CHAPTER 13

Renewable Energy

Modern economic growth and consumption has been concentrated in Western nations with oil, gas and coal providing most of the world's marketed energy; however, things are changing. Through carbon emissions capping, many Western countries have in fact limited the use of fossil fuels. Through outsourcing, many Western countries have also de-industrialised. The new growth economies are the 'BRICs' (Brazil, Russia, India and China) whose industries and populations need more energy and resist capping.*

Against the backdrop of global warming and resource scarcity though, how can 'un-capped' consumption be sustained?

In this chapter we consider renewable energy sources to identify what can effectively reduce oil and gas demand, not just theoretically, but in an environmentally friendly and cost-effective way[1].

Global Warming

Since the 18th Century and the Industrial Revolution, the temperature of the earth's lower atmosphere has been rising. Through the greenhouse effect, this has led to an

* The US has also resisted calls for carbon emissions capping, however the new President Barack Obama may pursue a different policy.

alteration of the delicately balanced global climate system which is gradually being warmed. The greenhouse effect is so termed because levels of certain gases in the atmosphere have increased which means that more heat is retained on the earth.

In normal atmospheric conditions, sunlight reaches the earth passing through a layer of gases such as water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), and ozone. Here, infrared radiation reflects off the earth's surface but does not pass through the thermal layer as part of it is trapped to keep temperatures suitable to life, about 60°F (16°C). If it were not for this heat trap, the average temperature of the earth would be below freezing. The rapid industrialisation of the 18th century fuelled the demand for agriculture, land development and transport. As more fossil fuels such as coal were burned and as forests were cleared for development, ever greater quantities of Greenhouse Gases (GHG) were produced. Other types of gases such as chlorofluorocarbons (CFCs) also led to rising temperatures. Consequently, this resulted in more heat being trapped and rising air and sea temperatures[2,3,4].

Since the Industrial Revolution, volumes of CO_2 in the atmosphere have increased from 270 parts per million (ppm) to 370 ppm. This affects the natural CO_2 cycle that takes place between the atmosphere, oceans and forests. As greater quantities of CO_2 are generated, this leads to excessive loading of the natural cycle and a decreased ability of the earth's natural mechanisms (ocean and forests) to absorb $C0_2$. This gas, CO_2, has the greatest effect of GHGs and projections show that emissions will continue to grow. For CO_2 emissions to stabilise at 550 ppm, there would have to be a major reduction in the emissions complemented by new energy technologies

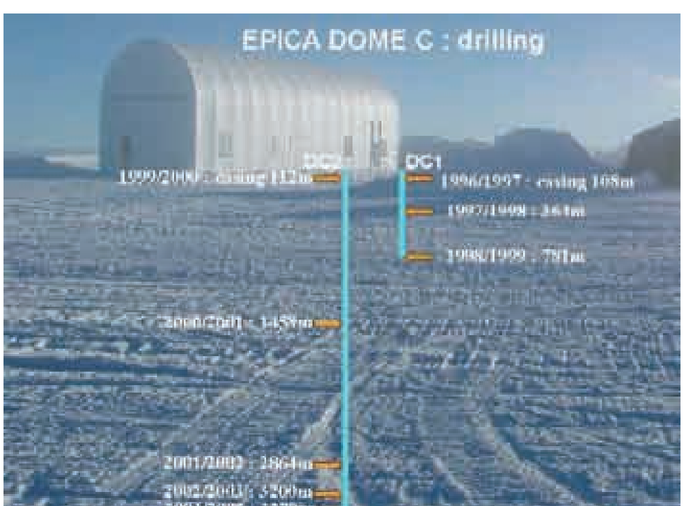

Figure 1 - EPICA.

that do not produce CO_2 at all; however, more than 80% of today's energy demands are met by fossil fuels, which make replacement even more challenging.

Scientists have also started tracking changes in the polar ice caps. Since1999, researchers working with the European Project for Ice Coring in Antarctica (EPICA) have drilled over 3000 m into the Dome C ice, which corresponds to a geological timeline dating back nearly a million years. Over time, solids and fluids are trapped in the ice, and these provide insight into the atmospheric mixture of gases present across the timeline[5].

Researchers have found that CO2 is now about 30% higher than at any time, and methane 130% higher. The rates of increase are absolutely exceptional: for CO2, this is 200 times faster than at any time in the last 650,000 years.

Antarctic Climate Record

EPICA aims to fully document the Antarctic's climatic record and to compare this with Greenland's record. To do this, scientists have employed drilling facilities to drill cores through the ice caps. Currently, further cores are needed to cover extreme timescales with one core at a site of higher annual snowfall to provide a detailed record of events over the last glacial cycle, and the other core in a region of low snow accumulation. Taken together, the two cores are expected to shed light on the following key questions not answered by the results from either the Greenland cores or the earlier Vostok drilling in Antarctica:[6]

1. Are the rapid climatic changes of the last ice age cyclic global events or are they restricted largely to parts of the Northern Hemisphere where it is possible that geographic conditions favour them?

