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# Executive summary

The promise of a future world dominated by rapid population growth and unparalleled energy demand presents many challenges to the global energy industry and indeed society as a whole. The need to satisfy people's energy needs whilst conserving resources, the environment and maintaining a viable economy gives a vivid impression of the dilemmas faced in piloting a sustainable future. Increased electrification will be central to future world energy development. The distributed generation concept offers many advantages over established electricity generation infrastructures and will play a major role in the provision of world energy needs. Distributed generation involves the deployment of small, modular generator units dispersed throughout the customer population. The close proximity of generation capacity to the regions of demand gives many advantages such as reduced transmission losses, increased network robustness, higher power quality and greater network flexibility. Environmental benefits include reduced fuel usage, lower emissions of $CO_2$ and other pollutants and an increased utilization of renewable power. The evolution to a distributed generation infrastructure is occurring due to existing centralized generator and transmission networks reaching capacity and lifetime limitations, along with the emergence of economically attractive technologies such as natural gas turbine cogeneration plants and advanced information technology based systems management tools. The most significant enabling influences driving the development of distributed generation are primarily regulatory in nature and the impact of policy in this area can be critical. The distributed generation concept embraces many issues central to the need for a sustainable energy future. This paper seeks to present in a general manner, some of the advantages, limitations, technologies and influencing policy mechanisms that are central to the development of distributed electricity generation.

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# 1 Introduction

## *1.1 Energy perspective and trends*

Electric utilities are the United States' largest industry, with more than $600 billion in assets and annual sales exceeding $200 billion. The magnitude of the electricity sector is representative of the critical role electricity plays in society. The electricity system is in many respects the most critical infrastructure of modern society as it enables all other infrastructures and is the 'prime mover' of society (Moore (1999)).

The generation and supply of electricity has historically developed, largely due to its strategic importance, as state controlled monopolies. In recent years, the United States (amongst other nations such as the UK and Australia) has sought to deregulate electricity utilities and open the industry up to competition (Munsen (1998)). Production from private non-utilities has doubled between 1990 and 1996 to around seven percent of US electricity production and this level continues to grow.

During the next century, global demand for electricity will surge on the tide of rapid population growth, increasing urbanization, global commerce and the needs of human welfare. By 2050, the earth is likely to contain at least sixty megacities (population above 10 million) situated mainly in the developing world, that will require up to four times the current global electricity consumption (Moore (1999)).

The global electricity industry is currently in a state of flux. The forces driving this transition are derived from a growing trend of market deregulation, increased competition and the emergence of new technologies. However, at a more profound level, the industry must adjust to satisfy the global electricity needs of the future in a world of rapid population growth and major environmental sensitivity, particularly with regard to carbon dioxide and the greenhouse effect. In essence, the electricity industry must find a way to strike a balance between satisfying global energy needs of a growing world population, whilst simultaneously achieving people's desired quality of life and conserving the natural environment. One avenue that is showing promise as a means of enabling these aspirations for a sustainable electricity future is the concept of *distributed generation*.

## 1.2 Distributed generation

The established electricity infrastructure typically consists of large, centralized power generation facilities linked to the final electricity consumers via a complex network of transmission lines, switch and substations and feeder distribution lines (Figure 1). The concept of distributed generation is based on the provision of many small capacity (1kW to 30 MW (Maskovitz (2000))) generation units situated much closer to the electricity consumers. The generation units can be operated at the point of use with excess sold to the grid, or by generator units dispersed within the local distribution network (Figure 2).

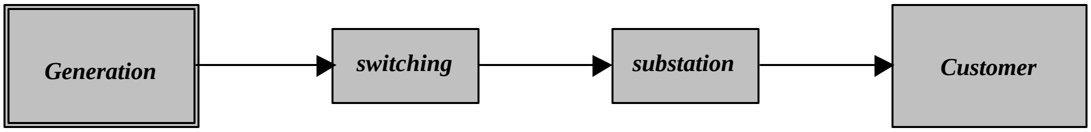

**Figure 1. Schematic illustration of conventional electricity generation and distribution.**

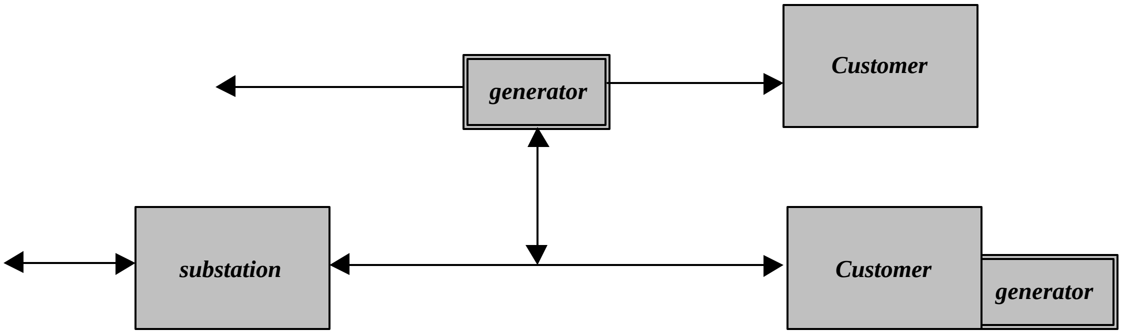

**Figure 2. Illustration of the distributed generation concept with generation capacity closer to the customer base. Generators can supply local customers and/or supply the greater network.**

