations may also drive up costs and hamper foreign competitors. For instance in Denmark's Greater Copenhagen Region, the regional authority has set a height restriction on wind-turbine towers of 70 metres, despite the fact that this is ten or more metres below the optimal height for constructing the most efficient modern wind turbines (Soren, 2005). The consequence of this is that local manufacturers build special models to satisfy parts of the local market but the market is too small to encourage foreign producers to build a special, short model just for Denmark. Here most relevant is the requirement under the TBT Agreement that technical regulations not constitute an "unnecessary obstacle to trade." Is the idiosyncratic height restriction really necessary to achieve a legitimate public policy objective?

Technical Specifications of Equipment

In order for wind power in the United States to gain greater acceptance the Federal Energy Regulatory Commission (FERC) mandated a low-voltage ride-through standard. This standard allows complying wind farms to remain connected to the grid during low voltage events. It is noteworthy that this standard was hailed as bringing U.S. practice closer to European practice (where wind farms are connected to the grid continuously) and the Danish wind turbine manufacturer, Vestas was closely involved in helping the FERC develop the new grid access standard for wind farms of which the ride through provision was a key part. This example is an illustration of how standardization can remove obstacles to trade in renewable energy equipment while not undermining and actually facilitating legitimate public policy objectives concerning reliability of the grid. The standard in question was designed to open up the market to imported equipment rather than to place an obstacle in the way of such trade.

Minimum Prices and Quotas

The characteristics of these two policy instruments are summarized by Fouqet et al. (2005): "The minimum price system is characterized by a legally determined minimum price and an obligation on the part of the grid operator or utility to purchase "green" electricity. In contrast, the key components of quota schemes are government mandates for specified groups of market participants to purchase or sell a minimum quantity of capacity or amount of electricity from renewable energy. The government allocates certificates in order to ensure compliance with the mandated quantity."

The case of quota schemes poses a rather different set of issues. In a document produced for the Commission on Environmental Cooperation under the North American Free Trade Agreement, Horlick et al (2001) have argued that US state renewable portfolio standard (RPS) laws, which require retail sellers of electricity to include in their portfolios a certain percentage or amount of electricity from renewable sources, may violate the National Treatment provisions in the GATT. This conclusion is in large part based on the assumption that "Electricity produced from renewable resources has exactly the same qualities as electricity generated from other (conventional) resources and it is the same whether domestically produced or imported."

On the basis of this assumption Horlick et al. apparently consider it a foregone conclusion that electricity from renewable sources would be found to be a like product to electricity from non-renewable sources. As has been pointed out in lengthy response to their study by the Union of Concerned Scientists, the legal analysis of Horlick et al is questionable in some respects. It seems based on the presumption that the WTO adjudicator could never find that two products with similar physical characteristics are nevertheless "unlike", for example, because the other factors probative of "likeness", such as consumer habits, point to a finding of "unlikeness." (Hempling and Radar). The evidence must necessarily include evidence of consumer preferences and habits, a factor that the Appellate Body has held must be addressed before making a determination of likeness. In this respect, Hempling and Radar note: "The public's demand for renewables, as evidenced by the interest in diversity and the willingness to pay more for the product, demonstrates that the purchase decision has more dimensions than merely physical ones."

Even if renewable sourced energy were deemed to be a "like" product to nonrenewable sourced energy, a finding of Article III: 4 violation would require the additional step of a determination of "less favorable treatment" of imports. Horlick et al conclude that "the generating methods included in the renewable portfolios tend to disadvantage out-of-State producers, including foreign importers, because of different regulatory, topographic and environmental conditions which influence electricity generation in different regions and countries." National Treatment, however, cannot possibly be interpreted to require a government in its regulations to neutralize the comparative advantage that some producers have over others due to such locational factors. This would be contrary to objectives of the WTO as stated in the Preamble to the WTO Agreement, including optimal use of the world's resources.

6. Renewable energy integration in restructured electricity industries

Renewable energy currently provides 14% of the world's energy supply and is projected to remain at the fraction by the IEA despite a projected 60% increase in global energy consumption by 2030 (Figure 13). As shown in Figure 14, renewable energy resources are often transformed into electrical energy for transfer to end-user premises (direct biomass combustion is an exception, and hydrogen may in future provide an alternative energy pathway). Thus it is important to consider the question of integration of renewable energy resources into the electricity industry. The IEA has been engaged in such activities for some time under implementing agreements for wind energy (www.ieawind.org) and photovoltaics (www.iea-pvps.org). For example, IEA (2005a) discusses the issue of managing variability of wind power and other renewables. Outhred and MacGill (2006b) discuss similar issues in the Australian context.

Distributed renewable energy resources are (often geographically dispersed) energy fluxes, some storable to varying degrees within varying timescales, some not storable at all. Forecasting is an important issue for all renewable energy resources, particularly those that are not storable, such as wind and solar energy. Different forecasting objectives may arise for security and commercial regimes unless they have been designed to be closely compatible.

Some renewable energy resources are best regarded as shared public resources – e.g. solar and wind energy – raising policy issues about access, management and forecasting accountability, particularly as they are often transformed into electrical energy using privately owned generators, which is then injected into shared networks. For example, relationships between wind energy fluxes at different locations means that privately owned wind farms cannot always be regarded as fully independent commercial entities. Solar energy has similar characteristics. Figure 9 shows an example of structure in the atmosphere that can create a relationship between wind (and solar) energy resources over a large area.

Figure 10 shows an Australian wind farm responding to a period of high and then declining wind speed over a 24-hour period. The wind farm initially shuts down due to excessive wind speed then restarts. Its output then declines initially slowly and then later rapidly as the wind speed steadily drops towards cut-in speed over the rest of the day. Such behaviour may impose significant ramping duties on other generators and, should, if possible be forecasted in a manner that is useful for commercial and security regimes. However, the public good nature of the wind energy resource blurs accountability.

6.1 Effects of electricity industry scale on renewable energy integration

Single user and small community electricity industries must use local renewable energy resources unless they can be transported to site (e.g. some biomass). It is more important to involve end-users to a greater extent in design, planning and operating decisions in small electricity industries than it is in larger electricity industries (e.g. Retnanestri et al., 2006).

Electricity industries with larger geographical scale can take advantage of any renewable energy resources within the network reach of that electricity industry, subject to network losses and flow constraints, which may be device-specific or system security constraints. Larger electricity industries may also be better able to absorb variations in electricity output from renewable energy sources. Renewable energy generators that are located away from major load centres and existing generation (e.g. wind farms) may require potentially expensive network augmentation to avoid flow constraints.

Subject to flow constraints, electricity networks can, in principle, exploit any diversity that exists between resources at different locations. Exploiting diversity is particularly important for non-storable resources such as wind or solar energy fluxes, which can vary dramatically in time and space. However, power systems have been traditionally designed for unidirectional energy flow from large, remote power stations to urban centres. The use of dispersed, time varying renewable energy generators is more likely to result in bi-directional flow as shown in Figure 15, which can lead to problems with voltage management and fault protection.

As previously discussed, questions of international law may arise for electricity industries of large geographical scale.

6.2 Compatibility of renewable energy with the electricity industry

If we use the analogy of the electricity industry as a single machine, renewable energy generators become new component types for that machine. It follows that compatibility will be an important issue, particularly given the complexity of electricity industries as illustrated in Figure 16. Compatibility will be considered in governance, commercial, security and technical dimensions.

Technical issues

The technical issues associated with renewable energy compatibility relate to the ability of renewable energy equipment to function effectively as part of the electricity industry as it exists today. Equipment must meet engineering requirements with respect to voltage, frequency, waveform purity, ability to rapidly isolate faulty equipment from the rest of the industry and reasonable ability to withstand abnormal operating conditions (fault ride through). Depending on the context there may be additional technical requirements with respect to control over operating level and the ability to actively contribute to voltage management. Technical requirements can usually be effectively dealt with in connection rules (e.g. AEMC, 2006b).

Security issues

Security issues can be regarded as an extension to technical issues from the component to the local or global industry level. They arise at both the transmission and distribution levels (IEA, 2005a, Outhred, 2003).