2. Are these rapid changes unique to the last glacial cycle or did they occur in previous cycles as well?

3. Is the relatively warm stable climatic period of the last 10,000 years an exception to the last 500,000 years?

Ice drill programmes have the twin goals of identifying changes in past climates and in atmospheric chemistry. One of the main ways of identifying climate change is to determine the proportions of oxygen and hydrogen, two isotopes at different levels of the core through their presence in water. Equally important is the reconstruction of past atmospheric chemistry, including aerosols and water soluble gases, in addition to the composition of atmospheric gases trapped in bubbles within the ice. A variety of techniques are used here including continuous flow analysis to measure chemical levels. Sodium, calcium and sulphate levels are also measured as these provide information, respectively, on past atmospheric concentrations of sea salt (Na), soil dust (Ca), and secondary aerosols derived from sulphur including marine biogenic and volcanic emissions[7].

All these measurements would be of little value, however, without accurate dating of the ice cores. For the last 50,000 years this has been relatively straightforward as detailed information has already been obtained from Central Greenland cores and from a core obtained in the western Antarctic deep Byrd ice. Dating of new cores can be performed by matching acidic sulphur signals against volcanic horizons identified within the Byrd core. To extend the dating back 250,000 years, other techniques are needed and include ice flow modelling controlled by matching features in the new cores (e.g. changes in atmospheric, gas isotopic and chemical composition) with corresponding features in the ice cores from Vostok and central Greenland as well as with the ocean sediment records.

Polar Ice Caps

Some projected long-term results of global warming include the melting of polar ice caps, a rise in sea level and coastal encroachment; extinction of species as habitats disappear; higher intensity tropical storms; and an increased incidence of tropical diseases. The Polar Research Institute has been conducting studies on physical glaciology and has noted that over the past 50 years the Antarctic and Greenland ice

Figure 2 - Polar Ice Caps

sheets are thinning near the coast due to accelerating glaciers and increased melting. Both are thickening inland due to increased snowfall. Overall, both sheets are close to balance, i.e. the snowfall gains are comparable to the coastal losses. This is leading to a rise in sea level. At present, the best estimate is that Antarctica and Greenland combined contribute 0.2 mm per year of the 1.8 mm per year global sea level rise[8].

Several polar ice cap trends have been identified, notably in the West Antarctic, where the ice sheet is losing ice mass because the glaciers are flowing too quickly, most likely due to warm ocean waters at their termini, and that Arctic sea ice area and volume have both decreased over the past 50 years or so.

The predicted theoretical consequences suggest that any retreat of West Antarctica would have to be an accelerating process. If these are correct, the retreat we see today could accelerate sea level rise, and there is enough ice in West Antarctica to raise sea levels by 5 metres. Arctic sea ice cover plays two important roles: it reflects incoming solar radiation and it removes freshwater from the North Atlantic ocean. If it decreases or disappears, the earth could warm and Arctic oceans could freshen.

Temperature's Up

Scientists keep track of global temperatures by registering air and sea temperatures. According to US environmental body figures, the global average temperature of the air at the earth's surface has warmed between 0.5°F and 1°F (0.3°C and 0.6°C) since the late nineteenth century, while atmospheric temperature has risen 1.1°F (0.6°C), and sea level has risen several inches[9].

Little Boy

First noticed by fishermen in 1992, 'El Niño', which in Spanish means 'Little Boy' or the 'Christ-child', describes the arrival of a warm weather event coinciding with Christmas. La Niña means 'Little Girl' and is used to describe a cold weather event. El Niño is an alteration to the ocean-atmosphere system, which starts in the tropical Pacific but has global repercussions. These include greater rainfall and flooding across the southern US and in Peru to drought and bushfires in the Western Pacific.

El Niño can be seen in sea surface temperatures in the equatorial Pacific Ocean, such as those shown above, which were made from the National Oceanographic and Atmospheric Administration's (NOAA) array of moored buoys[10].

Kyoto

In order to combat global warming, the UN held a meeting in Kyoto, Japan, in 1997.

This resulted in an international agreement to reduce emissions of GHGs by industrialised nations. Not all industrial countries, however, immediately signed or ratified the accord. In 2001, the US government announced that it would abandon the Kyoto Protocol. At the time, this was considered a major setback as the US generates 25% of global GHGs.

125 other governments agreed to a binding international treaty which runs from 2005 to 2012. Further to this, many individual US states have committed to respecting Kyoto emissions levels at a local level[11].

