“The Start of the Road: Energy and Chemical Engineering”

A report for the Institution of Chemical Engineers

Draft for Comment by members of the IChemE June 2008

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Introduction

Cheap, abundant energy is the greatest outcome of the industrial revolution. Every aspect of our current western lifestyle is dependent on it. Chemical engineers are involved in the production and distribution of stationary and transport energy at all levels from mining through to final delivery. The IChemE Roadmap recognized energy as one of the six core areas of concern for the profession and it permeates most of the other five.

The relevant Roadmap goals are:

- Nuclear Power: support a positive climate and R&D for new and replacement nuclear capacity
- Continuing Fossil Fuel Use: accelerate the deployment of clean generation technology with carbon capture and storage together with increased efficiency in energy use
- Renewable Energy: expand R&D and deployment of renewable technologies and power storage systems
- Biofuels: pursue biomass gasification and Fischer Tropsch synthesis for biofuels production
- Sustainable Energy: rapidly pursue the global use of non-fossil primary energy sources
- Sustainable Technology: accelerate the introduction of innovative and sustainable technology
- Performance: create cultures to deliver real improvement in health, safety and environmental performance

This paper sets out the current position of energy production and distribution including political, economic, social, and technical factors. The information is derived from chapters written by experts in the field and also from summaries of many of the international reports released in the last few years. The aim of this paper is to set out the current technologies involved in energy production and distribution, the changes in technology that might be expected over the coming decades and their consequences and the ways in which chemical engineers can work with these changes in order to achieve the goals of the Roadmap. A consequence of this analysis will be to review the consistency of the Roadmap goals and to continue the dialogue within the profession as to the best way of contributing to society.

This paper is obviously not exhaustive. Space constraints and the difficulties of finding appropriate authors has meant that several worthy topics have not been included. Some of these will be the bread and butter of process engineers fro the next few decades and some will represent major engineering challenges. As the Roadmap is the for the whole of the 21st century, members should be looking to inform themselves, their fellows and the public debate on some of these issues. The major omissions from this paper are:

- Refixing CO_2
- Energy efficiency technologies
- Embodied energy and lifecycle analysis concepts
- Recycling technologies
- Health aspects of energy technologies

CURRENT ENERGY USE AND TECHNOLOGIES

At present, the world uses approximately 500 EJ (5×10^{20} J) of energy per year. Most of this energy is derived from fossil fuels (Figure 1). Most emissions of carbon dioxide derive from the power and transport industries (*Figure 2*)

The world's leading energy forecasters agree on one thing – fossil fuels are likely to remain the primary source of global energy for several decades. However, the increasing use of these fuels results in a corresponding growth in the emissions of greenhouse gases – in particular carbon dioxide. The challenges facing the world's engineers are to develop ways of:

- generating electricity with the low carbon emissions
- preparing and using fossil fuels in a more sustainable way
- evaluating sources of renewable energy on a holistic basis

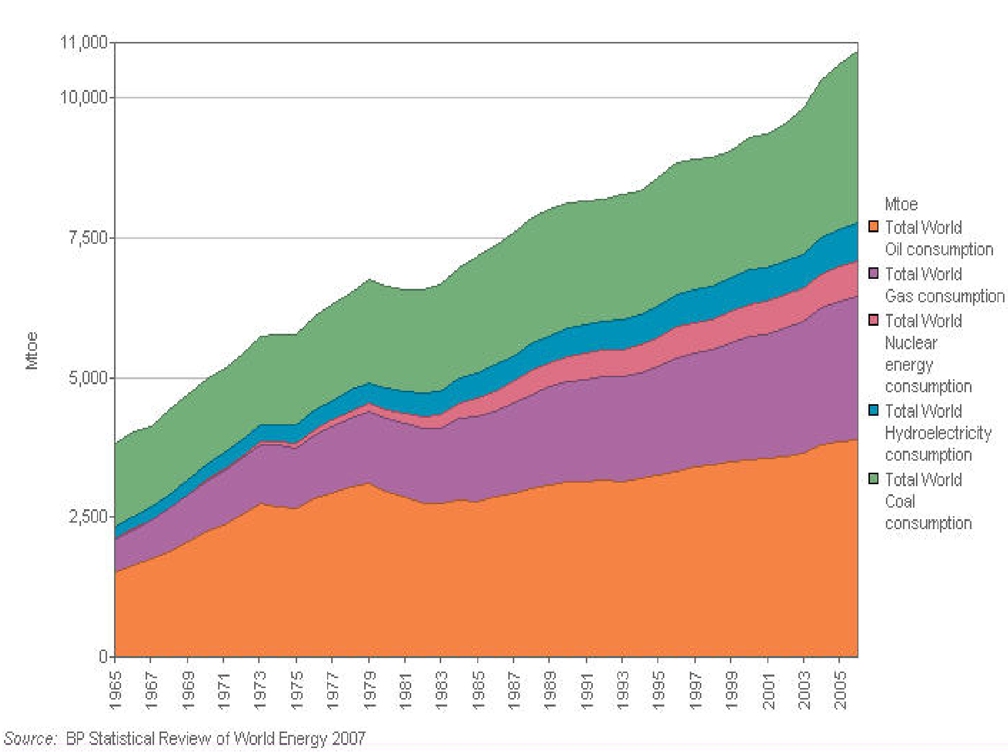

Figure 1 Predicted energy demand by fuel use (Source BP).

