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Optimization of Distributed Generation Using Sustainable Energy Technologies in California

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Table of Contents

Section 1 Introduction 1

Section 2 Literature Review 5

Section 3 Analysis: A Case for Distributed Generation 30

Section 4 Analysis: Evaluation of Distributed Generation Technologies 41

Section 5 Analysis: Physical Characteristics of San Francisco 75

Section 6 Analysis: Policy Considerations 82

Section 7 Recommendations 100

Bibliography 115

Appendix 119

List of Figures

Figure 3.1: *Net Generation by Energy Source in CA: 1998 to 2009* 34

Figure 3.2: *Net Generation by Energy Source in the US: 1998 to 2009* 34

Figure 3.3: *Emissions Levels in California from 1998 to 2009 in Metric Tons* 37

Figure 3.4: *Emissions Levels in the U.S. from 1998 to 2009 in Metric Tons* 38

Figure 4.1: *Traditional Electrical Power Grid* 43

Figure 4.2: *Solar Photovoltaic Panel Function* 49

Figure 4.3: *Wind Turbine Operation* 52, 53

Figure 4.4: *Wind Potential Map of the U.S.* 54

Figure 4.5: *Operation of Microturbines* 58

Figure 4.6: *Proton Exchange Membrane Fuel Cell Diagram* 63

Figure 4.7: *California State University Northridge Fuel Cell* 67

Figure 5.1: *Aerial Photo of San Francisco Region Topography* 76

Figure 5.2: *Average Monthly Temperatures in San Francisco* 77

Figure 5.3: *Average Monthly Precipitation Levels in San Francisco* 77

Figure 5.4: *Wind Power Densities in the Bay Area* 80

Figure 5.5: *Topography of San Francisco* 81

Figure 6.1: *Bay Area Transmission Line Proposed Extensions, 2002* 84

List of Tables

Table 3.1: *Contributions from Sustainable Sources in the U.S. and California 2009* 32

Table 3.2: *Growth of Sustainable Sources in the U.S. and California from 1998 to 2009* 33

Table 3.3: *Comparison between pollutant levels in 1990 and 2009 in California* 40

Table 4.1: *Fuel Cell Types Suitable for DG* 64

Table 4.2: *Long-Term Costs of Distributed Generation Technologies* 68

Table 5.1: *Solar Insolation Levels in San Francisco* 79

Table 6.1: *Agencies Involved with Energy Regulation in San Francisco* 87

Table 6.2: *Solar Energy Incentive Program Incentives Based on Land Use Type* 90

Table 6.3: *Self Generation Incentive Program Requirements* 94

Table 7.1: *Fuel Cell Model for San Francisco* 111

Table 7.2: *Emissions from Fuel Cell, Natural Gas, and Petroleum Based Power Production* 112

Table 7.3: *Annual Emissions Totals Comparing the Proposed Fuel Cell Model to the Potrero Power Plant in San Francisco* 113

Table 7.4: *Emissions Reductions with Transmission Losses Factored* 113

SECTION
1
Introduction

The traditional electrical power system model in the U.S. involves centrally-located power plants and a vast web of transmission and distribution networks, which make up the electrical grid. Although this model has been employed for many decades, the flaws associated with these systems have contributed to environmental degradation, threats to public health, and economic instability. Traditional systems are worn and outdated, inefficient, and commonly strained. The results of these issues are high emissions, large land disturbance, and utility fee fluctuations that are imposed on the general public. Historically, utility companies have had few incentives to manage these inefficiencies and revise practices. Legislation over two decades has forced these companies to meet more stringent emissions standards and incorporate more renewable energy technologies. Despite some improvement, additional action is necessary to improve air quality, public health, and other environmental aspects.

Many of the solutions and policies to address the problems created by traditional power systems have been based on technological advancement. New generation sources have been introduced and pollution mitigation devices installed, but air quality impacts from electricity production still exist. Because of this, traditional systems have remained largely unchanged, with the exception of simple technological upgrades. The model proposed in this analysis is design-based approach to address the inefficiency of traditional systems through the reconfiguration of electrical grids. The approach is referred to as distributed generation (DG), which shifts the design and layout of power generation and distribution systems to reduce pollution by increasing efficiency and promoting the inclusion of renewable energy sources. The primary goal of this analysis is to provide an electrical power system model that significantly improves air quality and public health.

The DG model operates on a smaller-scale than traditional systems. Rather than installing a central power plant, multiple DG sites are dispersed through communities closer to consumers. The DG configuration does not require transmission, as sources are connected directly to the lower-voltage distribution network. Transmission networks are comprised of the large galvanized steel towers used to carry high-voltage power lines. The distribution network includes the overhead power poles and underground lines installed throughout communities that deliver electricity directly to consumers at local transformers. DG essentially bypasses a large step necessary for traditional systems. Traditional grids involve voltage step-up and step-down and transporting power long distances prior to connecting to the distribution networks. This process wastes electricity through heat losses and requires significant land disturbance.

This analysis proposes the incorporation of the DG model on the utility-scale meet the demands of a large consumer population. The primary advantages of this model include higher efficiency ratings, adaptability, modularity, and the incorporation of a diverse group of power technologies. DG increases efficiency by avoiding transmission, which minimizes the amount of electricity wasted. Less waste means less power is produced to meet demand, resulting in lower emissions. DG offers adaptability, as systems may be quickly modified to meet demand at any given time. The modularity of systems allows easy expansion and reduction through the quick addition and removal of power sources. Also, DG can be used to supplement grid power as a base load or for peak demand conditions. DG systems are more conducive to the implementation of a diverse range of renewable energy sources because there are more sites. Central plants are generally comprised of a single power source. DG facilitates the installation of technologies that are optimal for specific site conditions and smaller-scale generation from a variety of possible owners. The small-scale dispersed nature of systems allows systems to be installed in close proximity to consumers. If there are any emissions at all, they are dispersed rather than concentrated by alleviating need for centralized power plants.

Features of DG:

- Small-scale
- Efficient
- No transmission required
- Adaptable
- Modular
- Conducive to renewables

The following research question will be addressed by this analysis:

Which sustainable distributed generation energy technologies are optimal for urban areas in California given technological feasibility, physical characteristics, and existing policy structures?

It is important to address what is meant by the term “sustainable” in the context of electrical power systems. “Sustainable” is used to refer to a power source or system design that significantly mitigates the health and environmental impacts caused by traditional systems.

“Renewable” could work in the sense of power sources, but sustainable does not necessarily mean renewable. For instance, if a power source is utilized that operates using a non-renewable fuel, but achieves a high efficiency rating, significantly reduces emissions, and offers low costs to consumers, then this is a sustainable solution.

The model proposed in this analysis is grid-interconnected. Grid interconnection allows the traditional grid to supply back-up power if necessary and calms apprehension of the public over significant changes to power systems. In addition, grid interconnection facilitates the creation of microgrids, which are made up of numerous DG nodes. The analysis will examine a provide statistics that compare DG to the traditional model, discuss various DG source technologies, address physical considerations that affect DG, and explore policies that support or inhibit widespread implementation. The findings will be synthesized in the Recommendations section that will provide a detailed framework for successfully employing DG strategies.

San Francisco will be used as the study area for this analysis because this city has set an extremely high bar for sustainable power systems. It felt appropriate to use a city that is in the upper echelon in terms of sustainable energy to determine the practices that have proven successful and areas of further opportunity. Ultimately, a model will be provided that can be adapted for use in various areas to promote the widespread implementation of DG. It is with great hope that others will find value in this approach and seek new innovative ways to incorporate DG into traditional power systems. If traditional practices continue, the damage to public health and the environment may be irreversible.

SECTION
2

Literature Review

Distributed generation (DG) provides a more efficient alternative to the traditional energy system utilized in the U.S. In many ways, this “innovative” technology is a reversion to past methods when energy systems had to operate on a smaller-scale due to lack of technological advancement and manpower to build complex networks. Over the past decade, the viability of this configuration has been recognized, which has resulted in additional academic research on the subject. The literature acknowledges the flaws of the traditional power system and explores new methods for electricity generation and distribution.

The Literature Review section will examine research that explores various DG technologies and configurations, advantages of this model, barriers to implementation, and provide a context for why this issue is relevant. The objective of this segment is to provide a foundation from which technical and policy decisions can be made in the Analysis section. A number of common themes were identified in the literature surrounding this topic. The four themes that will be addressed in the Literature Review are as follows:

1) **Benefits and Challenges**
2) **Environmental Considerations**
3) **Social Acceptance – Policy and Financial Mechanisms**
4) **Technological Considerations**

By understanding each of these components, informed policy decisions can be made that mandate a higher level of efficiency in energy systems, standardized grid interconnection, and the implementation of recommended DG power sources. In addressing these issues, improvement of air quality will be achieved through emission reductions, which will mitigate many of the public health impacts associated with poor air quality.

Power systems and their impacts are of particular concern to the planning field, as there is an obligation to provide healthy environments for the public. In identifying inefficiencies of the traditional system and the adverse effects imposed by this model on human health, planners are situated to propose an alternative that sufficiently addresses this problem. DG is an effective solution that requires further investigation and additional policy support to achieve widespread implementation and achieve the goal of implementing a power system that improves public health.

Benefits and Challenges

The literature that provides an analysis of the benefits and challenges associated with DG is most closely related to this analysis. In fact, a primary objective of this research is to showcase the benefits of this configuration while offering strategies to overcome challenges. By educating decision-makers, utilities, and the public about the advantages of DG systems, more widespread support for these applications can be achieved. Without recognition of the benefits associated with successful DG implementation, the traditional model status quo will continue to dominate the energy production and distribution arena. Some recurring benefits listed in the literature include adaptability, deferral of transmission and distribution system upgrades, more reliable power supply, higher efficiency, better cost-effectiveness, and lower emissions. The main challenges include the reluctance to change in the energy sector, lack of finance mechanisms, and existing policy structures.

Much of the literature surrounding the theme of benefits and challenges begins by explaining the differences between centralized energy systems and decentralized systems, showcasing the advantages of DG. The DG model is dispersed and decentralized in most cases, meaning there are numerous systems sited in various locations without one central plant. The traditional power system is centralized, as it typically consists of a large power plant strategically sited to serve the power needs of large population. DG offers the versatility of connecting to the larger grid network or operating autonomously.

The history of the DG concept is laid out by some of the literature, explaining that this model has existed for centuries. Alanne and Saari provide an example of decentralization by referencing furnaces fueled by local wood resources to heat homes. This rather simple model was overtaken by technological advances in the energy field, which later led to central power plants and vast grid networks. The authors express the increased efficiency, reliability, and security provided by the DG model (Alanne & Saari, 2006).

None of the literature I encountered theorizes that DG will completely replace the centralized power plant model. Rather, a combination of the two is proposed, which has some unique advantages. The idea of the virtual utility is presented as a method to promote effective interaction between both DG and traditional systems. The virtual utility is comprised of numerous DG sites that are interconnected and centrally controlled. This approach solves compatibility issues and optimizes demand-side management to more accurately match generating capacity with demand. In addition, surplus energy may be sold to the larger grid for reimbursement.

There are some configuration issues associated with integrating DG into the grid. Of particular concern are the costs required to train electrical utility and construction professionals who are not yet proficient with DG applications. While costs can be offset through the deferral of transmission system upgrades, there are also considerable coordination efforts required for these projects. In determining costs of DG systems, one cannot overlook grid interconnection expenses, which vary depending on existing system conditions, but can account for a large percentage of the total cost. It is important that system upgrade costs are not imposed on consumers that do not experience the benefits of the DG system through fee increases and taxes.

The traditional grid network was not originally configured for compatibility with bi-directional power flows and voltage fluctuations that are common among DG installations. Managing these issues requires equipment that creates stable voltage flows to ensure the reliability of networks is not compromised. Intermittent technologies, such as wind and solar photovoltaic sources do not create stable voltages because wind and sunlight patterns are not stable, themselves. Bi-directional power flow refers to the output of power into the grid from power plants and inputs from various sources. Net metering is used to determine whether more power was generated for the grid or consumed.

DG poses many new challenges that must be addressed for successful implementation. Due to the dispersed nature of DG configurations, standards are necessary to prevent safety hazards and issues of power reliability in the grid. Because this research promotes grid interconnection, it is imperative to ensure all DG installations are compatible with grid voltage levels, security equipment, and reliability provisions. Common regulations and standards must be established to ensure systems are functioning as intended. Additional research is necessary to determine optimal power source technologies, power storage, maintenance of systems, and forecasted demand levels. In essence, the large-scale implementation of DG requires a comprehensive plan that addresses issues such as system expansion, net metering and reimbursement, ownership of systems, liability, maximum sizes, and more (Dondi, Bayoumi, Haederli, Julian, & Suter, 2002). A set of universal standards will aid utilities and installers as well as manufacturers of power generation and interconnection equipment.

While these challenges pose a threat to the successful widespread implementation of DG, each of these issues can be overcome with proper planning and support. The benefits of DG certainly outweigh the challenges. Some of these benefits include flexibility and scalability due to the simple modification of systems in conditions that merit upgrades or expansion. Also, DG is highly versatile, as multiple energy generation technologies can be operated in conjunction. As technological advances take place, new more efficient technologies can be incorporated at a later date. In addition, the relatively small size of DG systems allows for easier identification of problems, faster repairs, and can even promote local job production.

The most significant advantage of DG is the exclusion of transmission networks because these systems are connected at the local distribution level. The distance between power production and consumption is reduced significantly. In the simplest of terms, traditional power systems involve a central power plant that generates electricity and uses series of transmission and distribution networks to deliver power to consumers. The transmission network is rather inefficient, wasting approximately 10 percent of the electricity generated through thermal losses and voltage step-up and step-down processes at substations (Office of Electricity Delivery and Energy Reliability, 2009). Reducing this distance allows for more efficient power generation because excess power generation to mitigate transmission losses is avoided. In addition, surplus energy may be sold back to the grid, possibly changing consumption patterns to lower demand through the incentive of being paid for unused energy.

In order to achieve widespread implementation of DG systems, many scholars propose deregulation of power systems. Deregulation refers to the privatization of power sources, open grid networks for DG interconnection, restructuring of utilities, and more (Dondi, Bayoumi, Haederli, Julian, & Suter, 2002). In terms of ownership of DG systems, much of the literature argues for community ownership as a means to increase self-sufficiency and empower local communities. One model is the energy co-op, where community members can purchase shares to assist in financing efforts for projects. In addition, development trusts may be established that create revenue while representing the interests of the community (Walker, 2008). One strategy used by contactors attempting to implement DG is to donate shares to the community to gain support for the proposed installation.

There are other methods proposed to promote DG projects, including education about local job creation, payback period, and sale of surplus energy to the grid. It is imperative to involve the community in the planning process in order to gain widespread support. This can be achieved by holding charrettes to make decisions involving system size, siting, environmental considerations, and other factors. In many cases, it will be vital to involve energy professionals who can share their expertise with the community and decision-makers. These experts may also help to establish strategic partnerships with local developers and energy contractors.

Environmental Considerations

Most scholars acknowledge the positive environmental implications of DG. That being said, there is minimal literature tied directly to the environmental factors associated with DG because of the general consensus that this model is more sensitive to the environmental than traditional systems. While widespread acceptance of the positive environmental effects of DG is beneficial to its cause, it is also important to avoid overlooking the need for more in-depth analysis of environmental considerations associated with DG. Additional scientifically-based research about this subject is desirable as a means to provide stakeholders with empirical facts that support DG. Facts should be collected on emissions profiles, costs, and other factors.

Although there is not a wealth of literature that specifically addresses the environmental issues associated with DG, much of the literature encountered is related to California, which is integral to this research. A significant portion of the environmental research is structured around the air quality benefits associated with DG as compared to the traditional power system. Rodriguez et al. evaluates various air quality projection models in order to identify and address any uncertainties that skew air quality projections and reduce accuracy (Rodriguez, Brouwer, Samuelsen, & Dabdub, 2007). The authors highlight the importance of selecting inputs as a key determinant of air quality impacts. Some of these inputs include meteorological considerations, standby conditions, and chemical reactions of emissions compounds. The findings show that DG has more spatially distributed air quality impacts, while the traditional model concentrates impacts to a certain area. It is important to recognize that downwind areas often experience the most detrimental impacts, as emissions react to form ozone or other harmful substances. Spatial and temporal factors play an important role in pollutant levels throughout an area. Regulations that provide requirements for the installation of appropriate energy technologies and spatial guidelines will more successfully mitigate air quality issues.

In the southern California air basin (SoCAB), different levels of nitrogen oxide (NO_x) emissions throughout the region react with volatile organic compounds (VOCs) to form ozone, which is poses respiratory threats to humans. The SoCAB is VOC-limited, meaning VOC to NO_x ratios are low (Rodriguez, 2007). This does not mean that VOC levels are low, but that NO_x levels are extremely high in this region due to fuel combustion for electricity, automobiles, and manufacturing processes. Areas downwind of Los Angeles experience particularly high ozone levels because of this reaction of NO_x and VOCs under high temperatures. $PM_{2.5}$ is another emission that has high levels in California. $PM_{2.5}$ refers to particulate matter that is less than 2.5 micrometers in diameter. These pollutants are formed through combustion of fuels in power plants, automobiles, and industrial applications. The dispersion of DG helps to limit chemical reactions and the concentration of these emissions. In addition, the use of clean renewable energy technologies for DG will mitigate negative air quality impacts.

Marc Carreras-Sospedra, a professor from University of California Irvine, conducted an analysis of the effects of DG compared to traditional power systems in the SoCAB. Interestingly, the author did not acknowledge renewable technologies for DG applications. In fact, the author generalized that fossil fuel sources are best suited to respond to rapid changes in demand, which is untrue given emerging technological advancement. Carreras-Sospedra fails to understand the effectiveness of sustainable technologies, such as fuel cells and microturbines that operate using a variety of fuels. The author may have left-out these technologies in order to establish an equitable standard for comparing DG and the traditional model. A baseline case was determined for the traditional model and compared to a design case for DG. The author used baseline dates from the summer of 1987, because these days are representative of normal conditions in the SoCAB. Natural gas-fired power sources were utilized because natural gas is the primary fuel used for power production in California.

Three proposed central power plants in southern California were modeled by Carreras-Sospedra. Surprisingly, central plants had lower overall emissions of all compounds except NO_x and ammonia (NH_3) as compared to DG generating the same capacity. Lower NO_x emissions are significant, though, because these compounds contribute to ozone production, which is a significant threat to public health. Interestingly, at a level above 15 parts per billion (ppb), high NO_x actually prohibits ozone production. But, high NO_x levels can actually increase the amount of $PM_{2.5}$ because of the increases in nitric acid (Carreras-Sospedra, Vutukuru, Brouwer, &

Dabdub, 2010). Therefore, DG performs better in terms of reducing particulate matter emissions. Also, dispersion of emissions actually contributed to better ambient air quality conditions, as concentrated impacts have been shown to be more detrimental. Overall, the findings of the model show that DG is the environmentally preferable method of power generation in terms of air quality impacts, despite higher emissions for some substances.

Regulations need to be enacted that consider atmospheric chemistry in ambient conditions (Carreras-Sospedra, Vutukuru, Brouwer, & Dabdub, 2010). When analyzing the environmental benefits of DG, one must factor the mix of technologies employed, total percentage of DG in the region, emission profiles, and air movement. It is important to understand how DG can result in improved ambient air quality conditions by increasing efficiency and reducing harmful emissions. At this time, there is not a sufficient literature directly addressing the environmental concerns associated with DG. Air quality is the main environmental impact associated with power generation, but habitat and landscape degradation are also worth exploring. This analysis will expand upon the larger body of literature to further explain the emissions improvements offered by DG.

Social Acceptance

Much of the literature related to DG has a social acceptance component. This can be attributed to the importance of earning public support when undergoing a major shift to infrastructural systems. As many other nations are further along than the U.S. in terms of sustainable energy, most of the literature is based on other countries. Even though the U.S. is the location of interest in this analysis, there is value associated with understanding how communities across the globe perceive the DG model.

The literature highlights frameworks that show the development of support for these systems. The manner in which planning professionals, developers, and utilities go about this process often dictates the level of support received from the impacted communities. In terms of policy, there is minimal literature addressing detailed policy structures for the increased adoption of DG applications. Many of the articles outline generic policies, but fail to provide the depth and specificity necessary to implement these policies. This may be due in part to the fact that DG has not yet achieved widespread acceptance. In fact, a large percentage of society and industry is unaware of DG and its potential benefits. Therefore, in order to achieve greater support, it is imperative that social acceptance is achieved followed by policy measures and finance mechanisms.

Up until the mid to late 2000s, there was minimal research around the social aspect of the transition toward greater DG. Around this time, a wealth of literature was published stressing the importance of the social acceptance component as a vital means to achieve widespread adoption of DG. Many scholars have identified the social acceptance issues to be equally as important as technological challenges. Both decision-makers and the public will have vital roles in the successful implementation of DG as the primary source of electricity generation and distribution.

People are generally resistant to change due to a lack of understanding or knowledge regarding a subject. Energy systems are very complex and certainly no exception. Consumers need to achieve greater awareness of how the electricity they consume is generated and the environmental impacts associated with production. Most are blind to these issues, caring only about the availability of reliable electricity at a reasonable price. A combination of top-down and bottom-up support is the key toward building what Schweizer-Reis calls "Energy Sustainable Communities" (ESCs) (Schweizer-Ries, 2008). This combination of top-down and bottom-up support should consist of measures like regulations that require public involvement in the planning of ESCs. Decision-makers, contractors, local community members, and nearby residents must be engaged in a public participation process.

It is crucial to educate and earn the trust of the public when proposing a major shift to power systems. The overall goal should be to promote sufficiency and flexibility. Sufficiency refers to a situation in which users are conscious of their energy usage and impacts (Schweizer-Ries, 2008). People need to be flexible and open to ideas of energy efficiency upgrades, siting decisions, and more. Educating stakeholders about the technological aspects is a difficult but critical task. People will be more open to DG if they understand system dynamics and technological aspects.

It is important to address landscape changes, economic issues and social justice factors associated with DG. Some renewable technologies, such as wind and solar, may pose visual obtrusion on the landscape, possibly diminishing the positive perceptions associated with unaltered landscapes. This brings about the NIMBY (not in my back yard) concept, in which communities support DG usage, but do not want to see the installations in their communities.