### *1.3 Motivation and scope of paper*

Distributed generation is emerging as an important option for the future development and restructuring of electricity infrastructure. Possible benefits of distributed generation include lower electricity costs, higher flexibility, improved power quality, higher system efficiency and greater reliability (Douglas (1999)). This paper seeks to examine some of the potential benefits and limitations associated with distributed generation, along with canvassing some of the key technologies driving its development. The enabling and prohibitive conditions, from regulatory and policy perspectives, are discussed in a general manner to introduce some of the broader implications of distributed generation.

# 2 Technology

A series of technological innovations (particularly within the last decade) have laid the foundation for the emergence of distributed generation. The advent of compact, highly efficient generation units; and advances in information technology and systems management are the two primary aspects of the enabling technology.

## *2.1 Electricity generation technology*

The function of an electricity generator is in essence to transform one form of energy (eg. Chemical energy in fuels or kinetic energy in wind) into electrical energy as efficiently as possible. As such, the choice of generation technology is strongly dependent on the primary energy supplies available at the point of generation. Some of the main generation technologies being canvassed for future distributed generation applications are discussed as follows.

### *2.1.1 Stand alone reciprocating engine generators*

Conventional engine based generator units (typically diesel fuelled) are an established technology that has found wide application as stand-by emergency generators. These units have found application as perhaps the first crude incarnation of distributed generation as power plants for remote (off-grid) communities (Figure 3). These generators are relatively inefficient and can be responsible for significant local pollution and so may ultimately be replaced by more modern technologies.

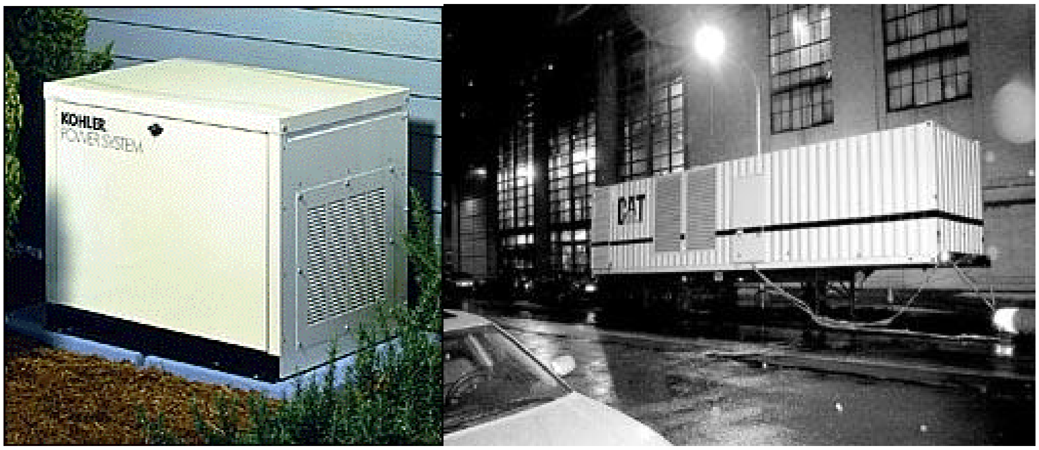

**Figure 3. Diesel generator units. Picture on left is of a small household generator of 8.5kW capacity. The larger truck based unit was rented by MIT as a backup generator for potential Y2K power-outages late last year.**

### *2.1.2 Gas turbines*

The gas turbine has emerged from the aerospace industry as a highly efficient, (relatively) inexpensive, mass produced technology that is finding growing application in modern generating units (). A natural gas turbine driven combined cycle unit combining electrical generation from shaft work of the turbine and a steam cycle converting waste exhaust heat into additional electricity (Figure 4) can achieve thermal efficiencies of up to 60%. Additional utilization of waste heat for domestic or commercial heating can even raise efficiencies above 90% (Munson *et al.* (1998)). High efficiencies coupled with cost effectiveness and availability of natural gas is making natural gas fired turbine based cogeneration plants a driving force in modern electricity infrastructures. It is likely that medium sized cogeneration plants will form the back bone of the distributed generation networks of the future.