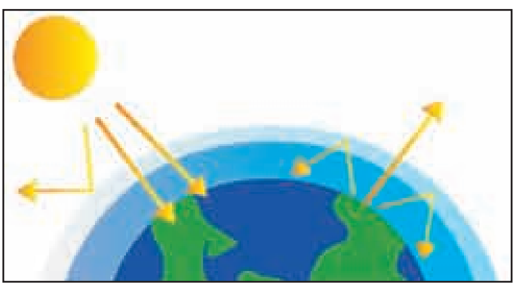

Figure 3 - Heat from the Sun is Trapped by the Gases in our Atmosphere.

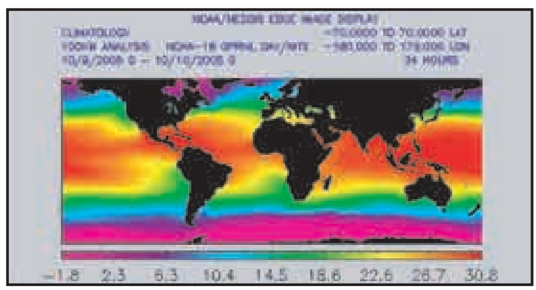

Figure 4 - Global Sea Surface Temperature Chart. Courtesy of the US National Oceanic and Atmospheric Administration (NOAA).

Deep divisions exist as to what should occur post Kyoto. The main objective will likely be to extend the treaty to include countries that have not currently signed such as the US, Australia and Russia. A major stumbling block is the exemption of so-called developing countries such as Brazil, China and India from Kyoto targets. These countries have argued that Western development was responsible for much of the CO2 emissions and this also led to these countries gaining developed status. The argument continues that applying CO2 emission targets to developing countries would then hinder their progress. The counter-argument is that the location of industry makes no difference to emissions and they must be capped. Only time will tell whether consensus can be reached on this issue. The arguments and debates continue.

Contributors to Climate Change

It is recognised that the main contributors of global warming are the burning of coal and petroleum products, deforestation which increases the amount of CO_2 in the atmosphere, the production of cement which releases CO_2 and increased livestock production which increases the volumes of methane gas released in animal waste.

Sceptics argue that the climate cannot be modelled as it is too complex. They also contend that observed climate changes may be normal fluctuations in global temperature[12].

Despite this, most leading scientists agree that part of the observed warming is the result of human activity, and that the trend for warming has to be broken. This means finding other options to CO_2 emitting products and a raft of energy initiatives.

Energy Initiatives

Plans to reduce emissions include improving road transport mileage per gallon, reforestation projects and energy efficiency in construction and public transport systems.

More ambitious plans would include replacing fossil fuels with safe alternates, improving manufacturing and operational processes that generate CO_2, replacing chlorofluorocarbons with safe alternates and reducing deforestation[13].

Emissions

In order to reduce GHG emissions, several initiatives have taken place. These include improved manufacturing and operational processes that would otherwise emit CO_2 and reduction of the usage of emissions when energy is generated, i.e. selecting less harmful options such as Liquefied Natural Gas (LNG) which produces less GHG as it has a lower carbon content. (See Chapter 3 What's in a Barrel – Hydrocarbon Types).

Carbon Capture

These types of technology have a crucial role to play in reducing CO2 emissions. Essentially, carbon capture or sequestration relies on the prevention of CO2 being released to the atmosphere. The CO2 is captured and injected deep into geological formations which are known to have natural traps or seals. Carbon capture plants can be located close to power stations and oil and gas production facilities. To accelerate

Figure 5 - Carbon Capture Schematic

acceptance and reduce the costs of carbon capture, several carbon capture projects were launched focusing on carbon capture technologies and processes[14].

In terms of geologic storage, oil companies have already implemented CO_2 compression and injection into oil and gas reservoirs.

CO_2 is readily soluble in water and oil and miscible with gas. Where producing oil and gas reservoirs are contemplated, the injected CO_2 could be used to maintain reservoir production. On production, it would be separated from the oil, gas or water and re-injected. Such reservoirs are obvious choices as they already have a seal or cap rock in place (see Chapter 1 Geology). In some gas producing provinces, as much as 10%-15% of the total gas in the reservoir is attributed to CO_2. In these cases, the CO_2 is not vented to the atmosphere, but is compressed and injected into the reservoir. CO_2 can also be injected into deep saline aquifers and unmineable coalbeds. It is estimated that large scale projects of this nature can take the equivalent of 200,000 cars off the road per year. Currently, several oil companies are involved in existing carbon capture projects, which are helping their acceptance from wider society[15].

