WISE
Washington Internships for Students of Engineering

Ensuring Reliable Electricity Supplies Using Distributed Generation

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EXECUTIVE SUMMARY

This report addresses distributed electricity generation for the purpose of ensuring reliable electricity supplies to consumers. This report requires no prior knowledge of electricity infrastructure and is keyed towards teaching the readers about the technical and economic issues associated with different types of generation facilities. The following questions are addressed in this document:

1. What problems exist in today's electricity infrastructure and what can be done to solve these problems?
2. What impacts will the introduction of local dispatchable generation have on the reliability and quality of electricity for consumers?
3. How do different types of proposed generation facilities compare based on their technical and economic feasibility?
4. What are some of the possible actions that are needed to encourage growth in the area of dispatchable generation?

This report attempts to educate lawmakers and stakeholders about the significance of power reliability issues and their causes, including technical limitations and market forces in the domain of the electricity producer and consumer. It also analyzes the potential advantages of a distributed generation network, specifically one made up of dispatchable generation units, and the ability of such units to prevent large-scale power shortages during periods of high electrical demand. The report recommends legislation directed towards increasing research and development related to dispatchable generation technologies and towards promoting the installation of dispatchable generation units through economic incentives.

PREFACE

About the Author

Gregory Tress is currently a senior at Carnegie Mellon University. He is pursuing a bachelor's degree in electrical and computer engineering.

About WISE

Founded in 1980, the Washington Internships for Students in Engineering (WISE) program is a collaborative effort among several engineering societies that has become one of the premier Washington internship programs. The goal of the program is to groom future leaders of the engineering profession who are aware of and can contribute to the important intersections of technology and public policy. Please see the WISE website at www.wise-intern.org for more information.

Acknowledgements

I would like to thank all of those people who helped in making this internship possible, especially the Institute for Electrical and Electronics Engineers and the other sponsoring societies that contribute to the WISE program. This paper would not have been possible without the help of many people and multiple organizations, so I would like to thank all of the people who provided me with valuable information regarding the technical and policy aspects of my topic. Finally, I would like to thank my mentor, Erica Wissolik; my faculty advisor, Dr. Jeffrey King; and the other WISE interns for the experience that I had during my 2008 WISE internship.

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1 INTRODUCTION

This paper focuses on the prospect of dispatchable distributed generation systems as a means to transform the structure of the North American power grid in order to promote system reliability. First, it will provide some background on the development of electricity generation and transmission systems during the 20th century. Next, it will explain the causes and effects of regional power shortages and the infrastructure issues that affect the operation of the power grid. The paper will then describe distributed generation systems, both dispatchable and intermittent, and provide a cost analysis that examines the costs associated with installing and operating dispatchable systems. Finally, it will address some of the policy implications of installing dispatchable generation systems.

2 BACKGROUND

2.1 Reliability Concerns

The demand for electricity in the Unites States has steadily increased since the mid-twentieth century and will continue to increase based on current projections (see AEO 2008). At the same time, the electricity delivery infrastructure is currently reaching its technical limits in its ability to reliably and economically provide electricity to both large-scale and small-scale consumers. According to the Energy Information Administration's estimate, total electricity sales will increase by over 1 trillion kilowatts from 2006 to 2030 – an increase of nearly 30 percent over the 2006 level, or an average increase of 1.1 percent per year (see Figure 1). This change will be most apparent in the residential and commercial sectors, while industrial demand will remain relatively constant.[1]

While electricity demand continues to increase, the technical and economic inefficiencies inherent in today's power grid have already resulted in numerous regional power failures and intentional removal of loads by system operators – commonly known as "rolling blackouts." These types of power shortages will become more common during periods of high demand if the nation's electricity infrastructure is not adjusted to meet today's delivery requirements.

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[1] "Annual Energy Outlook 2008." Energy Information Administration. <http://www.eia.doe.gov/oiaf/aeo/>.

Businesses in the U.S. lose over $100 billion every year to due to disruptions in the power supply; distributed generation systems could prevent nearly all of these disruptions.[2] This paper will outline some of the key problems in the current electricity infrastructure and the potential impacts of a distributed generation approach to solving the problem of power shortages.

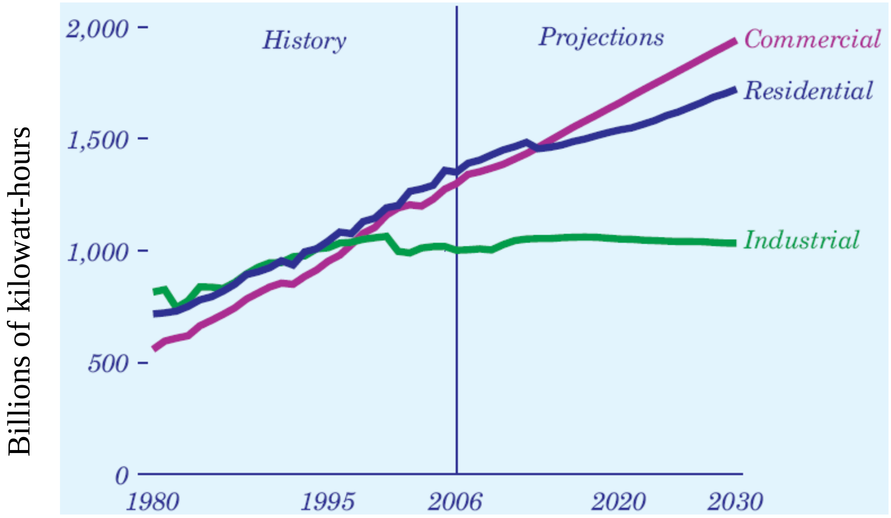

Figure 1. Projected electricity consumption by year

Source: Energy Information Administration

2.2 Historical Background

Large, centralized power plants became commonplace during the mid-1900s due to economies of scale. The greatest fuel-per-kilowatt efficiency for combustion-type generation is achieved with large-scale turbines and generators. Because of space requirements, pollution, the need for water to operate, and other factors, these power plants were often located in relatively remote areas and near water sources. Electricity became very cheap to generate at the plant, but remained far from the consumer. Consequently, transmission and distribution lines were constructed to transport electricity over long distances to satisfy residential, commercial, and industrial demand. Notably, this infrastructure developed at first in a strictly one-way fashion, with central power plants providing electricity directly to the consumers in the region.