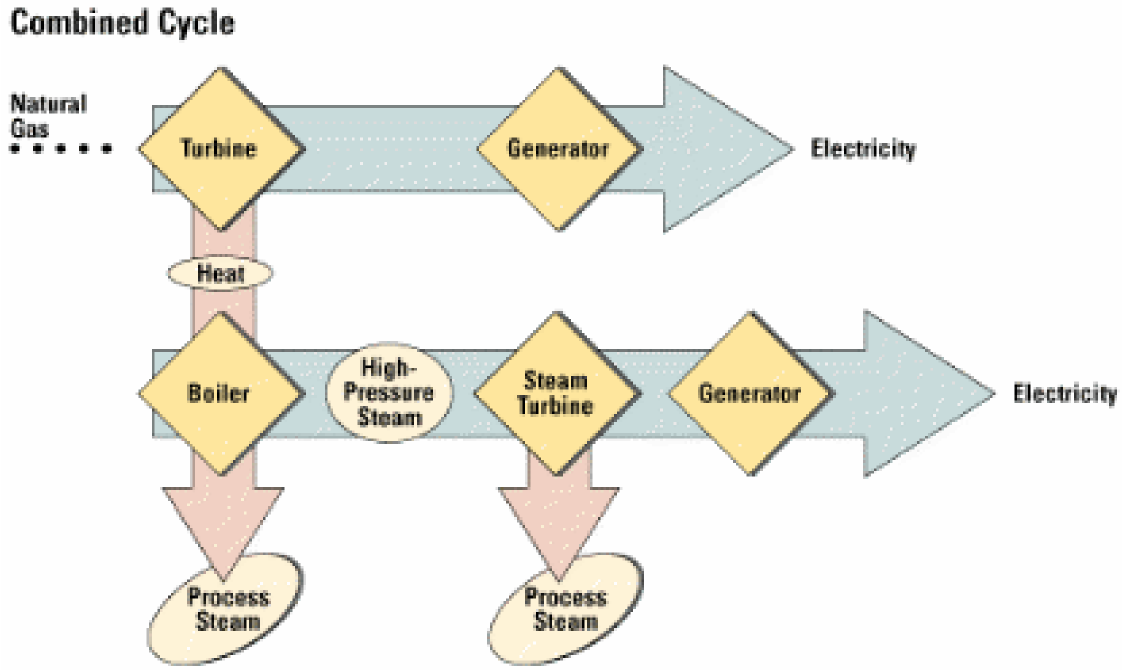

**Figure 4. Diagram showing the operation of the natural gas turbine combined cycle.**

### *2.1.3 Microturbines*

Microturbines are, as the name suggests, a smaller version of the gas turbines used for larger cogeneration plants. Developed largely as military power plants for tanks and missiles, they have typical power outputs of between 10 and 250 kW (Douglas (1999)). The compactness of microturbines makes these units ideal for small businesses or households and will offer new opportunities for peak shaving and cogeneration at a very localized level (Figure 5).

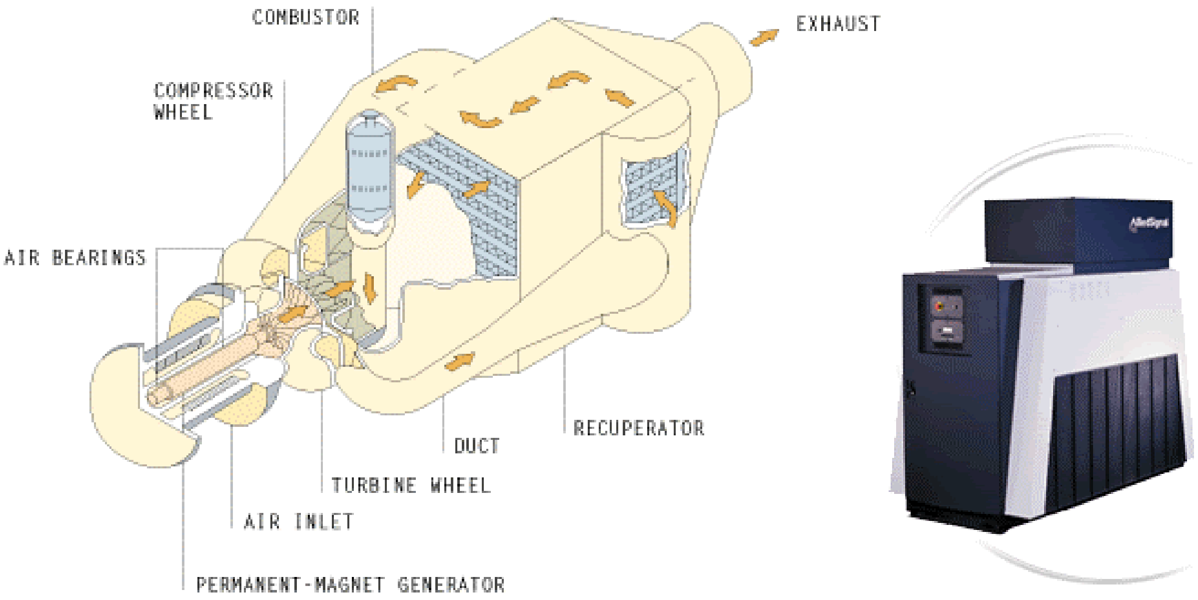

**Figure 5. Diagram of microturbine generator and a commercial unit.**

The emergence of turbines and microturbines will encourage and exploit a much broader characteristic of future energy infrastructure, namely the merging of natural gas and electricity grids. The merging of these two mediums of energy transport will give unparalleled opportunity for electricity generation (and thermal heating) at multiple scales within the overall network (Figure 6).