Visual intrusion on the landscape may reduce property values, but there is a financial incentive to selling surplus energy back to the grid in community ownership models, as well.

Social justice is also a vital component of social acceptance, which should include transparency in the process, facilitation of a participatory process, and shared benefits. Highlighting the benefits can be a useful strategy, educating the public about direct and indirect benefits. Examples of direct and indirect benefits are monetary compensation for surplus energy and increased job opportunities, respectively. Finally, in terms of climate change, people need to be educated about how DG can aid in reversing climate change effects. Generally, those who support renewable energy take greater participatory action. People act according to social norms, which can be positive if there is already support for DG. If society places high value on promoting healthy air quality and reversing climate change, this model will gain greater acceptance.

St. Denis and Parker conducted a study of 10 communities in Canada to determine perceptions about community energy plans. The study was performed because there is a growing trend toward local control over DG systems (St. Denis & Parker, 2009). The key findings of the study show that people were more inclined to support energy efficiency measures than they were to support renewable energy. Also, smaller and more remote communities were most likely to adopt DG programs as a means to increase their level of self-sufficiency. Larger communities already situated with energy transmission infrastructure may lack trust for renewable technologies. Community members are empowered through greater knowledge of renewable technologies as a way to minimize exposure to market volatility.

Community energy plans must address energy efficiency, energy conservation, and renewable technologies. These issues must be integrated in plans to maximize success. In addition to involving all stakeholders, top-down support is critical. Top-down support includes regulations, funding mechanisms, rebates, and other financial incentives. Methods that facilitate investment from community members stimulate widespread acceptance of the DG model. Successful implementation will provide an example that can be modeled by other communities.

Some of the literature examines the social acceptance of DG at various dimensions, including socio-political, community, and market dimensions. Wustenhagen believes government-supported market implementation should be the primary goal in deriving social acceptance of DG (Wustenhagen, Wolsink, & Burer, 2007). The largest constraints to the widespread implementation are lack of stakeholder support, ineffective or nonexistent policies, and lack of understanding regarding public attitudes. Socio-political acceptance refers to the idea that people will not be willing to support an idea if the government does not support the issue. In addition, acceptance in local communities and markets must be achieved. Market acceptance involves the increasing the level of DG technologies throughout the industry market by earning consumer and investor acceptance.

From a community standpoint, outside investors have more difficulty earning community support. This highlights the importance of transparency and flexibility in meeting the needs of the community. The asymmetry principle states that trust is built slowly, but destroyed quickly. This is important for outside consultants and experts that may be brought in to assist the community with the DG system.

Technological Considerations

The majority of the literature on DG contains a technical component. In order to increase the level of DG in society, the technical aspects must be considered and resolved. This literature contains a wide range of perspectives about the optimal technologies and configurations of DG systems. While no single article or book has all of the right answers, a great deal can be learned by evaluating the wide array of configurations. There is not one perfect configuration, so it is crucial that DG applications consider local climates, topography, regulations, politics, and perceptions in order to be implemented successfully. Site specific design is an important factor, as a rigid framework cannot be applied for successful widespread implementation.

The literature pertinent to this paper focuses on the technological issues associated with incorporating DG into traditional power systems. The traditional model involves producing high voltage power and transmitting it long distances to lower voltage networks, resulting in wasted energy through thermal losses. DG is an effective solution to the inefficiency of traditional systems. DG offers the versatility of operating in isolation or connecting to the grid. For the purposes of this analysis, the emphasis will be on grid-interconnected DG to increase reliability and facilitate power supplementation. According to Bayod-Rujula, in 2008, Spain had 2,221 MW of photovoltaic (PV) installations tied to the grid. By around 2016, Spain expects the cost of PV to equal conventional energy sources (Bayod-Rujula, 2009). Deregulation and technological innovation have been the keys to the success of Spain.

The International Energy Agency identifies technological developments of DG, construction constraints on transmission lines, demand for reliable energy sources, market liberalization, and climate change concerns as key drivers of DG. Some of the DG technologies include fuel cell, microturbines, PV, wind, biomass, hydroelectric, and geothermal. With this variety of technologies, a diverse energy profile based on local needs and resources can be achieved. Hydroelectric, PV, and wind technologies produce the lowest amount of CO_2 per kWh generated, while natural gas and coal resources contribute to significantly higher amounts of CO_2. As coal is the primary fuel source for power generation in the U.S., reducing these power plants will significantly mitigate climate change problems. In addition to this, the inefficiency of transmission systems further contributes to emissions. In fact, 30 percent of the cost associated with traditional power utilities is due to transmission and distribution losses. In essence, consumers are paying for the inefficiencies and high emissions of traditional systems (Bayod-Rujula, 2009).

The DG model facilitates rapid installation, adaptability, and simple siting decisions that consider specific site conditions. Operators of DG systems have the option to buy or sell to the larger grid and employ strategies, such as buying off-peak when energy is cheaper and selling during peak conditions when energy is more expensive. Some of the technical problems associated with DG are intermittency of wind and solar technologies that will be discussed in greater detail in the Analysis section. Intermittent technologies can produce voltage fluctuations that compromise grid security and reliability if the proper equipment is not installed.

Grid systems need to be upgraded to handle the injection of power from DG sources, which requires investment in existing infrastructure. Once the system is capable of handling DG, microgrids can be formed. Microgrids are comprised of interconnected DG sources, which form a larger distribution network. The concept of a virtual utility refers to a range of DG sources controlled by a central energy management system (Bayod-Rujula, 2009). Under the virtual utility, operators can prioritize, sending out the lowest-polluting sources first to optimize the efficiency of the entire network and minimize environmental impacts.

Microgrids cannot be formed overnight, so it is important to identify the incremental steps toward large-scale implementation. Much of the literature is in agreement that DG systems can be installed as a means to defer traditional utility upgrades. When central plant utilities experience increases in demand, systems become constrained due to the increased difficulty in meet this higher demand. The response to these constraints has typically been to build more transmission and distribution lines as well as expanding power plants. DG can be incorporated into traditional systems quickly and at a lower cost than entire system upgrades. The simplicity of DG systems results in fewer components that require maintenance.

The incremental nature of DG minimizes waste energy because systems can be easily expanded to accurately meet demand, resulting in less unused capacity. Central plant systems are built to accommodate future growth and demand. Until that growth level is reached, there is unused capacity, or waste energy. A study was conducted on a 500 kW distributed solar PV plant in Kerman, CA, owned by Pacific Gas and Electric (Hoff, Wenger, & Farmer, 1996). By deferring transmission upgrades and installing DG, over $1 million was saved. Hoff highlights the value of deferring utility upgrades offered by the DG model. DG systems are also more efficient by eliminating transmission losses and siting systems closer to users.

Research has been conducted regarding the integration of DG at the building scale in addition to the utility scale. In 2008, electricity contributions from DG sources in California totaled 2,000 MW. This would not have been possible without some DG installations at the building scale. By 2020, California expects DG to meet at least 20 percent of the power demands of the state (Medrano, Brouwer, McDonell, Mauzey, & Samuelsen, 2008). When analyzing DG capabilities of buildings, energy simulation software, such as eQUEST, should be employed to provide hourly energy consumption data. This will ensure renewable energy is integrated into the building design and optimized. Inputs for these energy models include location, weather data, utilities, construction, and systems, among others.

A study conducted by Medrano et al. investigated the performance of high-temperature fuel cells, microturbines, and photovoltaic panels at the building scale. The authors stress the importance of maximizing energy efficiency in buildings prior to implementing a DG system (Medrano, Brouwer, McDonell, Mauzey, & Samuelsen, 2008). Efficiency upgrades must be a prerequisite to system installations. Upgrades can be made to the building envelope, lighting fixtures, natural daylighting, and systems. These upgrades can result in energy consumption reductions of up to 30 percent.

Fuel Cell. The majority of the technical literature about DG is on the topic of fuel cells. This is somewhat surprising because this is an emerging technology. Some of the literature explains the function of individual fuel cells, which will be discussed briefly, while other sources focus on the incorporation of fuel cells into DG systems. In recent years, advances in fuel cell technology have increased efficiencies and reduced cost. Much of this innovation has been the result of energy deregulation with more small-scale power generation. There is still opportunity to further refine fuel cell technology, but it is equally important to optimize the use of current fuel cell technology. Simulation is a method employed that assists users in determining initial and operating costs, efficiency, reliability, and scale of fuel cell networks. Inputs for these models include energy demand, size of systems, emission profiles, configurations, and more.

Based on the needs of users, different fuel cell systems may be necessary. For instance, high-temperature fuel cells (HTFCs) have long start-up duration, but are appropriate for continuous operation. Low-temperature fuel cells (LTFCs) are meant for daily cycling, meaning they turn on and off throughout the day depending on demands. Fuel cells are adaptable and modular, making them conducive to expansion. Once systems are in operation, it must be initialized and monitored for performance.

Fuel cells offer advantages of quiet operation, durability, low emissions, and high efficiency rates. These devices have few moving parts, extending lifetimes and maintenance intervals. Rather than using combustion to generate energy, fuel cells utilize a chemical reaction, which occurs within a self-contained unit. It is important to provide a brief description of the function of fuel cells. The operation begins with a fuel reformer that derives pure hydrogen from a fuel, such as methane, natural gas, or others. The hydrogen enters the unit through an anode, which is located to one side of the electrolyte. From the opposite side, oxygen enters through a cathode. The protons and electrons of the hydrogen are separated on the one side of the electrolyte. In order to reach a stable state, the protons move through the electrolyte to combine with the oxygen and form water. The hydrogen electrons are unable to penetrate the electrolyte and are forced to proceed through an external circuit. These electrons provide usable electricity.

Two reactions take place during the operation of fuel cells. The oxidation reaction refers to the separation of hydrogen protons at the anode. The reduction reaction occurs once the energy generation process is complete and the hydrogen electrons and protons are once again combined to form water (Berenguer & Molina, 2010). In some cases pure hydrogen can be stored on-site in order to bypass the fuel reformer stage. Because hydrogen is such a light element that is difficult to store, it should be stored as a compressed gas to prevent leakage (Wu, Kotak, & Fleetwood, 2005).

Medrano et al. provides a few examples of the success of DG projects. Four 250 kW HTFCs were installed in a hospital, which reduced electrical costs by 61 percent, resulting in a savings of $860,000 per year. In addition one HTFC was installed in a 23,000 sf college building and 8,400 sf office building. Utility costs were reduced by 24 and 56 percent, respectively. HTFCs are the most efficient, but high initial costs result in a payback period of 6 to 12 years (Medrano, Brouwer, McDonell, Mauzey, & Samuelsen, 2008).

Photovoltaics. When most individuals think of renewable power sources, they tend to think of solar PV technology. Much of the current literature on technological considerations for DG does not place a great deal of emphasis on PV. This is likely attributable to the lack of efficiency, large space occupation, and aesthetic concerns as compared to other renewable DG technologies. PV panels collect solar radiation, converting it to electricity through a group of solar cells. Solar cells that make up PV panels are made up of semi-conducting devices that generate direct current (DC) voltage when struck by sunlight (Massey, 2010). While photovoltaic technology is effective at the building scale, it may not be effective for larger-scale DG applications, especially in urban areas.

J.M. Pearce provides a framework for hybrid PV systems to address intermittency issues. Pearce discusses a model where building power is supplied by PV panels that are supplemented by a natural gas engine generator on-site (Pearce, 2009). Waste heat resulting from the combustion process of the engine generator is captured to provide heat for the building equipment and HVAC systems. The recovery and use of heat generated by power production is known as cogeneration. Cogeneration can increase efficiency of systems significantly. Absorption cooling systems can be installed to further increase efficiency by utilizing waste heat for cooling applications as well as heating. The hybrid of PV and engine generator cogeneration is one method to solve the intermittency problems caused by PV alone.

Wind Generation. Under DG, there is minimal literature about wind power because these systems are commonly sited strategically away from most development. This results in long transmission distances, which does not fit with the DG model. Nonetheless, there are benefits associated with wind technology, including no fuel consumption and zero emissions. Wind turbines take advantage of atmospheric conditions by using wind resources. Winds turn fan blades, which are connected to a shaft. The shaft is connected to a generator and rotated. The rotation of the generator produces electricity. This technology will be discussed further in the Analysis section for its application in DG configurations.

Cogeneration. Cogeneration was discussed briefly in the hybrid solar PV example. This model involves a more efficient use of thermal energy produced during the generation of electricity. Basically, thermal energy produced from the conversion process is used to generate useful heat for building processes. Greater consideration needs to be placed on the utilization of waste heat to improve efficiencies. By implementing cogeneration strategies, energy demand can be reduced significantly, especially if absorption cooling and desiccant dehumidification strategies are employed (Medrano, Brouwer, McDonell, Mauzey, & Samuelsen, 2008). Absorption cooling and desiccant dehumidification are innovative technologies that allow the heat generated from energy produced to be used to provide cooling for buildings. When designing cogeneration systems, the electricity to thermal demand ratio (E/t) must be considered. Cogeneration allows cooling to be sourced from a thermal load, increasing the heat recovery factor by 37 to 97 percent (Medrano, Brouwer, McDonell, Mauzey, & Samuelsen, 2008). Hospitals are ideal for cogeneration applications that include absorption cooling because thermal load demands are high and constant. In smaller buildings that consume less energy, the payback period of these systems is increased because of the initial cost of the absorption chiller.

Storage and Superconducting Devices. Superconducting devices offer promising solutions to transmission and distribution losses, making them ideal for DG applications. Superconductors allow for electricity to flow without resistance when cooled below specific temperatures. These devices are comprised of metals, such as zinc, aluminum, or mercury and even some ceramics. Superconductors are cooled to temperatures as low as -273° C using liquid helium or nitrogen. Literature regarding superconductors includes explanation of devices that optimize DG as well as frameworks for superconductor integration.

Molina and Mercado provide a framework for regulating wind power, which has abrupt voltage fluctuations, using superconducting devices. Distributed static synchronous compensators (DSTATCOM) and superconducting magnetic energy storage (SMES) devices can be used in combination to control and stabilize the flow of wind power. DSTATCOM includes an inverter and step-up transformer to regulate flows back to the grid. The SMES is capable of storing surplus power, acting as a damper, and rapidly releasing stored electricity when necessary (Molina & Mercado, 2010). This stability achieved with this system improves the performance of microgrids.

Three superconducting devices are identified by Hartikainen et al. as well-suited for DG. These include SMES devices, flywheels with superconducting bearings, and superconducting cabling systems. Electrical storage devices include SMES systems and batteries, while flywheels and compressed air are mechanical storage devices. The efficiency, small size, and stability during peak periods of superconductors help to optimize DG technology (Hartikainen, Mikkonen, & Lehtonen, 2007). SMES have a lifetime of approximately 30 years and operate with 100 percent efficiency, losing no stored energy. Flywheels last approximately 25 years and have minimal losses. The key advantages of flywheels are the lack of maintenance required for electrical storage systems and absence of toxins that are commonly used in batteries. The key drawback is the large size, as flywheels are 30 to 40 times the size of superconducting electrical storage systems with the same storage capacity.

Superconducting cables include all wires and switchgear to connect generation sources to users. While conventional cabling systems lose approximately 50 to 65 Watts per meter (W/m), superconducting cables lose only between 15 and 25 watts per meter. Significant improvement in transmission losses will be achieved with the widespread installation of superconducting cables. The stability of these cables also prevents over-current conditions that compromise the reliability of energy systems (Hartikainen, Mikkonen, & Lehtonen, 2007).

Literature Review Conclusion

The literature on DG covers a range of topics, as discussed throughout the literature review. This is still a relatively new and emerging concept, which is beginning to receive more recognition. The DG model offers efficiencies and other advantages that cannot be achieved traditional power systems. Given that this concept is still in the preliminary developmental stages, there is much capacity for expansion. This analysis attempts to provide a comprehensive framework for integrating DG into power systems in California and the rest of the country.

DG will be examined as a method that provides solutions to the flaws of traditional systems. Much of the literature supports DG integration, but fails to provide adequate implementation strategies for the widespread adoption of DG. That is precisely what this analysis will address. The key factors that affect energy systems will be examined in this analysis, which include physical and atmospheric conditions, technological considerations, and policy measures. This seems like an appropriate time to rethink the design of energy systems, as concerns over climate change, public health, and market volatility grow.

Difficult times like these present opportunities for planners and other professionals. The reordering of energy systems is a task well-suited for planners because there is a wealth of factors to address. Planners must facilitate interaction among different groups in order to achieve successful implementation. Engineers, industrial designers, utility workers, government officials, and the general public must all interact through this process. Planners must be responsible for involving the right stakeholders and allowing the different perspectives to be heard. In addition, the changes to land use and zoning codes through more dispersed generation sites require coordination with local governments. Place-specific solutions and processes must be developed, as there is no single model that is appropriate for all locations. These are crucial steps for the effective shift of major infrastructural systems.

The following Analysis section will begin by differentiating between DG and the traditional energy model. Next, the physical, technological, and policy factors will be analyzed with a particular focus in San Francisco.

SECTION
3
Analysis: A Case for Distributed Generation

This section of the analysis will provide statistics showing trends of the traditional energy system. This shows the lack of sustainability of the traditional system, introducing a platform for how the implementation of DG can solve the emissions issues caused by power systems. The primary focus will be on lowering emissions as a means to mitigate public health issues associated with poor air quality. The following studies compare energy performance and emissions in the state of California to the entire U.S. Contributions from various power technologies will first be examined followed by emission levels over time. Pollutants identified in these examples will be further explored to determine which energy technologies are most detrimental to public health.

Energy Source Contributions

In California, the primary energy contributor is natural gas, which constitutes 54.2 percent of the total power generated in the state. Only 1.0 percent of the state's power comes from coal sources, which has significantly improved air quality. In 2006, the state passed Senate Bill 1368, prohibiting all electrical utility companies from entering into long-term contracts with coal companies to discourage its use as a fuel resource for power production.

Today, there are no coal-fired power plants in the state of California, as the minimal contributions from coal are from out-of-state imports.

In the U.S., coal resources generate more power than any other technology. Although contributions from coal have been in decline, it still produces 44 percent of the total power generated by the country. Natural gas is the second highest contributor, accounting for 23.1 percent of the total energy. Comparatively, California performs favorably given the reduced emissions of natural gas. Natural gas combustion emits approximately half of the Carbon Dioxide (CO_2) produced by coal combustion. Sulfur Dioxide (SO_2) is reduced by 99 percent and Nitrous Oxides (NO_x) are decreased by two-thirds (EPA, 2007). Despite the emissions improvements from replacing coal with natural gas sources, further emission reductions must be achieved to significantly improve air quality.

Table 3.1 on the following page shows the contributions of renewable and low-polluting power sources. California has higher percentage contributions than the U.S. from each renewable source, except nuclear power. Still, less than 40 percent of California's power is produced by sustainable sources. The major sustainable contributors are hydroelectric and nuclear sources. While the emission reductions associated with these technologies are beneficial, there are concerns with each of these two technologies. The sustainability of nuclear power is debatable given the security and safety concerns. Nuclear sites are vulnerable to acts of terror and natural disaster, as leakage of nuclear material can threaten the lives of millions. This is currently being experienced in the aftermath of the earthquake and tsunami in Japan. In addition, the disposal of nuclear waste material is controversial given the containment of this dangerous material. The damming of reservoirs for hydroelectric power disrupts ecosystems and increases turbidity and eutrophication through stored sediment, among other problems. Although, nuclear and hydroelectric sources are more sustainable than conventional power sources, more innocuous technologies, such as solar, wind, and fuel cells should be employed to minimize environmental degradation.

Table 3.1: Contributions from Sustainable Sources in the U.S. and California 2009.

Sustainable Technologies	CA Contribution	US Contribution	Difference
Solar	0.3%	0.0%	0.3%
Wind	2.8%	1.9%	0.9%
Biomass	1.2%	0.5%	0.7%
Hydroelectric	13.3%	6.9%	6.4%
Geothermal	6.1%	0.4%	5.7%
Nuclear	15.2%	20.0%	-4.8%
Total	**38.9%**	**29.7%**	**9.2%**

It is important to identify the growth of different sustainable energy technologies in both California and the U.S. As seen in Table 3.2, there is a dramatic difference in growth percentages from 1998 to 2009 between California and the U.S. While it appears that there has been a significant increase in the number of wind projects in California, this growth level in the rest of the country is tremendously higher. This may be due in part to the progressive nature of California in the energy realm and the fact that these technologies were implemented much earlier in the state than they were in the U.S., which would deflate growth percentages. The policy section will show that both California and the city of San Francisco have a wealth of policies promoting solar projects above other renewable technologies. Based on the popularity and growth of solar technology, it is surprising that this figure is not higher.

Table 3.2: Growth of Sustainable Sources in the U.S. and California from 1998 to 2009.

Sustainable Technologies	**CA Growth**	**US Growth**
Solar	28.9%	77.4%
Wind	111.8%	2342.0%
Biomass	2.8%	-17.8%
Hydroelectric	-43.7%	-15.4%
Geothermal	0.1%	1.6%
Nuclear	-8.2%	18.6%

The pie charts displayed on the following pages highlight contributions from the various power sources utilized by the U.S. and California. The renewable and low-emitting sources are shown in bold in the legend to differentiate from the unsustainable sources. It is apparent that these contributions are quite different between California and the rest of the country. The U.S. relies heavily on coal, natural gas, and nuclear power sources, while California relies mainly on natural gas, nuclear, and hydroelectric sources. By reducing coal contributions to almost zero, California is doing a better job of controlling emissions.

Figure 3.1: Net Generation by Energy Source in CA: 1998 to 2009 (thousands of MW Hours).