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[2] "The Cost of Power Disturbances to Industrial & Digital Economy Companies." Consortium for Electric Infrastructure to Support a Digital Society. June 2001.

After some time, utility companies began to form interconnections between transmission networks in order to increase overall reliability of delivery. This enabled power plants to supply power outside their immediate region when necessary; consumers would then be able to continue to receive power from other plants if their local plant experienced a failure. While this interconnection provided a significant benefit, it also established a system of power sharing that would later result in technical and economic problems for the national grid. With the ability to transfer large quantities of electricity from region to region, utility companies became complacent with buying and selling electricity on a regular basis to account for changes in demand. Financially, this was beneficial for both utility companies and consumers, but it established a complex network of dependencies between the utilities that puts unnecessary strain on the transmission system today.

This traditional centralized model of electricity generation and transmission is limited in its overall delivery capacity. The high-voltage transmission pathways that connect the various energy regions of the United States are now experiencing severe congestion during peak hours of electricity usage, ultimately causing power shortages in some regions. In order to overcome this problem, by the traditional model, current transmission pathways would have to be upgraded, and some new pathways would have to be constructed. The cost of these projects is prohibitive, and their economic benefit would be limited according to consumer demand.[3]

2.3 Modern Restructuring

An alternate solution to the problem is the implementation of distributed generation systems at the local level for use during periods of high demand. In general, distributed generation refers to any type of electricity generation that occurs in a decentralized network of generators and consumers. Distributed generation can also be classified as either intermittent or dispatchable. Intermittent generation refers to generation capacity that cannot be precisely controlled or predicted, most commonly wind and solar power. In contrast, dispatchable generation units are powered by physical fuel (fossil fuels and/or biomass) and can be turned on and off when needed to supply electricity for a local area. Establishing a system of decentralized generators near consumers can provide technical and economic benefits when used in

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[3] Lovins, Amory B. et al. *Small Is Profitable* Executive Summary.
<http://www.smallisprofitable.org/ExecutiveSummary.html>

conjunction with traditional large-scale power plants. Importantly, it provides a direct, reliable electricity supply that is not immediately dependent on the status of the larger transmission grid. New generator technology, coupled with combined heat and power systems, has enabled dispatchable generators to obtain efficiencies much higher than traditional large-scale fossil fuel power plants. However, barriers to the implementation of dispatchable generators, such as costs, regulatory issues, and environmental concerns, have prevented a full-scale restructuring of the power grid.

3 POWER SHORTAGES

3.1 Types of Failure

Power shortages can be visible in multiple forms. The most obvious of these is a *blackout*, or a complete loss of power to an area. Blackouts can be caused by natural phenomena, such as severe weather patterns, or any event that physically damages the power grid. In addition, high electricity demand in an area can cause a blackout by activating protection systems in the grid designed to limit power flow. If these systems were not present, excessive current flow through transmission lines could be unsafe and could damage lines and equipment.

System operators, who control the flow of electricity among regions, can intentionally implement *rolling blackouts* in a region during a period of exceptionally high demand. In a rolling blackout, power is removed from one or more areas within a region while the rest of the region maintains power. Each area goes without power in turn for a set length of time, causing the blackout to “roll” from one area to the next. This keeps the total level of demand within manageable limits, and no single area is without power for an extended period of time.

Another type of failure takes the form of a *brownout*, in which the voltage on the power line is reduced. Brownouts can be caused by malfunctions in the grid but may also be implemented intentionally. If demand is reaching exceedingly high levels, system operators can implement a brownout to reduce power delivery without completely cutting off power to any one area. However, brownouts can potentially cause permanent damage to consumer electrical equipment and temporarily cause some equipment to function improperly.

As overall demand increases, the power grid becomes more susceptible to *cascading failure* due to the potentially fragile interconnection of generation resources. Although grid interconnection is designed to increase system reliability under normal circumstances, it can lead to additional problems during periods of high demand. Normally, generation capacity is shared among many power plants so that no single plant is overloaded; however, it is still possible for one or more plants to be shut down – either intentionally or by automatic protection systems – due to excessive demand. This shutdown may be necessary for safety reasons and may also be designed to protect generation equipment from damage. When this happens, the existing demand must be redistributed among the remaining power plants. Since the remaining plants must now supply even more power, the risk of additional plants shutting down is increased. This causes a chain reaction in which a single plant shutdown can cut off power from an entire region.

Such a scenario occurred during the Northeast Blackout of 2003, which affected 40 million people in the northeastern United States and another 10 million people in Canada. A task force report on the blackout noted that a single power plant in Ohio was shut down at 1:31pm on August 14, 2003, causing excessive current flow in nearby high-voltage transmission lines; by 4:13pm the same day, over 250 plants were offline. The financial losses related to the blackout were estimated to be $6 million. This blackout demonstrated the overall fragility and instability of the power grid.[4]

3.2 Power Quality

Even when full-scale power shortages are not apparent, subtle issues regarding power quality can still affect consumers and equipment. *Power quality* generally describes how well electricity meets the technical guidelines for delivery to the consumer. Consumer electrically-powered equipment (ranging from small residential appliances to large industrial machinery) is designed according to specific voltage and frequency guidelines to match what is supplied by the power grid. When the voltage or frequency on the grid changes, even by a small amount, there is a possibility that consumer equipment may malfunction or be damaged. Very short power failures, including failures that last a fraction of a second, are also considered to be a factor in assessing power quality. Problems related to power quality often occur when loads are added to

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[4] "Final Report on the August 14, 2003 Blackout in the United States and Canada." U.S.-Canada Power System Outage Task Force. April 2004.

or removed from the grid. These variations in load are performed by the consumer and thus cannot be controlled by system operators.

Many appliances are designed to withstand minor fluctuations in the power supply. Depending on the nature of the device, power supply problems may be trivial. For example, an incandescent light may operate slightly brighter or dimmer depending on the supply voltage, but the variation is often so small that a consumer would not be able to notice it. If a power shortage occurred for just a fraction of a second, the light would appear to flicker, but it would not be damaged. However, digital high-tech appliances, such as televisions and computers, rely on precise supply voltages and are more sensitive to changes in the power supply. With the proliferation of digital technology, power quality has become an increasingly important topic.