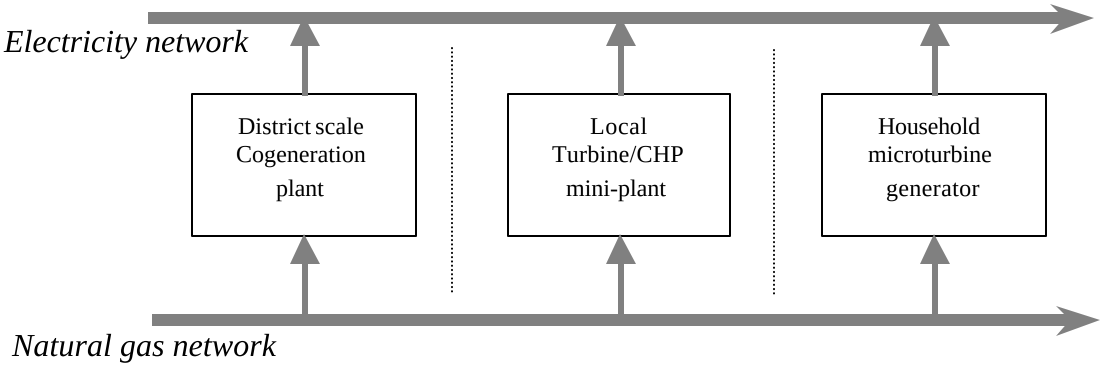

**Figure 6. Convergence of natural gas and electricity networks will give scale of generation capacity.**

### 2.1.4 Photovoltaic cells

Photovoltaic (PV) cells directly convert sunlight into electricity. The intricate, semiconductor based nature of PV cells requires sophisticated manufacturing technology and as such they are relatively expensive generation options. Increasing market demand and improvements in manufacturing efficiencies are likely to make PV cells more economically appealing options in the future. Two areas where PV cells are finding increased utilization are for rural communities and as premium priced green electricity utility options for discerning consumers. Problems with low and variable resource availability (capacity factor) makes solar energy a potentially troublesome generation method. Coupling PV units to energy storage devices would be a more practical option.

### 2.1.5 Wind power

A means of indirectly capturing solar energy is to convert wind power into electricity. Wind power units suffer from similar sensitivity to low availability as solar power and the use of efficient energy storage devices would again temper many of these difficulties. The role of wind power within a distributed generation infrastructure would most likely be limited to geographical regions with high quality and regular wind conditions or to remote areas isolated from the network (Figure 7). The coupling of wind, solar and diesel power for rural and developing communities is a particularly appealing possibility.

**Figure 7. Solar and wind power applications for remote localities.**

### *2.1.6 Fuel cells*

Fuel cells generate electricity by sustaining a chemical reaction by transfer of charged species across a membrane separating the fuel (eg. hydrogen, methane) and oxidant streams (Figure 8). By directly converting chemical energy into heat and electricity, and avoiding pollutant forming side reactions, fuel cells can achieve electric efficiencies close to 55%, and if the waste heat is recovered then higher than 90% efficiency (Munson (1998)). Fuel cells are being explored for use both in vehicles and as stationary generators, however their currently high capital cost must be reduced by at least an order of magnitude for them to find widespread use. A comparison of the costs associated with the main candidates for distributed generation are listed in (Table 1).