Transmission-level security issues can be industry-wide and are mostly related to the ability of renewable energy generators to:

- Ride-through disturbances emanating from the power system and thus avoid contributing to cascading outages.
- Reduce output if needed to avoid overloaded or insecure power system operation.
- Contribute to voltage and frequency control and to stabilising system operation following a disturbance.
- Behave in a manner that can be adequately predicted by mathematical models for use in power system simulation studies and that can be adequately forecasted for system security assessment and for informing derivative markets.

Distribution-level security issues are local and mostly relate to the ability of renewable energy generators to:

- Contribute to voltage control in the vicinity of, and down stream from, the generator, while complying with islanding policy requirements.
- Contribute to managing distribution network flows in the vicinity of the generator.
- Avoid excessive fault levels while still contributing to fault identification and clearance.
- Avoid contributing to (or actively reduce) waveform distortion.
- Behave in a manner that can be adequately predicted by mathematical models for use in power system simulation studies and that can be adequately predicted by forecasts of future wind farm production for use in system security assessment and derivative markets.

Some of these issues can be managed via connection guidelines and technical connection requirements, e.g. BSCE (2004), AEMC (2006b). The latter includes obligations for the provision of operating data, an important resource for which appropriate provisions should be made. Mathematical models and forecasting remain open research questions.

Governance issues

Governance issues are addressed here in the sub-categories of institutions, legislation and policy.

Institutional issues include the development and implementation of:

- A robust security regime that can effectively manage the additional uncertainty associated with variable, non-storable renewable energy fluxes. This cannot be taken for granted, even in the absence of significant renewable energy penetration (e.g. World Energy Council, 2006).
- An efficient commercial regime that can correctly value uncertain, time-varying renewable

energy generation at both transmission and distribution levels with respect to both energy and ancillary services, as well as encourage compatible technologies such as reversible storage and flexible generation and demand.

- An effective regulatory regime that correctly manages the interface between renewable energy generators and regulated network service providers, with respect to technical and commercial terms for connection.
- Compatible institutional arrangements for other energy vectors, including the natural gas industry, to support the use of flexible gas-based generation to accommodate time varying renewable energy generation.

Legislative issues include:

- Internalisation of the increasing environmental costs associated with fossil fuel combustion.
- Non-discriminatory treatment of risks associated with different energy resources, particularly between renewable energy forms, fossil fuels and nuclear energy.

Policy issues associated with renewable energy compatibility can be characterised as:

- Prioritisation between the various societal objectives for the electricity industry: system security, supply reliability, economic efficiency, social equity and environmental impact.
- Support for appropriate innovation in renewable energy technologies in a manner that enhances compatibility.
- Support for the installation of renewable energy technologies in appropriate locations and at an appropriate rate, with the objective of avoiding unnecessary costs. This involves a broad range of policy issues including planning processes, payment mechanisms and the establishment of a level playing field for renewable energy technologies in subsidy terms.
- Design of forecasting regimes for renewable energy fluxes (both primary energy and associated electricity production), with appropriate specification of industry-level and generator-specific roles and accountabilities.
- Strengthening and interconnection of transmission networks to enable electricity industries to take advantage of geographical diversity and to increase their capacity to absorb variable output from renewable energy generators.
- Compatible infrastructure development and restructuring of other energy industries such as natural gas, to accommodate the variable output from renewable energy generators.
- Development of market-pull policies to complement technology-push policies, in a manner that minimises the costs of renewable energy integration.

Commercial issues

The commercial issues associated with compatibility can be split into financial and legal aspects:

- Financial support for investment in appropriate renewable energy generation (type, location, timing) while avoiding inefficient subsidy.
- Development and implementation of commercial regimes at both transmission and distribution levels that can accommodate renewable energy generation on a level playing field with respect to traditional generating technologies and that encourage investment in complementary technologies such as reversible energy storage, responsive generation and responsive demand.

Development and implementation of commercial regimes that correctly specify and allocate risks associated with renewable energy technology and encourage and facilitate efficient (physical and/or financial) risk management by either renewable energy generator owners themselves or by other appropriate parties.

7. R&D on renewable energy integration: outcomes and identified needs

7.1 General renewable energy integration

IEA (2006) reviews R&D priorities for renewable energy. It focuses mainly on technology development but also reaches the following conclusions relevant to renewable energy integration (pp 186-187):

> *The issue of renewable energy integration into the electricity and heading grids of intermittent renewable sources remains a challenge and should be addressed via technology advances and adjustments in policy and regulatory frameworks. Interconnection safety, codes and standards that address the intermittent nature of renewables have made great strides in the last decade but more work remains.*
>
> *There is a growing interest in distributed energy systems as an adjunct or partial replacement of traditional electricity and heating grids. Distributed energy systems directly address the growing need for energy security, economic prosperity and environmental protection. These systems are often located closer to the consumer and are more efficient and reliable.*

IEA (2005a), which investigated options and strategies for managing the variability of wind power and other renewables found that there were “six main areas of structural change that will directly benefit renewables” (p 47):

- *Increased grid capacity and cross-border connections, corresponding to the projects from the IEA’s WEO.*
- *Balancing/regulating markets that are cost-reflective, transparent and interconnected with gate closure times reflecting the technical and economic needs on the system.*
- *Enhanced uptake of efficient demand-side response mechanisms.*
- *Installation of more flexible generating capacity, including hydro-power and biomass, as capacity reserves and increased efforts to reduce costs of novel storage solutions to widen the number of strategic options.*
- *A mix of different renewable energy technologies, taking advantage of different natural cycles and thus reducing volatility and uncertainty.*
- *Improved forecasting and modelling of natural fluctuations and increased utilisation of communication technologies to disseminate this information between grid operators and markets.*

These involve a range of technical, economic and policy questions, including how to strengthen electricity and gas infrastructure, how to improve the implementation of electricity industry restructuring, how to encourage an appropriate mix of different renewable energy technologies and how to undertake forecasting in a way that addresses the needs of the various stakeholders. Compatible gas industry restructuring is another important issue.

Gross et al. (2006) reports on a study of the costs and impacts of intermittent generation on the British electricity network. The report defines intermittent generation as that for which the output varies with environmental conditions and the operator can only control output in a downward direction by "spilling" the resource. While drawing mainly on experience with wind energy, the report also considers other intermittent resources such as solar and wave energy. It reaches the following conclusions:

- *There are two categories of impact, to do with managing short-run fluctuations and longer-term system reliability, which we will characterise here as short- and long-term resource adequacy respectively. The extent of the impacts depends on how effectively resource adequacy is managed as well as on the characteristics of the intermittent generation (including its forecast-ability) and the nature of the other resources available to the electricity industry.*
- *To keep impacts low, policy should encourage diversity in renewable energy generation type and location, investment in complementary resources (supply, storage and end-use), and monitoring of reliability outcomes using indicators appropriate for high levels of intermittent generation.*

7.2 Wind energy integration

Wind energy has received particular attention with respect to renewable energy integration because it is the first of the "new" renewable energy forms that exploit non-storable energy fluxes to reach high levels of penetration in electricity generation.

In 2001, the IEA implementing agreement for wind energy (www.ieawind.org) produced a report on long-term R&D development needs for the time frame 200-2020 (IEA, 2001) that contained the following conclusions in the report summary (p1):

> *For the mid-term time frame, R&D areas of major importance for the future deployment of wind energy are forecasting techniques, grid integration, public attitudes, and visual impact. R&D to develop forecasting techniques will increase the value of wind energy by allowing electricity production to be forecast from 6 to 48 hours in advance. R&D to facilitate integration of wind generation into the electrical grid and R&D on demand-side management will be essential when large quantities of electricity from wind will need to be transported through a grid. R&D to provide information on public attitudes and visual impact of wind developments will be necessary to incorporate such concerns into the deployment process for new locations for wind energy (especially offshore).*
>
> *For the long-term time frame, it is of vital importance to perform the R&D necessary to take large and unconventional steps in order to make the wind turbine and its infrastructure interact in close co-operation. Adding intelligence to the complete wind system and allowing it to interact with other energy sources will be essential in areas of large-scale deployment. R&D to improve electrical storage techniques for different time scales (minutes to months) will increase value at penetration levels above 15% to 20%.*

At present, the IEA implementing agreement for wind energy has a number of tasks that explicitly address wind integration issues at the transmission level:

- Task 21: Dynamic models of wind farms for power system studies
- Task 24: Integration of wind and hydropower