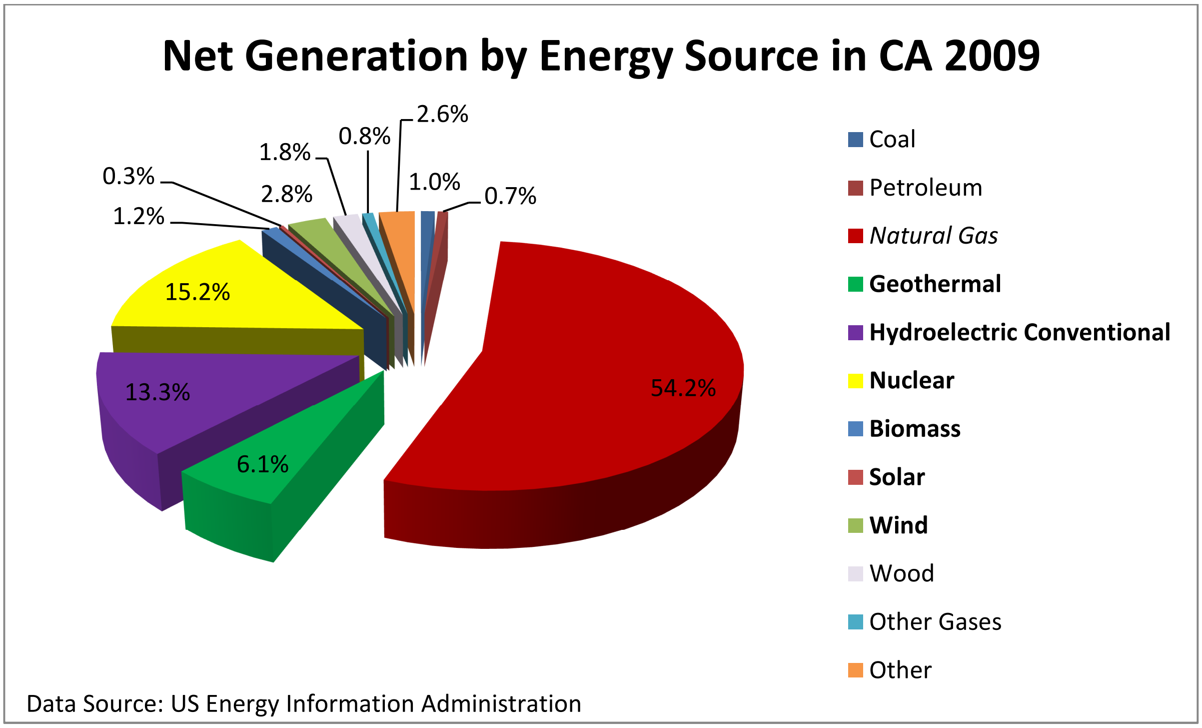
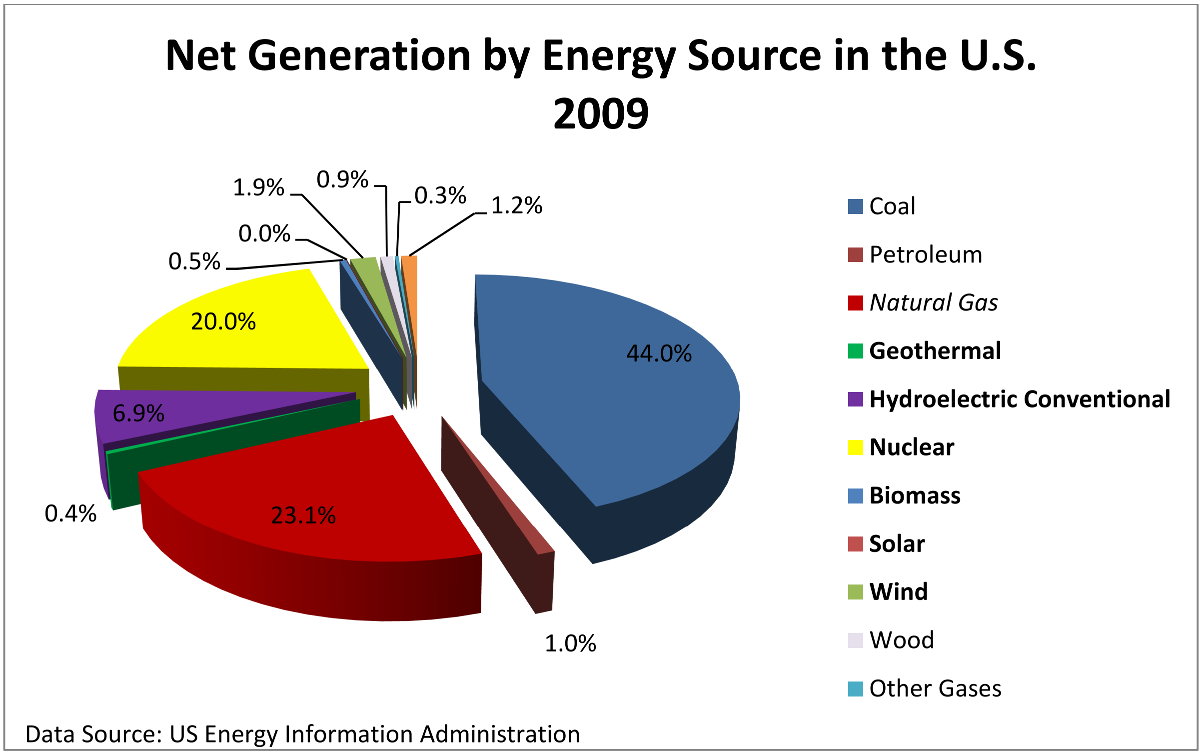


Figure 3.2: Net Generation by Energy Source in the US: 1998 to 2009 (thousands of MW Hours).



Emissions Profiles

Emissions profiles from power generation are important in determining the health impacts associated with energy systems in California. The figures on the following page show that state emissions data for Carbon Dioxide (CO_2) emissions have fluctuated over the years, but increased slightly since 1998. In fact, CO_2 is approximately 12 percent higher today than it was in 1998. CO_2 emissions in the U.S. peaked from 2005 to 2007, but decreased in 2008 and 2009. Many activities contribute to CO_2 emissions, but combustion of fossil fuels is the primary contributor to emissions.

The combustion of natural gas in California is a large contributor to CO_2 emissions in the state. Coal and petroleum sources account for only 1.7 percent of the total power generated, while natural gas combustion has increased by 51 percent since 1998. Although natural gas burning emits fewer pollutants than coal and petroleum, the increased utilization has offset the effects of reducing CO_2 emissions. From 1998 to 2009, total electricity production has increased by 15 million Megawatt Hours (MWh), with natural gas as the majority contributor. Natural gas must be phased-out, used more efficiently, or demand from utilities must be reduced significantly to achieve desired effects of reducing emissions.

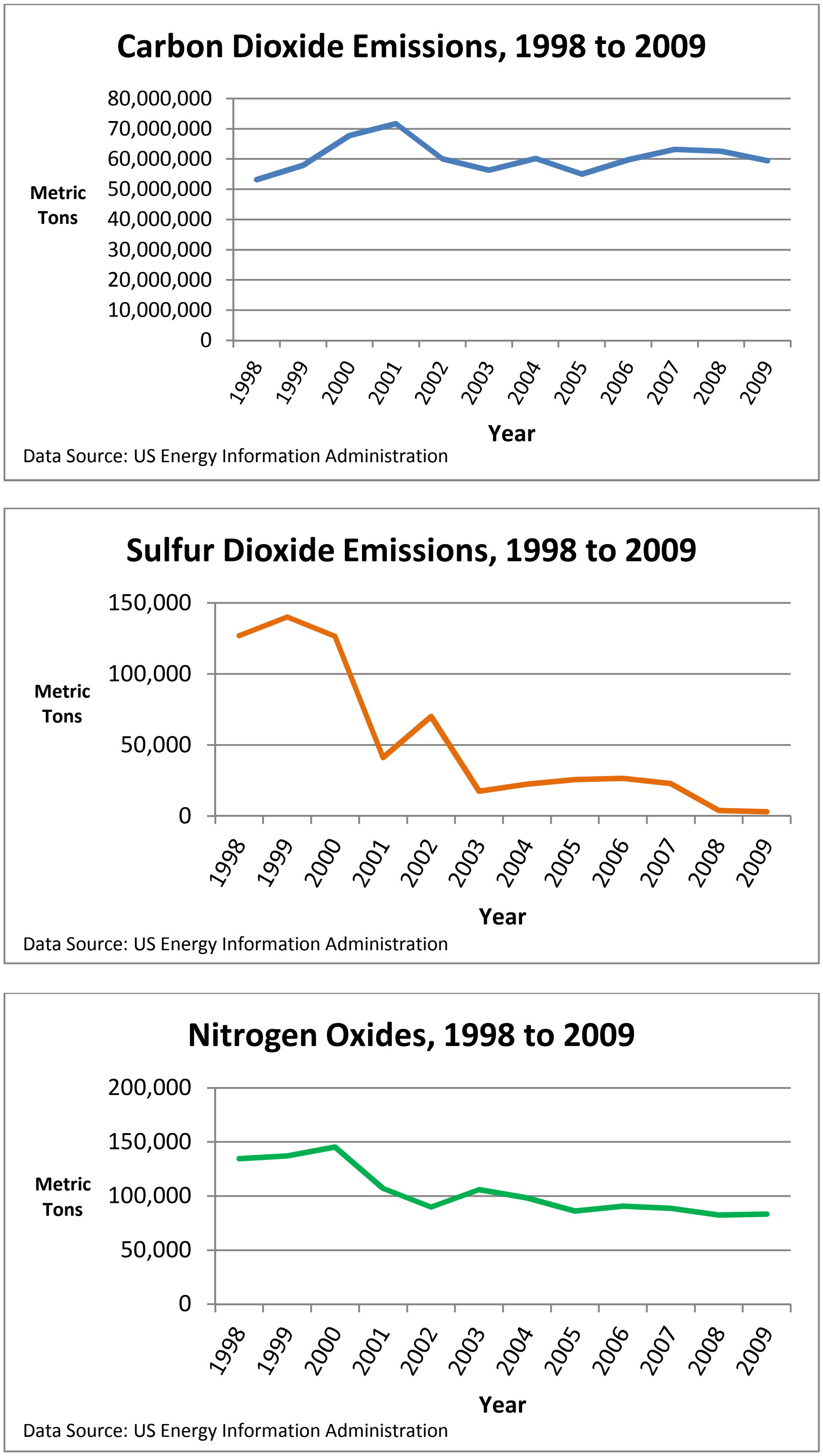
CO_2 emissions pose significant health and environmental concerns. CO_2 is the primary contributor to global climate change, which causes more frequent natural disasters and less predictable weather fluctuations. Climate change poses health threats by increasing temperatures, which facilitates ground-level ozone events triggered by the synthesis of nitrogen oxides (NO_x), volatile organic compounds (VOCs), and high ambient temperatures.

This causes respiratory ailments, especially in those who are already susceptible. In addition, more heat waves will occur, affecting ecosystems, human and environmental health, and even economic function. Particulate matter may increase, as well, due to more airborne dust and wildfire events. Warmer weather is more conducive to the spread of diseases, such as malaria carried by mosquitos. Revisions to power systems are necessary to slow climate change.

Sulfur Dioxide (SO_2) emissions have been drastically reduced due to reduced coal and petroleum combustion. In addition, more stringent regulations have required the removal of sulfur from coal and petroleum fuels prior to combustion. This compound contributes to acid rain events when combined with Nitrogen Oxides (NO_x). Acid rain does not have significant direct effects on humans, but has adverse impacts on biodiversity of aquatic habitats, soils and vegetation, and stone or concrete structures. SO_2 in the air causes respiratory ailments for susceptible demographics, such as asthmatics, children, and the elderly. Heightened SO_2 levels have been correlated to increased medical visits.

SO_2 levels in California are shown in the figure on the next page to be less than 3,000 metric tons per year, which has had a positive impact on air quality. National levels have decreased steadily over the past decade, but are still over 5,000,000 metric tons per year. This is due to the high number of coal-fired power plants in throughout the U.S. It is important to note that automobile and other transportation emissions also contribute to SO_2 concentrations due to the combustion of gasoline, which still contains lower sulfur levels.

Figure 3.3: Emissions Levels in California from 1998 to 2009 in Metric Tons.



Carbon Dioxide Emissions, 1998 to 2009

Data Source: US Energy Information Administration

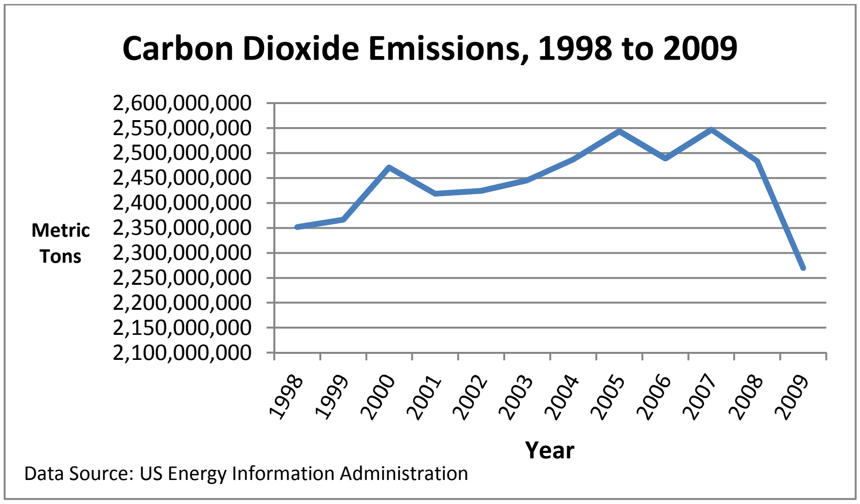
Sulfur Dioxide Emissions, 1998 to 2009

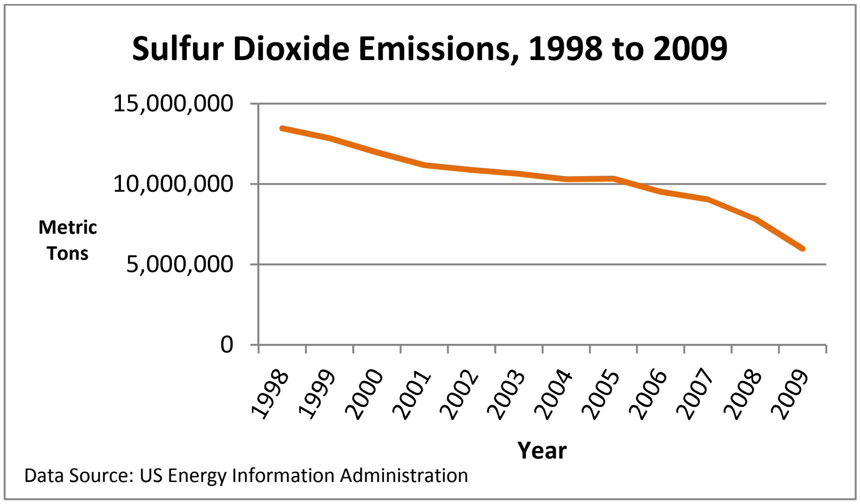
Data Source: US Energy Information Administration

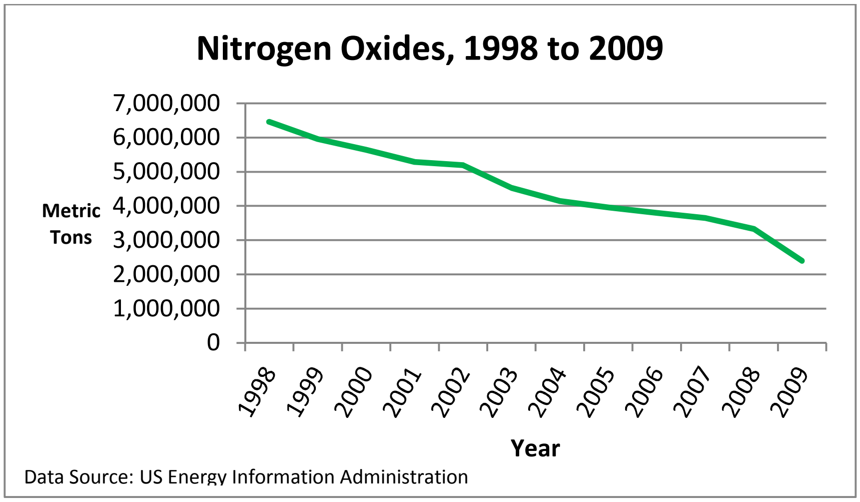
Nitrogen Oxides, 1998 to 2009

Data Source: US Energy Information Administration

Figure 3.4: Emissions Levels in the U.S. from 1998 to 2009 in Metric Tons.







Nitrogen Oxides (NO_x), like SO_2, causes respiratory problems in humans. Asthmatics, children, and the elderly are high risk demographics, but even healthy individuals are adversely affected by NO_x. Ozone is the result of NO_x mixing with VOCs and high temperatures, which can cause respiratory ailments and even death. NO_x is formed mainly through the combustion of fossil fuels. Automobiles are the primary contributor, but power production also plays a significant role, contributing to a little more than half of the emission levels produced by automobiles. Other emissions produced by electricity generation include particulate matter, carbon monoxide, mercury, lead, and the formation of ozone. These emissions cause acute and chronic respiratory illnesses, premature death, poisoning of aquatic life used as a food source, and more.

Although natural gas combustion virtually eliminates SO_2 emissions, there are still issues caused by CO_2 and NO_x emissions. One of the largest threats to public health is ground-level ozone formed by the combination of NO_x and VOCs at high temperatures. Increases in power demand may offset the benefits of shifting to greater natural gas combustion through increased generation. Therefore, it is necessary to elevate contributions from sources that use renewable fuel sources, like PV and wind, and those sources that utilize fuel more efficiently, such as fuel cells and microturbines.

According to the American Lung Association, almost 60 percent of Americans reside in places with unhealthy air pollution levels (American Lung Association, 2011). Of the 50 counties in California, 36 counties were given a grade of 'F' from the American Lung Association's State of the Air 2010 report, which focused mainly on 24-hour $PM_{2.5}$ levels, annual

$PM_{2.5}$, and ozone levels. San Francisco actually received an 'A' in this report, with zero high ozone days from 2006 to 2008. Nonetheless, there is still room for improvement, especially in terms of reducing particulate matter, which was elevated for 8 days from 2006 to 2008.

Table 3.3 shows emission profiles of CO_2, SO_2, and NO_x in California from 1990 to 2009. This is significant because California has a goal to reduce emissions limits to 1990 levels by 2020. CO2 levels were 52,655,643 metric tons in 1990 and 59,427,649 metric tons in 2009. SO_2 levels in 1990 were 81,786 metric tons and reduced to 2,949 metric tons by 2009, which is a significant improvement due largely to the shift away from coal-fired power production. NO_x in 1990 was 127,952 metric tons and 83,201 metric tons in 2009, which is also an improvement. Table 3.5 shows the difference in percentage over this time period. CO_2 requires the greatest amount of attention, but can be improved through higher energy contributions from sustainable power sources and grid reconfiguration strategies. Hypothetically, if the entire power system was shifted to DG, transmission waste would be almost vanish and CO_2 levels would be less than 3 percentage points above 1990 levels.

Table 3.3: Comparison between pollutant levels in 1990 and 2009 in California.

Pollutant	**1990 Levels (metric tons)**	**2009 Levels (metric tons)**	**Percentage Difference**
CO_2	52,655,643	59,427,649	+12.86%
SO_2	81,786	2,949	-96.39%
NO_x	127,952	83,201	-34.97%

SECTION
4
Analysis: Evaluation of Distributed Generation Technologies

Distributed Generation and Traditional Grid System Dynamics

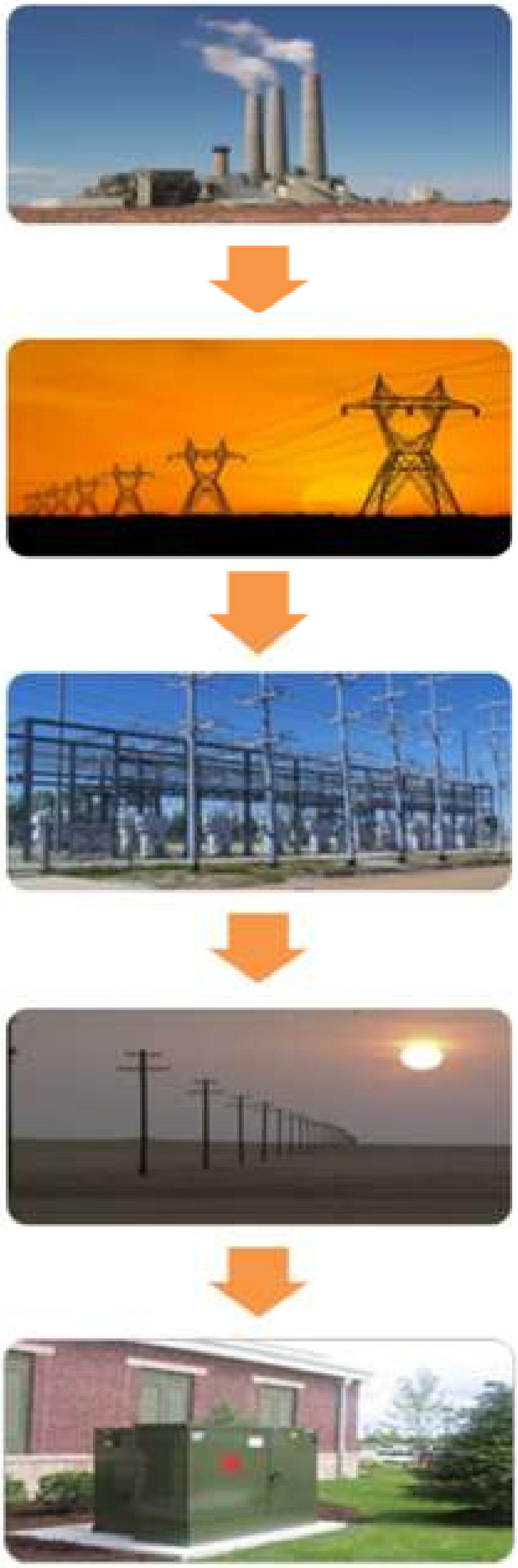
In order to address the inefficiencies of the traditional grid power system, the dynamics of this system must be explored and understood. This will be compared to the distributed generation (DG) model to show how these systems perform against each other. Understanding the functionality of DG systems and technologies will provide a basis for policy decisions that support this model and optimize power source technologies and configurations.