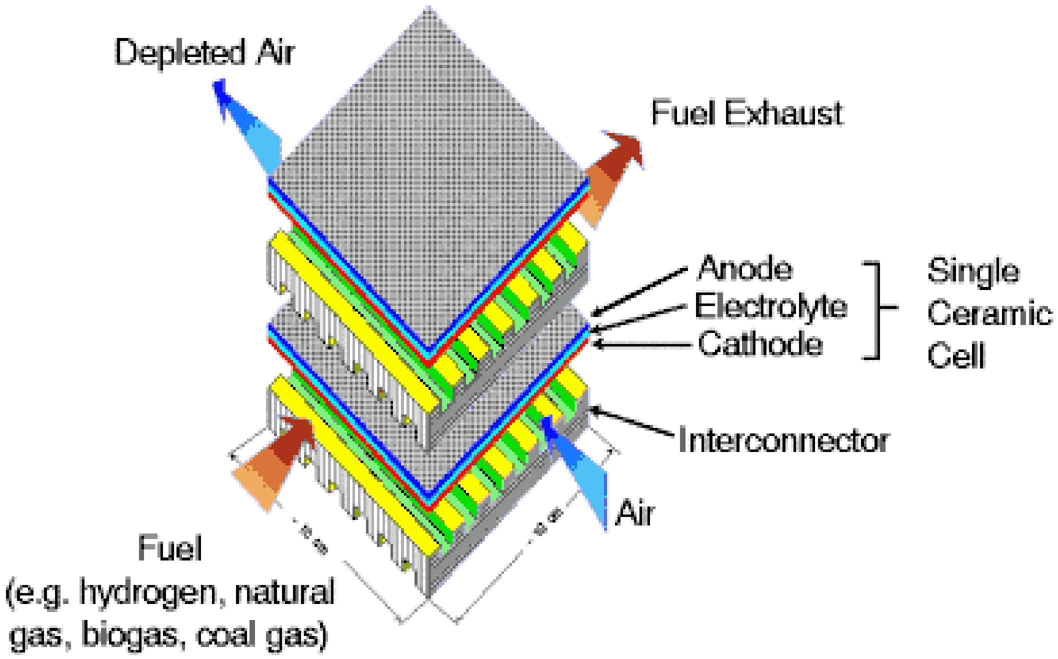

**Figure 8. Cutaway diagram showing construction of a typical fuel cell.**

One of the more ambitious applications of distributed fuel cells that is being proposed is to use fuel cell powered vehicles to provide power to the grid system when they are not being used for transport. One million fuel cell powered vehicles in use by 2010 could generate approximately 50-100 GW (5-10% of anticipated US capacity).

**Table 1. Summary comparison of the main distributed generation technologies (DPCA (2000)).**

| | *Engine Generator* | *Turbine Generator* | *Photovoltaics* | *Wind Turbine* | *Fuel Cells* |
|---|---|---|---|---|---|
| Dispatchability | Yes | Yes | - | - | Yes |
| Capacity Range | 500 kW – 5 MW | 500 kW – 25 MW | 1kW - 1MW | 10 kW - 1MW | 200 kW - 2MW |
| Efficiency | 35% | 29 - 42% | 6 - 19% | 25% | 40 - 57% |
| Energy Density (kW/m2) | 50 | 59 | 0.02 | 0.01 | 1.0 - 3.0 |
| Capital Cost ($/kW) | 200 - 350 | 450 - 870 | 6,600 | 1,000 | 3,750 |
| O&M Cost (&/kW) | 0.01 | 0.005- 0.0065 | 0.001- 0.004 | 0.01 | 0.0017 |
| NOx (lb/Btu) | | | | | |
| Natural Gas | 0.3 | 0.1 | n/a | n/a | 0.003 - 0.02 |
| Oil | 3.7 | 0.17 | n/a | n/a | - |

### *2.1.7 Zero Emission Power Plants (ZEPPs)*

An example of a highly novel generation technology that has been proposed for distributed generation applications is the so-called Zero Emission Power Plant (ZEPP). The ZEPPs would utilize a wet oxidation process with a circulating medium of supercritical $CO_2$. Methane would be injected into the $CO_2$ where it would react with oxygen to drive an ultra high speed turbine operating at high pressures. Liquid $CO_2$ would be bled off and diverted to sequestration (Moore (1999)). The ZEPPs would each supply an estimated 5GW and would be about the size of a locomotive.

### *2.1.8 Biomass and Municipal waste power*

Biomass fueled electric generators have found widespread application in industries such as paper manufacturing that can utilize much of their waste material stream for power generation. Biomass derived power of this kind is unlikely to find the same widespread distributed function of the smaller, modular units discussed previously. However, by satisfying in-house electricity generation requirements for industries with biomass waste streams and supplying excess power and heat to the surrounding communities these technologies will contribute to the overall role of distributed generation.

Municipal waste combustor plants can potentially play an important role in a distributed generation regime. By simultaneously satisfying both waste disposal and electricity generation services, these plants can take advantage of a fuel source present in the same vicinity as the energy need, along with an existing efficient waste collection infrastructure. By recovering energy from highly processed materials such as plastics; displacing fossil fuel powered energy sources; municipal steam heating and giving reduced $CO_2$ emissions due to the high proportion of biomass in the waste stream, these plants offer some significant advantages. Older generation municipal waste plants have historically suffered from highly publicized releases of dioxins, furans, heavy metals and acid gases to the atmosphere. However, the combination of improved combustor technologies (circulating fluidized beds), sophisticated air pollution controls and mechanized presorting of the feed stream to remove recyclables and non-combustible materials, in modern generation plants (Figure 9) has successfully addressed these environmental concerns (Foster Wheeler (1998)).