- Task 25: Power system operation with large amounts of wind power

In addition, other organizations are undertaking substantial R&D into wind energy forecasting and quite demanding functional requirements are now being specified for wind forecasting systems:

- In Australia, AEMC (2006) proposes revised technical rules for generator connection, including wind generators. As well as meeting technical standards, generators are required to provide information on energy production via the system operator's SCADA system. NEMMCO (2006b) sets out functional requirements for an Australian Wind Energy Forecasting System (AWEFS) that include forecast horizons from 5 minutes to two years for individual wind farms and, in an aggregated fashion, for wind farms in NEM market regions (up to the order of 1000km across) as well as smaller areas designated by the National Electricity Market Management Company (NEMMCO) for security reasons, which it may change from time to time depending on factors such as evolving transmission network flow constraints. Our research group at the University of New South Wales, with financial support from the Australian Greenhouse Office, is participating in a collaborative research program to facilitate high levels of wind energy penetration in the National Electricity Market. Further information on this project is available at www.ceem.unsw.edu.au, including reports of two recent workshops on wind forecasting and wind integration issues respectively.
- Van Zandt (2006) and Adams (2006) report on the recently completed Ontario Wind Integration Study and outcomes to date. Key findings for R&D include:
  - Wind farm data is of vital importance but lacking at this stage, apparently across all North America –power output and associated meteorological data should be collected from all wind farms (requirements of this type are now included in the Australian National Electricity Rules)
  - Wind farms should have advanced control capability to contribute to voltage and frequency control and to allow curtailment when required for system security reasons
  - There will be an increased need for flexible resources to handle the increased variability in energy flows due to the use of wind energy
  - With high levels of penetration, wind farm output may have to be curtailed for system security reasons, for example during low load periods. However, this need could be reduced by the development of a more accommodating resource mix that included more flexible generation and loads.
  - The importance of wind farm geographical diversity cannot be understated. Policies should be developed to encourage spatial and temporal diversity in the development of wind energy projects.
  - Electricity industry restructuring should evolve in a manner that efficiently manages network flow constraints, while avoiding system security violations.
- The Alberta Electric System Operator (AESO) is currently commencing its Wind Power Forecasting Pilot Project that will involve the comparison of wind forecasts for 12 wind farms for a year. One US and two European wind forecasting vendors are participating in this project, which has the intent of enabling AESO "to integrate as much wind as is feasible into the grid without compromising system reliability or the fair, efficient and openly competitive operation of the market". This is part of a larger project to develop a "Market and Operational Framework for Wind Integration in Alberta" (www.aeso.ca/10741.html).

7.3 Priorities for further R&D on the integration of renewable energy

Innovation in renewable energy integration in restructured competitive electricity industries can be thought of as a decentralised, symbiotic innovation process, involving government, regulators, industry participants, technology developers & researchers. It involves aspects of both technology push and market pull (IEA, 2003b, Figure 1, p14), as well as matters of institutional design.

Priorities for R&D on the integration of renewable energy technologies into electricity grids

The studies reviewed in the previous section provide a consistent list of R&D priorities:

- Data collection and analysis to support better understanding of the impacts in practice (which may be context-specific) of high levels of wind energy penetration.
- Enhanced forecasting techniques that can predict not only the behaviour of individual renewable energy generators but also the behaviour of groups of generators aggregated in ways that are appropriate in a particular power system context. Such forecasting techniques should pay special attention to unusual, extreme behaviour because of its importance to security assessment – differential behaviour may be important as well as summated behaviour. For example, Figure 11 shows a forecast of an anticipated pattern of changes in wind speed and direction, which is produced by the Australian Bureau of Meteorology for bush fire management (Xinmei and Mills, 2006). A forecast of this type would also be useful for predicting large changes in the output of groups of wind farms.
- Further refinement of electricity industry restructuring to provide appropriate commercial signals (cash flow and legal obligations), effective in both operation and investment times-scales, for diversity, flexibility and controllability in renewable energy generation, as well as flexibility and controllability in non-renewable energy generation and end-use energy services (supported by compatible gas industry restructuring).
- Further refinement of electricity industry restructuring with respect to developing short-term and long-term resource adequacy and security management strategies that are consistent with high levels of renewable energy penetration.
- Further refinement of electricity industry restructuring with respect to the provision, management and pricing of network services.

Technology issues for the integration of renewable energy technologies into electricity grids.

Rapid progress is being made on resolving the underlying technical issues associated with renewable energy integration for relatively mature technologies such as wind generators. However, there is now an increasing need for a multidisciplinary and multi-party approach to R&D to address interactions between commercial, economic, environmental, policy, regulatory & technical issues.

For example, manufacturers of renewable generators often design them for remote monitoring, functional upgrade and control, to facilitate field deployment of large numbers of generating units. Such generators could often provide security regime functionality to contribute to voltage and frequency control, respond to system operator start-up or curtailment directives and provide on-line data collection, analysis (including forecasts) and data transmission to a system and/or market operator. Without clear commercial signals as to the value of such functions to the power system, they may not be provided.

Similarly, the development of satisfactory mathematical simulation models requires cooperation between manufacturers, generator owners, network service providers and system operators. While progress is being made in a general sense, there will always be context-specific issues that must be addressed by the particular parties concerned.

Specific requirements for technical R&D include the design and demonstration of:

- Distributed resource systems consisting of embedded generators and possibly reversible storage and flexible demand that can contribute to efficient use of distribution network assets through the management of energy flows and quality and availability of supply attributes.
- Communication and control systems that enable distributed systems to function effectively and have interoperability with distribution network data acquisition and control systems.
- Advanced metering and information technologies that can measure and communicate the time-varying value of interval energy and ancillary service contributions by end-users and distributed resources.
- Control and optimisation technologies for industrial, commercial and residential end-use equipment that can facilitate flexible end-user response to time-varying prices and security management protocols.
- Improved power electronic devices that have lower life-cycle costs and can withstand higher voltages, currents, switching frequencies and power densities.
- Compact, high capacity and cost-effective reversible energy storage technologies.
- Modelling tools that can support the design and performance analysis of distributed resource systems.

Governance issues for the integration of renewable energy into electricity grids

Policy R&D should include:

- Further refinement of our understanding of the innovation processes associated with renewable energy generation, considering both the development of individual technologies and their successful uptake, and their deployment and integration into large and small electricity industries (e.g. Carbon Trust, 2006, Retnanestri et al., 2005).
- Review and enhancement of policies for electricity and gas industry restructuring to accommodate high levels of renewable energy penetration. This should include consideration of the sharing of responsibilities between the different categories of decision-makers with respect to forecasting and the management of resource adequacy and security from the short-term to the long-term future. Institutional arrangements are important as well as the detailed design of the security and commercial regimes.
- Review and enhancement of policies to incorporate the costs of environmental impacts in general and with respect to those associated with fossil fuel combustion in particular. This should include careful consideration of the roles of tradeable environmental instruments; environmental taxes and direct physical constraints on emissions (e.g. see discussion in Lohmann, 2006).
- Prioritisation of the various societal objectives for the electricity industry: system security, reliability of supply, economic efficiency, social equity and environmental impact.

8. Conclusions

There has already been considerable R&D effort into the integration of renewable energy into restructured electricity industries, however much remains to be done. There are issues to address for electricity industries of all sizes, from isolated rural households in developing countries to continental scale power systems. There is an increasing need for a multidisciplinary, multi-national and multi-party approach to R&D to address interactions between commercial, economic, environmental, policy, regulatory & technical issues.

Acknowledgements

Hugh Outhred wishes to acknowledge valuable discussions with his colleagues at the University of New South Wales as well as funding support from the Australian Greenhouse Office, Department of Environment and Heritage.