Traditional System Dynamics. Traditional energy systems in the U.S. are based on a complex infrastructure that has been in place for decades. Power plants are usually strategically situated away from human activity as a way to minimize exposure to concentrated emissions. When power systems were first introduced, plants were located near fuel resources and development to both reduce fuel transport distances and shorten power transmission distances to consumers. Today, large-scale energy systems are comprised of four main components – power plants, substations, transmission networks, and distributions networks. Power plants actually generate electricity, substations convert voltages to manageable levels, transmission lines transmit high voltage power across long distances, and distribution networks carry power directly to consumers. A great deal of coordination and equipment are required for each of these components to work effectively with each other.

Electricity is produced at power plants and sent to a transmission substation for voltage step-up on-site. Transmission lines transmit voltages ranging from 69 to 765 thousand volts (kV) (U.S. Department of Labor, 2011). Voltages are so high because less electricity is lost during transmission at these higher voltages. The transmission network carries electricity long distances, terminating at distribution substations for voltage step-down. The distribution network operates with voltages ranging from 7 to 13 kV. This network expands the reach of the transmission network, transmitting energy at more manageable voltage levels to end users. The distribution networks terminate at the community or site level where pole-mounted transformers or box transformers step voltage levels down one last time for conventional electricity use.

The traditional power system process that has been employed for decades is highly inefficient. Transmission network losses in the U.S. average 10 percent due to both voltage conversion processes at substations and thermal losses as a result of long distance transmission (Office of Electricity Delivery and Energy Reliability, 2009). Electrical utility companies have spent more money on transmission and distribution than power generation over the past twenty years (Randolph & Masters, 2008). Figure 4.1 diagrams the function and process of traditional electrical systems.

Figure 4.1: Traditional Electrical Power Grid.



Power Generation Facility
Electricity is produced at the power plant and sent to a substation on-site that steps up the voltage to a higher level for transmission.

Transmission Network
The transmission network transmits high-voltage power over long distances. High-voltages are desirable because less power is lost in the transmission process.

Substations
Transmission networks terminate at distribution substations. Transformers and other equipment reduce voltages through the step-down process to levels compatible with the distribution networks.

Distribution Network
The distribution network consists of the overhead or underground power lines that distribute electricity to consumers. This is essentially the vast web that stems off of the transmission network.

Transformer
The distribution network terminates at transformers that decrease voltages to levels suitable for standard electricity usage before connecting directly to buildings or devices.

The traditional energy model is not only inefficient in transmission, but in energy production, as well. Power plants achieve efficiency ratings of approximately 33 percent largely due to combustion inefficiencies. In the U.S., coal continues to be the primary fuel source, accounting for 44 percent of the net generation in the market (U.S. Department of Energy, 2011). California has successfully lowered coal contributions to only 1 percent. Sources such as natural gas are growing rapidly in places like California that have pushed away from coal. While natural gas combustion emits about half of the pollutants of coal, combustion of this resource is still not a sustainable solution in the context of growing electricity demand.

The combination of inefficient power systems and polluting fuel sources has substantiated air quality and climate change problems. Simply correcting the inefficiencies of transmission networks will have significant positive effects on air quality and climate change. DG provides a viable solution to the resolve the inefficiencies of traditional electrical power systems, while supporting renewable energy sources.

Distributed Generation System Dynamics. The DG model provides a more efficient alternative to traditional energy systems. Rather than relying on the traditional energy system model, which is comprised of a central power plant with vast transmission and distribution networks, DG systems are situated in close proximity to end users, alleviating the need for transmission lines. The result is greater efficiency, as less electricity is lost through long distance transmission and voltage conversion processes at substations. In addition, DG is more conducive to the utilization place-specific renewable energy sources.

DG may be installed on individual buildings or as *nodes* at specific sites to supply power to a larger group of users. The configuration proposed in this analysis focuses mainly on installing DG nodes, where an array of generation units is installed strategically to service a larger consumer base. This may refer to an entire residential community or meet demand for commercial or industrial facilities.

The proposed DG model refers to grid-interconnected projects. This is important for a variety of reasons. First, in order to achieve widespread acceptance, the public needs to trust that this new configuration will provide a reliable power supply. Studies listed in the Literature Review section show that most are somewhat skeptical about altering the configurations of the traditional system that they have relied on for many years. By connecting to the grid, users will have access to back-up power supplied by the traditional grid network. Second, grid-connection is important to facilitate simple connectivity between multiple nodes to form microgrids. The creation of microgrids allows energy systems to pull away from the traditional grid model completely, as nodes will supply back-up for others within the microgrid. Essentially, these microgrids form a more efficient and vast network of power distribution, capable of serving the majority of power demands. Finally, the grid-interconnection allows for centralized control.

The formation of microgrids from multiple DG nodes raises concerns about proper system control and power dispatching. The virtual utility model involves centralized control of microgrids as a means to ensure power quality and reliability are maintained. Uncontrolled inputs from many large sources can result in voltage fluctuations and strain systems, causing outages, equipment failures, and other problems. Virtual utilities can control voltage inputs and also create a hierarchy among power sources. For example, completely renewable sources that do not produce emissions may be favored to produce base loads for consumers. As demand increases, virtual utility operators can begin to pull from power sources that perform well in terms of efficiency, resources consumption, and emissions, forming a hierarchy based on these characteristics. During peak periods when demand is highest, operators may pull power from sources like microturbines that consume more fuel and produce more emissions than photovoltaic, wind, and fuel cell sources.

It is critical that DG nodes are sited strategically to allow for easy grid-interconnection and expansion as demand increases. DG applications are more suitable for demand-side management, as systems are sized to accurately meet electricity demand. As demand increases, additions can be made quickly and easily to increase the generating capacity of the system. This method is much more cost-effective than upgrading entire traditional energy systems. In the traditional model, systems are sized to meet projected demand levels at some point around fifteen or twenty years into the future. Electricity is generated regardless of whether or not there is demand, resulting in unused capacity until production and demand properly align in the future. Following the traditional model, once expansion is necessary, costly and time-intensive upgrades to power plants, transmission, and distribution networks are made. Incorporating DG within traditional systems actually has occurred with a great deal of success in terms of saving money and time by deferring power plant and transmission upgrades. This is an effective way to phase more DG into power systems.

Overall, the adaptability and flexibility of DG systems results in better demand management, lower costs, and easier installations. These factors reduce overhead and project durations for new construction and upgrades of energy systems. The bullets below provide a review of the DG model proposed in this analysis.

- *Grid-Interconnected*
- *Microgrids – interconnected DG nodes serving larger consumer bases*
- *Virtual Utilities – centralized control*

Energy Generating Technologies for Distributed Generation Applications

In order to make informed decisions about appropriate DG technologies for the urban setting, one must attain an understanding of the functionality and effectiveness of various power sources. The characteristics of urban areas create limitations that affect the applicability and performance of different systems and configurations. In addition, varying environmental conditions impact the effectiveness of these technologies. For the purposes of this paper, four distinct power source technologies will be evaluated for projects in urban San Francisco. The energy sources have been divided between passive and active generation technologies, which will be explained in detail later in this section. Passive generation technologies include solar photovoltaic (PV) and wind sources, while active generation technologies include fuel cells and microturbines.

Passive Generation Technologies

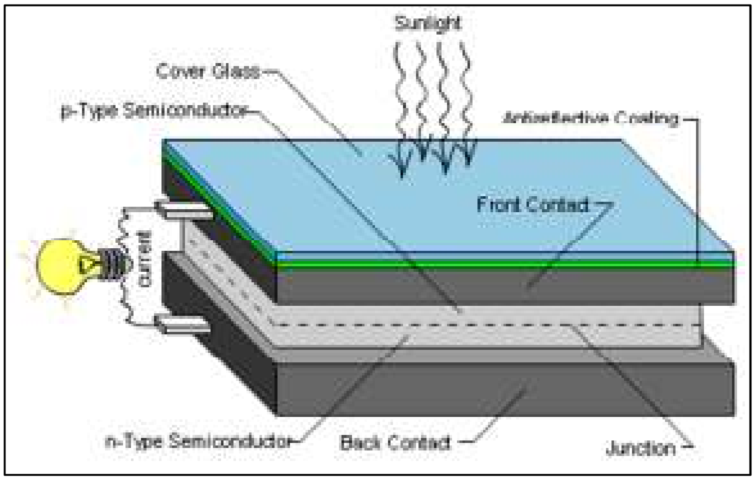
Passive generation refers to electricity production that cannot be controlled. While voltage can be constrained, there is no way to increase power output. Solar PV and wind power are examples of passive generation technologies because operators cannot control the amount of sunlight or wind on a given day. The passive nature of these systems affects DG projects because additional action must be taken to manage voltage fluctuations and ensure power quality and reliability is not compromised. Throughout the examination of the wind and solar passive generation technologies, the concept of efficiency will be addressed frequently. This is in reference to the ability of these technologies to covert a fuel (solar radiation or wind) to electricity and not issues like thermal or other types of efficiency.

Solar Photovoltaic Electricity

Functionality. Solar photovoltaic (PV) power is a renewable energy-generating technology which captures radiation from the sun to produce electricity. PV panels are comprised of a group of small solar cells made from semi-conducting materials that generate direct current (DC) voltage when struck by sunlight (Massey, 2010). Each of the solar cells are connected and encased in solar modules to create PV panels, as shown in Figure 4.2. These panels serve as a protection mechanism for the semi-conducting materials while allowing sunlight to penetrate. Numerous PV panels are connected to form PV arrays that collaboratively generate large amounts of power. PV arrays are commonly installed on roofs of buildings, but also may be installed in open areas with subject to significant levels of solar radiation.

PV panels are generally oriented with a south-facing exposure to maximize the amount of sunlight received by northern hemisphere destinations. PV technology generates direct current (DC) power and requires the installation of inverters to convert electricity to alternating current (AC) power compatible with buildings in the U.S.

Figure 4.2: Solar Photovoltaic Panel Function.



Source: California Distributed Energy Resource Guide.

Configurations. There are numerous configurations of PV arrays for DG applications. Fixed arrays are the traditional immobile PV panel installations on fixed supports at tilt angles usually within 15 degrees of the latitude of the region to maximize sunlight. In urban areas, such as San Francisco arrays need to ensure tall buildings, vegetation, and other structures are not prohibiting sunlight from reaching panels. Tracking system arrays shift tilt angles of the panels throughout the day to literally follow the sun, optimizing exposure and power generation. Tracking systems are capable of operating on one-axis or even two-axes, which further increases sunlight exposure. While tracking can be effective, this may not be optimal technology for urban areas due to increases in cost and difficulties locating sites that capture the full range of the sun.

Currently, there is a growing trend toward what are called concentrator arrays. These configurations include reflective materials and optical devices that redirect sunlight to focus radiation directly on solar cells (Massey, 2010). For simplicity sake, imagine a group of mirrors and magnifying glasses focusing the sun's rays onto PV panels. Concentrator arrays must be installed as tracking arrays to function properly, but require fewer PV modules because they are more efficient than flat-plate systems. Efficiency levels of 20 to 30 percent may be achieved using concentrator arrays (California Distributed Energy Resource Guide, 2008).

Sizing Photovoltaic Systems. The size of PV systems is determined by a variety of factors. Insolation plays the most crucial role in sizing PV arrays. Solar insolation indicates the number of peak sunlight hours in a given day and plays the most crucial role in sizing PV arrays. It is a metric of the amount of solar radiation received by a surface over a period of time and is measured in kilowatt hours per meter squared. The average insolation for flat panel arrays in San Francisco is 5.34 kWh/m^2, which is slightly higher than the national average of 4.9 kWh/m^2 (Massey, 2010). The higher the insolation, the fewer PV panels necessary to achieve the desired rating. As one might expect, insolation levels are higher during summer months when there are more hours of sunlight. Utility-interactive inverters must also be sized appropriately to ensure they can meet the needs of the system. Larger inverters may want to be installed for projects where expansion is forecasted.

Advantages. Solar PV power offers numerous benefits as a renewable power source. The main strength of this technology is that it produces zero emissions and requires no fuel source, except for solar radiation. This is one of the cleanest power sources given the fact that no resources are consumed during operation and air quality is not impacted. In addition, PV requires virtually no maintenance aside from simply keeping the panels clean. It is important to routinely remove any dust or debris that may prohibit sunlight from reaching solar cells. This technology is appropriate for rooftop installations as well as remote locations that have limited access to power. Rooftop installations make efficient use of a space that is otherwise unused. This is important given the large space requirements for this technology. Concentrator arrays further increase the efficiency of solar technology and can reduce space occupation if designed properly.

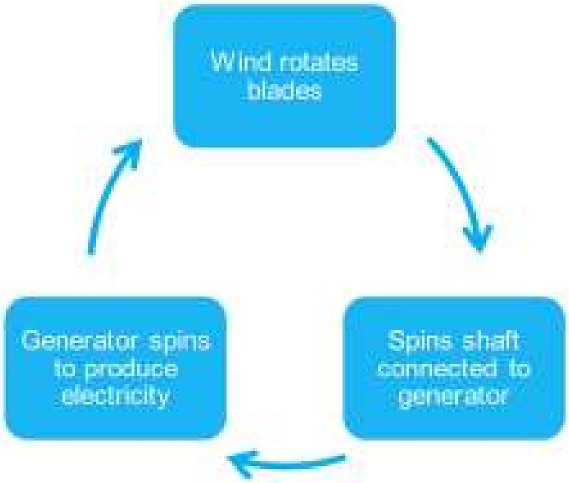
Drawbacks. While PV technology offers a viable option for DG systems, there are some drawbacks. First, as a passive generation energy source, PV systems produce unreliable intermittent power, which creates voltage fluctuations, as these systems cannot generate steady power flows throughout the day. With many distributed installations, it is imperative to manage intermittency to avoid grid reliability and quality issues. To solve intermittency issues, PV arrays have been combined with storage or supplementary generators that complement PV power to ensure demand is met and a steady power flow is discharged by the system. Hybrid systems, such as those that combine PV with generators, can be used for cogeneration applications to reduce electricity demand by capturing and utilizing waste heat produced by generators. Cogeneration will be explained in greater detail later in this section.

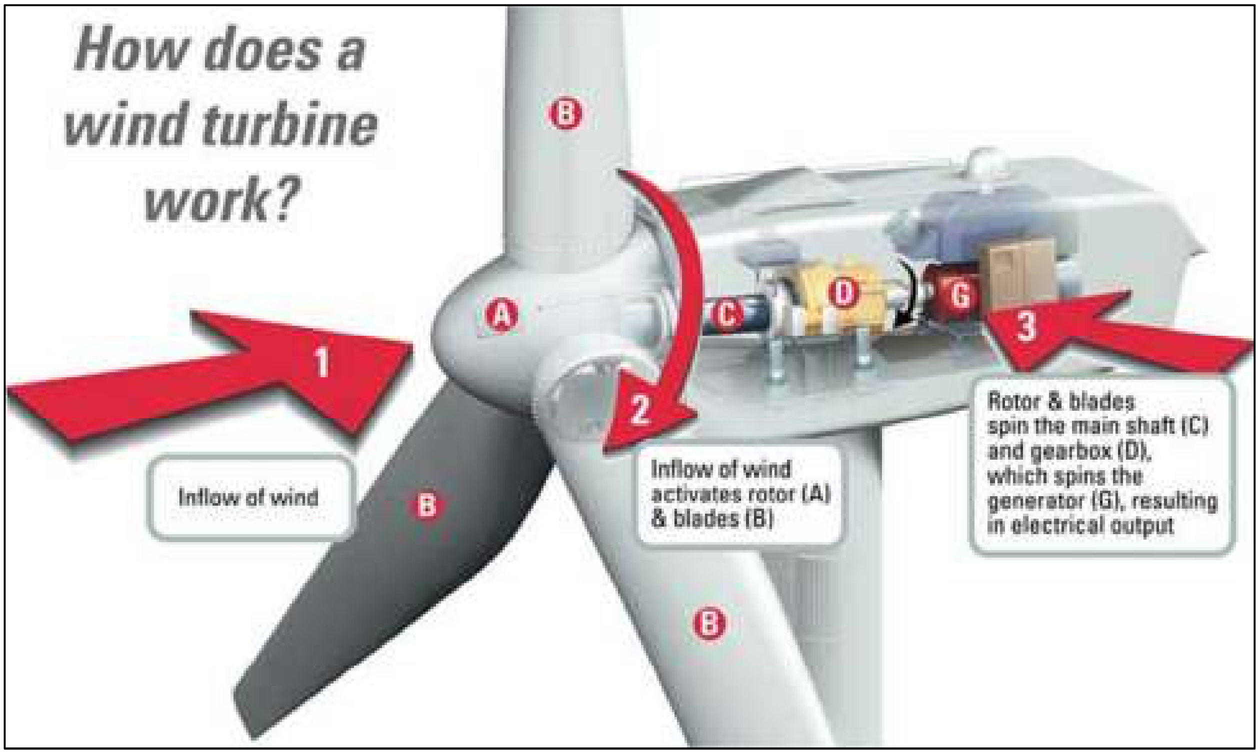
PV may not be appropriate for all areas, especially those that do not receive a great deal of sunlight. Although PV is a renewable technology that produces no emissions, standard arrays achieve efficiency levels of only 5 to 15 percent (California Distributed Energy Resource Guide, 2008). In order the optimize efficiency, siting decisions that maximize solar exposure without visual obstructions are crucial. Solar PV has the potential to act as an effective technology for DG, but these systems will need to maximize efficiency while minimizing space occupation for urban installations, especially in urban areas where land is more expensive. The largest barriers to widespread implementation are low power production and large land consumption compared to other technologies. This may be a significant issue for San Francisco due to high land values, limited space, and frequent overcast conditions.

Wind Turbines

Functionality. Wind turbines are another intermittent renewable energy technology that can be implemented in DG applications. Like PV, this technology produces no emissions or pollution, operating solely on the supply of wind. The function of wind turbines is rather simple. Wind causes fan blades to rotate, which spins a shaft connected to a generator that produces electricity. Figure 4.3 provides greater detail about the operation of wind turbines. Turbines are installed on tall towers (usually at least 300 feet above the ground) to capture unobstructed winds and avoid safety hazards. It is imperative to mount turbines so that the bottom of the blades is at least 30 feet higher than any obstructions within 300 feet of the tower (Massey, 2010). Weather vanes or active controls are devices installed on wind turbines that shift the direction of the blades to take full advantage of head winds.

Figure 4.3: Wind Turbine Operation.



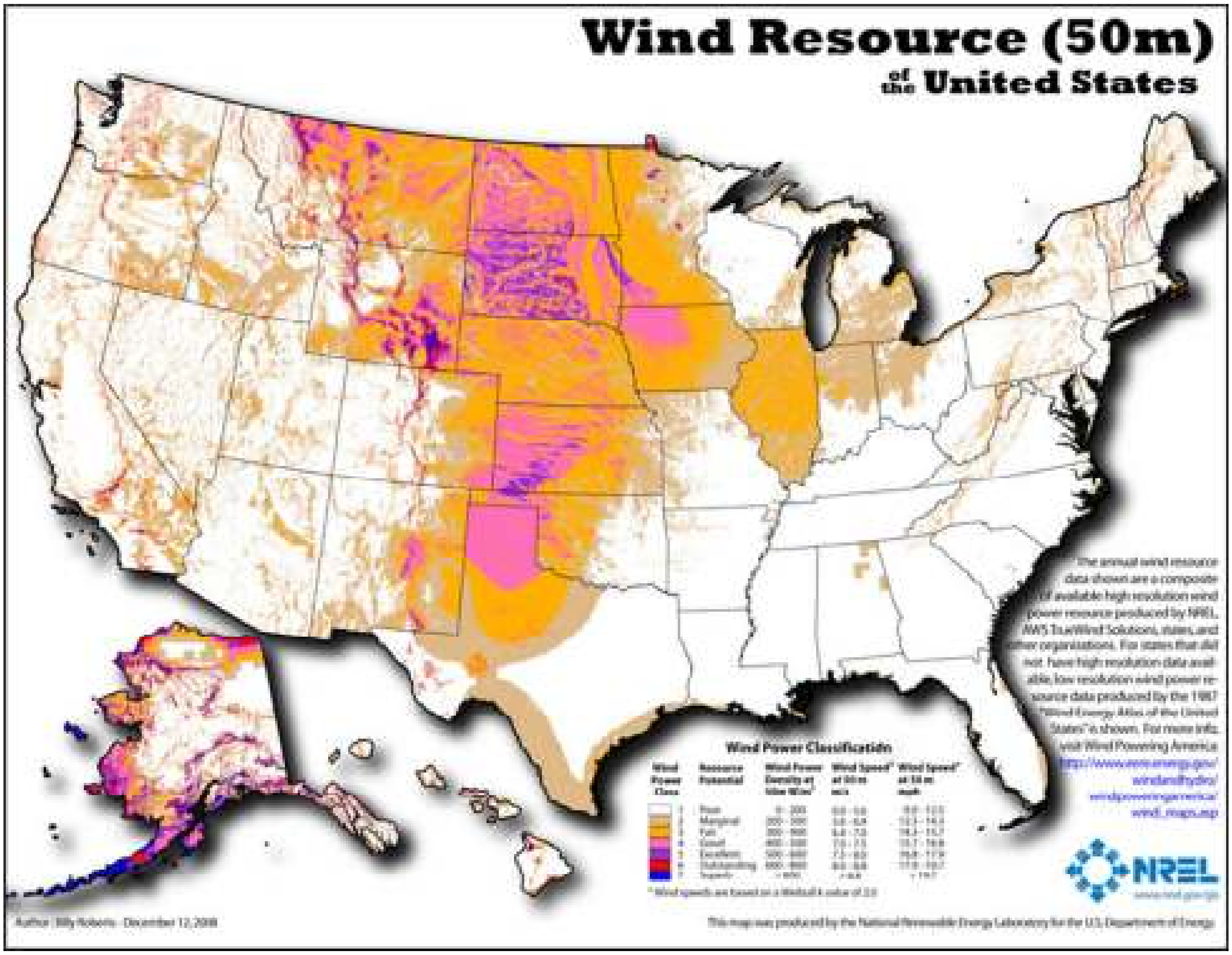


Source: ONE NATION Renewables, 2007.