Gas Technologies

Gas has grown from being an unwanted hazard to the preferred energy for power generation. Illustrating this is the fact that Combined Cycle Gas Turbine (CCGT) technology has become the standard by which other power generation plants are measured*. Here we look at the group of gas technologies – LNG, Gas to Liquids

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* Nuclear power generation is the main competitor and has always been a more complicated and expensive option. This may remain the case as long as gas prices do not rise excessively and carbon emissions are capped.

Figure 6 - All Gas Technologies

(GTL), Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG) and gas hydrates. It is worth quickly noting that LNG and CNG are formed of naturally occurring fractions, principally methane and ethane; however, LNG is subjected to low temperatures and high pressures to maintain its liquid state. CNG is subjected to compression alone as is LPG, which is principally composed of propane and butane[16].

LNG

LNG describes the liquid state of purified natural gas, principally methane and ethane, that has been subjected to temperatures of minus 160ºC. LNG has been a major boon for natural gas because it adds cost-effective transportability of large amounts of natural gas where pipelines are impractical, e.g. across the ocean.

Figure 7 - LNG Schematic

Over the past decade, the LNG industry has grown significantly with the creation of new markets for what was previously deemed stranded gas, which was too remote to be linked to existing pipeline systems but can now be safely transported to market.*

Typically, offloading facilities for LNG tankers require special berthing and unloading apparatus, with individual facilities varying in their handling capacities. Offloading involves the connection of unloading arms that pump the LNG onto storage tanks. These operate at atmospheric pressure and need to be especially well insulated to maintain the gas as a liquid[17].

LNG storage tanks are built with a double membrane wall using high strength steel nickel alloys to prevent heating. The outer wall membrane is made out of concrete. The revapourisation of LNG consists of thermal exchange processes which often use ambient seawater or other liquids to regasify the LNG before connection to pipelines.

LNG Markets

Comprising four main stages—E&P, liquefaction, shipping and storage and regasification—LNG projects require sizeable investments, often exceeding US $3 billion and highly specialised technical know-how, for these reasons they are generally the preserve of majors.

The liquefaction facility is usually the highest cost component within LNG projects.

Production, shipping, and re-gasification usually account for the remainder in roughly equal costs[18].

Process enhancements, technology advances and cost savings have reduced capital costs for liquefaction plants from US $600 per tonne of capacity in the late 1980s to about US $200 per tonne in 2001 and US $160 .

LNG suppliers will sign contracts, typically 20 years, with buyers confirming the purchase before the projects go ahead. This explains why the LNG market has been the preserve of the major International Oil Companies (IOCs) and National Oil Companies (NOCs). The LNG global market is roughly divided into hemispherical

* Neither LNG, nor its vapour, can explode in an unconfined environment. It must mix with air first.

lines, with the Western hemisphere consumers (the US and Europe) being supplied mainly by the Caribbean and North and West African exporters. The Eastern hemisphere countries of Japan, South Korea and Taiwan are mostly supplied by exports from Middle Eastern and Asia Pacific Rim countries.

LNG prices tend to follow a crude oil price index but are higher in the Asia/Pacific basin than in the Atlantic Basin. In the US and Europe, LNG prices are more volatile following Henry Hub and seasonal demand fluctuations[20].

Figure 8 - LNG Exporters

Exporting 38.48 Bm^3 in 2007, Qatar is the world's largest LNG exporter, with most of its exports split between Japan and South Korea. Qatargas is a joint venture between Qatar Petroleum, Total, Exxon Mobil and Mitsui and Marubeni. It also produces approximately 60 thousand barrels per day (bbl/d) of condensate in addition to sulphur. Qatargas operates ten purpose-built LNG vessels, each with a capacity of 135,000 m^3 [21].

Malaysia was the world's second largest LNG exporter, providing 29.79 Bm^3 of LNG in 2007. Most of its exports went to Japan who consumed 17.65 Bm^3. The major part of Malaysia's LNG exports is handled through its Bintulu Complex in Sarawak.

Indonesia is the world's third largest LNG exporter having exported 27.74 Bm^3 of LNG in 2007. Indonesia exported 18 Bm^3 to Japan which is the world's largest importer of LNG (88.82 Bm^3 total for 2007). Most of Indonesia's gas production centres on the Arun field in Aceh, the Badak field in East Kalimantan and the Natuna D-Alpha field (the largest gas field in Southeast Asia)[22].

Algeria exported 24.67 Bm^3, most of which went to France and other European countries. Sonatrach Algeria was the world's first major LNG producer when it began exporting LNG to Britain in 1965. The first liquefaction plant in the world was commissioned at Arzew in Algeria. Hassi R'Mel is the country's largest gas field (discovered in 1956) and contributes a quarter of Algeria's total gas production. Other Algerian gas reserves are located in the south and southeastern regions of the country[23].

Nigeria exported 21.16 Bm^3 and this was mainly imported by Spain and other European countries as well as North America[24].