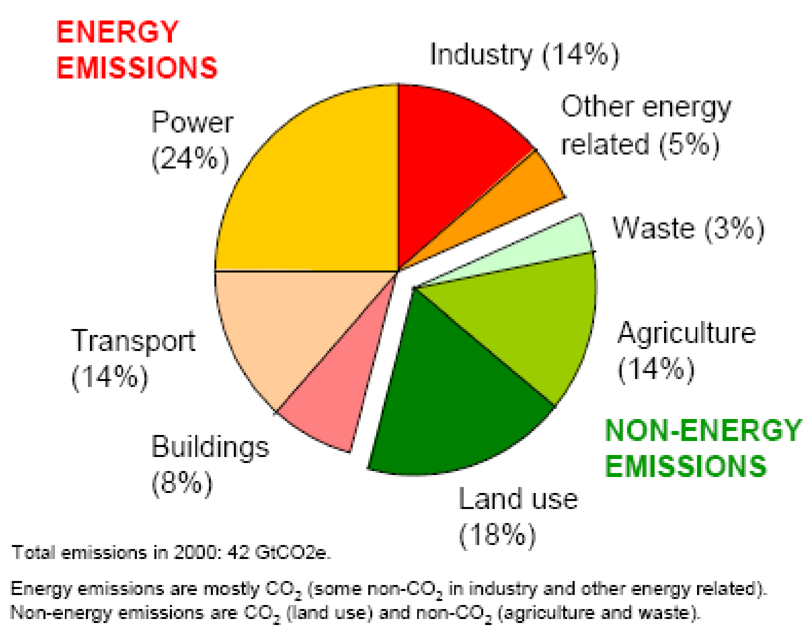

Figure 2: Energy Emissions by Sector (Source: Stern Review)

Fossil Fuels

The high energy density of fossil fuels combined with the huge existing infrastructure for their use mean that they are likely to be the main source of primary energy for some time to come.

There appears to be expert agreement that liquid fuels will remain the main source of energy for the transport sector for the next 50 years. **Oil** is expected to remain the dominant raw material although it will be progressively supplemented by biofuels. The biofuel options will be discussed later.

Europe and the USA has led the world in requiring reduced emissions from vehicles beginning with NOx, CO, particulates, SOx and unburnt hydrocarbons. This has already led to the removal of organic lead compounds, a dramatic reduction in sulphur content and the use of catalytic converters in exhaust systems. The drive is now towards reduction in carbon emissions with further regulatory pressure on fuel quality improvement especially diesel quality. Fischer Tropsch technologies are likely to become more widely used with gas, coal and biomass as feedstock to produce very high quality product free of sulphur and aromatics with a high cetane number. Improvements in diesel quality enable auto manufacturers to achieve efficiency gains through new engine design with reductions in carbon emissions.

Globalisation is also having an impact on fuel quality. Historically, many developing countries have run their vehicle fleets on a quality of fuel inferior to that used in the developed countries. For example, the octane of Brazilian gasoline has been in the low 80s while Europe is 95 RON. As engine design improves to meet the emissions requirements of the developed market, engine manufacturers are progressively reluctant to build to varying fuel standards so fuel quality is likely to improve towards the best and not be as diversified as today. This requires more intensive refinery processing. Nevertheless, there is a trade-off between the carbon emissions from the additional refinery processing needed and the vehicle emissions running on higher quality fuels.

The drive for lower carbon emissions has led to a surge of demand for natural **gas** particularly in the power generation sector. The availability of gas in the 1990s was paralleled by improvements in the efficiency of combined cycle gas turbine technology. State-of-the-art CCGTs offer a reduction of over 60% carbon emissions per kWh generated versus existing coal-fired systems. Their low cost, speed of construction and small footprint led to a rapid expansion in their use with unprecedented growth in gas demand.

The rate of demand growth has led to a global shift in supply patterns requiring. BP's Statistical Review of World Energy shows 75% of the world's gas reserves in the Middle East and Europe/Eurasia. BP also gives the reserves to production ratio of natural gas as 63 years on a global basis. Transport of the gas is largely by pipeline but a new fleet of LNG carriers is being built along with LNG liquefaction facilities and receiving terminals.

The dynamic shift in the market to areas of the world some perceive as politically sensitive has also raised the issue of long-term supply security and primary energy diversity in a number of the developed countries. These issues now influence energy policy as an overlay to economic and environmental drives.