Configurations. Wind turbines offer added versatility compared to PV in that they can generate either DC or AC power, bypassing the need for inverters in cases where AC power is produced. In addition, each type of wind turbine generator warrants different grid interconnection configurations. High-speed generators can be tied directly to the grid, as they operate compatibly at 60 Hertz (Massey, 2010). Low-speed generators may produce either AC or DC currents and may be connected to the grid only through a utility-interactive inverter. To manage intermittency issues, synchronous generators are commonly installed along with wind turbines to prevent voltage fluctuations and reactive power output. Synchronous generators, which are typically powered by an external source, manage the operating voltage and frequency from the turbines.

The siting of wind generation projects are key variables for successful implementation. When siting wind turbines, one must take into consideration local weather patterns, wind characteristics, local development patterns, and natural resources, among other factors. Figure 4.4 shows the regions best-suited for wind generation in the U.S. California has strong wind potential along the coast and scattered in desert areas to the south. San Francisco has a range from "Good" to "Outstanding" in terms of wind potential, meaning wind power has the ability to supply a significant portion of electricity to the region. Due to the high cost of wind turbines, it is not cost-effective to install this technology in places that lack strong constant winds.

Figure 4.4: Wind Potential Map of the U.S.



The annual wind resource data shown are a composite of available high resolution wind power resource produced by NREL, AWS TrueWind Solutions, states, and other organizations. For states that did not have high resolution data available, low resolution wind power resource data produced by the 1987 "Wind Energy Atlas of the United States" is shown. For more info, visit Wind Powering America.

Author: Billy Roberts - December 12, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Source: U.S. Department of Energy, 2008.

Sizing Wind Systems. Due to the variability of wind power generation, systems are sized based on an average output level. This is derived from annual calculations of wind speed and wind distributions. These variables are used to determine the capacity factor, which is a ratio of predicted energy output per year to the yearly output rating. The equation below shows the calculation of a 250kW wind turbine expected to produce 650,000 kWh per year.

$$Capacity\ Factor = \frac{650{,}000\ kWh}{250\ kW * 8{,}760\ h} * 100\% = 29.7\%$$

Capacity factors typically range between 25 and 40 percent (Massey, 2010). High capacity factors are achieved for the best designed systems in high constant wind areas. This metric estimates the amount of power produced as a percentage of the rated capacity of the turbine. Capacity factor can also be used to describe output trends of other power sources, as well.

Advantages. The benefits of wind power technology are similar to those of PV. Wind turbines utilize no fuels other than wind and produce no emissions. The only resources consumed are materials used in construction and installation and land required for turbines. Wind turbines are typically situated in remote locations. These locations include land for farming, animal grazing, or even near highways. Wind turbines are capable of producing large amounts of power when sited properly under strong constant wind conditions. In these situations, wind turbines are very cost-effective as long as transmission networks are already available. Wind power is ideally suited for remote locations to minimize noise and visual obtrusions, which makes the application of wind for DG questionable. Nonetheless, if conditions are optimal and land is available, wind power may prove effective for DG projects in urban areas.

Drawbacks. This siting of wind turbines is the largest drawback to implementation in urban areas. Not only are adequate wind resources necessary, but sufficient space and buffers must be available. Most urban areas do not support the installation of turbines because of space restrictions, noise, and visual obtrusions. These projects utilize a large amount of land, which tends to be more expensive in the urban setting. This is not to mention wind projects will compete with other land uses in urban areas. Locating near urban areas may also result in turbulence due to obstructions, creating voltage fluctuations and possibly damaging the internal components of turbines. Since turbines are optimally suited for remote sites away from development and obstructions, this may not be the ideal technology for DG because of the need for extended transmission distances.

Active Generation Technologies

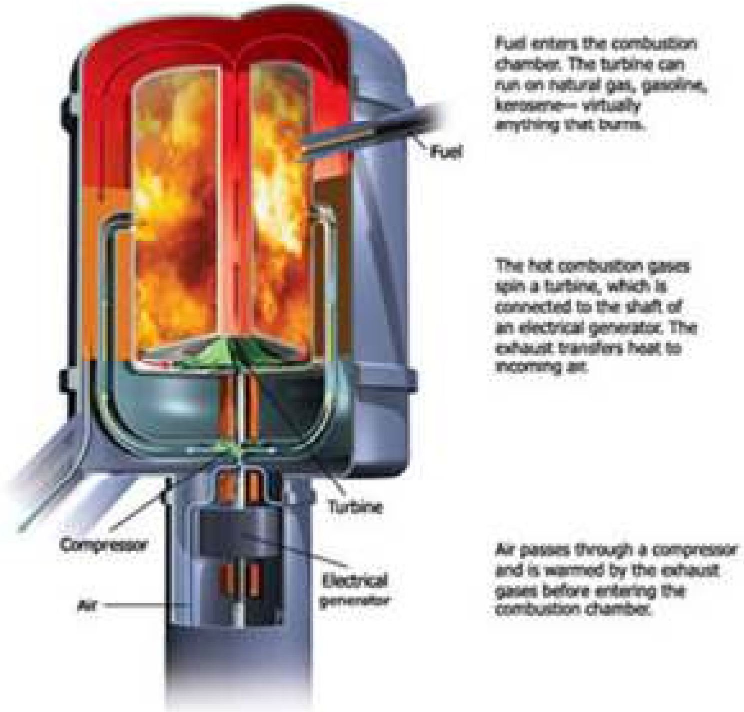
Active generation refers to electricity generating technologies that afford users control of power output levels. Operators have the ability to control when to produce or restrict power flows. Technologies that utilize a fuel source are generally active generators because fuel input levels are regulated to control production for these systems. Microturbines and fuel cells are the active generation technologies that will be explored in this analysis. Active generation systems are much easier to optimize because output can be continually altered to meet changes in demand. These technologies will be evaluated based on performance and levels of efficiency. It is important to note that by efficiency, I am referring to the ability of these technologies to convert a fuel source to electricity. Higher efficiencies mean that less fuel is required to provide a certain level of power output.

Microturbines

Microturbines are compact combustion turbines which are compatible with a variety of fuel sources including, but not limited to, natural gas, hydrogen, ethanol, and methane. Individual units are rated from 25 to 500 kW. The renewability of this technology is dependent on the fuel source utilized for combustion. Renewable fuels include hydrogen, ethanol, or methanol, while non-renewable fuels include diesel and natural gas. Currently, natural gas is the primary fuel source used to fuel microturbines. Even if non-renewable fuels are used, this technology offers more sustainability benefits than traditional technologies due to increased efficiency, adaptability, and easy expansion. The modularity of units is conducive to simple interconnection of units to increase generating capacity and match demand.

Functionality. Microturbines function similar to engines to generate electricity. Compressed air combines with fuel in a combustion chamber for ignition. Exhaust gases from the combustion process spin a turbine, which is connected to the generator that produces electricity. Waste heat from this process is collected by the recuperator, which heats the compressed air used to inject the fuel into the combustion chamber for greater efficiency. Figure 4.5 provides a visual diagram of the operation of microturbines. Similar to most combustion processes, microturbines are only about 25 to 30 percent efficient.

Figure 4.5: Operation of Microturbines.



Source: Whole Building Design Guide, 2011.

The operation of microturbines is regulated by controls that stabilize and manage power flows. For grid compatibility, this controller reduces the output frequency to 60 Hertz. Power controllers often have the capability to monitor voltages of the grid and match the output of the microturbine(s) to this voltage. When the voltage generated by a group of microturbines is not in alignment with the grid system voltage, a transformer must be installed to manage voltage levels. These systems are quite effective for DG applications, as they generally produce stable voltages, can be easily expanded, and operate effectively in virtually all areas. The controllability and stability, combined with configurations which increase efficiency, make microturbines a potential option for DG.

Configurations – Cogeneration. Given the focus of this research on efficient electrical technologies and distribution, microturbines may not seem well-suited for DG applications.

While this may be true when used alone, this technology is highly efficient when configured in hybrid cogeneration systems. The cogeneration model, also known as combined heat and power (CHP), involves capturing and utilizing the thermal energy byproduct generated from combustion and electrical generation. Typically, the heat is stored and discharged for thermal comfort functions in buildings or used in industrial processes. In some cases, excess heat can actually be utilized to cool spaces through the incorporation of absorption cooling systems. Absorption cooling conditions air in buildings by removing the heat from recovered thermal energy. The heat is used to convert water into vapor, which is absorbed by what is known as an absorbent that removes heat from the vapor. Interestingly, water is actually the refrigerant and a lithium bromide compound the absorbent used in most situations (Renewable Energy Institute, 2011). Typically another substance is used as the refrigerant in cooling applications.

Microturbine-cogeneration configurations are effective because heat is not wasted, but captured and utilized to reduce electricity demands. In the U.S., 31 percent of electricity consumed in residences is used for heating, while 12 percent is used for cooling. Commercial buildings account for 14 and 13 percent of the total electricity consumed for heating and cooling purposes, respectively (Energy Efficiency and Renewable Energy, 2008). Buildings with near constant heating demand, such as hospitals or manufacturing plants are ideal for this configuration. Without significant amounts of waste heat, installation of absorption chillers is not usually cost-effective. Given the reduced demand capabilities of this configuration, the microturbine-cogeneration hybrid can achieve an efficiency level above 80 percent (Randolph & Masters, 2008).

Advantages. Microturbine technology offers many advantages for DG systems. The compact size of these units minimizes the amount of land area required and eases siting decisions, which is particularly important in urban areas. Additionally, wind, sunlight, and most other atmospheric conditions do not play a role in microturbine projects. The variety of potential fuel sources, especially renewable fuels, enhances the versatility of these devices. Although, combustion is relatively inefficient, microturbines offer the advantage of rather low emissions. Efficiencies can be driven approximately 50 percent higher by microturbine-cogeneration projects. In addition, bypassing transmission networks decreases the amount of electricity lost by these systems. The small number of moving parts and durability of these devices requires minimal maintenance.

Traditional grid systems commonly supplement peak loads with engine generators. A more viable option is to install microturbine-cogeneration systems that have higher efficiencies. Also, these systems can assist in deferring costly and time-intensive transmission upgrades to traditional power plants and transmission systems. Microturbines require minimal maintenance and operate more quietly than reciprocating engines, providing stable power flows while minimizing the burden on users.

Because microturbines are active generation technologies, the sizing of these systems is very simple. The power output rating of individual units indicates the amount of electricity that can be generated when operated at full capacity. The power output ratings of multiple units should be added to determine total generating capacity of the system. An assumed capacity factor around 0.5 should be factored because these devices will not be operated at full capacity at all times to prevent overheating and mechanical malfunction. One should account for peak demand periods and install a system large enough to supply a load slightly above highest peaks (5 to 10 percent). The modularity of microturbines encourages installation of a system that closely meets demand because units can be added rather easily.

Drawbacks. Like any energy technology, there are some drawbacks with microturbines. Because of the combustion process, systems have low fuel conversion efficiencies. As mentioned earlier, only 25 to 30 percent of the fuel is converted into electricity. Combustion is an exothermic reaction that involves three types of energy: chemical (potential), thermal, and mechanical (kinetic). Some energy is lost in the conversion of each of these forms of energy. The chemical energy is stored in the fuel source that is combusted and turned into thermal energy. In coal-fired power production, the thermal energy is used to boil water to create stream that spins a turbine through the use of mechanical energy. The energy lost throughout this process results in an inefficient method of electrical generation.

Cogeneration offers an effective solution to the efficiency problem by capturing wasted thermal energy. But, heat recovery systems increases costs by 30 to 70 percent depending on the size of the system, site conditions, land values, and more (California Energy Commission, 2008). Low fuel conversion efficiencies and high costs are the largest drawbacks to microturbine technology. There are also regional concerns with microturbines. Performance of systems declines under high elevation and hot ambient air temperature conditions. This is of particular concern in desert and mountainous regions. While this is an emerging technology that offers versatility and higher efficiency than most forms of combustion, these drawbacks may prevent this technology from being the ideal solution for large-scale DG project implementation.

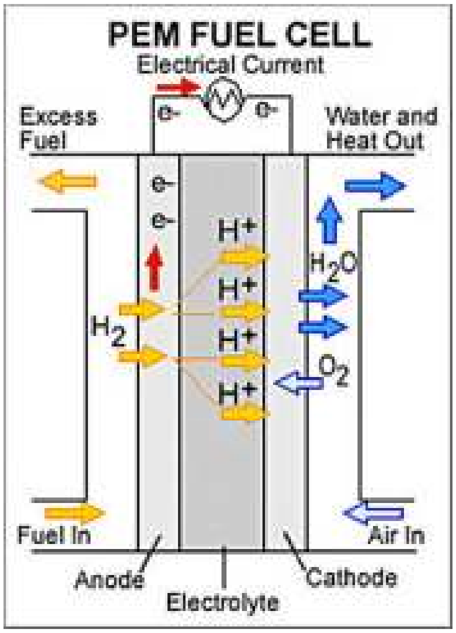
Fuel Cells

Fuel cells are an emerging energy technology that provides many benefits for the DG model. Rather than using combustion to generate power, fuel cells utilize a chemical reaction within a self-contained unit, allowing them to achieve fuel conversion efficiencies up to 65 percent (Randolph & Masters, 2008). This technology offers a solution to move away from combustion, which has historically dominated power production. This allows fuel cells to achieve much higher efficiencies than most other power sources. This increased efficiency results in reduced fuel consumption and lower emissions. Pollutants, such as carbon monoxide, nitrogen oxide, and sulfur oxides, are virtually eliminated with the operation of fuel cells.

Functionality. Fuel cells operate quite differently from most other power sources. The main components of fuel cells include a fuel processor, reformer, electrodes (anode and cathode), external circuit, and electrolyte. The operation begins with the fuel processor that derives hydrogen from fuels, such as natural gas or methane, which are used most commonly in fuel cell operations. The fuel processor is not necessary in situations where pure stored hydrogen is available for direct injection into the unit. The reformer separates the carbons from this hydrogen gas to create pure hydrogen by injecting oxygen from the ambient air.

Purified hydrogen enters the unit through the anode on one side of the electrolyte membrane and the oxygen enters at the cathode, which is on the opposite side of the electrolyte. A catalyst in the fuel cell separates the hydrogen protons and electrons. The electrolyte is the key to this process as hydrogen protons from the anode-side are capable of passing through the electrolyte membrane, while the electrons, which are trying to penetrate the membrane to reach a stable state, are prohibited from doing so. The separation of protons and electrons is referred to as an oxidation reaction. This creates a negative charge on the anode side and a positive charge on the cathode side. The electrons at the anode are able to move through an external circuit to the cathode where DC power is discharged (Randolph & Masters, 2008). The positive hydrogen ions from the anode meet negative oxygen ions from the cathode to recombine and form water. This is known as the reduction reaction. Figure 4.6 below provides a diagram of this process for the proton exchange membrane (PEM) fuel cell, which is representative of the function of most types of fuel cells.

Figure 4.6: Proton Exchange Membrane Fuel Cell Diagram.



Source: U.S. Department of Energy.

Fuel cells are also capable of deriving pure hydrogen from electricity by reversing the process, which is known as electrolysis. Electricity is injected into the unit, breaking down water molecules into hydrogen and oxygen while also separating the protons and electrons of the hydrogen. The protons and electrons are recombined in the unit, creating pure hydrogen, which is then stored as a compressed gas for later usage as a fuel source (Wu, Kotak, & Fleetwood, 2005). This is important for off-peak periods when it is cheaper to derive fuel from electricity which can be used later for electricity production during peak periods.

Configurations. There are numerous fuel cell types suited for stationary installations, some offering higher fuel conversion efficiencies than others. Table 4.1 provides advantages and disadvantages, efficiency, and operating temperature for each of the fuel cells suited for DG projects. Molten carbonate and solid oxide fuel cells are best-suited for larger utility-scale projects. Due to the high operating temperatures of these devices, monitoring and maintenance requirements are best performed by electrical utility professionals.

Table 4.1: Fuel Cell Types Suitable for DG.

Fuel Cell Type	Operating Temperature	Efficiency	Advantages	Disadvantages
Proton Exchange Membrane (PEM)	122 - 212° F	35%	- Low temperature - Minimal maintenance or corrosion - Rapid start-up	- Sensitive to fuel impurities - Expensive catalysts
Phosphoric Acid (PAFC)	302 - 392° F	40%	- High temperature suitable for cogen. - Tolerant to fuel impurities	- Long start-up - Expensive catalysts (Platinum)
Molten Carbonate (MCFC)	1112 - 1292° F	45 – 50%	- Highly efficient/flexible - Well-suited for cogen. - Compatible with variety of catalysts	- Corrosion and frequent maintenance due to high temperature - Long start-up
Solid Oxide (SOFC)	1202 - 1932° F	60%	- Highly efficient/flexible - Well-suited for cogen. - Compatible with variety of catalysts	- Corrosion and frequent maintenance due to high temperature - Long start-up

Data Source: U.S. Department of Energy, 2011.

Although fuel cells are already more efficient than most DG technologies, efficiencies can be increased even more when installed with cogeneration. High-temperature fuel cells (HTFCs) are ideal for cogeneration when there is sufficient demand for the heat and, possibly, cooling when absorption chillers are included. Highly efficient operation combined with reduced thermal comfort demands in buildings results in overall efficiencies ranging from 80 to 90 percent (California Energy Commission, 2008).

Advantages. Fuel cells offer high fuel conversion efficiencies, quiet operation, durability, and low emissions. These devices contain few moving parts, extending lifetimes and reducing maintenance intervals. Most fuel cells contain a fuel reformer, which is capable of deriving hydrogen from a variety of fuel types, lessening dependence on one specific fuel. Fuel cells also utilize a chemical process to produce power, which is much improves efficiencies and reduces emissions significantly. In the Recommendations section, a petroleum and natural gas power plant is phased-out and replaced with a fuel cell model. The fuel cell model reduces sulfur oxides and nitrogen oxides by over 99 percent and decreases carbon dioxide by almost 35 percent.

Fuel cells are extremely versatile, capable of operating effectively in virtually all conditions. This technology is uninhibited by high elevations and atmospheric conditions, which include cloud cover, wind, or sunlight. PV, wind, and microturbine technologies do not offer this same versatility. In addition, fuel cells require minimal space occupation. While siting decisions are difficult for PV and wind projects, fuel cells can be sited in the location most appropriate for operators and users. This is of particular importance in urban areas where land has higher values and more competition.

Sizing of fuel cell projects is rather simple due to the active generation status of this technology. Similar to microturbines in this sense, each fuel cell has a power output rating that indicates the amount of electricity generated when the device is operated at full capacity. The power output ratings of multiple units should be added to determine total generating capacity of the system. Like with microturbines, it makes sense to assume a capacity factor of approximately 0.5 because the fuel cells will not be operating at constant full capacity. Utility-scale installations allow relatively simple expansion, but not as simple as microturbines because fuel cells often require more labor intensive installations. Projects must account for peak demand conditions and install enough units to exceed highest peaks. Overall, fuel cells are an effective energy technology for DG applications due to the high fuel conversion efficiencies, minimal space occupation, and effective operation in almost all site and atmospheric conditions. Figure 4.7 shows part of a 1 MW fuel cell station at California State University Northridge near Los Angeles.

Figure 4.7: California State University Northridge Fuel Cell.

Source: Fuel Cell 2000.

Drawbacks. While fuel cells appear to be well-suited for DG applications, there are a few concerns with this technology. Because this is an emerging technology, there is some apprehension with the use of fuel cells. Without proven long-term success, it may take some time to gain widespread acceptance of this technology. Also, from a sustainable energy standpoint, most think of PV and wind turbines, as opposed to fuel cells and microturbines. Energy professionals may already be convinced by the viability of this technology, but it may take some time to generate greater public acceptance. This is an important factor because public support is essential to a significant shift to traditional energy systems.

While efficiency is high and required land area is minimal, fuel cells are still very expensive because these devices are still being introduced into the market. While they may not be as expensive as some of the other technologies examined, many might opt for PV and wind sources due to greater familiarity with these sources. Fortunately, California offers generous financial incentives for renewable energy projects that apply to fuel cells. Despite the drawbacks associated with fuel cells, the numerous advantages offered by this technology outweigh the concerns and make this a viable option for DG projects.

Costs of Distributed Generation Technologies

The cost of the various DG technologies is important in determining whether these sources make economic sense for widespread implementation. Figure 4.9 provides the cost per kW, which takes into account the efficiency of sources. The costs, operational characteristics, and physical space considerations are key variables in selecting the appropriate technology for DG projects.

Table 4.2: Long-Term Costs of Distributed Generation Technologies.

Technology	Long term cost (per kW)
Solar Photovoltaic Panels	$6,000 - $10,000
Wind Turbines (farm scale)	$1,000
Wind Turbines (indiv. building scale)	$2,500 - $3,500
Microturbines	$700 - $1,100
Proton Exchange Membrane Fuel Cell	$1,000
Solid Oxide Fuel Cell	$1,000 - $1,500
Molten Carbonate Fuel Cell	$1,200 - $1,500
*Heat Recovery Systems (Cogeneration)	add 30 - 70% to initial cost

Data Source: California Energy Commission.

As one might expect, solar PV has the highest cost per kW due to very low efficiencies. The passive generation status prohibits PV from producing power during nights and storm events, which decreases cost-effectiveness. Nonetheless, the majority of incentives apply to PV, improving the cost-effectiveness of these sources. The next section will address the policy and incentive programs applicable to these technologies.

Wind turbine prices are reasonable at the farm level, but approximately three times higher at the building scale. Wind farms involve large installations of many turbines in remote locations, requiring long-distance transmission. Wind power does not suit the DG model because this requires transmission, which has built-in inefficiencies. This is in addition to the costs associated with land acquisition, voltage regulation equipment, and installation. Challenges in the urban setting prevent effective siting and operation of wind turbines, while also increasing costs due to higher land values.

Microturbines have a long-term cost as low as $700 per kW. This is tremendous from an economic standpoint, but utilizing microturbines as primary generation sources will produce more emissions than any of the other sources examined. This technology is most efficient in cogeneration hybrid systems, which adds an additional 30 to 70 percent to the installation cost, depending on the size of the system, location, and heat demand. The heat recovery system makes this technology much less cost-effective than fuel cells.

Solid oxide fuel cells (SOFCs) have relatively low costs, but higher efficiencies than any other technology used alone. SOFCs, as well as other fuel cells, require minimal space, which results in lower costs in acquiring land for these installations. The low cost and high efficiency of fuel cells makes this an effective power source for large-scale DG efforts.