Australia exported 20.24 Bm^3 and nearly all of it was imported by Japan. Most of Australia's production comes from the North West shelf[25].

Trinidad and Tobago exported 18.15 Bm^3, almost all going to the US. Trinidad's LNG started in April 1999 and now has the Atlantic LNG project in Trinidad and Tobago (BP, BG, Repsol and NGC)[26].

Russia is becoming the newest Asia/Pacific basin exporter. Its first LNG plant is under construction in Sakhalin Island off the country's east coast, with exports aimed at Japan.

Due to its position as the largest holder of gas reserves, it clearly has potential to develop its own reserves and supply growing demand.

Compressed Natural Gas (CNG)

Comprising purified natural gas (principally methane) that is pressurised at approximately 3,700 psi (255 bar) and stored in metal canisters, CNG is an efficient means of transporting fuel and fuelling transportation.

CNG and LNG are both delivered to engines as low pressure vapour. LNG can be used to make CNG which is a substitute for gasoline (petrol) or diesel fuel. It is considered to be environmentally 'clean' and is made by compressing methane extracted from natural gas[27].

Figure 9 - CNG

Liquid Petroleum Gas

LPG is a highly portable and convenient fuel, which can be liquefied at relatively low pressures and high temperatures. This means it can be stored in metal canisters without the need to maintain subzero temperatures or the infrastructure of LNG. LPG contains varying ratios of propane and butane that have been compressed to form a liquid. Propane is used in propane gas burners at 203 psi (14 bar) and as butane in cigarette lighters 29 psi (2 bar).

LPG is a widespread fuel used in transportation (buses, cars), domestic usage (heating and cooking) and power generation. Both alkanes are used as propellants in aerosol sprays too. Many developing countries such as Brazil, India and Pakistan have very advanced markets for LPG, with many petrol pumps offering it as a petrol (gasoline) alternative[28].

Gas to Liquids

A promising technology with a bright future, GTL is a generic term for the catalytic processes that synthetically produce petroleum fuels from gas.

The most commonly known processes are based on the Fischer-Tropsch concept where very light hydrocarbon fractions are subjected to high temperatures and pressures in the presence of a catalyst.

Figure 10 - Fischer Tropsch Process

This partly oxidising gas is then converted into liquid and fractionated in a manner similar to conventional refining, which achieves the desired blend of refined petroleum qualities within the limits of the process configuration. Companies such as Shell have successfully trialled GTL fuel in the UK and Germany with major car manufacturers. GTL will be a key bridging application for natural gas that will reduce the demand for high-demand light automotive applications (see the demand supply equation above)[29]. Presently, GTL is prohibitively expensive unless volumes are high. It has been put forward as a way to commercialise stranded gas (where no viable market exists for the gas) as an alternative to flaring.

Gas Hydrates

Gas or methane hydrates are ice crystals that contain high amounts of methane. They are formed when water and methane are present in freezing or below freezing temperatures. Deep and ultra-deepwater conditions are ideal for the formation of gas hydrates which are most commonly found in sedimentary beds below the ocean. Gas hydrates are thought to be created as gas migrates from source rock and is crystallised on contact with freezing seawater. Gas hydrates are of future interest as the large amounts of trapped energy may be harnessed to generate usable methane. Not surprisingly, estimates vary as to global reserves and the technology for efficiently harnessing the hydrates has not yet been developed[30].

Figure 11 - Nuclear Power

Nuclear Power

Principally used for the generation of electricity, nuclear power harnesses nuclear reactions to release energy. Other uses include submarine jet propulsion and heat. Although, the reactor is the heart of nuclear power generation, it represents a small part of the process. Uranium ore must first be mined and then converted into a manageable form known as yellowcake. It is then processed to form uranium hexafluoride which must undergo sufficient enrichment before it is configured in shape and size to make reactor-specific fuel rods.

These fuel rods remain inside the reactor until approximately 3% of their uranium has undergone fission at which point the rods are termed 'spent'. The spent fuel is then moved to a cooling pool for five years or more where the decaying isotopes can be safely managed. After this period, the spent fuel is radioactively cool enough to handle and it is moved to dry storage casks or reprocessed[31].

The production of spent fuel is a major drawback associated with nuclear power generation. In fact, fresh spent fuel is so radioactive that less than a minute's exposure to it will cause death. Spent nuclear fuel becomes less radioactive over time, although it is still dangerously radioactive. There are over 400 nuclear reactors generating electricity in the world[32].

The pressurised water reactor is the most widely-adopted nuclear reactor technology The ongoing improvements in technology and performance have resulted in continuing reductions in the costs of power generation from nuclear stations.

CO2 is not released during the generation of electricity from nuclear power and it is a major factor in favour of nuclear energy. GHG emissions are very low across the whole life cycle and are comparable with the best renewables.