The issue of power quality is especially important for institutions that have a significant installed base of electrical devices, including hospitals, technology companies, manufacturers, and financial institutions. Even very short power disruptions can have a considerable impact on the operation of such institutions, indicating that there is a potential market for ensuring power quality and reliability at an additional cost.

3.3 Demand Patterns

In order to provide adequate power to all consumers at all times, total power generation must be able to continuously adjust to match or exceed consumer demand. System operators who control the flow of power among regions are able to infer general demand patterns on a daily, weekly, and seasonal basis according to historical usage data, weather forecasts, and other factors. However, since consumers are free to connect and disconnect loads from the grid at any time, system operators cannot predict future demand precisely. As a result, operators must have the ability to add and remove generation capacity from the grid in real-time as demand changes. This is especially important during periods of high demand, often occurring in the summer, in which demand can rapidly rise as many consumers simultaneously add loads to the network. This effect is common when many buildings activate air conditioners at approximately the same time of day during periods of warm weather.

Because of their size and design, large-scale regional power plants are well equipped to handle large, consistent loads for long periods of time, often generating thousands of megawatts at a single plant. Thus, these plants are used for *base load* generation, which satisfies the loads that are always present in the system. Base load plants are often powered by coal, nuclear fuel, or large hydroelectric turbines.

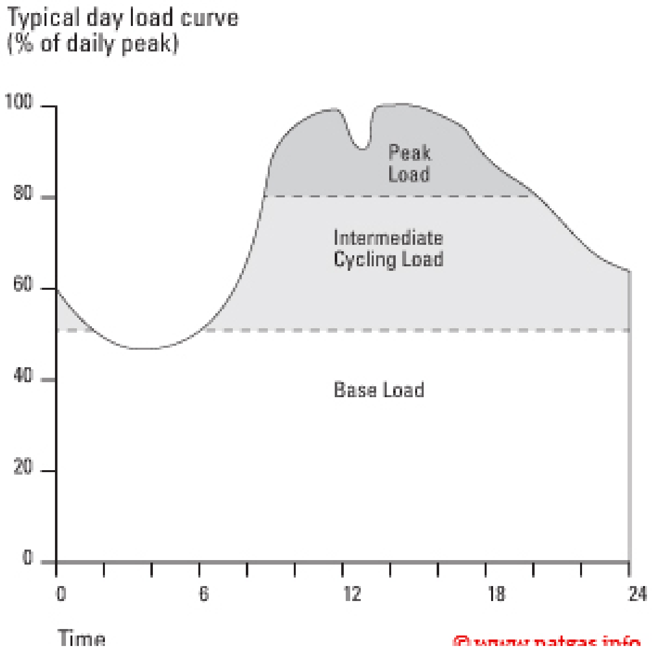

Figure 2. Sample daily demand variation

Source: Chandra, Vivek. “Gas Usage.” NatGas.info.

Overall electricity usage generally increases during the day and decreases at night (see Figure 5). To account for these changes, another set of power plants, known as *cycling load* plants, are activated and deactivated on a daily basis. Cycling load plants satisfy most of the additional load that is added during the day. They are generally mid-sized plants and powered by oil or natural gas. There is also a third set of “peak load” generation facilities; these are activated only when necessary to satisfy the highest levels of demand. Peak load plants are smaller-scale facilities and often powered by diesel fuel or natural gas. Because power shortages often occur as a result of extremely high peak demand levels, it is in this area that smaller-scale dispatchable systems would be most effective.[5]

3.4 The Cost of Disturbances

At first glance, power shortages appear to cause a temporary inconvenience to consumers but do not seem to have substantial economic effects. In 2001, The Electric Power Research Institute created a report which outlined the industrial and commercial impacts of power shortages. This report noted that:

"The importance of reliable, high-quality electrical power continues to grow as society becomes ever more reliant on digital circuitry for everything from e-commerce to industrial process controllers to the onboard circuitry in toasters and televisions. With this shift to a digital society, business activities have become increasingly sensitive to disturbances in the power supply."[6]

The Electric Power research Institute states that 40 percent of the U.S. gross domestic product is made up of industries which are "particularly sensitive" to power disturbances (see Figure 6). These companies are loosely classified as either "industrial" or "digital economy" firms. Some of these areas include:

- Data storage, retrieval, and processing
- Research and development
- Telecommunications
- Financial services
- Manufacturing
- Transportation
- Utilities (water, gas, etc)

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[5] "Gas Usage." NatGas.info. <http://www.natgas.info/html/gasusage.html>
[6] Ibid 2.

It is estimated that the U.S. economy as a whole may be losing well over $100 billion a year due to power disturbances; this accounts for total power failures as well as power quality issues. Disturbances that last a very short time, even as short as a few seconds, can result in hours of wasted time and money while critical systems and processes are restarted. Some equipment may also experience damage after a power disturbance and may need to be repaired or replaced, which could potentially take days or weeks. The overall breakdown of costs for an outage includes factors such as lost production and sales, labor costs, loss of materials, equipment damage, backup generation costs, and general restart costs.[7]