The forecast also suggests that LNG with its higher production and handling costs is likely to influence the international price of gas. This trend has already led to studies for the gasification of coal, for example, in areas where CCGT investments have been rendered uneconomic for power generation because of high local gas prices.

Coal remains by far the largest global energy resource. The BP Review indicates that in 2006, the world's reserves remained at over 900,000 million tonnes with a reserve to production ratio of 147 years. Their definition of "reserves" indicate that they can be recovered a under existing economic and operating conditions i.e. conventional mining. The estimate of reserves would increase with increased energy prices. It also excludes vast coal resources in the earth's crust that would require extraction by other methods such as a successful demonstration of underground gasification e.g. in Australia.

Demand for electricity continues to grow throughout the world. Although much progress has been made to improve the efficiency of electricity use, a significant part of the world's population has little or no access to it and demand in the non-EEC countries is rising rapidly. Growth continues even in the developed countries with improved living standards.

The rapid increase in the prices of oil and gas along with the abundance of coal in many countries has led to renewed interest in conversion processes. South Africa mounted a major programme of coal processing for fuels, pharmaceuticals and chemicals some 30 years ago. From their work has emerged a major advance in coal-to-liquids technology using the Fischer Tropsch process (FT). China, Japan and the USA have used gasification as a pathway to chemicals and fertilisers. The US

Ministry of Defence has also decreed that 50% of military fuel should be derived from indigenous coal by 2015 and 100% by 2020. Other companies have developed advanced FT technology and projects are progressing.

Integrated gasification combined cycle systems have been demonstrated on coal and heavy oil residues for clean power generation. Many new proposals are progressing in several parts of the world with the potential to remove some 90% of the CO_2 in the coal if a price is put on CO_2 reduction that supports the investment. Polygeneration (power and other products) using gasification is commercially attractive and major project is progressing in Texas with CO_2 extraction for Enhanced Oil Recovery. 3 other projects are progressing to demonstrate zero emissions generation from coal in the FutureGen project in the USA, at BP's Carson City refinery in California and BP's Kwinana refinery in Australia.

If coal is to be an acceptable fuel to the limit of its reserves, the carbon dioxide produced will need to be prevented from entering the atmosphere. The British Geological Survey has assessed that to achieve stability at the 450-500 ppm level, some 50% of the reduction will have to come from capture.

Currently, 4 methods of capture are possible.

- Post-combustion – flue gas scrubbing
- Pre-combustion - gasification
- Oxy-fuel combustion with capture (Doosan Babcock)
- Partial combustion with oxygen then syngas combustion with oxygen and recycled water (Jacobs Engineering)

The scrubbing of flue gases is possible using either amine scrubbing or chilled ammonia. Amines have been widely used for 50 years in the refining industry so their performance is well known albeit not at power plant scale. The drawback is the vast volume of gases at elevated temperature and atmospheric pressure that have to be handled. The cost is high and the parasitic power high, reducing efficiency considerably (of the order of 20-30%). The two main sorbents are the family of ethanolamines for example marketed by UOP and chilled ammonia – promoted by Alstom. There is undoubtedly a huge retro-fit market if capture becomes necessary on a massive scale.

Gasification is a well established technology that enables the fuel - say coal – to be converted to CO plus H_2 and then the CO can be put through a Shift reactor to produce more H_2 and CO_2 at very high pressure for capture. The hydrogen can be routed for use as a fuel to a combined cycle gas turbine or refinery hydrogenation. The reactor pressure of say 80 Bar reduces the volume of gases to be scrubbed substantially. This is currently considered to be the least cost route for capture in US studies but this is often challenged by post-combustion advocates and less definitive by the ICCR. If massive reduction programmes were to be required by global agreement, both pre- and post-combustion capture and storage will be required on a substantial scale.

The oxy-fuel combustion process is at the developmental stage and in concept, reduces the volume of gas to be handled by eliminating the nitrogen. The fuel is combusted with pure oxygen diluted with recycled flue gas – a CO_2 rich stream. Part of that stream is then withdrawn for scrubbing/separation to capture the CO_2. The developers are currently developing burners that go beyond pilot stage to scale up to large boiler design and that may take another 2 years.

Biofuels

Renewable energy in all forms is recognised as an increasingly important component of sustainable energy supply. This section will focus on liquid biofuels primarily for the transport sector. A range of biofuels can be produced to make a contribution to the growing demand for vehicle fuel. However, the options carefully evaluated with the application of sound science especially to establish the holistic impact on CO_2 emissions. In the rush to stimulate biofuels production, US and EU targets have been set in terms of percentages of total transport fuel demand without a thorough assessment of the implications. The benefits of some biofuel options are being challenged because the full environmental impact was not correctly assessed. A number of these issues remain to be resolved and will be expanded in this section.