Other Considerations

Interconnection. There are a number of standards that provide requirements for grid interconnection of DG sources. In California, the interconnection standard developed by the Institute of Electrical and Electronics Engineers (IEEE 1547) is used to ensure standardized interconnection practices are implemented. California enacted Rule 21, which is a state interconnection standard based largely on IEEE 1547 with additional provisions to address conditions specific to the state. Rule 21 and IEEE 1547 address interconnection systems and testing, while Underwriter's Laboratory (UL) 1747 focuses on interconnection equipment, such as utility-interactive inverters. These devices are installed to protect the grid and ensure sources deliver power in an efficient manner. These devices convert DC to AC power, if necessary, and recognize the voltage frequency of the grid in order to reconfigure the frequency of the power source to match the grid.

There are some issues with connecting to the grid. During power outages, DG sources may discharge power to the grid, energizing portions of the network not recognized by utility workers. The threat of electrical shock becomes a serious health risk, there is increased difficulty in restoring power, and damage to the system equipment can occur. UL 1741 requires the installation of utility-interactive inverters that are capable of identifying outages and discontinuing the exportation of power in less than 2 seconds (Whitfield, 2004).

The ultimate goal of this analysis is to have DG supply the majority of power to consumers. This must occur incrementally, as this objective cannot be achieved overnight. Below, several DG grid interconnection configurations are listed to explain how DG can contribute to traditional power systems in the movement toward dominating these systems one day (Massey, 2010).

- **Base Loading** refers to a configuration where a generation source (usually active) supplies a constant amount of power to the grid to meet minimum demand conditions. The variable demand increases are accounted for by an additional source that supplements the base load. This may reduce demand at the central power plant in grid systems.
- **Peak Shaving** is essentially the opposite of base loading, as DG sources supply the meets variable demands in electricity, which is supplemented by base load supplied by another source. This is of great significance to utilities because there is a constant struggle to meet peak demand, especially during excessive demand periods of extreme heat or cold that increase demands for heating, ventilation, and air conditioning (HVAC) systems.
- **Load Sharing** involves the installation of multiple generation sources that supply equal ratios of their output ratings. For instance, two equally rated sources could be operating at 50 percent to meet the total output rating of one of those sources. The units do not need to have the same output ratings, but do have to produce the same amount of power to engage in load sharing.
- **Exporting Power** occurs when the DG sources generate more power than what is demanded by users. Excess power is sent back into the grid network.

- **Importing Power** refers to a scenario where the DG sources cannot meet the demand of users and the grid utility supplements this power to meet demand.
- **Zero Power Transfer** is an ideal situation where the DG sources react to the power demand and respond by supplying the exact amount of electricity demanded at any given time.

Storage. Storage plays a significant role in certain DG applications. Passive generation technologies can take advantage of storage to help meet demand during periods where wind or sunlight is not available. Wind power generated at night during low demand periods can be stored to meet future demand at peak periods. Storage can also supplement power during peak conditions when sources are unable to meet demand themselves. This has been shown with great success in remote locations that do not receive sufficient power during peak periods. Power is stored off-peak and utilized to supplement peak periods in this case.

There are both electrical and mechanical storage devices. Superconducting magnetic energy storage (SMES) devices and batteries are examples of electrical storage devices. Mechanical storage includes flywheels and compressed air. These storage technologies have lifetimes of about 25 to 30 years, and efficiencies of about 100 percent. Electrical storage offers perfect efficiency, but requires maintenance and chemicals for battery units. Flywheels are over 30 times the size of electrical storage units, but require no chemicals and virtually no maintenance. Storage will help stimulate the use of intermittent power sources in the future.

Superconducting Cables. When discussing the efficiency of energy systems in the U.S., it is necessary to address superconductivity. Today, the Federal government is involved with demonstration projects in New York, Ohio, Georgia, and Louisiana to replace typical copper transmission and distribution lines with superconducting cables. The objective is to showcase the efficiency of this technology to promote widespread usage of these cables. Superconducting cables are cryogenically cooled using inert liquid nitrogen. The cooling cuts the resistance to almost nothing, reducing losses to about 5 percent or less. As mentioned earlier, approximately 10 percent of electricity generated is lost in transmission and distribution (Office of Electricity Delivery and Energy Reliability, 2009). This is of particular concern to energy customers, as the cost of electricity losses are imposed on consumers.

Superconducting cables are smaller and weigh less than conventional copper cable systems. This reduces space occupation and increases spans between power poles. Traditional cables use dielectric oil for cooling, while superconductors use non-flammable, non-hazardous inert liquid nitrogen, minimizing environmental hazards (Office of Electricity Delivery and Energy Reliability, 2009). The issue with superconducting cables is the high cost. Even though these systems can transmit more electricity at a higher efficiency, they are still more expensive than standard copper lines. The goal of the demonstration projects is to lower costs by encouraging more superconducting cable installations. Superconductivity should be incorporated in distribution network additions and upgrades to take full advantage of the efficiency benefits. It is important to note that I am not proposing transmission, but feel that superconducting cables are well-suited for distribution networks.

Technological Considerations Conclusion

Now that the technological aspects and power sources for DG have been explained, it is important to address the physical land characteristics and policy components that affect the function of DG systems. The following section will explore the physical attributes of San Francisco to determine which technologies and configurations are most suitable and how they can be implemented successfully.

SECTION
5
Analysis: Physical Characteristics of San Francisco

San Francisco is a city situated along the northern California coast. It is located at the northern tip of the peninsula, surrounded by three bodies of water. The Pacific Ocean and San Francisco Bay sandwich the city and the Golden Gate Strait runs along the north. The location and physical attributes of the city pose unique challenges for different power systems and configurations. This section will explore the physical characteristics of San Francisco that are relevant in the context of energy systems, addressing space, climate, and topography variables. Space will look at density and land values, climate will delve into sunlight and wind features, and topography examines physical land features.

Space Characteristics

Figure 5.1 shows the location of the San Francisco and the surrounding Bay Area region. The city and the county have the exact same boundaries. The total land area is 46.69 square miles. As of 2009, the U.S. Census determined that the city had an estimated population of 815,358 persons (U.S. Census Bureau, 2010). This results in a high density of 17,463 persons per square mile. The Bay Area as a whole has about 7.5 million people. This includes most of the area shown in Figure 5.1, which includes Oakland to the east and San Jose to the south.

Figure 5.1: Aerial Photo of San Francisco Region Topography.

Source: Digital Globe, 2011.

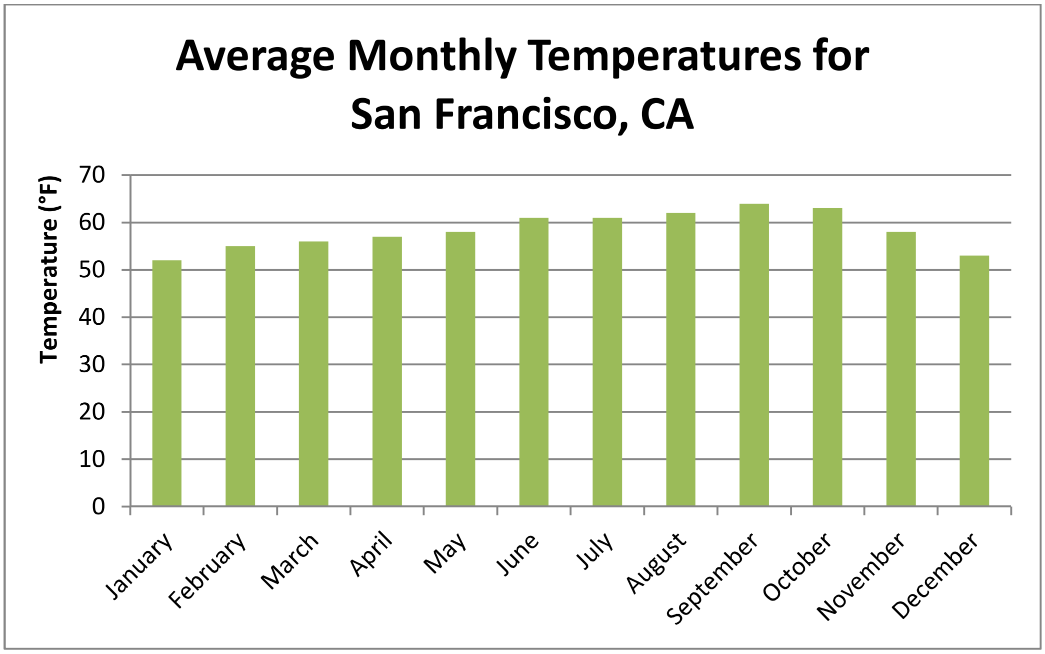
Median home prices at the end of 2010 in San Francisco were $844,784. Of this total, $650,569 accounts for the median land value per residential parcel (Lincoln Institute of Land Policy, 2010). The median home value for the state of California is $454,200, with $257,086 of that figure accounting for the value of land. San Francisco not only has very high land values compared to the state of California, but is among the highest in the country. This is relevant to the acquisition of land for the installation DG sources.

Climatic Features

San Francisco has a temperate climate with rather stable temperature averages throughout each year. Averages range from the low 50's to low 60's, as shown in Figure 5.2.

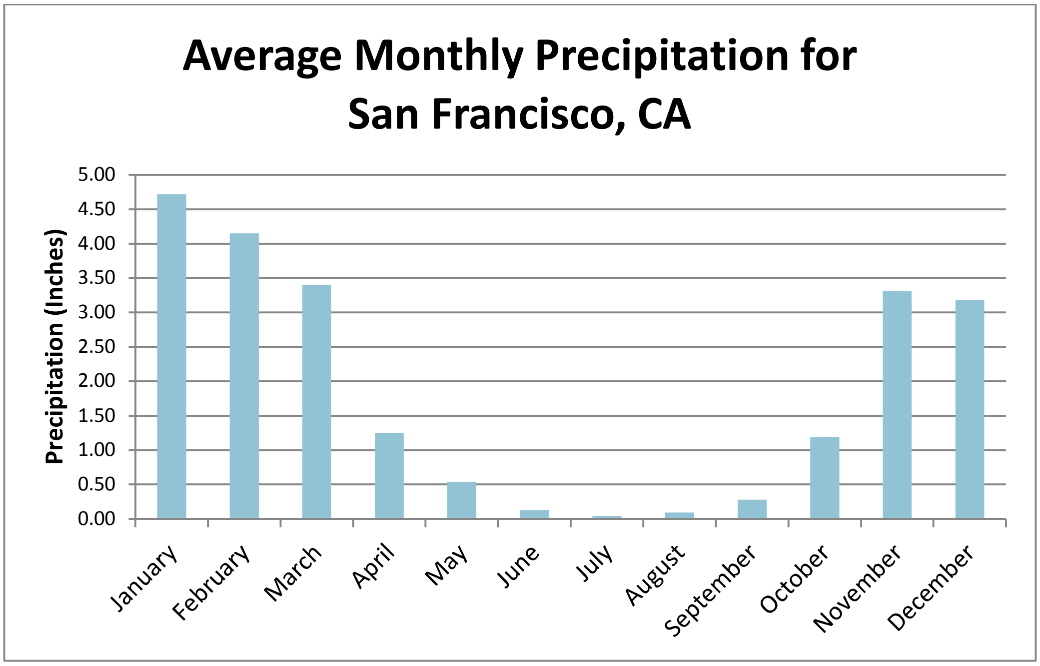
Precipitation levels are highest in the fall and winter months, ranging from 3 to 5 inches during these months.

Figure 5.2: Average Monthly Temperatures in San Francisco.



Data Source: The Weather Channel, 2011.

Figure 5.3: Average Monthly Precipitation Levels in San Francisco.



Data Source: The Weather Channel, 2011.

As discussed in the Technological Considerations section, insolation refers to the amount of sunlight received by a surface throughout the day, shown in kilowatt hours per meter squared per day (kWh/m²/day). This is a critical variable for assessment of possible sites for solar photovoltaic technologies.

Table 5.1 below shows the insolation factors for San Francisco, broken-down between fixed flat panel arrays and dual-axis tracking arrays. The dual-axis tracking arrays actually adjust throughout the day to follow the path of the sun to maximize solar radiation and power output. The fixed flat panel arrays are stationary and, thus, less efficient but also less expensive than the tracking arrays. The yearly insolation level averages account for sunlight, cloud cover, and geographic characteristics throughout the year. The fixed flat panel array for the city has an average isolation level of 5.34 kWh/m²/day while the dual-axis tracking array has a value of 7.07 kWh/m²/day. In other words, one square meter of a standard fixed PV panel will produce 5.35 kWh of electricity each day, which exceeds the national average of 4.90 kWh/m²/day (Massey, 2010). This does not factor in the range of efficiencies found in various types of panels, but provides an average.

12.5 cents is the approximate value per kWh of electricity produced in San Francisco. This is used to determine the monthly and annual value per square meter (m^2) of PV panels. The fixed flat panel array produces 5,660 kWh of power per m^2, which equates to over \$700 per year. The dual-axis tracking array produces 7,605 kWh/ m^2, resulting in almost \$950 annually.

Table 5.1: Solar Insolation Levels in San Francisco.

Fixed Flat Panel Array				2-Axis Tracking Array			
Month	**Solar Radiation (kWh/m^2/day)**	**AC Energy (kWh)**	**Energy Value ($)**	**Month**	**Solar Radiation (kWh/m^2/day)**	**AC Energy (kWh)**	**Energy Value ($)**
January	3.57	323	40.23	January	4.27	386	48.07
February	4.53	374	46.58	February	5.51	458	57.04
March	5.12	467	58.16	March	6.41	593	73.85
April	5.86	511	63.64	April	7.78	692	86.18
May	6.10	554	69.00	May	8.75	816	101.62
June	6.37	554	69.00	June	9.35	828	103.12
July	6.62	595	74.10	July	9.66	883	109.97
August	6.36	570	70.99	August	8.73	797	99.26
September	6.21	533	66.38	September	7.93	693	86.31
October	5.36	478	59.53	October	6.63	595	74.10
November	4.30	373	46.45	November	5.22	457	56.91
December	3.63	329	40.97	December	4.45	408	50.81
Year	**5.34 (avg.)**	5660	704.90	Year	**7.07 (avg.)**	7605	947.13

Data Source: National Renewable Energy Laboratory, 2011.

Wind patterns in San Francisco fluctuate greatly due to the diverse topography and location along the Pacific coast and bay. The California Energy Commission created a map to show the wind potential in different areas of the state. Figure 5.4 shows a portion of that map centered on the Bay Area. San Francisco actually has a lower wind potential than one might expect. At a height of 50 meters above ground-level, wind speeds in the city generally range from 0 to 14.5 miles per hour, or 6.5 meters per second. The National Renewable Energy Laboratory (NREL) has actually created a point system for wind energy potential, as shown below in the legend. San Francisco is better suited for wind technology offshore or inland near Contra Costa and Alameda counties compared to the city.

Figure 5.4: Wind Power Densities in the Bay Area.

Source: California Energy Commission, 2011.

Topography

San Francisco has a rather varied terrain despite the fact that it occupies a less than 50 square miles. Uniquely, the city is surrounded by water on three sides and is only about 100 miles west of the Sierra Nevada mountain range. Wind is essentially channelized by this topography, resulting in a wide range of weather patterns throughout the city. San Francisco has been referred to a city of hills. In fact, the city reaches elevations above 900 feet, which is impressive given such close proximity to the Pacific Ocean. Figure 5.5 provides a diagram of the topography of the city of San Francisco.

The topography is important in not only determining weather patterns, but for siting of wind and PV panels. Given the hilliness of San Francisco, it is important that PV panels are installed in places where sunlight is not inhibited by geographical factors. Varied topography can interfere with wind patterns by providing intrusions and creating valleys that might reduce the amount of wind necessary for successful wind turbine projects.

Figure 5.5: Topography of San Francisco.

Source: Digital Globe, 2011.

The following section will delve into the policy considerations for San Francisco and the state of California. This will tie together the technological characteristics and physical conditions relevant to DG.

SECTION
6
Analysis: Policy Considerations

San Francisco Electricity Resource Plan

This research is specific to San Francisco because this city offers the benefits of a dense urban area with progressive views toward energy systems. In fact, San Francisco has made more progress in terms of sustainable energy planning than any other major city in California. It seemed appropriate focus on a city that has set the bar for energy sustainability so high so that other regions in California can mimic or adapt the practices of San Francisco to suit their own needs. The areas for improvement in San Francisco will be addressed to set the bar even higher. In addition, the state policy frameworks have been instrumental in promoting renewable DG solutions. A proposal will be developed later in this analysis to that can be adapted to for specific regions to promote the widespread implementation of DG.

The basis for energy decisions in San Francisco has been set by their Electricity Resource Plan (ERP), which was last revised in December 2002. Although, somewhat dated due to rapid technological advances in energy systems, the plan provides a framework for the energy vision of the city. A draft update to the San Francisco ERP is currently in progress. Distributed generation (DG) is referred to in the ERP as small-scale energy generation technology consisting mainly of fuel cells, microturbines, and combined heat and power (CHP) configurations. The goal of the plan is to have 72 MW generated from distributed sources by 2012 (San Francisco Public Utilities Commission, 2002). The Utilities Commission recognizes the need for cooperation with Pacific Gas and Electric (PG&E) for interconnection of DG sources to the grid. PG&E is the primary electricity utility provider for the Bay Area. In order to ease DG projects, permits will be streamlined from the city. It is apparent that San Francisco does not regard photovoltaic (PV) and wind generation sources as DG technologies. Wind power is a reasonable exclusion because of the difficult siting decisions and need for long-distance transmission. It is interesting that PV technology is not included with DG systems. This may be due to the fog patterns of the city that reduce solar insolation levels or the large space occupation required for these projects. Nonetheless, PV may have some viability for DG projects in SF.

The San Francisco ERP explains the importance of upgrading and adding transmission systems to meet growing demand from users, such as the proposed project on the peninsula from the Jefferson substation in Brisbane (North end of the peninsula) to the Martin substation in San Carlos (South of the city). Figure 6.1 provides a map of the transmission extension project. With transmission expansion and upgrade projects, the plan outlines an objective to inject more power from renewable sources in the grid. While the incorporation of renewables is a noteworthy goal, the new transmission lines are somewhat disconcerting. Incorporation of DG into the existing grid will alleviate strain on transmission systems and defer costly upgrade projects. DG can be installed quicker and at a lower cost than transmission upgrade and expansion projects. Unfortunately, the Jefferson-Martin 230 kV transmission line was completed in August 2006. While this line provides power to a vast amount of people, it will contribute to the power losses associated with transmission.

Figure 6.1: Bay Area Transmission Line Proposed Extensions, 2002.

Source: San Francisco Electricity Resources Plan, 2002.

The key objectives of the ERP include the following provisions, which will be explained individually as they pertain to DG.

Maximize Energy Efficiency. The plan focuses on achieving this goal through efficiency upgrades at the building scale, such as installations of energy efficient appliances, equipment, and systems. The plan fails to address the efficiency of energy systems by identifying energy losses from transmission systems. In order to maximize energy efficiency, greater emphasis should be placed on configurations like DG that minimize waste.

Develop Renewable Power. In 2001, Proposition B was passed in San Francisco, which authorizes the $100 million in bonds to fund renewable energy projects for public buildings. The renewable energy technologies listed include PV, wind, fuel cell, and tidal generation. The plan acknowledges issues with interconnection as a potential challenge to the successful application of this goal. Interconnection is a shrinking problem as standards, such as IEEE 1547, NEC 705, and UL 1741, receive more widespread acceptance. Small-scale DG implementation of renewable technologies is very common, further supporting expansion of DG systems.

Assure Reliable Power. The ERP lists efficiency, local control, renewable sources, and small-scale power production as primary means to provide reliable energy sources to users. These are key components of the DG energy system model. By employing a diversity of small-scale generation sources, more reliable and secure systems can be achieved. DG can also supplement the grid during peak conditions, reducing strain on the grid. Centralized power plants with long distribution lines are subject to natural disaster, terrorist attack, and other issues that could threaten the power supply for a great deal of people.

Support Affordable Electric Bills. The costs from the inefficiencies of the traditional grid network are imposed upon the consumers. The rates are determined by the California Public Utilities Commission (CPUC) and factor fuel costs, transmission, distribution, operations and maintenance, and production into rates. The consumers have no control over electricity costs. By implementing more DG projects, consumers will not have to pay for inefficiency of the system and have more control over power generation that better meets demand, minimizing waste. The ERP recognizes growing demand from the public for additional small-scale generation and local control. The plan encourages the city to involve the public in efficiency efforts and reduction of peak demand. The public is aware of the need for more efficient methods of power production and distribution.

Support Environmental Justice. The ERP mentions the high rates of childhood asthma in southeast San Francisco, which is a lower-income community with a high concentration of minority groups. A public meeting was held to address this issue, concluding that polluting power plants should be phased out and that high-polluting plants, such as coal fired plants, will not be constructed. Central power plants often concentrate pollutants that have detrimental effects on local communities and downwind areas. In DG projects that utilize polluting sources, pollutants are dispersed, usually keeping levels within the safe range. In addition, the efficiency achieved in bypassing transmission requires electricity production, resulting in less pollution.

Promote Opportunities for Economic Development. The plan focuses mainly on local manufacturing and production of energy equipment as an economic stimulus. With greater incorporation of DG, workforce development will occur with operations, maintenance, and installation of energy systems, as well. San Francisco is already known for being a CleanTech city, committed to sustainable energy, transportation, manufacturing, construction, and more. DG can aid in the expansion of the city's CleanTech industries.

Increase Local Control over Energy Resources. Local controls will involve more of the community in decisions that affect energy systems and efficiency. The ERP acknowledges that the most effective way to gain local control is through small-scale generation efforts. Local control will guide education of the public and involve more of the workforce in energy projects. Local agencies must be involved with siting decisions and the city still needs to figure out who will be in control of distribution networks.

Given the energy goals of San Francisco, DG is an ideal solution to achieve these objectives. After describing the goals for the city, the ERP importantly identifies the entities involved with the energy system. The entities most important to DG efforts include the California Public Utilities Commission (CPUC), California Energy Commission (CEC), Bay Area Air Quality Management District (BAAQMD), California Power Authority (CPA), and Pacific Gas and Electric (PG&E) as shown in Table 6.1 (San Francisco Public Utilities Commission, 2002).