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Appendix A: Commentary on issues raised by participants in the IEA workshop on 20/11/06

Issue	Commentary
Categories of RE	• Storability of primary energy resource affects ease of integration: *Should we focus on wind energy as an important but difficult case? The key issue is not so much the variability as the predictability of wind energy in an aggregate sense, where aggregation is geographic to a scale that depends on the technical characteristics of the host power system and that may change with time. Present wind forecasting techniques are in their infancy and, in many cases, are focussed on the wrong problem (from an engineering perspective) due to poor electricity market designs – e.g. day-ahead forecasts for individual wind farms.* • Potential for "disruptive" technologies with respect to the traditional electricity industry paradigm: *Perhaps most likely with PV, biomass, power electronics, energy storage and advanced metering interfaces and distributed control. What emphasis should we give to these possibilities? At the very least I think we should be designing systems that can accommodate them.*
Network connection & augmentation for RE	• Connection at transmission versus distribution level: *Differences can be due to design features of governance, technical, security and commercial regimes. What are the fundamental differences as against cosmetic differences (we could discuss this)?* • Extent of grid augmentation required: *Who plans, designs, builds & pays, particularly when multiple owners or different technologies are involved? Again the answers reflect choices in regime design.*
Nature of the host electricity industry	• Continental scale electricity industries: *These typically suffer from inconsistencies in one or more of the Regimes. In fact, the Australian National Electricity Market probably has one of the highest levels of consistency. Thus in future work, it may be useful to explore how well integrated, in governance, security, technical and commercial terms, the continental-scale networks of Europe and North America are, and how they could be improved.* • Isolated State-level electricity industries: *There are at least some particular characteristics that favour or deter renewable energy integration. Future work could document this and suggest ways in which systems might be improved.* • Small community and residential scale industries: *There are at least some particular characteristics that favour or deter renewable energy integration. Future work could document this and suggest ways in which systems might be improved.* • Generation and demand characteristics: *There are at least some particular characteristics that favour or deter renewable energy integration.* • Network characteristics: *Are there particular characteristics that favour or deter renewable energy integration?*
Effectiveness of the decision-making regimes	• Technical regime characteristics: *How well defined are technical connection requirements and other mechanisms that help to ensure that the electricity industry can operate as a single machine with high levels of renewable energy penetration? How can we improve technical robustness?* • Security regime characteristics: *How robust is security with respect to the additional uncertainty & variability associated with non-storable renewable energy? How can we improve security robustness?* • Governance regime characteristics: *Are the formal governance arrangements for the industry sufficiently effective and robust to support high levels of renewable energy penetration? How can we improve governance robustness?* • Commercial regime characteristics: *Can the formal market design accommodate high levels of renewable energy penetration and correctly price electrical energy, ancillary services and the associated financial risks? How can we improve commercial robustness?* • Regime compatibility & interfaces: *Are the four regimes implemented in a compatible manner? Are the interfaces between the regimes well defined and effective?*

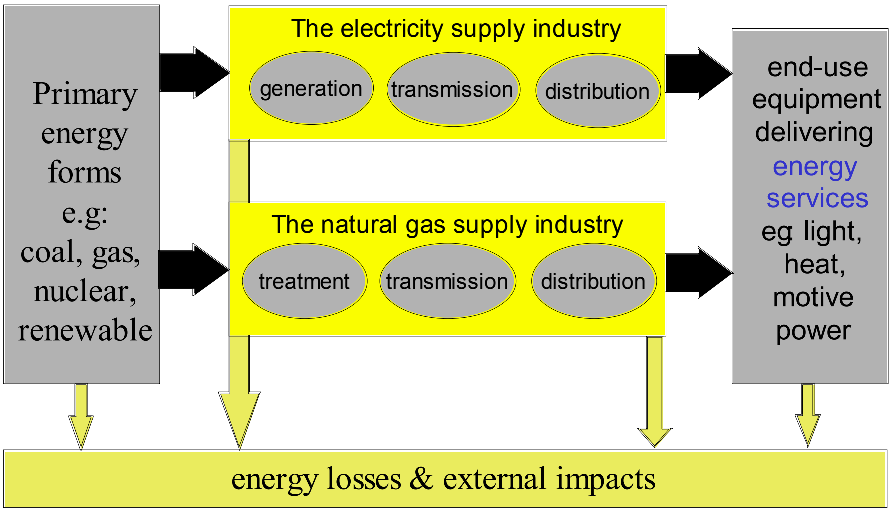


Figure 1. Energy conversion chains for the electricity and gas industries (Outhred, 2006b)

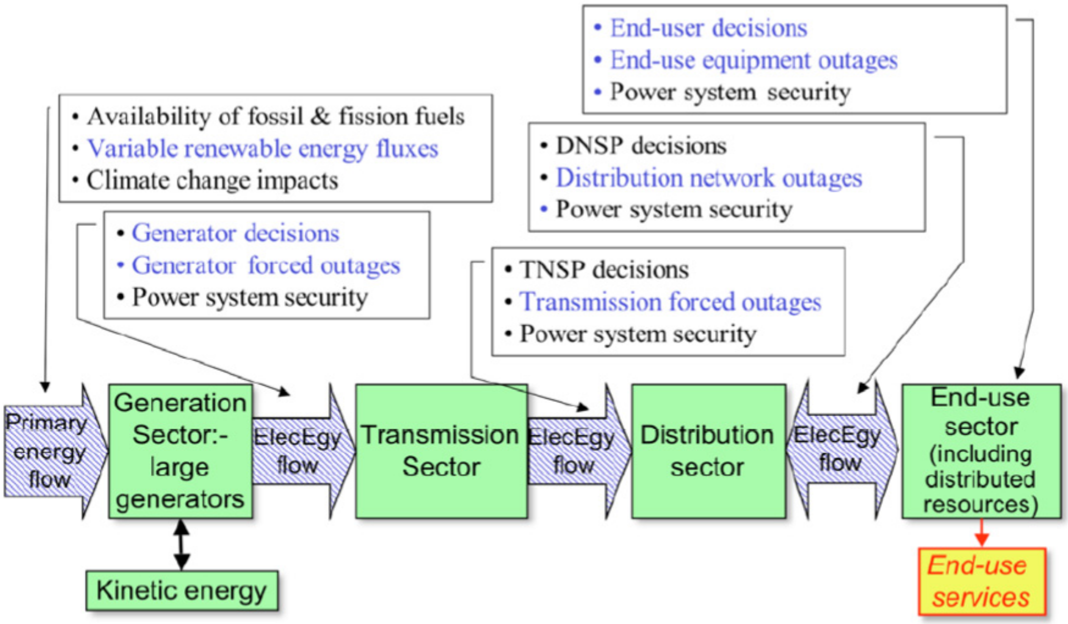


Figure 2. Uncertainties and risks to the delivery of end-use energy services (geographically localised issues in blue) (Outhred, 2006b)

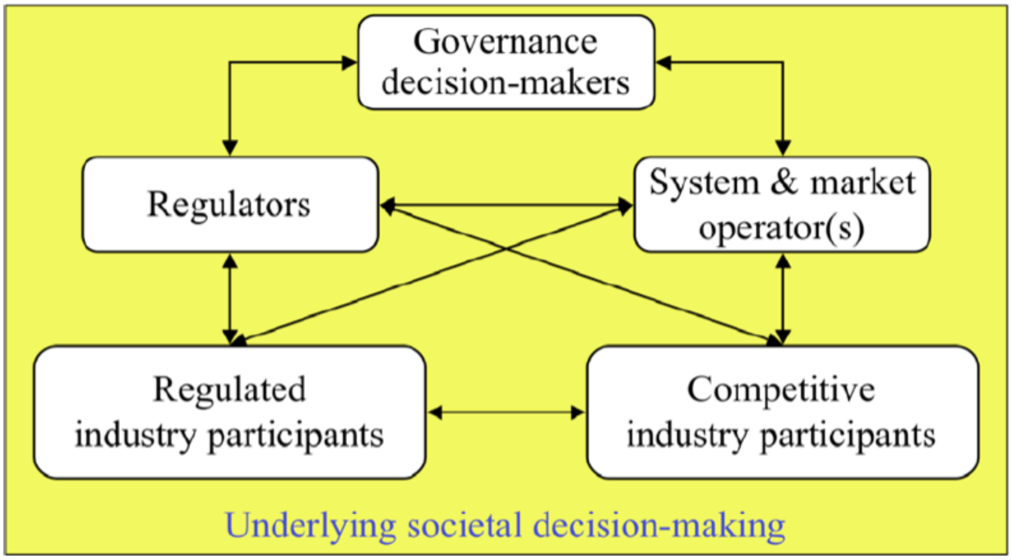


Figure 3. A decision-making framework for a restructured electricity industry (Outhred, 2006b)