Globally, nuclear energy helps avoid the annual emission of over two billion tonnes of CO_2 that would otherwise be generated from fossil fuels. Nuclear generation is the largest single source of electricity in the European Union (EU). Of the 15 EU countries, those which have significant proportions of nuclear energy are consistently among those with the lowest CO_2 emissions[33].

Hydro Power

Hydro power systems generate electricity by releasing stored water in a controlled manner to drive turbines.

In certain rural planning situations such as irrigation or flood barrier schemes, a hydroelectric power plant may be added with relatively low construction cost. 'Fuel' in the normal sense is not required to power hydroelectric plants which also have the advantage of zero GHG emissions. Hydroelectric plants tend to have a longer shelf-life than hydrocarbon generation plants, with some plants still generating power after a century's service. This is probably due, however, to the lack of harmful emission associated with hydroelectric plants as opposed to older hydrocarbon plants producing high emissions[34].

Low levels of rainfall or drought are the major limitation of hydro power. This can cause large reductions in power generation or may cause a complete halt. Environmental groups have stated that large hydroelectric projects can damage fluvial and marine ecosystems. The reservoirs of hydroelectric power plants in tropical regions may also produce large amounts of GHG. This is due to newly flooded and decaying plant material releasing methane once it enters the turbines[35].

Solar Power

Photovoltaic cells are most commonly seen in handheld calculators where they provide energy through the use of solar power.

Applications of the technology are used on much larger scales where they are classed as being 'on-grid' or 'off-grid' and convert daylight into conventional electricity allowing everyday appliances to be powered.

The main advantages of solar energy are self-sufficiency, reduced carbon emissions and the sale of excess energy where connection to a grid exists, given adequate generating conditions.

Solar power, however, has limitations. The energy generation may not coincide with demand and consequently, power generated during off-peak periods must be stored so that it can be used effectively during peak demand.

On-grid systems can be found in urban areas and range from applications in governmental, commercial and residential systems where large numbers (50 or more) of panels are joined to create a solar farm generating a large enough amount of solar power that can be sold back to the electricity grid wholesaler[36].

Off-grid systems are mostly found in remote locations that are unconnected to wholesale electricity grids. This includes both villages and industrial applications such as in power generation or telecommunications.

The photovoltaic cell converts solar energy directly into electricity. Cells usually consist of several wafers of silicon or other semi-conducting material. The cell itself is a semiconductor diode that, depending on its configuration, can convert visible, infrared or ultraviolet light into direct current electricity.

When the cell is exposed to light, electrical charges generated in the silicon are conducted by metal contacts as direct current. Many cells are required to generate meaningful amounts of electricity and these are found in the form of glass solar panels[37].

Depending on the output required and other factors such as location, as many panels as can be configured to generate the required electrical output are required.

According to Shell, Copper Indium Diselenide or CIS refers to thin-film technology that may provide further cost savings as it is cheaper and more durable than silicon[38].

Large sets of photovoltaic cells can be connected together to form solar modules, arrays, or panels.

Major advantages of photovoltaics include the fact that they are non-polluting, only require real estate (and a reasonably sunny climate) in order to function and rely on solar energy which is unlimited in supply.

By making use of the photovoltaic effect, solar cells produce electricity. Absorbed light excites the electrons with negative electrons (-) attracted to the N-layer, and positive electrons to the (+). Once the circuit is closed, electricity is created.

Graphic Photovoltaic Cell Composition

Fuel Cells

Continuous electrochemical reactions form the basis for fuel cell energy. As well as offering high theoretical efficiency, fuel cells emit low or even zero levels of pollutants.

The fuel cell itself runs off hydrogen, but with the use of steam, reforming or partial oxidation can be powered by gas and GTL products. Fuel cells have the potential to be used in power generation and light automotive applications; however, the major limitation is the prohibitive costs associated with the technology.

The competitive target for fuel cells to compete with the internal combustion engine is US $50/kW. In stationary applications, a cost of US $1000/kW is seen as the long-term goal. Battery replacement can absorb very high costs per kW and

Figure 12 - Fuel Cell

lowest economic hurdle to entry. Today, prior to mass production and essentially in custom-build mode, fuel cells are somewhere in the US $2000/kW to US $20,000/kW range.

At between US $4000/kW to US $20,000/kW for stationary applications, they are well above a mature technology such as gas turbines at US $400/kW to US $600/kW. Even novel micro-turbines currently cost US $1000/kW to US $2000/kW. Mass production is seen as the solution to the high cost. In the meantime, funding from government agencies and companies interested in the technology has provided support for demonstration projects[39].