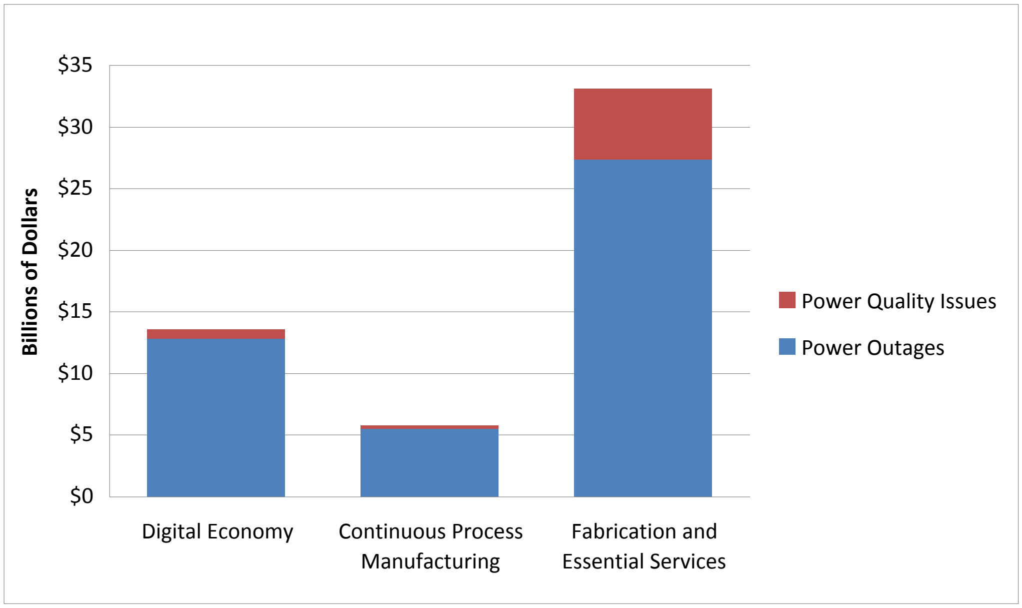

Figure 6. Estimated annual cost of power disturbances to select sectors

Source: Electric Power Research Institute

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[7] Ibid.

4 INFRASTRUCTURE ISSUES

4.1 Technical Limitations

A single large-scale coal or nuclear power plant can typically produce several thousand megawatts of electricity, which is carried over long distances by high voltage transmission lines. Although generation capacity has generally been able to keep pace with consumer demand, the transmission lines that were built several decades ago are not designed for the high levels of demand that are present today. Important factors behind transmission line construction include the prediction of future loads and the need for utility companies to minimize expensive construction costs. Several technical limitations related to this transmission capacity are having an effect on power shortages.[8]

- *Increasing demand*. Following current year-by-year trends in electricity consumption, overall electricity demand will continue to increase steadily for the foreseeable future. Many critical transmission pathways will become increasingly congested if the current infrastructure is not upgraded, leading to an increase in the number of local and regional power shortages.

- *Equipment reliability*. All components in the grid, including transformers, power lines, generators, switches, and safety systems, have some risk of failure. More distance, and therefore equipment, between the generator and the consumer translates into more possible points of failure.

- *Cascading failures*. The interconnections in the power grid utilize equipment to automatically disconnect transmission lines or generators in case of an emergency. While this disconnection protocol is necessary for safety, its implementation results in increased risk of failure. The reliability benefit resulting from grid interconnectivity disappears due to the increased fragility of a power grid operating at its peak capacity. Minor equipment problems can therefore result in a web of related power disruptions.

- *Varying demand*. The additional demand during peak hours can become more severe as additional daytime-use appliances, such as air conditioners, computers, and high-tech

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[8] Abraham, Spencer. “National Transmission Grid Study.” May 2002. <http://www.ferc.gov/industries/electric/gen-info/transmission-grid.pdf>

devices, become even more widespread. Therefore, predicting fluctuations in demand from day to day and from hour to hour becomes increasingly difficult for system operators. When demand spikes uncontrollably and transmission pathways are congested, operators may have no choice but to implement rolling blackouts in order to forcibly reduce demand.

- *Transmission losses*. As electricity flows through transmission lines, a small percentage of it is lost for each mile it travels (see Figure 3). This loss also increases as demand increases. During peak hours, as much as 6-8% of the total power generated may be lost by the time it reaches the consumer's local substation, and a total of 15% may be lost by the time it reaches the consumer's residence or business. As a result, some of the power generated at the plant will always be wasted in the form of heat released into the atmosphere, which makes some percentage of the transmission line capacity unusable for useful power delivery.

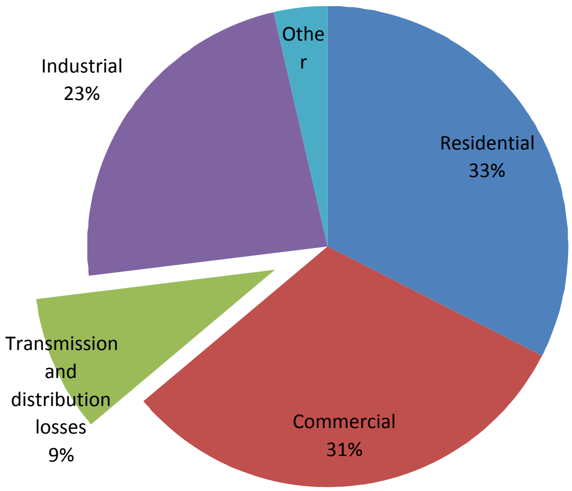

Figure 3. Electricity net use by destination

Source: Energy Information Administration

4.2 Economic Limitations

Power shortages are also affected by economic factors which limit the efficiency and usability of the power grid.

- *Decreased investment in transmission.* Even though demand has increased steadily over the years, the corresponding investment in the transmission infrastructure has lagged behind (see Figure 4). This is partially due to the notion that most transmission lines would handle limited power flow in a single service area, rather than act as high-density bridges to link large regions together. Since utility companies have begun to buy and sell power over larger distances, many critical pathways that connect the various power regions of the country are simultaneously reaching their delivery limits. According to the National Commission on Energy Policy (NCEP), "Inadequate investment in transmission infrastructure in many regions of the country is a significant and growing national problem that costs consumers tens of billions of dollars a year in higher energy costs and lost productivity."[9] In 2006, NCEP reported that this trend may be changing for the