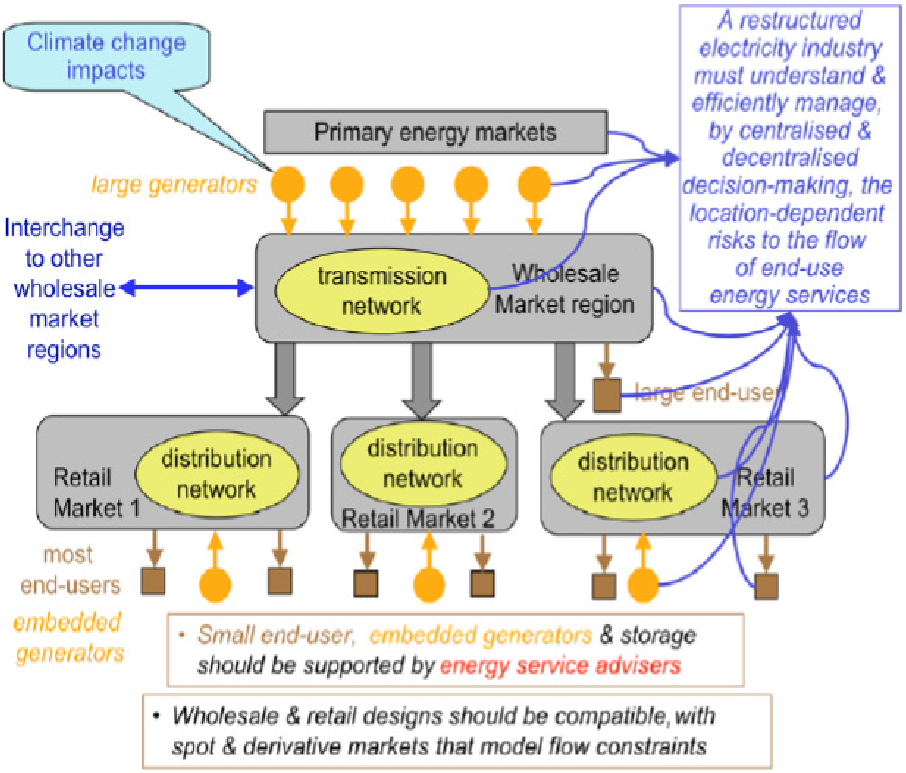


Figure 4. Risks to the flow of end-use energy services in the electricity industry & their management by centralised and decentralised decision-making (Outhred, 2006b)

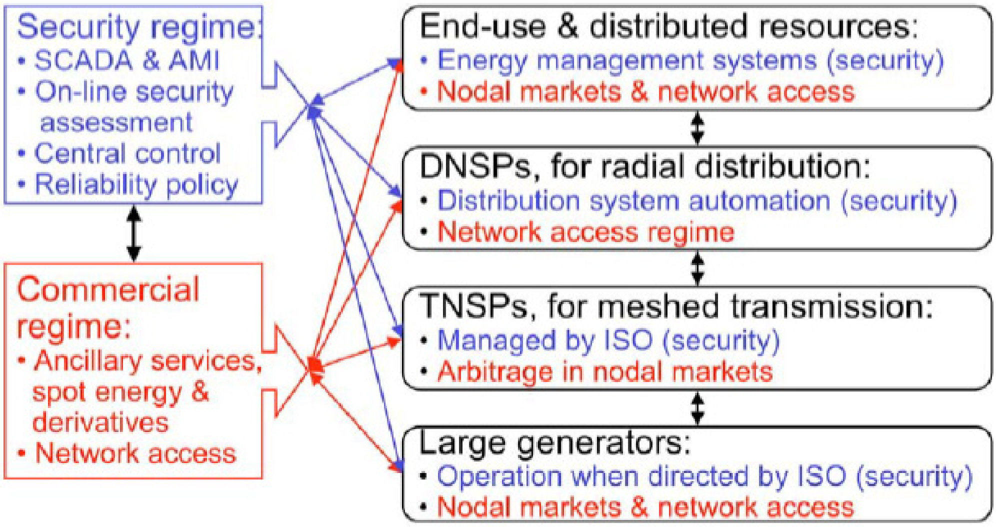


Figure 5. Shared responsibility for managing risks to energy service flow (Outhred, 2006b)

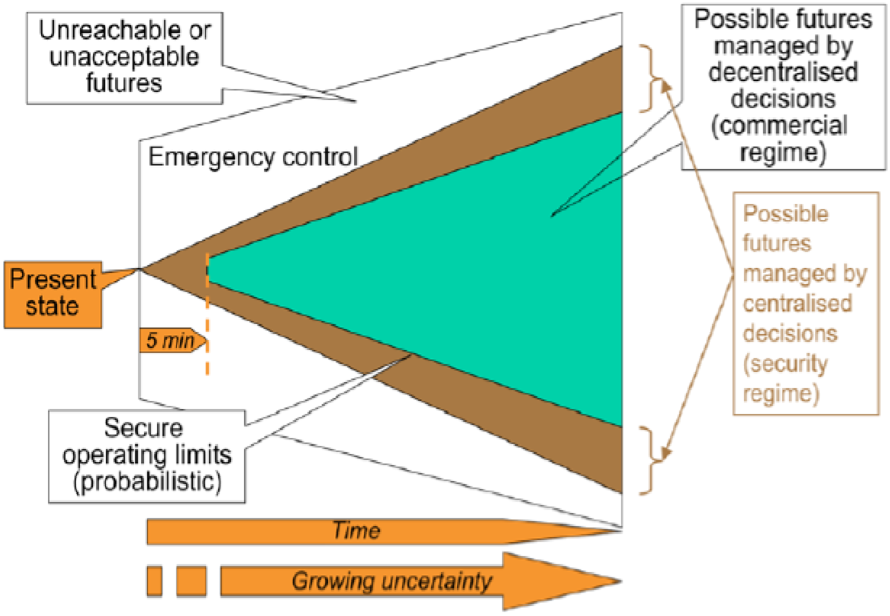


Figure 6. Relationship between the transmission-level security regime and the commercial regime (Outhred, 2006b)

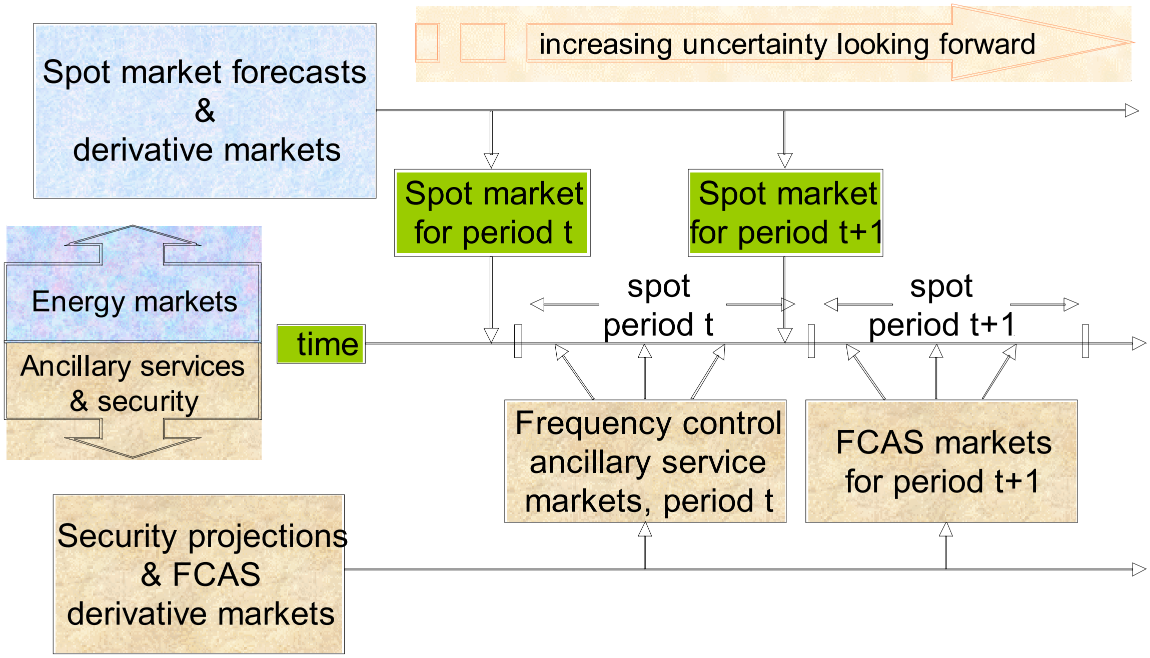


Figure 7. Relationship between the security regime and ancillary service and energy spot & derivative markets (Outhred, 2006b)