Some of the key issues that apply in the UK and globally are:-

- the availability of land for fuel crops
- water availability and impact on potable water supply
- de-forestation to create the land needed and possibly desertification
- food versus energy – e.g. wheat, sugar, soy and the economic impact
- food miles

- energy consumed in growing, fertilising, harvesting and processing biofuel
- the product, infrastructure and interface with vehicle needs

A range of liquid fuels can be made from crop material. Fuels such as methanol, ethanol, butanol, di-methyl ether, fatty acid methyl ester, diesel, gasoline, palm oil, jatropha oil and rape seed oil can all be produced. There are advocates for all these products and others. Many may have a valuable role to play in a local community or in some countries. However, the mainstream of demand is likely to remain broadly based on diesel and gasoline where blending of products such as bio-diesel and ethanol can be accommodated in the present infrastructure.

The UK's Research Centre at Rothamstead has done a great deal of work to identify land availability for biocrops on a global basis. The world's growing demand for food will require a large part of the land considered to be arable. There is insufficient land to come near to meeting the global demand for bio-fuels or energy. However, there is land available to contribute to energy in a number of parts of the world where bio-fuels could make both a local contribution and export – e.g. Brazil with ethanol. For a country such as the UK, biofuel production would be less than half the transport fuels demand even if all the arable land was given over to fuel and food were to be imported. Similarly if all of the sugar produced in Queensland were turned into ethanol, it would account for ~10% of Australia's petrol needs.

The issue of food versus fuel has become a critical issue recently. Global wheat prices are at an all-time high driven up by poor harvests, changing diet in developing countries and a major push for biofuels. A recent Goldman Sachs Report indicated that vulnerable regions of the world risk famine while all regions are experiencing the impact of animal feedstock rises. The Report mentions the effect of the US incentive for biofuels via tax relief and the EU 10% biofuels target by 2010. This puts a global political focus on the mechanisms for introducing bio-fuels to the market to supplement oil.

There have been many studies on the use of biomass as an energy source, particularly in the biofuel sector, but with research in this area progressing to the commercialisation stage, there is the question of whether we are now intending to utilise our valuable agricultural lands for fuel production rather than food. If we look at the current global use of biomass, as shown in Figure 2, the current use attributed to food is extremely low, with over half of all production being utilised in livestock feed.

This suggests that a better political tradeoff would be between luxury foods like meat and fuel rather than between staples and fuel.

In the longer term conversion of non-food crops to energy is more likely to be sustainable. High quality diesel can be produced by converting any form of biomass via gasification into CO and H_2 and then using the Fischer Tropsch (FT) process to make excellent products fully compatible with current material. It would be sulphur and aromatic-free quality with very high cetane diesel. Another advantage of the FT route is that it enables biomass to be co-processed with coal – a technique already proven in the Netherlands and the basis of a new 1200 MW power plant design. This assists in limiting the amount of low energy-density biomass that has to be delivered to one location

The chemical engineer's solution would therefore be to avoid food crops as a starting point but grow lingo-cellulosic biomass for processing to what are usually described as second generation biofuels. While the process is currently more expensive than fermentation of sugar to alcohol, the benefits are much greater because the infrastructure investment in the fuel distribution system is minimised. The yields per unit of land are at least doubled. Furthermore, the forecasts all show a very substantial growth in heavy goods vehicles and they are likely to stay on conventional diesel longer than the light van and car fleet.

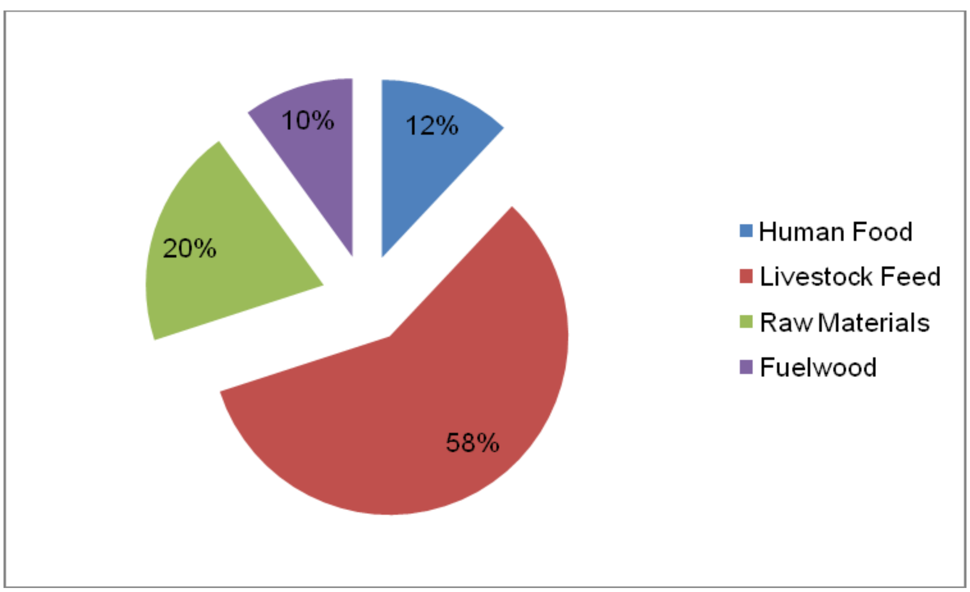

Figure 2 Global Biomass Use (Source: Krausmann et al. 2008)