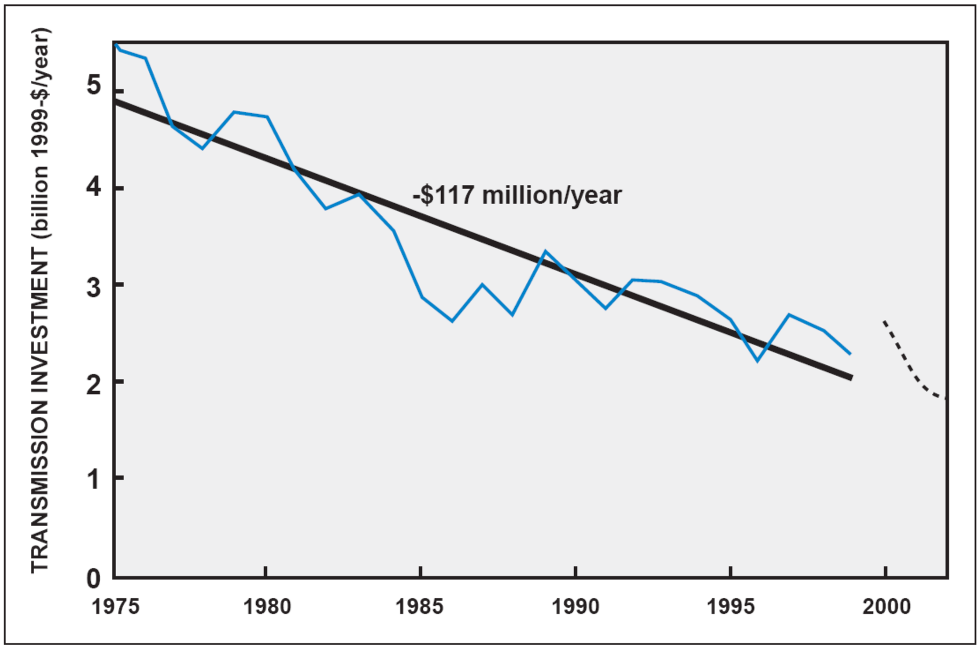

Figure 4. Transmission system investment by year

Source: Abraham, Spencer. "National Transmission Grid Study." May 2002.

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[9] "Ending the Energy Stalemate." National Commission on Energy Policy. December 2004. pg. 90-94.

better: $5 billion of transmission investment was recorded for 2002, and projections indicate $7-$10 billion per year by 2010.[10]

- *Potential underutilization.* Variations in demand are severe enough that transmission lines constructed to satisfy peak demand would experience significant underutilization. Because this would be an inefficient use of capital, the construction of additional transmission lines is not an economically friendly option for utility companies.

- *Constant billing.* Consumers are generally billed according to a fixed price per kilowatt-hour of energy used. This allows most consumers to disregard the congestion present in the grid when making decisions about personal electricity use, especially during peak hours. For a single residential customer, there is little direct incentive to reduce electricity consumption during peak times; this contributes to higher aggregate peak consumption. It is possible to charge consumers a variable rate based on demand, but this requires special metering devices which are not installed in most residential locations.

- *Rerouting.* When a region's primary transmission pathways become congested, supplemental power can be routed from other nearby transmission lines. However, this creates a less efficient pathway, since electricity has to travel a longer distance to reach the same destination. This type of rerouting increases transmission losses and complicates the power flows in other parts of the grid, potentially causing additional congestion in other regions in order to solve a local congestion problem. The severity of this rerouting pattern is shown in the number of *transmission loading relief* procedures, or TLRs (see Figure 5). A TLR results in shifting a transmission load from one pathway to another due to congestion. The increase of TLRs in recent years demonstrates the increased congestion of the grid.[11]

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[10] "Siting Critical Energy Infrastructure." National Commission on Energy Policy. June 2006. Pg. 17.

[11] Lerner, Eric J. "What's wrong with the electric grid?" *The Industrial Physicist*. <http://www.aip.org/tip/INPHFA/vol-9/iss-5/p8.html>

- *Losses.* Consumers are ultimately forced to pay for the losses associated with transmission and distribution. Essentially, these consumers are paying for wasted energy -- the portion of the generated electricity that can never be used. As long as the generation of electricity is located far from the consumer, this loss is inevitable.

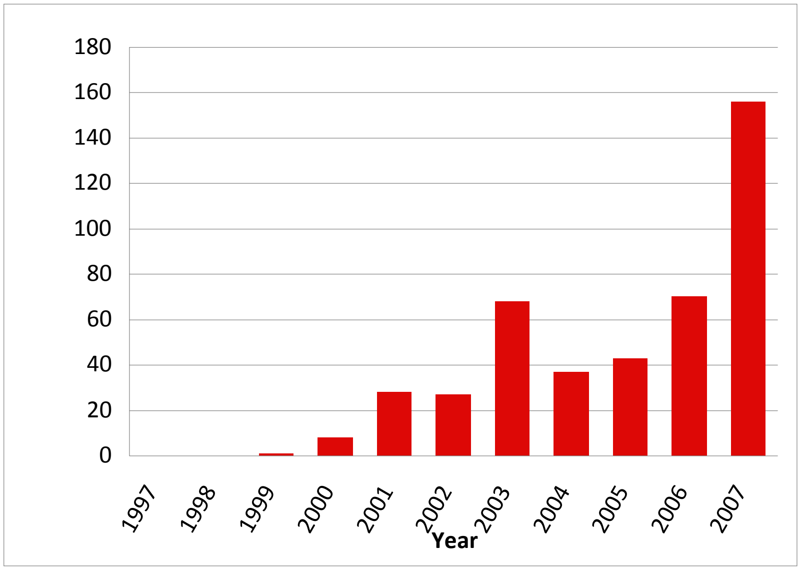

Figure 5. Transmission loading relief events by year.

Source: North American Electric Reliability Corporation

5 DISTRIBUTED SYSTEMS

5.1 Power Reliability

When electricity demand is greater than the grid can supply, there have traditionally been two ways to fix the problem. The long-term solution is to upgrade the grid infrastructure to support higher levels of demand; the short-term solution is to decrease demand by implementing forced brownouts or rolling blackouts. Brownouts and rolling blackouts are prevented whenever possible, but are still necessary in extreme conditions to prevent region-wide grid failure. These are accepted as short-term fixes during high-demand periods, but are not satisfactory from the perspective of the consumer. Thus, the more reliable fix for power shortages would be to construct additional power plants and transmission pathways where necessary. However, these projects are expensive and not necessarily cost-effective. If a certain transmission pathway is overloaded for only a few hours per day, or for a few days or weeks per year, the construction of a supplementary transmission line to satisfy this peak load would be an inefficient use of capital, since the supplementary line would only be in use for a relatively limited period of time and cannot be moved or used for other purposes.

Using a distributed generation system, local areas would be able to generate electricity at a smaller scale on demand. This would alleviate additional load from the large-scale transmission pathways during periods of high electricity demand, preventing traditional grid overloads and power shortages. Depending on the type of installation, a dispatchable generator could be used for minutes or hours at a time, or even days or weeks for extended periods of high demand. By turning dispatchable generators on and off when necessary, grid controllers can easily match electricity supply to demand. Large-scale power plants would still provide base load generation capacity in this scenario.