**Figure 9. The Robbins waste-to-energy facility near Chicago. This plant utilizes presorting, modern circulating fluidized bed furnaces and comprehensive air pollution control technology to achieve extremely high environmental performance (Foster-Wheeler (1998)).**

### *2.1.9 Miscellaneous renewable technologies*

The development of distributed generation promotes the use of renewable generation technologies. The generally small capacity of generator units would allow communities a larger say in the technology employed in their locality, an influence that would conceivably tend to favor the use of renewable and clean technology. The small size and modular construction of generators for distributed networks would likely help to reduce the cost of renewable hardware. Additional renewable electricity generation technologies that could find a role in the distributed network of the future could include geothermal (hot dry rock and hydrothermal), low-head hydroelectric, sewage composting, landfill derived methane and tidal power.

### *2.1.10 Energy storage*

An important technology that would be necessary to achieve the full benefits of distributed generation is energy storage. In particular, photovoltaic cells and wind turbines can be made far more effective by smoothing their fluctuating generation patterns with an energy storage buffer. Potential energy storage devices could be based on electrolysis of water, flywheels, pumped hydro, super-conducting storage devices, super-capacitors and battery arrays. Water electrolysis has been proposed as a means of utilizing off peak electricity and generating hydrogen for use in vehicles or stationary fuel cells (Moore (1999)).

### *2.1.11 Carbon sequestration*

The capture of $CO_2$ from fossil fuel power generators and the subsequent sequestration in carbon repositories will be an integral part of the overall distributed generation strategy. A front end method of $CO_2$ capture could occur at the natural gas well head with re-injection of $CO_2$ into the well to improve production capacity and only the reformed $H_2$ would be shipped to the generator (Lovins (1999)). End of pipe $CO_2$ sequestration would involve capturing $CO_2$ produced from the generator and transport to a suitable repository such as the ocean or rock caverns.

### *2.1.12 Generation portfolio*

Future energy generation capacity will most likely utilize a portfolio of technologies drawing from established and emerging technologies discussed previously and from technologies that are yet to be invented. The World Energy Council (WEC) envisions that by 2050 at least seven different generation sources will be utilized with each maintaining no more than 30% market share (Moore (1999)). There is also great scope for the coupling of technologies for mutual advantage, such as wind turbines and diesel generators. It is also important to note that the present day generation infrastructure will not be replaced entirely (at least not in the short term). Large nuclear and coal fired generators will continue to provide baseload power for the immediate future, with distributed generation developing to meet the growth in electricity demand above the conventional baseload.

## *2.2 System management*

The use of smaller, modular generation units dispersed throughout the energy consumption community offers many benefits, however the distributed generation regime also poses some significant challenges in terms of practical implementation. These challenges are essentially related to the question of how to coordinate and control a myriad of diverse and dispersed generation units, whilst satisfying customer demand along with economic and environmental objectives. Advances in telecommunication and information technology in the last decade mean that we now have the capabilities to address many of these issues.

The coordination of distributed power generation units to satisfy customer demand both in the locality of the unit and also the broader network requires efficient real-time, two-way communication (Munson (1998)). A vivid illustration of the need for effective coordination is the proposal of fuel cell powered vehicles supplying power to the grid. There are also significant issues associated with ensuring that the individual generators link up with the greater power network, however this can be resolved through early development of standards and protocols. Electricity distribution networks currently rely on electro-mechanical switching controls that are too slow to control the complex dynamics of a distributed generation network in real time. The transition to faster acting digital controls is already proceeding with the emergence of flexible AC transmission system (FACTS) and wide area measurement system (WAMS) technologies (Douglas (1999)). Electronic control of the supply grid will enable coordination of truly continental scale power systems, alleviate congestion and reduce power losses. Other technologies that show promise in the area of distributed system management include superconducting cable, advanced power meters, and billing software that is capable of identifying the source of power generation, and automatically dispatching payment whilst simultaneously seeking lowest cost suppliers (Douglas (1998)).

The successful implementation of distributed generation is dependent on the advances in information technology and telecommunications (Hodge *et al.* (1997)). Distributed generation networks will be able to dynamically tune the overall generation ensemble to optimize to cost, supply, maintenance and environmental objectives whilst alleviating congestion on the baseload transmission network and reducing overcapacity fuel use.

# 3 Potential benefits and limitations

## 3.1 Benefits

### 3.1.1 Economic

The implementation of a distributed generation system would offer some significant economic benefits. One of the most immediate gains from introducing additional capacity closer to the consumer is that transmission and distribution costs can be dramatically reduced, as the loads on these bottlenecks are alleviated along with the need to invest capital in larger capacity transmission. The advantages of economics of scale can be realized through the production of small, modular power generation units that can utilize common engineering, maintenance and supporting resources (Lovins *et al.* (1999)). Smaller capacity plants would also require low capital investment and would enjoy short lead and payback times (DPCA (2000)). The enhanced level of market competition implicit in the distributed generation concept will result in greater consumer choice and service (Moskovitz (2000)). Customer services would most likely be enhanced through the provision of integrated services such as communication and heating within electricity supply companies (Douglas (1999)). The central role of real time pricing and billing in distributed generation would give consumers unparalleled opportunity to search for the cheapest deals whilst allowing producers to take advantage of spot market arbitrage opportunities.