Solar

The sun represents the ultimate in renewable energy sources. Solar power is free during operation as well generating no emissions. However the embodied energy and emissions of photovoltaic (PV) cells means that PV solar has emissions comparable to nuclear power per kWhr over a whole lifetime. The other major problem with PV power is its intermittenat nature. Obviously, power cannot be delivered at night but even moderate cloud can severely decrease the quantity of energy being produced. For this technology to be practical on a very large scale it needs to be combined with quality energy storage, distribution and conversion technologies.

On smaller scales, the ability to incorporate PV cells into the built environment means that the vast areas of roof space available within the urban environment can be used to collect electrical energy. This electrical energy is available during office hours when loads are high and more energy is generated on hot sunny days when the energy requirements of air conditioners are highest. Connecting these systems to the grid eliminates distribution and storage problems which have increased with the wider use of air-conditioning plant.

The sun can also provide vast quantities of usable thermal energy. As this heat is generally of low temperature and hence unable to do much work, currently solar thermal is mostly used in the heating of domestic hot water. It has been estimated that with appropriate design of solar capture equipment up to 10-60% of combined domestic hot water and heating can be meth using solar energy even at latitudes .Other uses of solar thermal include space heating, drying desalination and other industrial processes

A number of projects exist which use large scale collection systems (generally tracking parabolic mirrors) to generate electricity through steam cycles. These have been used as stand alone systems or in combination with existing coal fired power stations. The intermittent nature of the energy supply for these systems can be offset by thermal energy storage. Calcualtions have shown that this fom of solar thermal can deliver baseload power. Distribution of this power from areas of consistent high sunlight has proved in some cases to be costly. Areas of desert tend to be remote from areas of high electricity use although projects in Spain and California have shown success.

Geothermal

While the overall emperature of the earth represents a vast reservoir of energy, there are few places where it is convenient and cost effective to access this energy. Most projects at present use hydrothermal energy as the direct use of the high pressure, high temperature water is simple way of generating electricity. Experiences in New Zealand indicated that the removal of hot water from the ground resulted in subsidence affecting local buildings, with the problem being resolved by re-injecting water back into the same area. Similarly it was also found that the intensity of local natural geysers, important natural tourist attractions for most areas with significant resources close to the surface also suffered. This has resulted in other countries, such as Japan, deciding against a greater use of this potential energy source due to possible negative repercussions on the natural environment.

Like all energy, the geothermal process also has a number of emissions, including CO_2; however levels are approximately 90% less than those of coal-fired plants. In addition other emissions need to be either treated or monitored, including H_2S, As, B, Hg and dissolved ammonia.

Use of direct gothermal energy for heating of domestic water and space heating I practiced extensive in Turkey and Iceland. The number of locations where this use of geothermal is practical is small.

A further use of geothermal energy is the injection of water into hot dry rocks and generating electricity using the resultant steam. No commercially viable system exist yet for the technology although there are demonstrations in Europe and Australia. The quantities of energy available are vast however the locations are remote and distribution and storage of the energy will present further technical problems and increase costs

Hydropower

Hydropower is the most mature and widely used of the renewable technologies,. Roughly 15-20% of the world's electricity is generated by hydropower and the potentials exists for hydropower ot provide approximately 50% of the world's electricity.

Until comparatively recently, emissions from hydroelectricity were regarded as low. The measured emissions of methane from anaerobic degradation of the vegetation in a flooded valley are substantial and make hydro power a relatively high emitter of greenhouse gas with one estimate making them comparable to a gas fired power plant over the 100 years (these calculations depend heavily on the estimated life of the dam). Further concerns of safety (dam breaks), habitat loss susceptibility to drought, loss of arable land and resettlement have lead to a marked reduction in enthusiasm for large hydropower projects.

On a small scale some of these problems are lessened sufficiently to make local hydropower projects acceptable. These are of the order of 10 MW in capacity and often represent off grid generating capacity for power at a village level.

Wind

The generation of power from the wind is being harnessed on an increasing scale to boost clean electricity production around the world. The statistical rate of growth is high but it is starting from a low base and will be making an increasing contribution to power supply over the coming years. At present, it is receiving substantial government support in some countries.

In Europe, Denmark, Germany, Ireland and Spain, wind power has grown rapidly and represents between 15-20% of power production. The UK programme is being encouraged to expand rapidly. However, analysis of the experience in these countries is important to gather an appreciation of the levels of power than can be accommodated into the power supply system. The proximity of Denmark to the Nordic hydro system has enabled the building of transmission links equivalent their installed wind capacity. As a result, 20% of the annual power comes from wind turbines but some 80% of wind turbine output is exported to Norway and Sweden with the Danish demand balanced by hydro power.