5.2 System Description

Dispatchable generation units can be constructed in different sizes depending on the desired power output and expected time of use. Because these units need to be turned on and off at varying times, it is most convenient to utilize easy-to-transport fuels, such as petroleum and natural gas. The fuel supply for a natural gas generator, for example, can be tied into a municipality’s existing gas distribution system. Larger generators may be gas turbines, with or without combined cycle generation, which can generate additional electricity from exhaust heat. Standard gas turbines can achieve efficiencies around 40 percent, while combined cycle generation can push efficiency to around 60 percent. Smaller generators may be internal combustion engines (running on diesel or natural gas) or “microturbines,” a scaled-down version of the traditional gas turbine.[12]

Large dispatchable generators can produce tens (or even hundreds) of megawatts, within the same order of magnitude as centralized power plants. This type of generator may be useful in dense commercial or industrial areas, but would not be as cost-effective in a residential setting.

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[12] “Distributed Energy: Towards a 21st Century Infrastructure.” The Consumer Energy Council of America. July 2001. pg 31-34.

In comparison, small micro turbines could produce tens or hundreds of kilowatts, but possibly at the cost of efficiency. Since the average residential power use is only 30 kWh per day, it is likely that peak demand would only require a few additional kilowatts per house. With 5 kilowatts peak supply per house (on top of base load supply which is already provided), a mid-sized 500 kilowatt generator could power several neighborhoods.

Generators can be used in residential, commercial, and industrial settings with different benefits in each area. The specific locations available for installation of these generators are limited by several factors including land availability, fuel availability, noise, and pollution effects. In general, units could be installed in any area where it is convenient, including existing building space, underground facilities, or open land. Towns and cities would be able to significantly mitigate the effects of peak demand with a few strategically-placed generators.[13]

5.3 Combined Heat and Power

Combustion engines and gas turbines can be used to provide combined heat and power generation, or CHP. In a CHP generator, waste heat from the combustion process is recovered to perform useful work, such as providing heat for a building, generating steam, or controlling water temperature. These systems can generally operate at 70 to 85 percent efficiency, more than double the efficiency of a traditional coal power plant.[14] Under the right conditions, CHP generators can achieve over 90 percent energy efficiency.[15] The CHP generator must be located close to the site where the heat will be used in order for the system to be effective. Commercial and industrial facilities that have a consistent need for heat production would have the most cost-effective CHP installations.

The technology required to design and construct CHP systems is available now and is already being implemented in some areas. However, in order for waste heat to be useful, the owner of the installation must also construct site-specific systems to trap and transport heat from the generator and deliver it to individual components in a useable form. The need to construct these additional systems and to retrofit existing components requires a substantial investment for the owner on top of the added cost of the CHP system itself. According to the U.S. Department

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[13] Ibid. pg 98.

[14] “CHP Basics.” U.S. Department of Energy. <http://www1.eere.energy.gov/femp/der/derchp_chpbasics.html>

[15] “CHP Basics.” U.S. Clean Heat & Power Association. <http://www.uuschpa.org/files/public/CHP%20Basics.pdf>

of Energy, the commercial and industrial interest in CHP is high, but the high capital costs and a lack of favorable policies and regulations have been significant obstacles in the market.[16]

5.4 Intermittent vs. Dispatchable Generation

The growing concern surrounding emissions from fossil fuel-based power plants has led to an increased public awareness of renewable electricity. Solar and wind power have already received tax credits to encourage their growth. However, solar and wind are intermittent sources of power by their nature of operation; their generation is dependent on weather patterns which we cannot control or precisely predict. Still, the popularity of these renewable sources continues to increase. Some companies and residential customers have installed rooftop solar panels to supply a portion of their electricity. The price and efficiency of these panels has improved to make them cost-effective long-term investments.

As intermittent sources of power become a more significant percentage of total grid-based generation, the risk of a regional power failure increases. In extreme cases, wind and solar generation may be virtually nonexistent in a certain region for days at a time due to weather conditions. This may coincide with periods of high peak demand. Fortunately, dispatchable generators can directly offset the reliability issues introduced by intermittent generation. This does not suggest that consumers will have to choose between renewable and fossil fuel-based energy sources. In fact, in an ideal scenario, both intermittent and dispatchable generators would be used together in the same region. Consumers will gain both the environmental benefits of renewable energy and the reliability benefits of dispatchable generation.

5.5 Benefits of Distributed Supply

A distributed system of generation has practical, measurable benefits for both producers and consumers.

At the generation level, the addition of dispatchable generation units into the grid can allow utility companies to defer the construction of more expensive large-scale power plants. These smaller generation units are also better equipped to handle severe fluctuations in demand, allowing large-scale plants to continue to provide a consistent base-load supply. It is technically conducive to handle these fluctuations close to the consumer so that the changes in demand are

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[16] Ibid 14

not seen at the base load plant. Additionally, the added system stability provided by distributed units reduces the risk that large-scale plants may be forced to shut down, such as in the case of a cascading regional power failure; these shutdowns would otherwise result in lost revenue and technical difficulties when restarting the power plant.

At the transmission level, distributed generation eases the burden of the limited transmission resources already installed. By moving generation closer to the consumer, energy losses are minimized and transmission line congestion is reduced during peak hours and seasons. As a result, utility companies can defer the construction of additional transmission pathways, which can be very expensive and subject to legal and environmental disputes regarding land usage. These utility companies can instead construct transmission pathways in response to increases in the base loads rather than in response to peak loads. This provides the most economical solution to long-term prevention of power shortages.

At the consumer level, the most apparent benefit of a distributed generation system is the provision of a "backup" power supply in case of a regional generation or transmission failure. Depending on the size of the installed dispatchable units, entire cities would be able to maintain power for most or all residents even while off the grid. At the same, consumers would observe fewer power failures in their region – even consumers who do not have a locally-installed dispatchable generator. For some consumers, especially those with power-sensitive high-tech equipment, power quality is also an important factor. The added stability of redundant, nearby generation units can protect regions from potentially damaging fluctuations in voltage and frequency. This provides additional economic benefits for critical consumers, including hospitals and emergency-response services, which have a need for stability in the power supply especially when a power shortage may be imminent.