Table 6.1: Agencies Involved with Energy Regulation in San Francisco.

Agency	**Responsibility**	**Suggestions for DG Implementation**
CEC	Involvement with energy efficiency and issuing licenses to power plants.	Increase difficulty in earning power plant licenses to promote DG projects.
CPUC	Responsible for regulating the distribution network and pricing for energy efficiency and transmission network projects.	Ought to promote DG as opposed to transmission upgrades by ensuring lower pricing for these projects.
BAAQMD	Focuses on emissions profiles, cap and trade efforts, and permitting.	Additional renewable DG projects will significantly decrease emissions by 10 percent or more. Provide streamlined permitting for DG efforts.
CPA	Involvement with financing projects related to reliability, energy efficiency, and renewable technologies.	Provide financing options which facilitate diverse owners of DG projects. For example, community ownership of local power generation site.
PG&E	Owners of most of the transmission systems in Northern CA, many distribution systems in the city, and power plants.	Rather than upgrade transmission lines, install interconnected DG to supplement grid power and reduce strain on the system.

The most recent electricity use trends shown in the plan are for the year 2001. Although these are not the most up-to-date statistics, it is important to understand conditions that informed the ERP. Commercial and Residential buildings consume 60 and 27 percent of the total electricity consumed by the city, respectively (San Francisco Public Utilities Commission, 2002, p. 27). Today, trends are rather similar. Given these figures, targeting commercial districts ought to be the primary objective of energy efficiency, followed by residential. By 2002, San Francisco already has 12 percent of its electricity supplied by renewable sources through the grid. Today, this figure is about 14 percent. It is important to note that most of these sources are from inland wind and remote solar arrays. An even higher percentage may be achieved with more grid-interconnected urban DG projects. This is the precise challenge examined in this analysis.

The San Francisco ERP includes an Action Plan section that provides expands upon specific objectives and addresses implementation. Short-term plan includes "aggressive efforts" to promote and install DG using renewable and clean natural gas technologies, but do not provide any further detail (San Francisco Public Utilities Commission, 2002). The medium term plan basically calls for the same DG measures. The recommended portfolio for 2012 calls for DG source production to reduce central plant generation by 444 GW. Is this on-track? It is important to note that in order to shut-down power plants in San Francisco, other sources must be installed to make up for the loss in generation capacity. Currently, the city has installed four large 52 MW generators to aid in peak demand periods. These generators ought to be replaced by renewable DG sources that result in greater efficiency and less pollution. The growth of natural gas power plants in California is acknowledged by the plan. While this is more efficient than coal-fired plants, of which new installations in the state have been outlawed, it is still polluting and experiences transmission losses. The incorporation of DG offers a promising solution to this problem.

Overall, the ERP for San Francisco provides specific goals and timelines while emphasizing significant changes to the traditional energy system. DG is recognized as an important tool, but deserves even more attention given its tremendous efficiency.

Local Policies and Programs

Senate Bill 581. While the San Francisco ERP provides insight as to the energy goals of the city, existing policies must also be examined. On January 1, 2010, Senate Bill 581, driven by Senator Mark, Leno went into effect. This bill extended financing mechanisms historically used for solar projects to also apply to other renewable energy technologies. This is critical, as other sustainable power sources will receive greater attention. As varying conditions and siting decisions are commonly encountered in the urban setting, one must have multiple options for electricity generation to install the optimal technology. Now, technologies such as fuel cell, wind, microturbine, tidal, and others will be promoted along with solar, which has been given the greatest level of attention as a renewable technology. PG&E was not in support of this bill due to the greater oversight from the San Francisco Public Utilities Commission (SFPUC), but solar organizations like the Vote Solar Initiative and Solar Alliance backed the bill. This bill is not specific to San Francisco, but the city comprises a large percentage of the power generated and transmitted by PG&E.

Solar Energy Incentive Program (GoSolarSF). The SFPUC has implemented a program through the city to provide incentives for all solar projects that produce at least 1 kW of electricity. The incentives provide upfront financial support to promote solar projects. These incentives apply to single-family residential, multi-family residential, low-income residential, commercial, and even non-profit buildings. Incentive figures are based on the type of land use. The program promotes installation by local businesses by offering an additional $750 for residential projects. In addition, projects for low-income groups receive additional funding. Table 6.2 below provides a breakdown of the funding available through the Solar Energy Incentive Program. This program targets commercial and residential projects because these land uses account for a high percentage of total energy consumed in the city.

Table 6.2: Solar Energy Incentive Program Incentives Based on Land Use Type.

Land Use	**Credit Terms**	**Maximum Credits**
Single-Family Residential	N/A	$3,750
Multi-Family Residential (if owned by non-profit)	$3,500 per kW	$60,000
Low-Income Residential	N/A	$7,000
Commercial	$1,500 per kW	$10,000
Non-Profit	$1,500 per kW	*NO MAXIMUM

Data Source: San Francisco Public Utilities Commission, 2011.

GreenFinanceSF. This program was implemented in 2010 as a Property Assessed Clean Energy (PACE) finance program to provide owners of residences and businesses the opportunity to take out loans from the city of San Francisco for energy efficiency and sustainable generation source projects. This includes, building envelope improvements, HVAC system upgrades, PV, solar hot water installations, and other upgrades. The American Recovery and Reinvestment Act provided the funding necessary to implement the program. GreenFinanceSF is configured to allow property owners to pay back loans through property taxes. The city will loan anywhere from $5,000 to $50,000, while affording participants up to 20 years to repay the loan (Renewable Funding LLC, 2010). The program is being amended to require all eligible candidates to conduct energy audits of homes or businesses, showing the efficiency improvements of the proposed retrofit. This program may contribute to the success of DG if implemented in a community-wide scale where commercial or residential communities may install generation sites to serve a number of buildings. Also, the $50,000 limit ought to be increased to promote larger projects. Nonetheless, encouragement of projects for individual buildings aids in reducing demand for central plant-produced electricity.

Propositions B and H. These propositions facilitate increased purchasing of renewable energy resources. Proposition B focuses on energy conservation efforts and renewables by selling $100 Million in bonds for projects on public lands. Most of the bonds are for solar and wind installations, with about 20% going to conservation efforts. Other sustainable technologies, such as fuel cells, are not excluded, but have not been included in projects yet. City taxes will not be increased because the cost savings experienced by the city from the installations will be used to pay back the interest and principal on the bonds. The utilization of public lands is ideal for more public ownership of DG sites, which increases the level of competition among the monopoly of PG&E. Also, the potential to use funds for any type of sustainable technology is conducive to site-specific project needs.

Demand-Reducing Programs. PG&E – provides rebates and cash incentives for energy efficiency upgrades at the building level. The program applies to both residential and nonresidential projects. Also, new home construction projects that exceed Title 24 requirements by at least 15 percent are eligible for rebates when verified by a (Home Energy Rating System) HERS rater.

Overall, the city of San Francisco has focused primarily on the financial elements to promote DG and other renewable energy projects. There are even more state-wide measures to further support DG projects, which will be discussed in the next section.

State Policies and Programs

Tax Exemptions. AB 1451 was amended in September 2008 to provide property tax incentives for solar projects ranging from PV, solar hot water, solar heating, and more. Certain equipment included in the solar installation may be eligible for an exemption of up to 75 percent of the cost of the equipment. The catch is that this applies only to projects where the owner does not intend to utilize. Essentially, the owner may be exempt from a portion of the property taxes in the sale of the property.

California Solar Initiative (CSI). This program was established to generate at least 300 MW of power from solar sources by the year 2016. Include performance-based metrics to promote optimal design and installation of systems for essentially all building-types. $3 Billion worth of incentives are distributed based on the level of performance on individual projects. The program was adopted by the CPUC, but is run by PG&E and Southern California Edison utility companies as well as California Center for Sustainable Energy. All eligible projects must be grid-connected, helping to facilitate the DG model presented in this analysis. Unfortunately for the

Bay Area and the rest of northern California, PG&E has utilized all of its funds to incent PV projects at this time. Additional funding is needed to continue the incentive program. The New Solar Homes Initiative is a part of the CSI that focuses primarily on residences and is operated by the California Energy Commission (CEC).

Emerging Renewables Program. The Emerging Renewables Program is managed by the CEC, offering financial incentives for grid-connected fuel cell and small-scale wind generation projects. The program applies to wind projects below 50 kW and fuel cell projects that utilize a renewable source, such as landfill gas for conversion to hydrogen. Fuel cells receive a rebate of $3 per Watt installed for up to 30 kW. For wind power, rebates of $2.50 per Watt for the first 10 kW installed and $1.50 per Watt between 10 and 30 kW will be received (California Energy Commission, 2011). When projects are eligible for other incentives, the Emerging Renewables Program will reduce rebates so that rebates don't exceed the cost of the installation. This is an ideal program for DG, as it strongly promotes the installation of DG, especially in situations where one may not be able to afford the project costs upfront. The program ought to be extended to include microturbines that operate on renewable fuel sources, as well. It is important to enact programs that apply to renewable technologies other than solar.

Self-Generation Incentive Program (SGIP). This program was implemented on December 31, 2008, and has resulted in the production of over 337 MW of power produced by DG sources to date. In 2008 alone, the SGIP resulted in offsetting 175,000 tons of CO2, which is equivalent to taking approximately 29,000 automobiles off of the road for one year (California Public Utilities Commission, 2011). The original purpose of the program was to supplement peak demand periods. The success of the program has deferred upgrades and investments in transmission networks. Eligible projects include wind, fuel cell, and storage up to 5 MW, although, incentives are granted up to 3 MW. Like with the Emerging Renewables Program, the SGIP excludes solar and should include microturbines that operate using renewable fuel sources. Nonetheless, this is a highly successful project that has showcased the benefits of DG. Table 6.3 below provides eligibility requirements for various technologies.

Table 6.3: Self Generation Incentive Program Requirements.

Renewable Fuel Sources	Minimum Requirement	Incentive Payment
Wind	30 kW	$1.50 per Watt
Fuel Cell (renewable fuel source)	30 kW	$4.50 per Watt
Fuel Cell (non-renewable source)	30 kW	$2.50 per Watt
Advanced Storage	Tied to eligible SGIP	$2.00 per Watt

Data Source: California Public Utilities Commission.

Senate Bill (SB) 32 – Feed-In Tariffs. SB 32 was passed in October 2009 to allow electrical producers to establish contracts with utilities to be reimbursed for up to 3 MW of power discharged into the grid. This revises the CPUC Code 399.20, which provided reimbursement for up to 1.5 MW. Originally, the bill applied only to water and wastewater facilities, but has been expanded to apply to all customers of utilities. This was an amendment to the Tariffs change based on demand period (off-peak / peak). This is a requirement for any utility that serves 75,000 or more customers. These were established to assist utility companies in achieving the renewable portfolio standard (RPS). It is unlikely that any RPS could be met without small-scale generation of renewable sources, so this is effective for facilitating DG expansion. Tariffs are capped at the point where total state generation exceeds 750 MW.

Net Metering. Net metering is a method used to measure the amount of electricity generated and consumed by a customer. This is generally achieved through the installation of a simple bi-directional flow meter. This allows for reimbursement by utilities for customers whose generation exceeds consumption, also referred to as Net Excess Generation (NEG). California required net metering beginning in 1996 for solar and wind projects up to 1 MW. Today, fuel cells and landfill gas are also eligible for net metering. In NEG situations, customers may roll-over excess power or receive financial compensation for power generated over a one-year period. This is important for DG because it ensures any excess power sent to the grid results in compensation, further promoting DG projects by reducing payback periods for these efforts.

Interconnection Standards. California enacted Rule 21 specifically for grid interconnection of DG projects below 10 MW. This standard is based largely on the IEEE (Institute of Electrical and Electronics Engineers) 1547, which was adopted as the national standard for DG interconnection by the 2005 Energy Policy Act. Rule 21 addresses a larger scope and includes data specific to California, such as tariff rates with the electrical utility companies of the state. Requirements must also comply with the UL 1741 standard that regulates the equipment necessary for interconnection, including utility-interactive inverters, controllers, conversion equipment, and more. Different standards apply to projects below 10 kW. Overall, California has sufficiently addressed grid-interconnection of DG by utilizing nationally and internationally-recognized standards while including state-specific guidelines. Historically, this has been a significant challenge to the successful widespread implementation of DG.

Policy that Supports Renewable Technologies. Solar easements have been established across the state to ensure solar installations are capable of functioning at full efficiency. For instance, The Solar Shade Control Act prevents trees and plants from shading more than 10 percent of any solar array if the vegetation was installed after the array. Other codes allow municipalities or subdivisions to enact programs that promote coordination amongst neighbors to prevent the hindrance of solar projects. The Solar Rights Act prevents any public institution, including HOAs from receiving state funding if they prohibit solar projects. Promoting greater integration of solar in buildings is a crucial step in the advancement of the DG model.

AB 45 allows counties to enact programs for small wind projects below 50 kW. The bill provides examples of the strictest requirements for noise and visual effects, tower height, site assessment, and more. Attempts of wind projects in close proximity to urban areas have had a lack of success due to high degrees of site, habitat, and personal disturbance. The public would prefer these projects take place is remote areas that require transmission. Given this lack of success, wind is not an ideal technology for DG projects in urban settings.

Renewable Portfolio Standard (RPS). The RPS in California was last designated in 2009 by a bill signed by Governor Schwarzenegger. The target is to have 33 percent of power supplied by renewable sources by 2020. Included in the renewable energy sources are fuel cell, wind, PV, solar thermal, biomass, landfill gas, but not microturbines. The inclusion of microturbines ought to be included in this list when installed in CHP hybrid projects due to the high levels of efficiency. The California Air Resources Board (CARB) oversees the RPS with assistance from the CPUC and CEC. There is a strong correlation between air quality and power generation, so it is appropriate for CARB to take command of this initiative. Air quality goals include meeting 1990 emission level by 2020 and an 80 reduction to that level by 2050 (State of California, 2011).

Federal Policies and Programs

There are not many more California policies in place that promote DG in urban areas than there are Federal policies. This is not surprising considering the high level of progressivism in California and commitment to sustainable energy and buildings. In fact, California is the first state to pass a mandatory state-wide green building code, which went in to effect January 2011. Nonetheless, it is important to address those Federal policies that promote DG.

The Business Energy Investment Tax Credit offers Federal tax rebates for Commercial, Industrial, Utility, and Agricultural facilities that implement renewable energy projects. Solar, wind, and fuel cells receive a credit for 30 percent of the cost of the technology and equipment. Microturbines, geothermal, and CHP projects receive a 10 percent credit. Maximum amount available varies depending on the type of technology, but the solar, wind, geothermal, and CHP are favored by the program. This is one of the few policies that include microturbines among the other renewable technologies.

The Residential Renewable Energy Tax Credit is similar to the Business Energy Investment Tax Credit, but applies to homes. A credit of 30 percent of the renewable project cost may be earned. The difference is that microturbines and CHP projects are not eligible for the tax credit. This credit was originally enacted by the Energy Policy Act of 2005 and revised by the Energy Improvement and Extension Act of 2008. Only fuel cell technology has a maximum amount of eligible credit.

Measures for other buildings, such as residences, include the Energy-Efficient New Homes Tax Credit for Home Builders, which provides incentives up to $2,000 per house for homebuilders that reduce energy consumption of HVAC systems by 50 percent or more below the International Energy Conservation Code. Policies like these don't apply directly to DG, but reducing electrical demand is a crucial step in designing effective energy systems. In fact, building-level efficiency upgrades ought to precede any generation capacity upgrades.

Clean Renewable Energy Bonds were established through the Energy Policy Act of 2005 to help fund renewable energy efforts. Between 2007 and 2008, $1.2 billion was allocated for these projects (Internal Revenue Service, 2007). States and municipalities are limited to $750 million of the total budget, with the remaining to be utilized by electrical utility companies.

Policy Conclusion

Policy will play an imperative role in expanding widespread adoption of DG in grid systems. The CPUC has implemented Energy Efficiency Policy measures, such as AB 2021, to require a 10 percent reduction in forecasted power consumption by 2016. Transmission networks in the traditional grid systems lose approximately 10 percent through the transmission networks. By transmitting and distributing power more efficiently, these goals can be met. In addition, the CPUC has sought the reduction of natural gas resources and stable electricity prices. DG will more efficiently utilize natural gas in fuel cell and microturbine installations, promote a diversity of power sources, minimize losses, and result in lower pollution levels.

SECTION
7
Recommendations

The previous sections of this analysis have explored many issues relating to DG. The advantages of this model, technological considerations, physical land characteristics of San Francisco, and relevant policies have been presented to provide decision-makers with an informed implementation strategy for incorporating DG into traditional power systems. The ultimate goal is to facilitate greater understanding of how traditional power systems can be altered to improve air quality through increased efficiency and incorporation of more renewable power sources.

The Recommendations section applies the knowledge presented in this analysis to the city of San Francisco, California. The section will conclude with a study that implements the proposed model to replace the primary large power plant in San Francisco. San Francisco has been chosen as the study area for this analysis due to its progressive energy policy, high-tech businesses, and previous success in the field of energy. The city has set the bar high in terms of sustainable energy, so it seems appropriate to analyze a place that has achieved success in this arena in order to determine how to further improve the effectiveness of DG implementation. The recommendations presented can be examined and adapted to other locations to assist decision-makers in adopting the DG model. The section will explore how physical conditions in

San Francisco affect the DG model, recommended technologies and policy measures, and a study that shows the effects of implementation.

How Physical Characteristics of San Francisco Shape Energy Decisions

The Physical Characteristics Analysis section discussed the site and atmospheric conditions specific to San Francisco. The city is surrounded by water, has varied topography, and includes rapidly fluctuating weather patterns. In addition, San Francisco has some of the highest property values in the nation. Given these considerations, it is important to promote power technologies that minimize space occupation, are unaffected by the topography, and can handle fluctuating atmospheric patterns while supplying sufficient power to a dense urban population.

The physical conditions of San Francisco place some pretty significant constraints on power systems, as weather patterns are difficult to predict. That being said, it may be better to adopt power sources that offer controllability, such as microturbines and fuel cells. Technologies that are optimal in other regions may fall short in San Francisco given these unique regional characteristics.

Recommended Technologies and Configurations for San Francisco

Solar photovoltaic, wind, microturbine, and fuel cell technologies have been examined in this analysis. Each of these technologies has unique advantages and disadvantages, but some characteristics prove unsustainable for use in urban DG applications. Fuel cell technology is the most suitable power source for DG in the urban setting of San Francisco. This is due mainly to the high efficiency and minimal space occupation of these devices. By themselves, fuel cells are capable of achieving efficiencies up to 65 percent, which is the highest among the technologies examined in this analysis. Given the fact that fuels are required for the operation of fuel cells, a high efficiency rating is necessary to ensure emissions are kept to a minimum.

Fuel cell technology also minimizes space occupation, which is imperative in dense urban settings, like San Francisco, where land acquisition is highly competitive and expensive. The 100 kW ES-5000 Energy Saver solid oxide fuel by Bloom Energy has dimensions of 224" x 84" x 81". This is about the size of one standard parking space (Bloom Energy Corporation, 2010). These devices can be installed on individual building sites or grouped together to supply a larger user demand. The ease of siting decisions and minimal costs associated with land acquisition make fuel cells the most viable technology for large-scale DG implementation.

Solid oxide fuel cells achieve average efficiency ratings of 60 percent, the highest average among other fuel cells. Therefore, it is not necessary to install hybrid cogeneration systems in most cases. Although I advocate for waste minimization, cogeneration will increase costs anywhere from 30 to 70 percent depending on the configuration and system size. Efficiency increases will not exceed 30 percent, so this model does not make financial sense (California Energy Commission, 2008). The cost increases associated with proposing the cogeneration model could convince decision-makers to opt for continued support of traditional grid systems. To optimize cost-effectiveness, fuel cells are best-suited without heat recovery for cogeneration. Instead, consumers are better off lowering heating and cooling demand through building-scale measures, such as tightening building envelopes, insulating walls and ceilings, and installing efficient HVAC systems, rather than using waste heat from high-temperature fuel cells.

Many fuel cells include internal voltage regulation and protection equipment, which simplify the installation and grid interconnection processes. As an emerging technology, advancement is continually taking place in the fuel cell arena. Recent innovations in this technology have significantly decreased the cost of these devices. This type of innovation promotes greater implementation by stimulating competition and lowering prices. The efficiency benefits offered by fuel cells coupled with minimal land area requirements will facilitate rapid introduction of this technology into the California power sector.

Where the Other Technologies Fell Short

While it would be ideal to exclusively use only those technologies that are renewable and produce zero emissions, the power demand of a large population must be met with a reliable power source. Unfortunately, the passive generation status of solar and wind technologies are not optimal to meet the needs of San Francisco. Passive generation sources may have some applicability in high-density urban areas, but they are not suited to be primary sources under the DG configuration.

Solar PV technology may be the most popular renewable power source. It has been implemented in both large and small-scale applications. For the urban setting, I feel this technology is ideally suited for small-scale projects. This refers mainly to rooftop installations that are capable of providing base loads for users. This technology can be used at the individual building scale to meet a percentage of demand, reducing the amount of power consumed from the grid (or microgrid).

Large-scale PV projects in California are typically sited remotely in desert regions subject to an abundance of sunlight. These projects require long-distance transmission that further reduces the already low efficiency rating. Therefore, solar technology ought to be encouraged by policy measures for individual building-scale installations to reduce demand on the larger power utility. Despite the fact that PV is completely renewable and requires no fuels, there are too many drawbacks that limit the capability of the technology. High land values coupled with large land occupation, low efficiency, and the intermittent passive generation status restrict the use of this technology as the primary source for DG applications, although it can play a role to reduce the grid demand of individual buildings through rooftop installations.