Germany has raised it installed capacity to about 15% of its total but has started to hit technical problems of accommodation and the largest operators point out the high cost of carbon abatement because of the need to balance with fossil fuelled capacity running sub-optimally. Ireland also met accommodation problems with power management, back-up flexibility and its cost.

The major drawback is that the wind is variable, unpredictable and non-continuous in many parts of the world. In contrast, electricity demand is continuous with a need for stable voltage and frequency. The majority of power is used the moment it is generated and the skill of the supplying companies is to maintain a dynamic balance between supply and demand. Wind has a significant role to play in remote and island situations where power grids may not exist. However, on major grid networks such as the UK or Germany, the accommodation of viable wind power output has to be matched with local demand balanced by adjusting conventional power generation. Since areas such as the UK can suffer anticyclonic conditions for days, peak power demand needs to be fully covered by conventional generating capacity. Recent studies indicate that as the proportion of wind power increases, the need for conventional cover becomes proportionally greater with a very substantial increase in the asset base required to provide the total power output.

Better wind conditions often exist offshore so many countries see these areas as prime development sites. The trade-off for better wind conditions is the construction cost and maintenance coupled with the cabling cost necessary to link back to a grid system. The transmission loss and additional transmission and power management systems also need to be taken into account when considering the delivered power cost and the true cost of carbon abatement. In the UK for example, the wind itself provides CO_2-free power at point of generation but the saving to the system is only about 440gm/KWh. Another factor in the use of offshore windpower arises in high wind conditions when storm-force winds can trip the turbine at full power output on an entirely unpredictable basis. Such incidents have already disrupted both the Danish and German supply systems for several hours and such problems would be exacerbated by increased wind input and developments in very windy areas subject to storms.

Energy conversion technologies

A key role for the chemical engineering profession will be the comprehensive understanding of energy conversion technologies. Fossil fuel supplies will require an increased degree of preparation to reshape the molecular structure to the needs of user equipment. Sources of energy will become more complex. Heavier, higher sulphur crude oils will needed to be introduced along with tar sands, shale oils, weathered crude (such as in the Orinoco basin) and a wide range of coals. Refining, purification and conversion processes such as fluid coking, hydro-desulphurisation, hydro-cracking and gasification will all be required. These processes have to be of increasing efficiency while minimising pollution. - a major challenge to the industry. New catalysts will be required to shift the equilibrium of processes to the high value products needed.

Biomass processing creates similar challenges in order to produce fuels that match the needs on new drive trains. While purists may resist the concept of co-processing, some biomass may be most effectively co-processed with coal or petroleum coke. This has already been demonstrated in the

Netherlands where up to 30% of bio-mass has been successfully processed to generate power. A second major investment in a 1200 MW units is being progressed by Nuon in Eemshaven. Co-processing enables the quantity of biomass to be more manageable and economic.

Anaerobic digestion is another conversion process that is gaining interest in that it can solve a waste disposal problem by converting it to energy on a modular scale.

The nuclear industry will continue to seek ways to reprocess spend fuel and develop better ways to minimise and store waste. Work will continue on fission and high temperature dissociation of water to produce hydrogen more efficiently in reactors. Hydrogen will be of growing importance especially for the refiners whose newer processes will leave a shortfall of hydrogen in the refinery balance. The fuel cell is also an energy conversion step and considerable work will be needed to evaluate the purity of hydrogen and the sensitivities of the materials of the cells to trace impurities.

Energy Storage and Distribution

Hydrogen

Hydrogen is often seen as the holy grail for a low emission energy "source". It does not occur naturally and it is not a source of energy but an energy carrier. It has to be made wither from a hydrocarbon source such as fossil fuel or biomass or by the dissociation of water usually by electrolysis. Neither route is cheap. Commercial hydrogen is currently produced from methane and a rule of thumb cost of processing in bulk is roughly 2.5 times the price of the methane from which it is made.

Current electrolysis systems consume about 50 - 55 kWhr of power to produce 1 kg of hydrogen. The energy in 1 kg of hydrogen is 35 kWhr so there is an inherent inefficiency in electrolysis. If the hydrogen is then compressed to pressures suitable for transport use, another 10 kWhr of compression energy is required reducing the efficiency of the process still further.

Consequently, if hydrogen is to be used for zero carbon emissions, the use cycle must be very efficient and that is best done in a fuel cell and not an internal combustion engine.

Perhaps the biggest obstacle to the use of hydrogen as a transport fuel is the weight of the cylinder required to contain it at very high pressure. Liquid hydrogen has been considered but its boiling point is so low that some ingress of heat is inevitable even with excellent insulation that evaporation will take place and hydrogen is a potent greenhouse gas.