5.6 Potential Disadvantages

Distributed generation has its technical and economic disadvantages, but some of these can be addressed through policy and technological improvements. First, generation units using fossil fuels have tended to be large in scale due to economic and efficiency issues. The prevalence of large-scale coal and natural gas plants follows from this fact. Nuclear power is feasible almost exclusively in a large-scale setting today because of the high costs of plant construction and operation. While these coal, oil, and natural gas plants present the greatest efficiency for their physical methods of generation, improvements in small-scale turbine technology are narrowing the efficiency gap for distributed systems. Microturbines and combined cycle gas turbine systems provide moderate efficiency, although not equal to today's existing power plants. In addition, the transport of fuel to distributed units requires additional infrastructure, such as natural gas pipelines. Long periods of use for these units may affect the availability of gas in the immediate area, placing a strain on the delivery system if it was not designed for such a load. Regulations regarding efficiency and fuel usage can mitigate the negative effects of these systems.

For the consumer, a local dispatchable generation unit can cause some practical problems. Audible noise and localized pollution in residential and commercial areas must be controlled, which will require a specific policy for siting the generators. The magnitude of the effects will depend on the type and size of the generator. A consumer may also encounter increases in electricity pricing depending on the capital costs and operating costs of the system. This may be increasingly problematic during peak seasons when the sporadic operation of the dispatchable generator can intermittently vary electricity prices for the consumer. A fair billing system must be established to prevent overcharging consumers for peak generation when they do not contribute to peak loads. [17]

5.7 Cost of implementation

The construction and use of dispatchable generators will incur additional financial overhead in the following major areas:

- Construction
- Operation and maintenance
- Fuel

The following table describes some of the estimated construction costs for various types of generators. This cost is represented as a per-kilowatt value, so larger installations incur a proportionally larger cost. Note that most types of generators can be built to scale depending on electrical demand.

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[17] Ibid. pg 9.

Table 1. Comparison of dispatchable installation types

Source: The Consumer Energy Council of America

Type of Installation	Capacity (kW)	Projected Efficiency	Cost per kW
Gas Turbine	1,000 - 50,000	28% - 42%	$650 - $900
Gas Turbine, Combined Cycle	400,000	55% - 60%	$350 - $450
Internal Combustion Engine	500 - 5,000	35% - 50%	$600 - $1,100
Microturbine	25 - 300	20% - 40%	$450 - $750

It is possible for owners of distributed equipment to pay for the capital costs of the equipment itself through reasonable charges to customers. Actual electricity consumption varies greatly from building to building, but we can estimate that the greatest peak usage is only a few extra kilowatts per residence; this would be the accumulation of lighting, air conditioning, and appliance usage during peak times. For commercial and industrial buildings, the increase would be much greater. As an example, if a distributed generator is used to supplement a specific neighborhood or town and is used near its full capacity, we can expect that individual residences will use approximately 0-5 kilowatts of supplemental electricity, depending on the size of the building and the usage pattern. Knowing the exact peak increase is not necessary since the generation capacity of a dispatchable unit will be distributed to different buildings as required. Usage of this electricity will also require the customer to pay for the corresponding capital investment. For example, a mid-sized gas turbine unit costs $750 per kilowatt to construct in a certain area. Then, for every 1 kilowatt of supplemental electricity that a customer uses, that customer is utilizing $750 of installed equipment, which he must pay for as part of the price of electricity.

Today, electricity prices generally remain near 10 cents per kWh. If a customer was charged an *additional* 10 cents per kWh, doubling the price of electricity during peak hours, that customer’s portion of the capital investment (say $750) could be recovered in 7500 hours of generator use. This is equivalent to nearly a year of continuous generator use. Increasing the price of electricity during peak hours is useful in reducing extremely high demand, but it is possible to distribute the capital cost over a larger span of time to reduce the immediate impact on the customer. If the price of electricity were increased by just 1 cent per kWh at *all* times, the same $750 would be recovered in roughly ten years. The cost of operation and maintenance for distributed units is expected to be less than 1 cent per kWh of capacity, which will also increase prices by a small amount. Hence, the capital and operational costs associated with constructing these types of generation units are reasonable when measured per customer, but will require a large initial investment.

The price of fuel is critical in determining the affordability of dispatchable generators. Figure 7 shows estimates for the mainstream prices of electricity, petroleum, natural gas, and coal as projections through the year 2030. In general, prices are expected to remain relatively consistent; this is important in order for dispatchable generators to remain economically viable. Notably, the price of natural gas is much less expensive than the price of consumer electricity. Given an efficiency of 40 percent, a natural gas generator would require 2.5 times the amount of fuel input (in BTUs) for the same electrical energy output. With natural gas prices near $5-$7 per million BTUs[18], the resulting electricity price would be $12.50-$17.50 per million BTUs. This is less expensive than mainstream electricity prices, allowing for capital and operational costs to be added to the dispatchable generation price. In the end, a dispatchable generation unit could sell its electricity at nearly the same price of mainstream electricity and be able to recover capital

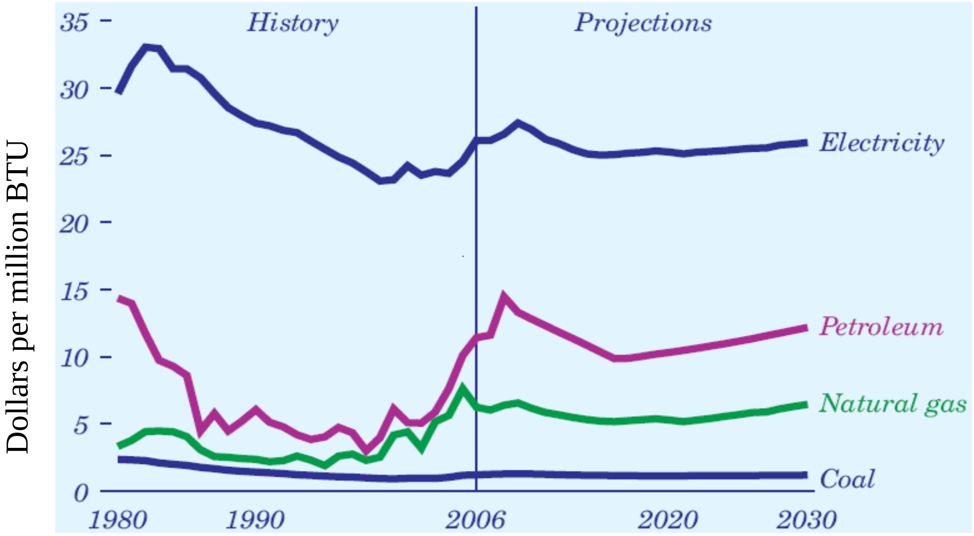

Figure 7. Energy price projections for electricity generation, 2006 benchmark

Source: Energy Information Administration

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[18] Ibid 1.

costs in a reasonable time. This suggests that, given a suitable capital investment, a consumer would not be negatively impacted when purchasing electricity from a dispatchable generator.