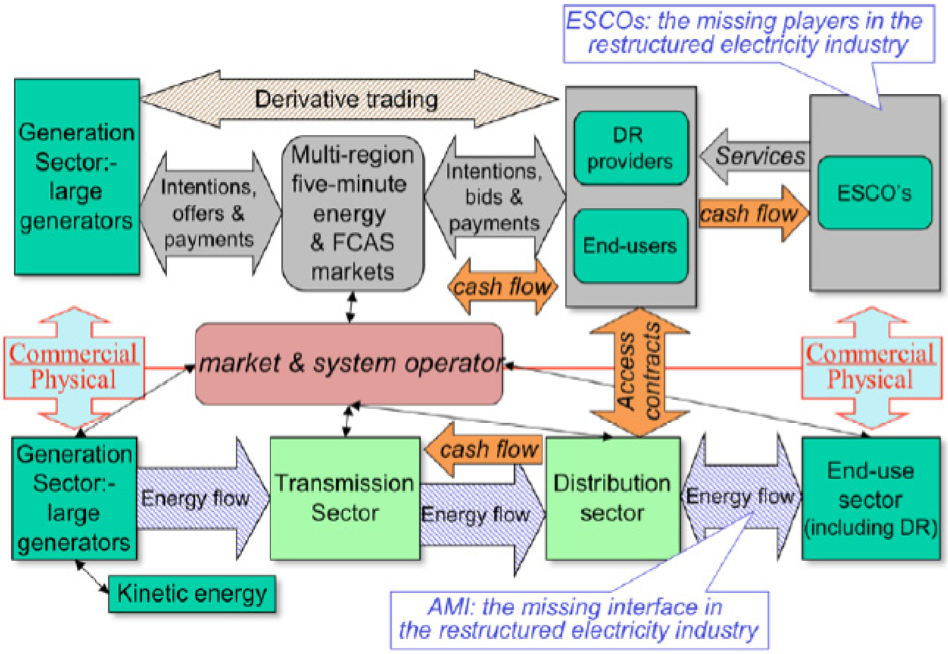


Figure 8. Industry structure to treat end-users in an even-handed manner with generators (Outhred, 2006; Outhred and MacGill, 2006a)

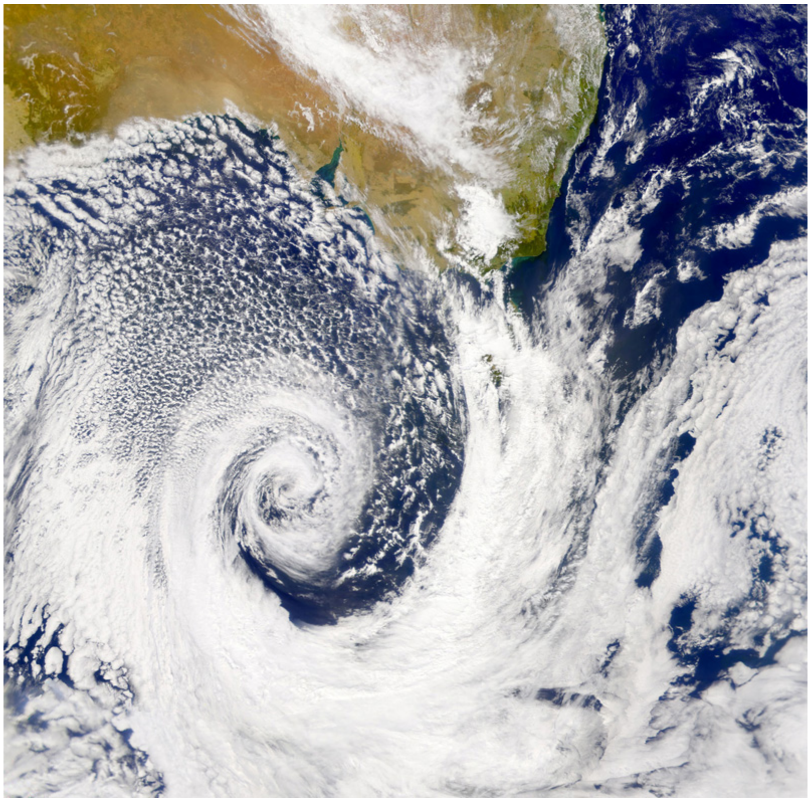


Figure 9. A low-pressure cell over southern Australia

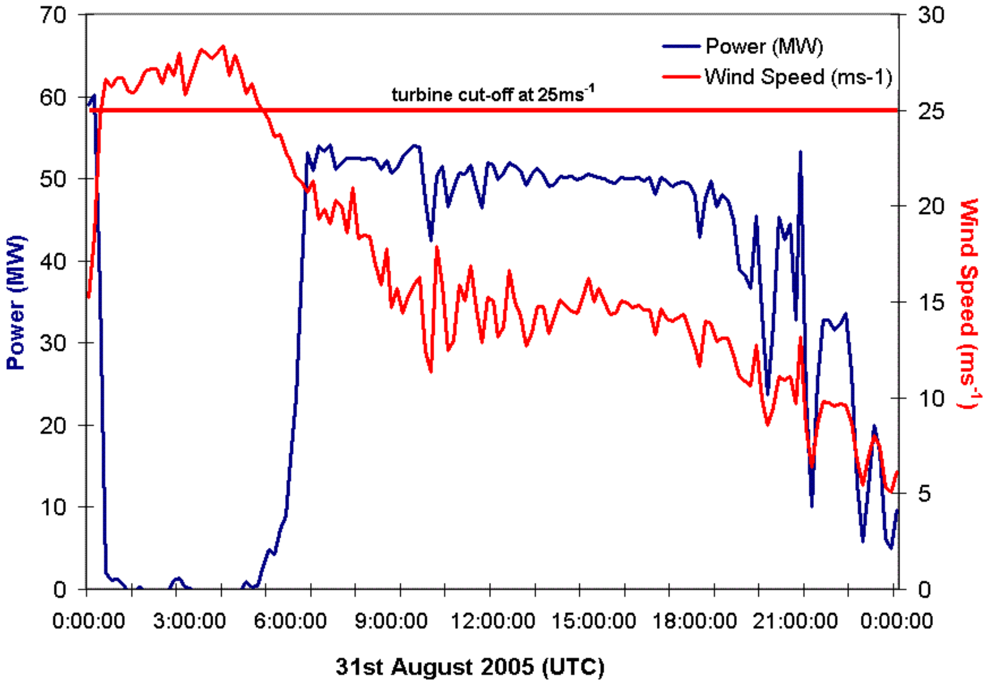


Figure 10. A wind farm shutting down and then restarting due to a period of high wind speed (Kay et al, 2006)

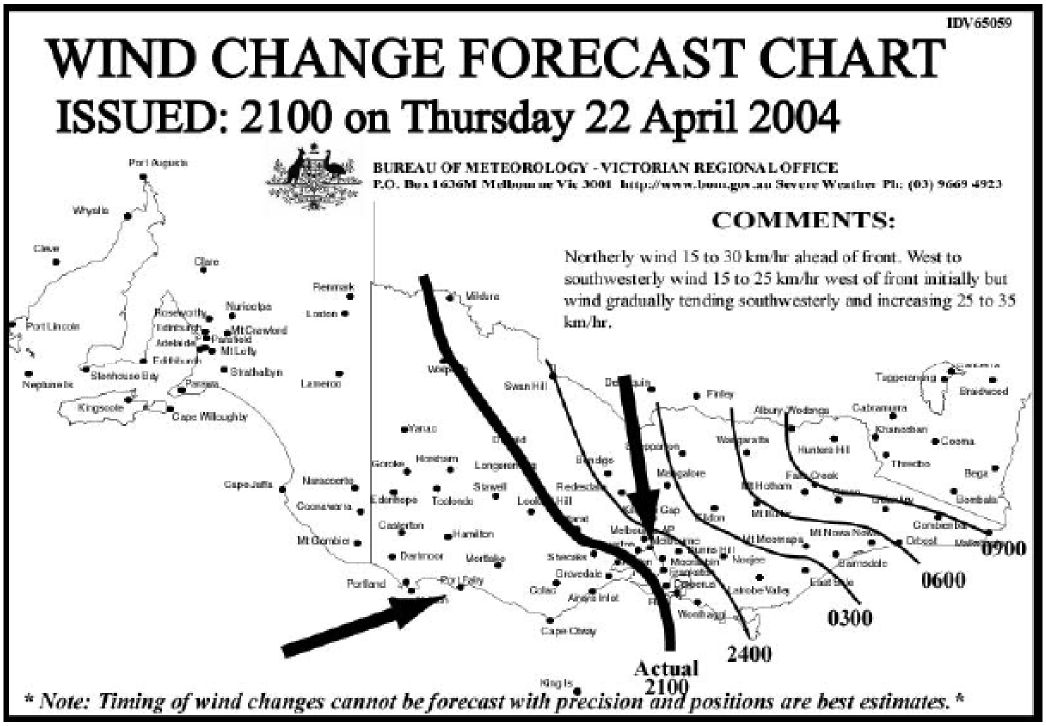


Figure 11. Wind change forecast chart (Xinmei and Mills, 2006)