Much research work is in progress by most major auto companies and energy companies to find ways of storing, using hydrides for example and also small on-vehicle reformers to make the hydrogen in-situ at a rate related to vehicle demand. Exxon for example is researching hybrid designs where a battery and a reformer would handle variations in power to an electric motor. BMW and Ford have also done much work on hydrogen in internal combustion engines but range, weight and NOx control remain problems.

The pathway for hydrogen into the transport sector is more likely to be via vehicles operating within a limited radius and able to refuel at a facility. The cost of infrastructure to have hydrogen widely available at filling stations could only take place at huge cost.

As mentioned above, most auto manufacturers have research in progress on fuel cells. Daimler-Benz has buses in 12 cities demonstrating fuel cells under different climatic conditions. Honda has plans to launch a hydrogen car within 5 years and hydrogen fuelling is now possible in Los Angeles, Hamburg and London.

The theoretical efficiency of fuel cells is very high and even today, cells are substantially more efficient energy converters to small scale electric power than any other method. A limiting factor is cost in that they are currently much more expensive than internal combustion engines per unit of output. However, with improvements in materials and manufacturing methods, they are already starting to be used on power tools and other portable electric appliances.

In parallel with the automotive use is the stationary cell for combined heat and power systems. The route shows promise because it enables piped hydrogen to be utilised with power and heat utilisation. Hydrogen networks already exist in parts of Europe mainly associated with the chemical industry e.g. Teesside, Rotterdam, Ghent and the Ruhr.

Larger scale (2 MW) cells are being tested using solid oxide technology. China and Japan are demonstrating the use of coal gasification with solid oxide gas to power conversion rather than a combined cycle gas turbine.

Batteries

Electricity storage has always been a high cost step and for decades, batteries have not been a commercially attractive way to store power. However, after much research and ongoing improvements, battery technology is emerging as a potential solution to zero emission vehicles for say inner city areas. They can also be used in hybrid designs to restore the range of current vehicles, improve efficiency and reduce emissions. Nevertheless, their more widespread use involves generating the power they need for recharging at a clean stationary source. So any major switch of energy demand from liquid fuels has to be picked up by an equivalent amount of energy input to the recharging system.

Another aspect that needs to be considered is the life cycle of the battery and the energy needed to recycle because lead acid batteries are being replaced by more sophisticated metals that may prove to be expensive to reprocess at the end of the life.

Nuclear Fission

The controversial issues of weapons proliferation, waste disposal, safety cause difficulties with licensing., siting and operation of these plants. In addition the decommissioning of nuclear power plants remains an area of experimentation and research rather than routine procedure of demolition and remediation. Despite these difficulties, many countries with existing nuclear programmes are planning to develop these further and many other countries are exploring nuclear power as an option.

The chief advantage of nuclear fission is its capacity to provide relatively cheap, low emission base load power. Current reserves of uranium appear to be adequate to ensure supply for at least the next 100 years at current prices and technology levels and some predictions give reserves of the order of 2000 years given predictions in exploration and improvements in mining and reactor technology.

While the fuel costs of fission reactors is very low, the construction, commissioning and operating costs are high. Efficiany gains by enriching fuel rods have increased the potential "burn-up" rate of uranium fuel rods from 40 GWd/kg U to 60 GWd/kg U. This means that the fuel rods can remain in the reactor for longer lowering the operating costs. This also results in higher temperatures within the reactor, an increased neutron flux (leading to embrittlement of the cladding) and increased hydrogen production. New materials and fabrication methods will be required to sustain these high burn up rates which in turn ill be necessary if fission is to be competetive with other low emission technologies.

The disposal of nuclear waste remains, at present, an unsolved problem with thal of the worlds existing high level qaawaste in "temporary" storage. While Finland is planning to open a final disposal site in Olkiluoto at Eurajoki in 2020, no other country appears to be as advanced in the construction of such a facility. The estimated cost of the Finnish project is €3 billion piad for by a levy on nuclear power. It is anticipated that this will store all of Finland's nuclear waste. The design problems do not appear to be intractable nor is the technology unavailable. There is, however considerable public resistance to the long term storage of nuclear waste.

Safety of nuclear power plants is the key area of concern. While many nuclear power plants have been operated quite safely since the 1950s. Accidents like those at Chernobyl and Three Mile Island, have highlighted the widespread, long term and devastaing consequences of a nuclear accident. Improvements in the intrinsic safety of nuclear fission reactors will be required before wide spread public acceptance of nuclear paower can be expected. Current developments in pebble bed technology, the use of uranium/thorium fuel cycles and the development of passive (rather than powered) emergency cooling systems are necessary before the use nuclear fission can be easily expanded

Nuclear Fusion

Fusion energy offers many advantages if it can be practically realised. Because its fuel energy density is significantly greater than most others (by factors of more than million c.f. fossil fuels, wind, wave, solar, geothermal, hydro etc., and even about a factor 3 to 4 compared with fission fuels, relatively little fuel is required for a given power output, and the fuel supply is sustainable.