6 POLICY IMPLICATIONS

6.1 Existing Policies

The shift in energy sources and energy economics in the United States has already captured the attention of Congress and a number of federal agencies. The Energy Policy Act of 2005 allocated $800 million for the research and development of distributed generation and related technologies.[19] While this is a significant move forward for the energy industry, much of the focus of the research remains on reliability, emergency supply, effects on consumer electricity rates, metering techniques, and grid planning, rather than the direct development of generator technologies or fuels.[20] Since distributed generator technology already exists in a useable form, and is already being installed in some commercial and industrial facilities, it makes sense to invest in these related infrastructure upgrades to ensure that the power grid as a whole can be managed effectively. However, no specific motivation or timeframe for the widespread installation of dispatchable sources is described.

As part of the economic restructuring of the power grid in the 1990s, the Federal Energy Regulatory Commission (FERC) introduced Order 888, which effectively opened transmission and distribution lines for use by any electricity supplier.[21] This paved the way for private parties to own and operate small-scale generation units and to sell their electricity to other customers. In addition, the related FERC Order 889 provided a technical framework for utilities to monitor (and provide access to) real-time grid operation capacity and statistics. This framework is necessary to ensure to correct operation of distributed generators.[22] To facilitate the addition of various generation resources, FERC has also introduced "Standard Interconnection Agreements for Wind Energy and Other Alternative Technologies" (Order 661) and "Standard Interconnection Agreements & Procedures for Small Generators" (Order 2006). The Institute of

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[19] Malmedal, K. et al. "The Energy Policy Act of 2005 and its Impact on Distributed Generation." Rural Electric Power Conference, 2006 IEEE. April 2006.

[20] Ibid

[21] "Order No. 888 – Legal Resources." Federal Energy Regulatory Commission. <http://www.ferc.gov/legal/maj-ord-reg/land-docs/order888.asp>

[22] "Order No. 889 – Legal Resources." Federal Energy Regulatory Commission. <http://www.ferc.gov/legal/maj-ord-reg/land-docs/order889.asp>

Electrical and Electronics Engineers has developed its own “Standard for Interconnecting Distributed Resources with Electric Power Systems” (IEEE Standard 1547). These and other technical and economic policies already form a basis for the implementation of distributed generation.

6.2 Environmental Issues

The operational details of each generator (time of use, fuel consumption, pollution, etc.) will vary from unit to unit. Factors include local demand patterns, geographic location, and amount of power supplied to the grid. The EPA Clean Air Act provides strict limitations on air pollutants, which can influence the usability and cost-effectiveness of combustion generators.

Air pollution policy must be adapted to account for limited-use combustion generation in order to prevent additional barriers to entry for the marketers of generators. The policy must take into account factors such as the reduced losses of localized generation, the high efficiency of combined heat and power generation, and the pollution reduction in large-scale combustion power plants. As generators become more widespread, the environmental analysis will become more complex.

6.3 Market Growth

Distributed generators are already on the market in a variety of scales and functional types; the technology for efficient small-scale generation exists and works. However, even with existing policies, there have been no specific directives for the widespread construction of distributed generators. In fact, the notion that generators may be installed in *every* populated area may not feasible due to costs, environmental effects, and factors specific to different municipalities and geographic regions. Some organizations, such as the United States Clean Heat & Power Association (uschpa.org) are already involved with the promotion of commercial and industrial installations of dispatchable equipment. Due to demand requirements, scalability, and the effectiveness of combined heat and power generation, the most cost-effective installations are often in these larger facilities rather than in residential areas.

Government-funded research and incentive programs would be most effective in this area, focusing on larger-scale installations in facilities that have the ability to offer a significant capital investment in the technology. Commercial and industrial facilities will also benefit from specialized loan programs to encourage the adoption of the technology in a timely manner. Agencies such as the Federal Energy Regulatory Commission and the Energy Information Administration will then be able to monitor and assess the effects of these installations on regional power capacity reliability. This will provide a benchmark and a model for the installation of additional resources, and will help determine whether or not widespread installation incentives or policies should be implemented.

6.4 Future Reliability

The desire for a clean nationwide energy portfolio for the United States is putting upward pressure on renewable energy and downward pressure on traditional fossil fuel generation. As environmental, fuel-security, and fuel-cost arguments motivate the replacement of large base-load coal and gas generators with wind turbines and solar panels, reliability becomes a subtle but important concern. The technology of electricity storage (batteries and fuel cells) is far from the capacity necessary for ensuring reliable wind and solar supplies on a large scale.

As this trend continues, the government interest in renewable generation must include provisions for reliability. Dispatchable generation, which can provide a backup power source for renewable-intensive areas, must be installed at the same rate as renewable generation. Investment in the transmission system is also necessary in order to deliver electricity from active solar and wind locations to inactive ones. This can be regulated indirectly via reliability rating policies.

6.5 Summary

Distributed generation, in both intermittent and dispatchable forms, is a functional technology that can overcome many of the issues we currently face in terms of reliable electricity delivery. However, this type of localized generation may not be practical for everyone. Research in the short term should focus on commercial and industrial installations of dispatchable equipment, where efficiencies are highest and the installations are most cost-effective. Widespread adoption of dispatchable generation units will require economic and environmental assessments, and an analysis of existing distributed impacts, before policies begin to regulate that market. Reliability must be ensured as intermittent sources are adopted at an increasing rate, requiring the promise of transmission investment and dispatchable sources as backup.