Biomass

Biomass is a catch-all term used to describe any solid, liquid or gas fuel that is derived from organic mass itself or its residues or byproducts. Each fuel type needs be distinguished if we are to understand the potential role each fuel has in replacing oil and gas demand. Liquids include 'biodiesel' that can be used in compression engines and are produced by modifying esters in vegetable seed oil. Liquids also include 'biogasoline' (ethanol) that can be used in spark engines and are produced from the fermentation of sugars. Finally, liquid fuels also include 'bioGTL' that can be used in both types of engines and are produced from GTL technology using biologically or man-made produced methane (biogas)[40].

Figure 13 - Biomass Fuel Types

Biogasoline

Biogasoline is the liquid biomass subset that contains ethanol, a well known alcohol fuel, but increasingly other fuels such as propanol and butanol.

Brazil is a major producer of sugarcane derived ethanol fuel, which is commonly available in roadside filling stations along with petroleum spirit and LPG. The US also produces corn-based ethanol but uses as a complement to petroleum rather than a substitute; however, ethanol replacement of petroleum is increasing. Detractors claim that its cost is greater than any value it brings to the equation[41].

Production

Ethanol can be produced from the fermentation of sugars or the steam cracking of ethane.

In the former, juice from sugarcane, corn or other feedstock is mixed with yeast and water at just above room temperature. Enzymes in the yeast break down the sugars into ethanol and CO_2. The CO_2 is vented to stop the ethanol from oxidising and becoming ethanooic acid (vinegar). Fractional distillation increases the yield of ethanol to 'fusel oil' or anhydrous ethanol (5% water by volume)[42].

Ethanol can also be produced by the steam cracking of ethane in the presence of a strong acid catalyst. The reversible reaction is carried out at a moderately high temperature (e.g. 300oC) and a high pressure (e.g. 900 psi [62 bar]). The higher temperature and catalyst speed up the reaction and increasing pressure moves the equilibrium to the right (the side with the least gaseous molecules at 300oC). Although it is a faster and more continuous process, the disadvantage of the ethane route means further demands on oil and gas[43].

On average a tonne of sugarcane renders 65 liters of ethanol. The average cost of production, including farming, transportation and distribution, was US$0.31-0.35 per litre in Brazil, with a pump price of US$0.63-0.69 per litre in mid-2006. It is striking to trace these prices since 1999. At that time, the pump price of ethanol was US$0.09.. Interestingly, this is a quadrupling of price over a seven year period. It is even more striking when we correlate the prices of ethanol and oil since 1999 to mid-2006. We see there is a quadrupling of price from US$10 to US$70. As a rule of thumb, the price of ethanol per litre is a tenth of the price of a barrel of crude oil[44].

Figure 14 - Figure Crude Oil v Ethanol Prices 1999-2006

Even though the differences between low-cost sugar producers such as Thailand, Pakistan, Brazil are not prohibitive, Brazil has the infrastructure to remain the lowest cost ethanol producer.

It is highly probable that the sugarcane farming for ethanol production will increase as is illustrated by the demand/supply equation. This may have unwanted consequences and a balance will have to be struck as ethanol tends to become a cash-crop in certain replacement scenarios for gasoline; when oil prices are high, it displaces other crops[45].

Biogas

Biogas refers to biologically produced methane which is generated from any biomass feedstock i.e. organic waste material such as wood pulp, animal residues or municipal organic waste. It is worth considering this process in detail as it can convert contaminants into commodities. Solid biomass includes the use of wood or dried animal dung for domestic cooking and heating. Liquid biomass includes animal or farming waste that has not been treated.

Methane gas is produced by bacteria during the decomposition of organic feedstock in a highly controlled process. The gas formed in this way is renewable and is a highly flexible form of generating gas as the feedstock can literally be any type of organic material.

The methane produced synthetically is often pure enough to pass directly through gas engines to generate direct electricity commercially or on a local scale. The biomass methane can also be used as the feedstock for the GTL process to create synthetic fuels. It is wells suited to electrical co-generation and waste treatment.

Biomass plants (also referred to as waste transformation plants) convert a potential contaminant (farmyard waste or other residues) into a marketable commodity (fertiliser).

Waste transformation plants allow the generation of electrical energy in a separate market from hydro-electric, gas turbine or nuclear based energy.
Feedstocks include (but are not limited to):

- Biodegradable waste
- Sewage treatment sludge (primary or raw sludge and/or secondary sludge)
- Slaughterhouse waste
- Food waste
- Farm waste, and
- The organic component of mixed municipal waste.

Biomass plants are a sustainable clean and green energy process whose emissions and by-products (CO_2 and H_2O) are released to the atmosphere in a controlled manner. Ammonia and other by-products are re-incorporated within the fertiliser or, where required, are retrieved separately in liquid form. There is no release to the atmosphere.