**Table 2. Potential for savings in transmission and distribution costs from implementation of distributed generation (DPCA (2000)).**

| *Area* | *US$ saved/ MWh produced* |
|---|---|
| Substation Deferral | 1.60 - 60.27 |
| Transmission System Losses | 2.34 - 3.14 |
| Transmission Wheeling | 2.78 - 7.14 |
| Distribution Feeders | 0.67 - 1.72 |

### *3.1.2 Environmental*

Distributed generation promises a number of environmental advantages including reduced fossil fuel consumption and lower $CO_2$ emissions (Shelor (1998)). The distribution of smaller, modular units would also encourage the permeation of renewable generation technologies into the mainstream energy portfolio (Douglas (1999)). The widespread adoption of natural gas and displacement of coal would lead to gains in $CO_2$ reductions and improved air quality (Table 3). In 1989 the United Kingdom began a shift from coal to natural gas power and after six years $CO_2$ emissions had been reduced by nearly 40% and $NO_x$ by 51%. By combining the electricity generation and district thermal heating functions, combined heat and power (CHP) plants have been able to make significant gains in fuel efficiency. Currently in the USA, electric generators produce one third of $CO_2$ emissions and another third comes from separate stand alone thermal heating plants. By continued development of CHP, significant cuts to $CO_2$ emissions will be realized (Munson (1998)). The Netherlands is an example of a country that is widely implementing CHP to achieve these benefits (Jeffs (1994)).

**Table 3. Environmental benefits through emission credits (DPCA (2000)).**

| *Emission* | *US$ saved/ MWh produced* |
|---|---|
| $SO_2$ Emission Offset | 1.50 - 4.50 |
| $NO_x$ Emissions avoided control costs or emissions offset | 1.15 - 28.40 |
| $CO_2$ Emissions, potential tax offset | 0.00 - 15.00 |

### *3.1.3 International development and social benefits*

The implementation and operation of distributed generation infrastructure will create significant job growth. Estimates also suggest that nearly five times as many jobs will be created from investment in distributed generation than for the equivalent level of additional conventional utility capacity (Lovins (1999)). Distributed generation may also offer significant benefits to developing countries. Developing rural communities may be serviced by household/community scale renewable sources such as solar and wind power (also coupled to storage or diesel power) that avoids the prohibitive costs of ambitious transmission based networks. A broader consideration of the term ‘distributed’ shows that there may be opportunities to forge closer relationships between bordering nations by cooperative use of mutual energy resources, such as the Mekong river dam project in south-east Asia (Hennagir (1995)).

### *3.1.4 Operational benefits*

The enhanced operational flexibility of a distributed generation network offers some additional advantages. More efficient system regulation will enable improved power quality, which is a premium commodity for the growing electrotechnology intensive commercial sector. Network reliability is a central concern in modern power industries as many transmission systems are currently operating close to their stability limits due to congestion. The cost of a single outage in the western United States during 1996 alone is estimated at nearly $1 billion (Douglas (1999)). Enhanced system reliability will be achieved through the additional redundancy built into the electricity distribution network (networked versus conventional radial configuration).

## *3.2 Limitations*

There are many potential benefits of the distributed generation model, however there are also some drawbacks. Not all of the technologies that can be adopted in a distributed network offer improved air emission performance. The move to distributed power generation sites dispersed throughout the consumer community would also mean that emissions are released in closer proximity to the local community. This could be considered (albeit controversially!) a positive in some ways as it avoids high air borne concentrations in specific locations in favor of low (potentially very low with latest generation technology) and benign concentrations dispersed over a wider area. The placement of electric generation units within the community could face significant community resistance from poor public perception. The ‘NIMBY’ (not-in-my-backyard) syndrome can often give rise to very emotive and forceful rejection of development proposals. One could (idealistically) speculate that public awareness of greenhouse and energy related issues must be fostered, particularly if the general community is to embrace the need to change infrastructure and energy use to minimize global warming effects. The positioning of local energy generation stations may in some ways aid this by giving the community ‘ownership’ of their power supply and greater first hand awareness of the central role that electricity plays in their lives. Land prices for situating units within the consumer community may be prohibitive however this should be alleviated to a degree by the compactness of the proposed units.

# 4 Enabling and prohibitive conditions

The critical factors that can either enable or prohibit the implementation of distributed generation are principally policy and regulatory mechanisms.