Wind power has the capability to supply a great deal of power to San Francisco, but only through remote installations, which require long-distance transmission. Some inland locations throughout the area have strong wind potential, but most of the potential is along the coast where real estate is most expensive. Off-shore wind farms could prove effective, but these are considerably more expensive than land installations,

Wind is not well suited for dense urban areas, like San Francisco for a variety of reasons. First of all, the varied topography of the city increases the difficulty in siting wind turbines. In addition, turbines create noise and visual obtrusions that act as a nuisance for residents. The passive generation status creates power reliability issues during periods where wind flows are not present, which is unacceptable for a dense city like San Francisco with a large power demand at all times. Finally, wind is not a viable solution for DG projects given the high level of difficulty in siting this technology, which requires remote siting and long distance transmission in most cases. For these reasons, I do not recommend wind power for San Francisco and other similar urban areas.

The level of sustainability offered by microturbines is still under debate in the energy realm. The modularity, adaptability, fuel type flexibility, and ability to supplement power from the grid support the sustainability of this technology. The key drawbacks of microturbines are the fuel inefficiency and emissions caused by combustion. The goal of this research is to implement an energy system that meets the needs of consumers, but significantly reduces air pollution. Given the fact that microturbines are comparable in cost to fuel cells while utilizing more fuel and producing greater emissions, this is not the optimal technology for DG applications.

The efficiency of microturbines is increased significantly (up to 80 percent) when used in cogeneration systems, but this also brings the cost up 30 to 70 percent (California Energy Commission, 2008). This technology is suitable in virtually any setting, including dense urban San Francisco, but the inefficiency of combustion limits the level of sustainability offered by this technology.

Policy Recommendations

The policies that have been most effective in promoting DG in California have been those that provide financial incentives. The Self-Generation Incentive Program (SGIP) and

Emerging Renewables Program (ERP) offer capital to reduce the initial expenditures for projects. These programs and many other financial incentives now apply to fuel cell technology. The study presented later in this section shows that these incentives reduced the initial cost of this project by 40 percent. The policy recommendations are based divided into three main categories: Incentives for the Sustainable DG Sources, Market Restructuring, and Community Education.

Incentives for Sustainable Distributed Generation Sources. The recommended policy measures begin with financial incentives that encourage DG. Measures such as the SGIP and ERP must be continued and extended. The SGIP has made California the leader in stationary fuel cell projects. Increasing the capacity of these programs will stimulate growth among renewable DG projects. Although renewable sources produce lower emissions, the primary focus of this effort is on the types of fuel resources consumed for power production. In addition, financing mechanisms must be firmly established, which provide low-interest loans for these efforts. Effective financing allows a larger percentage of the population to get involved with DG projects using renewables. Additional programs should be enacted that provide tax credits based on reductions in pollutants. This focuses directly on the pollution effects of electricity generation, which complement programs that are aimed at resources used for generation.

Market Restructuring. The second approach recommended to facilitate greater electricity contributions from DG sources is through market restructuring efforts. The market-based approach allows the functions of the economy to promote this model. California has already established a renewable portfolio standard (RPS) of 33 percent by 2020. A portfolio standard for DG would require utility companies to build more DG sites or source more power from these installations. Also, promoting the sale of electricity back to the grid is an effective market approach. Community ownership models may increase as the public realizes the economic benefits from selling power to the larger grid.

In addition, pricing schemes must be revised to better facilitate widespread implementation of DG. A dynamic pricing model can better reflect the actual value of electricity throughout the day. Controlled-average pricing has been employed to regulate pricing, but has failed in allowing the actual value of electricity to be realized. Dynamic pricing should better reflect the value fluctuations of power throughout the day, especially in peak and non-peak conditions. This method should factor externalities, such as public health, environmental, and place specific characteristics into utility rates. The result will be consumer recognition of the actual effects of the power they are consuming. Ideally, a model is developed that allows individuals to select which generation sites they use to meet power demands.

The main objective of the market approach is to allow distributed resources to compete with the central plant model (California Energy Commission, 2007). The ability of DG to compete will stimulate growth among innovative renewable energy technologies. Utiltiy rates will be decreased by developing a system that includes a higher number of power generation sites that compete to serve the electricity needs of the region. Security is also improved through additional back-up power and decentralized generation sources (California Energy Commission, 2007).

Community Education. The final policy approach proposed in this model is the based on educating the public. Outreach programs ought to be established that educate the public about the function of power systems, emissions, health effects, and pricing methods. There is a need for greater transparency, if a major shift to the traditional system is to take place. Transparency includes providing consumers with access to cost profiles throughout the day. The ultimate goal is to facilitate heightened demand from the public for electricity sources from sustainable DG projects. The public needs to be made aware of the air quality impacts from different types of power generation, transmission, and distribution and the associated health effects. The proposed dynamic pricing approach helps to encourage individual energy conservation efforts and more efficient use.

Outreach efforts can help to educate the public about the impacts of power generation, but the public should be introduced to programs that promote DG and various ownership models. The other recommended policies should be discussed and understood upfront. Too often, stakeholders are not made aware of policies and programs until they have already decided to engage in a project. Knowledge of these programs upfront may drive a group to begin a DG project that may have not occurred otherwise. In addition, community ownership models can be presented that show initial expenditures, financial incentives, payback periods, and long-term health and environmental impacts.

These policies should be adapted and employed by local governments, such as San Francisco. To date, most of the efforts of the city have centered on providing financial incentives, which have been effective, but additional measures will further promote DG. Much progress can be made by better addressing market and public education factors involved with shifting the traditional model to a DG-based system.

California has two primary partnerships that encourage fuel cells. The California Hydrogen Business Council (CHBC) and California Stationary Fuel Cell Collaborative (CaSFCC) facilitate collaboration among groups to promote stationary fuel cell installations. The CaSFCC has involvement from the California Air Resources Board, National Fuel Cell Research Center in Irvine, California, and other organizations. The California Public Utilities Commission has authorized a utility-owned 3 MW fuel cell project for California State University, San Francisco and has authorized other university campus to engage in similar projects. The San Francisco region is home to multiple fuel cell businesses, including Bloom Energy, UltraCell Corporation, CleanEdge Power, Oorja Protonics, Altergy Systems, Jadoo Power, and PolyFuel, which specializes in fuel cell membrane technologies.

San Francisco Fuel Cell Study

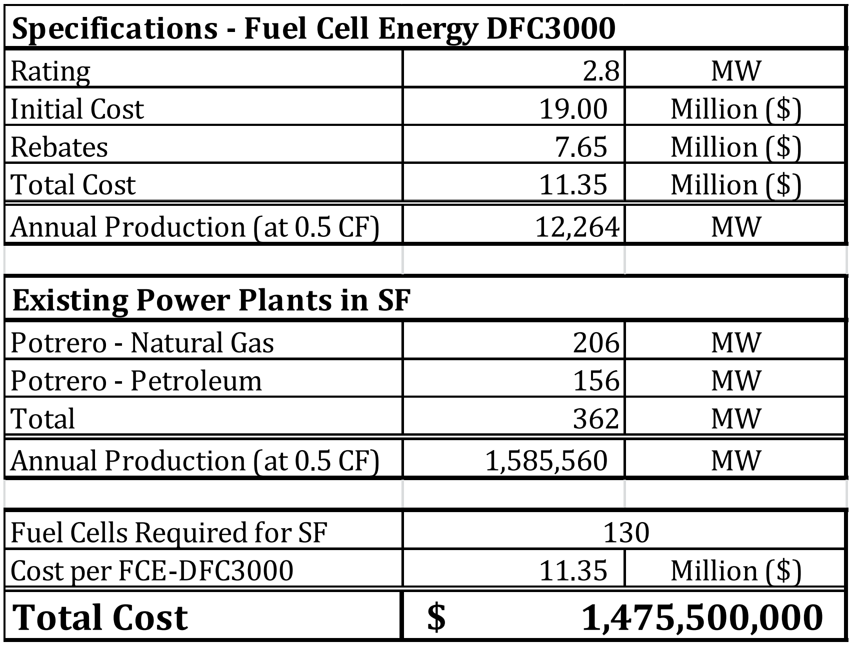
In order to understand the model proposed in this section, it is important to apply it to a specific project. The proposed fuel cell model in this study will be utilized as a phase-out strategy to the major power plant in San Francisco. The annual power consumption for the city is slightly above 6,000,000 MW (San Francisco Energy Watch, 2011). Although approximately three-fourths of the electricity is supplied by three hydroelectric power plants at the Hetch

Hetchy reservoir, there is only one major power station in the city. The Potrero power plant is located on the east side of the city and includes natural gas and petroleum plants. The natural gas section of the Potrero plant is rated at 206 MW and the petroleum plant has an output rating of 156 MW. Together, the output rating totals 362 MW. A capacity factor of 0.5 will be utilized for this study, which is common among power technologies. As you will recall, capacity factor refers to the level at which a power source operates in relation to its full capacity. With a capacity factor of 0.5, total output for the Potrero plant is 181 MW. This equates to an annual generation 1,585,560 MW.

The Potrero power plant is currently being phased-out, which is appropriate given this study. The proposed model uses a fuel cell project at the University of California, San Diego (UCSD) as a point of reference. UCSD is installing an $11.35 million system capable of generating 2.8 MW, which is the largest university fuel cell project in the country. This project will be complete by the end of 2011, so it is appropriate in the context of time. The initial cost was $19 million, but state incentives from the Self-Generation Incentive Program, Emerging Renewables Program, and other measures provided $7.65 million in rebates. The fuel cell being installed on the UCSD campus is manufactured by a company called Fuel Cell Energy.

Fuel Cell Technology makes the DFC3000, which is rated at 2.8 MW. This fuel cell and its cost of $11.35 million for the UCSD project will be applied to the San Francisco study. The annual generation for one DFC3000 with a capacity factor of 0.5 is 12,264 MW. To match the generation of the Potrero plant, 130 of the DFC3000 fuel cells must be installed throughout the city. The total cost including installation is approximately $1.48 billion. Table 7.1 breaks down the specifications and costs for this proposal.

Table 7.1: Fuel Cell Model for San Francisco.



Specifications - Fuel Cell Energy DFC3000		
Rating	2.8	MW
Initial Cost	19.00	Million ($)
Rebates	7.65	Million ($)
Total Cost	11.35	Million ($)
Annual Production (at 0.5 CF)	12,264	MW
Existing Power Plants in SF		
Potrero - Natural Gas	206	MW
Potrero - Petroleum	156	MW
Total	362	MW
Annual Production (at 0.5 CF)	1,585,560	MW
Fuel Cells Required for SF	130	
Cost per FCE-DFC3000	11.35	Million ($)
Total Cost	**$ 1,475,500,000**	

The dimensions of the DFC3000 are about 56’ by 78’. This is approximately one-tenth the size of a football field from goal line to goal line. To match the output of the Potrero plant, 130 fuel cells must be installed throughout the city. This equates to a total land area of approximately 567,840 square feet, or 0.0204 square miles. That is less than 0.05 percent of the total land area of San Francisco. The Potrero plant produces only about a quarter of the electricity supplied to the city, but if this model was used to meet the total power demands of the city, the land area required would still be less than 2 percent of the city and less than 1 square mile.

The implementation of this fuel cell-based approach will result in a significant reduction in emissions. Petroleum-fueled power plants produce very high emissions. Table 7.2 shows power generation emissions from petroleum, natural gas, and fuel cell sources. The emission levels for natural gas and petroleum power plants are based on EPA averages. Natural gas performs better than petroleum, especially in terms of SO_x emissions, but still produces higher emissions than the DFC300 fuel cell. The DFC3000 outperforms natural gas and petroleum in all areas.

Table 7.2: Emissions from Fuel Cell, Natural Gas, and Petroleum Based Power Production.

Pollutant	**Fuel Cell (DFC3000)**	**Natural Gas**	**Petroleum**	**Units**
NO_x	0.01	1.7	4	lb/MWh
SO_x	0.0001	0.1	12	lb/MWh
PM_{10}	0.00002	N/A	N/A	lb/MWh
CO_2	980	1135	1672	lb/MWh
CO_2 (with heat recovery)	520 - 680	N/A	N/A	lb/MWh

Data Source: U.S. EPA, 2007; Fuel Cell Energy, 2010.

The figures presented in Table 7.2 may not mean much in the abstract, but Table 7.3 shows annual emissions data for the three power sources. The proposed fuel cell model reduces NO_x and SO_x emissions by over 99 percent each. This has positive implications for public health by reducing ground-level ozone production, respiratory problems, and other physical ailments. In terms of CO_2 emissions, over a 28 percent reduction will be experienced. When factoring the exclusion of transmission lines, these reductions are even greater. Table 7.4 shows that CO_2 is reduced an additional 6.5 percent when the average 10 percent loss in transmission is factored, resulting in a total reduction of 34.80 percent.

Table 7.3: Annual Emissions Totals Comparing the Proposed Fuel Cell Model to the Potrero Power Plant in San Francisco.

Power Source	**Annual Generation (MW)**	**NO_x**	**SO_x**	**CO_2**
Potrero Plant - Natural Gas	902,280	1,533,876	90,228	1,024,087,800
Potrero Plant - Petroeum	683,280	2,733,120	8,199,360	1,142,444,160
Total Potrero Plant	1,585,560	4,266,996	8,289,588	2,166,531,960
Fuel Cell Energy DFC3000	1,585,560	15,856	159	1,553,848,800
Difference (Reduction)	0	4,251,140	8,289,429	612,683,160
		99.6284%	99.9981%	28.2794%

Table 7.4: Emissions Reductions with Transmission Losses Factored.

Power Source	**Annual Generation (MW)**	**NO_x**	**SO_x**	**CO_2**
Potrero Plant - Natural Gas	992,508	1,687,264	99,251	1,126,496,580
Potrero Plant - Petroeum	751,608	3,006,432	9,019,296	1,256,688,576
Total Potrero Plant	1,744,116	4,693,696	9,118,547	2,383,185,156
Fuel Cell Energy DFC3000	1,585,560	15,856	159	1,553,848,800
Difference (Reduction)	158,556	4,677,840	9,118,388	829,336,356
		99.6622%	99.9983%	34.7995%

The reductions in emissions of NOx and SO_x are highly significant for reducing acute and chronic public health concerns. CO_2 emission reductions improve public health by minimizing the effects of global warming. A reduction of almost 830 billion pounds of CO_2 is achieved for the phase-out of Potrero plant and replacement with distributed fuel cells. Replacing one large power plant in a dense city shows that much progress can be made to reduce global warming and other detrimental effects that result from power generation.

Concluding Thoughts

The model proposed in the Recommendations section shows that a great deal of progress can be made by reconfiguring power generation and transmission systems. The study of San Francisco shows how much more effective this model can be to reduce emissions and improve efficiency, while facilitating sustainable technologies. The DG model won't takeoff overnight, but it is important to shift practices to those that more efficiently utilize our resources. By shifting away from the traditional model of central plant combustion power generation and long distance transmission, great strides can be made in improving air quality and reducing resource depletion, while providing consumers with an even more reliable and stable power supply.

It is with great hope that decision-makers will learn about the advantages offered by the DG model and push for implementation. It is imperative to begin shifting traditional power generation, transmission, and distribution trends as soon as possible. California is well-suited for this shift given their progressive approach to energy reform. It begins with phase-out plans for high-polluting power plants and replacing the output from these sources with sustainable DG. In time, DG will become more prevalent and microgrids will be formed, which are better-suited to meet demand and promote renewable technologies. These efforts will improve public health and the environment as well as economies.

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Appendix

Table for Figure 3.1 (page 34)

Net Generation by Energy Source in CA: 1998 to 2009 (thousands of MW Hours).

Year	Coal	Petroleum	Natural Gas	Geothermal	Hydroelectric Conventional	Nuclear	Biomass	Solar	Wind	Wood	Other Gases	Other	Total
1998	2,159,070	2,213,072	75,131,992	12,839,684	49,548,200	34,594,206	2,399,711	502,339	2,757,869	3,148,981	3,076,556	6,225,537	194,597,217
1999	2,296,082	2,137,916	85,098,862	13,045,715	40,736,667	33,371,857	2,382,646	494,996	3,229,953	3,469,703	2,417,613	5,887,316	194,569,326
2000	2,363,607	2,839,794	103,218,973	12,308,471	38,333,786	35,175,505	2,610,332	493,334	3,518,023	3,573,501	2,687,177	6,260,678	213,383,181
2001	2,232,851	3,054,893	111,932,271	12,181,294	25,541,776	33,219,520	2,082,536	542,271	3,499,738	3,323,777	1,130,499	4,454,276	203,195,702
2002	2,327,809	1,961,066	89,624,044	13,073,615	31,140,628	34,352,340	2,018,759	554,372	3,802,645	3,957,589	1,240,053	5,197,642	189,250,562
2003	2,326,305	2,392,249	91,432,181	12,981,763	36,370,704	35,593,789	2,254,281	533,606	3,895,431	3,880,037	1,759,015	5,639,052	199,058,413
2004	2,237,808	2,262,897	100,222,233	13,105,306	34,140,929	30,267,887	2,161,922	570,890	4,305,875	3,826,906	2,065,965	5,892,871	201,061,489
2005	2,135,375	2,543,697	93,353,849	13,022,639	39,631,867	36,154,898	2,223,526	536,713	4,262,229	3,609,139	2,279,584	5,888,723	205,642,239
2006	2,235,342	2,368,174	105,691,116	12,821,434	48,047,380	31,958,621	2,294,495	494,572	4,882,801	3,422,093	2,022,446	5,444,539	221,683,013
2007	2,298,306	2,333,974	115,700,470	12,990,711	27,327,751	35,792,490	2,305,228	556,969	5,584,933	3,407,416	1,818,106	5,225,522	215,341,876
2008	2,280,401	1,741,590	119,991,737	12,883,000	24,127,810	32,482,351	2,361,946	670,481	5,384,955	3,483,555	1,684,863	5,168,418	212,261,107
2009	2,049,947	1,542,848	113,463,455	12,852,783	27,888,036	31,763,804	2,467,660	647,390	5,839,813	3,732,016	1,622,844	5,354,860	209,225,456
Percentage of Total (2009)	1.0%	0.7%	54.2%	6.1%	13.3%	15.2%	1.2%	0.3%	2.8%	1.8%	0.8%	2.6%	

Table for Figure 3.2 (page 34)

Net Generation by Energy Source in the U.S.: 1998 to 2009 (thousands of MW Hours).

Year	Coal	Petroleum	Natural Gas	Geothermal	Hydroelectric Conventional	Nuclear	Biomass	Solar	Wind	Wood	Other Gases	Other	Total
1998	1,873,515,690	128,800,173	531,257,104	14,773,918	323,335,661	673,702,104	22,447,935	502,473	3,025,696	36,338,384	13,492,230	49,830,614	3,671,021,982
1999	1,881,087,224	118,060,838	556,396,127	14,827,013	319,536,029	728,254,124	22,572,175	495,082	4,487,998	37,040,734	14,125,592	51,166,326	3,748,049,262
2000	1,966,264,596	111,220,965	601,038,159	14,093,158	275,572,597	753,892,940	23,131,314	493,375	5,593,261	37,594,866	13,954,758	51,549,624	3,854,399,613
2001	1,903,955,943	124,880,222	639,129,120	13,740,501	216,961,044	768,826,308	14,548,153	542,755	6,737,332	35,199,905	9,039,473	44,239,378	3,777,800,134
2002	1,933,130,354	94,567,394	691,005,745	14,491,310	264,328,833	780,064,087	15,043,712	554,831	10,354,279	38,665,040	11,462,686	50,127,726	3,903,795,997
2003	1,973,736,750	119,405,640	649,907,541	14,424,231	275,806,328	763,732,695	15,811,992	534,001	11,187,467	37,529,097	15,600,020	53,129,117	3,930,804,879
2004	1,978,300,549	121,145,057	710,100,017	14,810,975	268,417,308	788,528,387	15,420,570	575,155	14,143,741	38,116,883	15,252,431	53,369,314	4,018,180,387
2005	2,012,873,046	122,225,017	760,960,254	14,691,745	270,321,255	781,986,365	15,420,393	550,294	17,810,549	38,856,417	13,464,144	52,320,561	4,101,480,040
2006	1,990,511,135	64,166,414	816,440,770	14,568,029	289,246,416	787,218,636	16,098,525	507,706	26,589,137	38,762,096	14,176,808	52,938,904	4,111,224,576
2007	2,016,455,584	65,738,978	896,589,791	14,637,213	247,509,974	806,424,753	16,524,554	611,793	34,449,927	39,014,024	13,453,354	52,467,378	4,203,877,323
2008	1,985,801,247	46,242,612	882,980,599	14,839,977	254,831,385	806,208,435	17,733,759	864,315	55,363,100	37,299,853	11,706,876	49,006,729	4,162,878,887
2009	1,755,904,253	38,938,193	920,796,875	15,008,658	273,445,094	798,854,585	18,442,596	891,179	73,886,132	35,595,736	10,629,031	46,224,767	3,988,617,099
Percentage of Total (2009)	44.0%	1.0%	23.1%	0.4%	6.9%	20.0%	0.5%	0.0%	1.9%	0.9%	0.3%	1.2%	

Table for Figure 3.3 (page 37)

Emissions levels in California from 1998 to 2009 in metric tons.

Emission	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Carbon Dioxide (CO_2)	53,189,522	57,884,698	67,796,616	71,663,002	60,018,466	56,308,410	60,169,585	54,998,800	59,732,083	63,139,829	62,548,568	59,427,649
Sulfur Dioxide (SO_2)	126,994	140,154	126,498	41,064	69,977	17,496	22,311	25,628	26,537	22,820	3,840	2,949
Nitrogen Oxides (NO_x)	134,445	137,101	145,435	107,027	89,763	106,093	98,232	86,239	90,597	88,568	82,493	83,201

Table for Figure 3.4 (page 38)

Figure 3.4: Emissions levels in the U.S. from 1998 to 2009 in metric tons.

Emission	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Carbon Dioxide (CO_2)	2,351,599,517	2,366,302,296	2,470,834,445	2,418,606,723	2,423,963,090	2,445,094,300	2,486,981,558	2,543,838,163	2,488,917,751	2,547,032,486	2,484,012,111	2,269,507,628
Sulfur Dioxide (SO_2)	13,464,481	12,843,369	11,963,314	11,174,367	10,881,432	10,645,809	10,308,805	10,339,543	9,523,561	9,041,697	7,829,798	5,970,324
Nitrogen Oxides (NO_x)	6,458,698	5,955,499	5,638,125	5,289,879	5,193,632	4,531,725	4,143,036	3,961,097	3,799,447	3,650,010	3,330,223	2,395,450