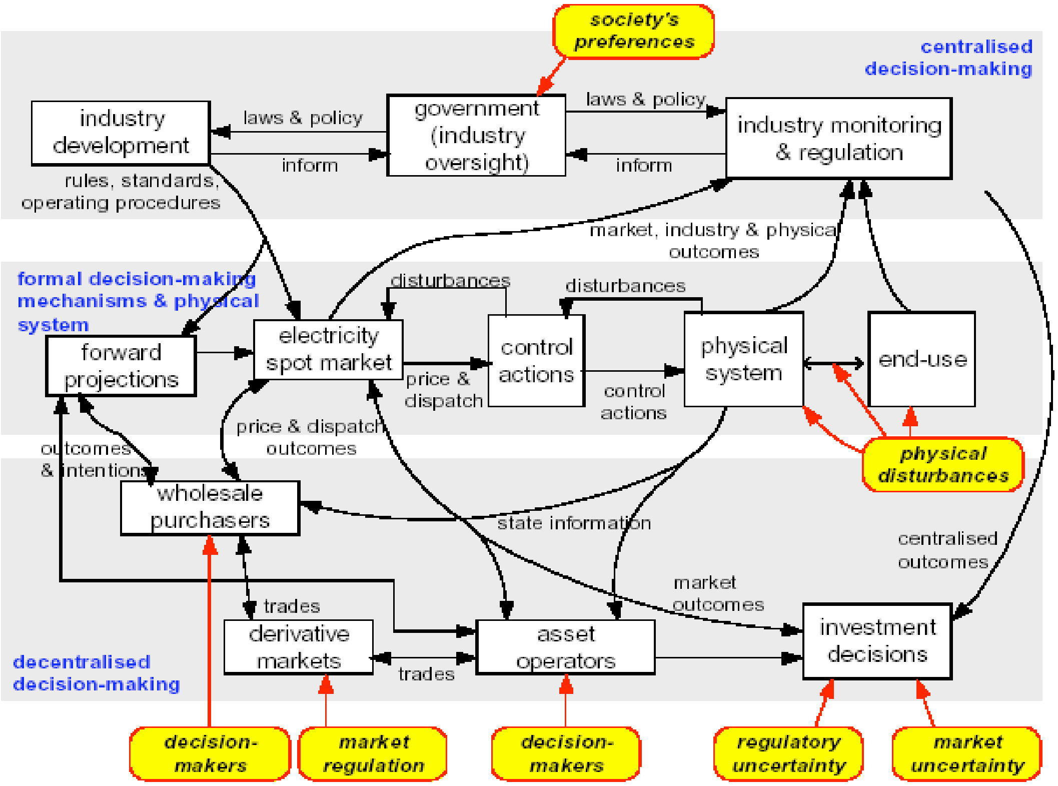
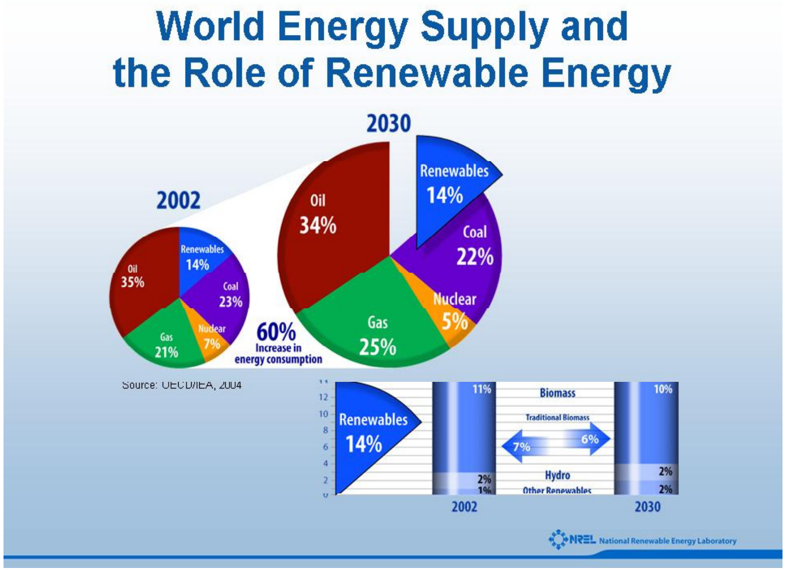


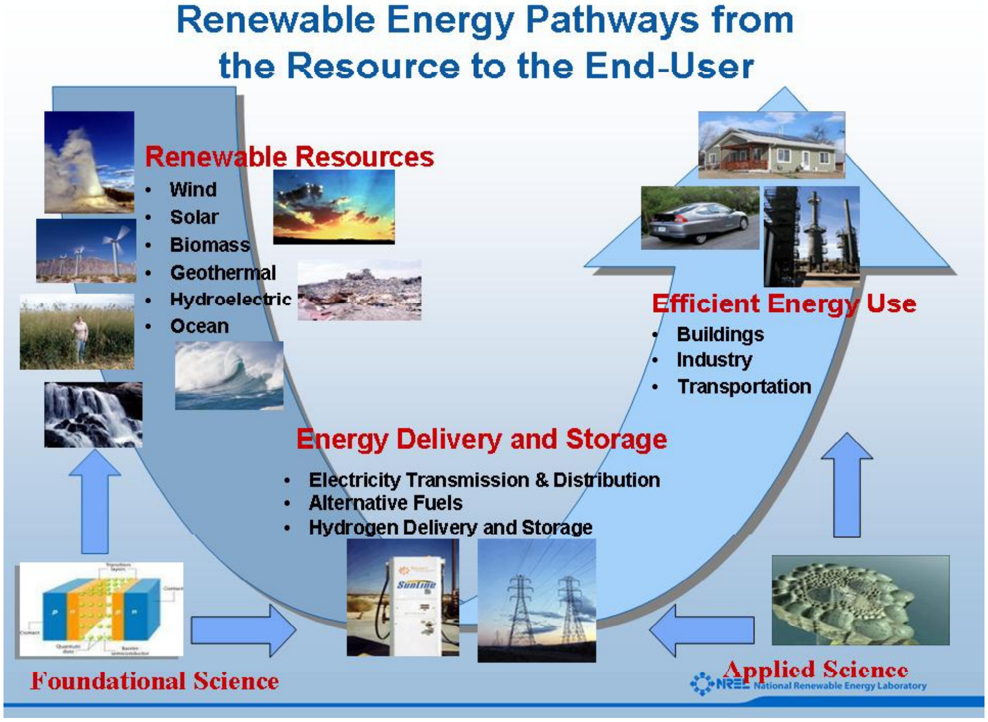
Figure 12. Interactions between decision-makers in a restructured electricity industry (Thorncraft, 2006)



World Energy Supply and
the Role of Renewable Energy

Source: OECD/IEA, 2004

Figure 13. Global energy supply and the role of renewable energy (NREL)



Renewable Energy Pathways from
the Resource to the End-User

Renewable Resources

- Wind
- Solar
- Biomass
- Geothermal
- Hydroelectric
- Ocean

Energy Delivery and Storage

- Electricity Transmission & Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