## *4.1 Enabling factors*

The progressive deregulation of electricity utilities in the United States and across the globe (others include the UK and Australia) has seen the thawing of market domination of monopolistic utilities and the entry of non-utility generation capacity. Non-utility suppliers contributed nearly 7% of the total US electricity production during 1996 (Munson (1998)). The driving force behind the growth of competition in the US was initially the *Public Utilities Regulatory Policy Act* (PURPA) of 1978 followed by deregulation of the natural gas market and the *Energy Policy Act* of 1992 (Munson (1998)). These policy mechanisms initiated the opening of competition and more recently the movement towards distributed generation.

Accelerated development of distributed generation could be encouraged by a variety of policy mechanisms. Regulatory tolerance of entrance producers to hold short term monopolies in areas of high electricity distribution costs (Shuler (1999)) would encourage infrastructure development. Policies to expand emissions trading beyond $SO_2$ to $CO_2$ and other pollutants in tandem with a publicly advertised emissions reduction timetable would drive development of cleaner technology and promotion of distributed generation (Munson (1998)). Government levied incentives for renewed research and development in electricity and energy supply in general would foster a foundation of knowledge for innovation and related flow-on developments to build on.

## *4.2 Prohibitive factors*

Mechanisms that deliberately or inadvertently discourage the development of distributed generation exist both within government bodies and the established electric utilities themselves. The *Clean Air Act* of 1970 is (a seemingly unlikely) prohibitive policy mechanism as it penalizes a new generator for increasing local emissions without accounting for efficient new facilities eliminating higher rates of emissions from older facilities for the same amount of power generated (Munson (1998)). The Clean air act also exempts older 'grandfather' facilities from penalties which amounts to a subsidy to highly polluting plants and discourages cleaner distributed generation. Depreciation schedules for electric utility equipment are on average three times longer than equivalently sized manufacturing industry equipment. A more rapid turnover of capital would encourage efficiency and technological innovation (Munson (1998)).

Some utilities have implemented measures to actively discourage the development of distributed generation. High exit fees under the guise of 'stranded' cost recovery fees are often imposed on customers leaving a utility for another producer or indigenous generation. In 1995 MIT moved to develop its own cogeneration facility and was initially charged very high exit fees by Cambridge Electric Company which MIT successfully overturned in the Massachusetts Supreme court in 1997 (Munson (1998)). Utilities can also impose prohibitively expensive interconnection requirements and discourage energy self sufficiency by very high rates for backup or supplemental power. There is a need for common national connection standards to remove restrictions on grid access of this kind (Munson (1998)). The attitude of utilities towards distributed generation is remarkably varied however, with some utilities actively collaborating with distributed generation technology companies to develop the distributed services market.

# 5 Conclusions

The electric utility industry has historically utilized a centralized, hierarchical structure where electricity is generated in large power plants and then distributed through an extensive transmission network to the points of demand from the industrial, commercial and residential customers. The refinement of new generation technologies within the last decade has revealed opportunities for an alternative electricity supply system based on a distributed generation structure. By deploying smaller, modular generation facilities closer to the customer demand, the distributed generation approach can relieve capacity constraints on existing generation and transmission infrastructure, defer the need for capital intensive centralized power plants and related distribution needs whilst delivering many additional benefits.

The emergence of efficient generation technologies including natural gas turbine systems (with and without cogeneration), microturbines, fuel cells, photovoltaic cells and wind turbines has made this paradigm shift possible. The use of a distributed generation structure offers many benefits to complement (and perhaps ultimately replace) the existing centralized system. Distributed generation can be used to provide additional capacity and energy to the network and provide flexibility of operation through quick start and load following capabilities. Optimal siting of smaller, dispersed facilities can reduce investment in transmission and distribution by diverting demand from existing networks. The economy of scale from mass production of generic, modular generation systems can lead to low capital costs, short lead and payback times and also allows streamlining of maintenance, operational and upgrading activities.

Distributed generation can lead to significant environmental benefits through the use of an ensemble of efficient generators including natural gas plants, fuel cells, renewable power sources and local power storage options. Increases in overall network efficiency through reduction of distribution losses and increased baseload flexibility would require a lower overall fuel supply leading to significant emission savings, particularly those of carbon dioxide.

Successful operation of a distributed network of generation facilities is dependent on the ability to dynamically coordinate many individual units to give the overall system output. Modern information technology capabilities can achieve this task and furthermore allow an unparalleled opportunity to give optimal electricity supply tailored to local requirements, grid spot-market opportunities and a means of dynamically minimizing environmental releases.

The barriers to the development and wider adoption of distributed generation are largely regulatory. The technologies (most notably those based on natural gas turbines) are already attractive options, particularly in areas where electricity distribution is expensive or localized generation can give additional benefits such as steam for industry or heating. The future transition towards the wider use of distributed electricity generation potentially offers many benefits to a society demanding a flexible, cheap, reliable and environmentally sound energy supply.

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