It is worth noting that the biomass process has an application in any geographical location that presents a demand for electricity, the need to treat farmyard or other organic waste such as timber residues and offers a ready supply of natural gas. Locations within Canada, Brazil, Bolivia and other European countries would fit this category; however, factors such as average temperature can dictate the overall energy efficiency and profitability of biomass plants. In the case of animal waste, in cold climates during the winter, energy is required to sufficiently dry the waste. Biomass plants, however, can act as a catalyst for the development of, and demand for, natural gas in separate markets from traditional consumer or industrial sectors. In countries where natural gas supply outstrips demand (Trinidad, Bolivia and Canada), co-generation plants can be an economical way of sustaining energy development as well as meeting growing electrical energy demand.

Biogas Description

A thermoelectric co-generation plant receives farmyard animal waste which is dried using natural gas fired ovens. Ducts are connected to combustion chambers enabling exhaust gases to be harnessed to drive turbines which generate electrical energy. Excess exhaust gases and heat generated by the system is regulated through a calorific control process and is used to dry animal waste. After drying in the ovens, the waste has lost a high percentage of its water content and is characterised as stable—it will not ferment nor liberate toxic fumes. Effectively, this means that it has been converted into commercial fertiliser that meets environmental and legal requirements.

The process offers six major advantages:

- Generation of electrical energy
- Stimulation of natural gas demand
- Conversion of a potential contaminant into fertiliser
- Sustainability

• Controlled emissions

• Scalability (up and down) of plant size to meet market specific conditions

This process is increasingly attractive as it meets energy needs in an environmentally friendly manner.

Waste Processing

This case study presents a co-generation plant complete with technical considerations and Return on Investment (ROI) calculations. The quantity of waste that can be collected from various farms in the area is approximately 350,000 kg per day with a humidity varying between 65% and 70%. For the purposes of this study 216,000 kg of waste would be treated. Final humidity is calculated to be approximately 20%, a figure recognised by the waste treatment industry as the standard for compost or fertilisers.

This plant runs for 8,000 hours per year due to the demand created by non-stop farmyard waste production.

The electrical and thermal co-generation plant uses natural gas-driven motors to dry waste from untreated levels of humidity (67.5% to 20%). The make and number of motors, however, can be modified to meet market specific needs. The gases liberated during the drying process are used as exhaust gases to drive engines which generate electricity. The dried waste is converted into marketable fertiliser for which there is ample demand.

Co-generation Plant

A schematic diagram of the proposed plant using Guascor SFGLD560/55 engines, with a 952 kWe rating follows.

The co-generation plant consists of the following equipment:

1. Natural gas engines

2. Waste pre-treatment system to condition waste before it is fed to the drying ovens. This maintains humidity and pH at controlled levels.

3. Thermal drying ovens utilising the energy released from the exhaust gases and the water refrigeration units.

4. Gas filters to absorb volatile particles and ammonium

5. Engine exhaust gas conduits and chimneys

6. Thermal exchange units to dissipate residual heat in the system, Air coolant and cooling towers to dissipate unused residual heat from the thermal exchange units

7. Water circulation pumps

8. Electrical equipment (Engine control unit, transformers etc guaranteeing power output)

9. System and instrumentation management and control, Anti-incendiary system,

10. Ventilation and climate control of all areas.

Not only is a potential contaminant treated and converted into a valuable commodity, but electrical energy is generated in a renewable process. Additionally, demand for natural gas is stimulated. This is important as gas reserves are increasingly being seen as a mobile commodity due to the liquefaction and storage innovations.

Wind Power

Using a combination of turbines and nacelles, wind energy can be used to create mechanical and electrical energy. Wind power has the major advantage of zero emissions, but has output and aesthetic limitations. Consequently, wind power generation needs power storage capacity so off-peak power generation can be used effectively during peak demand. Such power generation types are generally more expensive per unit of electricity generated than base-load generators, so electricity suppliers prefer to minimise their use. Despite this increasing numbers of wind farms and standalone wind turbines are being set up by companies and individuals seeking their benefits.

Figure 15 - Offshore Wind Power Schematic

Considered more appealing due to their unobtrusive offshore location, these wind turbines can be configured on a larger scale than their onshore counterparts. Offshore construction is, however, more complicated and expensive and such installations must withstand harsh conditions and subsea cables must be installed to transfer electricity.

Offshore turbines are also considered more efficient as higher average wind speeds are recorded over water, which offers less drag than land. Several Northern European countries such as Denmark have implemented wind generation, which provides more than a quarter of the country's total electricity.

This review of renewable technologies and oil and gas applications serves as a base so that we can develop the final part of energy - the complex energy demand/supply equation. In the final chapter, this complex inter-play is outlined so that we may understand how oil and gas applications may co-exist with other energy supplies.