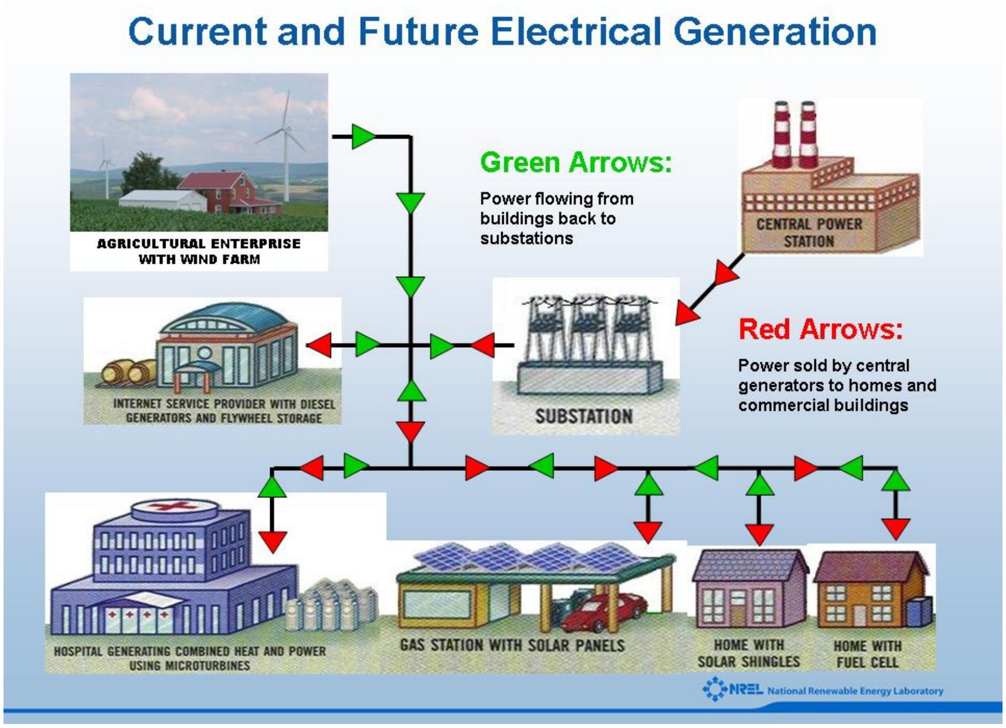
Efficient Energy Use

- Buildings
- Industry
- Transportation

Foundational Science

Applied Science

Figure 14. Renewable energy pathways from resource to end-user



Current and Future Electrical Generation

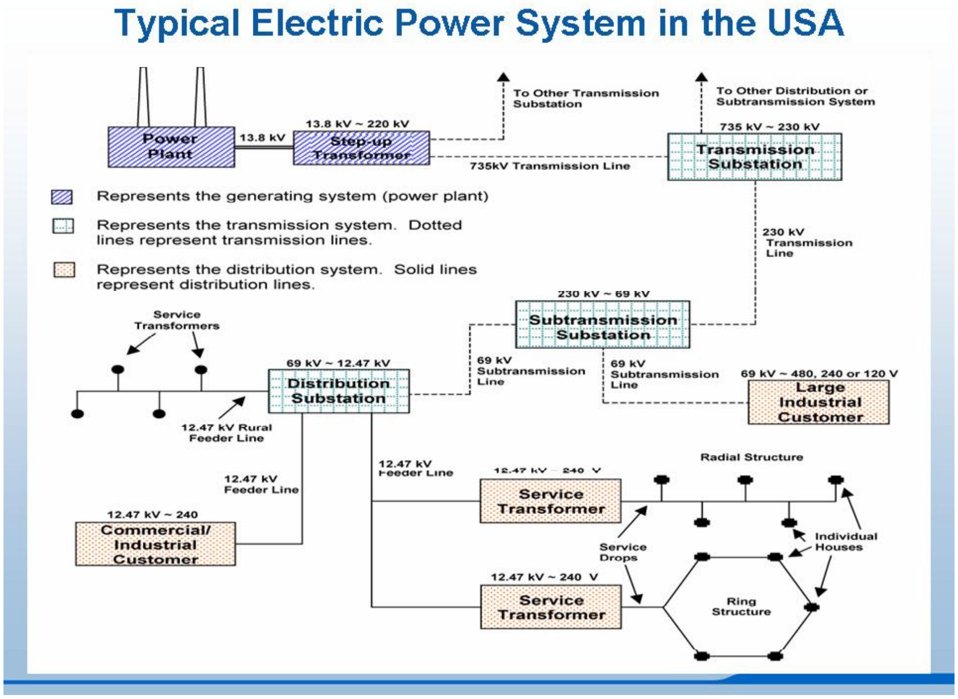
Green Arrows:

Power flowing from buildings back to substations

Red Arrows:

Power sold by central generators to homes and commercial buildings

Figure 15. Bi-directional power flows may result from the use of dispersed electricity generation technologies, particularly time-varying renewable energy generation (NREL)



Typical Electric Power System in the USA

▨ Represents the generating system (power plant)

⊞ Represents the transmission system. Dotted lines represent transmission lines.

▩ Represents the distribution system. Solid lines represent distribution lines.

Figure 16. The structure of a typical US power system, illustrating its complexity (NREL)

Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office

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renewable energy and international law

The IEA Invites You to an Experts Workshop on

Integration of Renewables into Electricity Grids

20 November 2006

Venue: Residence of the UK Ambassador to France
39 rue du Faubourg Saint Honoré
75008 Paris

In accordance with the G8 Gleneagles Plan of Action, Item #17, the IEA is undertaking a project called "Integration of Renewables into Electricity Grids" to provide insight into technical and policy issues in this area. The experts workshop will launch a series of workshops which will focus on the role of renewables in liberalised electricity markets, as well as evaluate and promote means by which to overcome technical, regulatory and commercial barriers to the connection of renewable energy to the grid. The experts workshop will identify and discuss issues that need to be addressed and explore strategies and solutions. The outcomes of the workshop will form the basis of an IEA report on the challenges of integrating renewable energy technologies into electricity grids, and optimising the efficiency of those grids. The meeting will also lay a foundation for the development of an international network of Centres of Excellence to assure these challenges are met. **We hope you will be able to join us.**

Seating is limited. Please RSVP to Jennifer Ronk
at jenniferronk@reilproject.org

this invitation is non-transferable

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The IEA Invites You to an Experts Workshop on

Integration of Renewables into Electricity Grids

20 November 2006

9:30 – 9:45	WELCOME AND INTRODUCTION **Neil Hirst** *Director, Office of Energy Technology and R&D, International Energy Agency (IEA)*
9:45 – 10:00	PROJECT OUTLINE **Antonio Pflüger** *Head, Energy Technology Collaboration Division, International Energy Agency (IEA)*
10:00 – 10:15	SCIENCE AND TECHNOLOGY ISSUES **Stan Bull (US)** *Associate Director, Science and Technology, National Renewable Energy Laboratory*
10:15 – 10:30	WHAT IS THE US DOING **Suedeen Kelly (US)** *Commissioner, US Federal Energy Regulatory Commission*
10:30 – 10:45	LEGAL OPPORTUNITIES, ISSUES, BARRIERS **Rob Howse (US)** *Professor, University of Michigan Law School*
10:45 – 11:10	BREAK
11:10 – 11:25	REGULATORY AND COMMERCIAL ISSUES **Hugh Outhred (Australia)** *Joint Director (Engineering) and Presiding Director, Centre for Energy and Environmental Markets, University of New South Wales, Australia*
11:25-11:40	CASE STUDY OF THE EU-DEEP PROJECT **Jürgen Schmid (Germany)** *Institute for Solar Energy Technology, University of Kassel (invited)*
11:40-11:55	DENA GRID STUDY **Speaker, TBA**
11:55-12:30	QUESTIONS AND ANSWERS
12:30-13:45	LUNCH
13:45 to 15:20	ROUNDTABLE DISCUSSION Moderator: **Antonio Pflüger** *Head, Energy Technology Collaboration Division, International Energy Agency (IEA)*
15:20 – 15:40	BREAK
15:40 – 17:10	ROUNDTABLE DISCUSSION, (CONT'D)
17:10 – 17:30	CLOSING REMARKS **Antonio Pflüger** *Head, Energy Technology Collaboration Division, International Energy Agency (IEA)* **Neil Hirst** *Director, Office of Energy Technology and R&D, International Energy Agency (IEA)*
18:00– 20:00	RECEPTION

Current Agenda as of 1 November 2006

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