Fusion is not anticiapated to produce high level nuclear waste. While the fusion structure will be activated, this is not a long-term burden as it should qualify for near-surface storage of waste (low to medium level) for a term of about 100 years, with some recycling possible.

Although it is difficult to cost fusion energy in the absence of actual fusion reactors, (actual costs will depend on development which has yet to take place), nevertheless studies with conservative assumptions indicate that it should be competitive with other large-scale energy sources (e.g. fission and fossil). External costs for fusion energy (those costs of the remedial measures necessary to provide an "acceptable" environmental impact), are significantly lower than those for fossil-fueled energy.

Many technological issues remain to be resolved before a commercial fusion reactor can be built, but perhaps the major one is that of materials. The reactor-internal materials will be subjected to significant fluxes and fluences of heat and high-energy neutrons. For the economic operation of the reactor, these materials must retain their physical characteristics for a sufficiently long time avoiding frequent replacement which would, if at all possible, be complex and expensive. What makes this issue novel is that the neutron bombardment energy is significantly higher than in other neutron irradiation situations (e.g. fission reactors) and the material operating temperature goals are also higher. However, the development of more efficient and safer, fission reactors includes the use of higher energy neutrons and higher operating temperatures, so material development is an area where fission and fusion research communities can mutually support each other. In fact, in the present absence of a high flux source of fusion neutrons, the irradiation of fusion reactor-relevant materials (to study their properties and develop low activation, radiation-resistant types) is being carried out largely in fission reactors.

Actual net fusion power has been produced in experimental devices and measured. The European Union tokamak, JET, first produced a peak of 2 MW in a fusion power pulse of about 2 s in 1991. In 1994, the US tokamak TFTR achieved a shorter fusion power pulse with a peak of 10 MW. This was subsequently exceeded by JET in 1977 with a fusion power pulse peaking at 16 MW. Each of these fusion power performances was limited in time by plasma behaviour (an uncontrolled degradation in the plasma performance). In fact, probably the most significant achievement (JET 1977) is the "steady" production of about 5 MW fusion power, the extent of which (about 5 s) was limited only by the capacity of external power to supply the plasma heating system and not by uncontrolled plasma behaviour. In other words, the fusion power pulse could have been extended in time with additional power supply capacity.

Embodied Energy

The embodied energy of a product refers to the total energy utilised in the construction of that product. There is much energy expended in the extraction of resources used in the manufacturing sector not to mention the energy expended during the manufacturing process itself (Morawski

2006). There have been many studies, primarily within the building industry, that look at the CO_2 emissions resulting from the manufacture of the building materials however this process can be equally applied to any manufacturing activity.

Research into low-energy buildings found that embodied energy accounted for approximately 40% of the total energy use of the building over a 50 year lifespan. Between 37-42% of this embodied energy may be recovered through recycling (Thormark 2002).

Further studies have looked at material substitution and the effect that it has on the embodied energy and recycling opportunities. Conclusions reached indicate that material selection during the design phase is of great importance. This selection process should look not only at the embedded energy of the proposed materials, but also at the ability to recycle, including the form of recycling, which will affect the disassembly process (Thormark 2006). Recycling will be discussed in a later section.

Results have shown that adopting a life cycle assessment during the design process can reduce embodied energy by approximately 10-15% (Thormark 2006). Quantifying the amount of embodied energy from different products can help prioritise recycling. In addition these calculations are able to be used in cradle-to-grave profiles used by manufacturers when making initial material selection (Morawski 2006).

POLITICAL AND SOCIAL CONSIDERATIONS

Any solution to the emissions and energy problem will be a combination of the political and the technical. While almost anything is possible technically, without a political will to change there will be no change. Traditionally, the profession has not been involved in political debate. The extent of the problems faced in the area of energy means that it is no longer ethical for the Institution to remain silent in areas where it possess the expertise to contribute to the debate.

Politicians in general lack specific scientific knowledge while lobby groups and NGO’s try to influence policy decisions to suit their cause. Chemical engineers are likely to be called upon increasingly to articulate the case for choosing technically sound and economic solutions to problems as the issues become more complex. This becomes applicable in the choice of bio-fuels, clean power generation and carbon capture options.

It is important to remember that the same social and political issues have arisen time and time again over the range of social problems noted above. If the IChemE is to be a useful participant in the energy debate, we need to recognize how objections to energy (indeed all) projects develop. These objections are epitomized by the 'not in my backyard' syndrome or 'NIMBY'. This has been one of the major barriers to many planned energy projects, particularly those proposing to use wind, biomass and municipal wastes as fuel sources. However, it does not only affect the renewable energy sector, with many proposed generating facilities utilising fossil fuels receiving the same attention.

The basis of this proposition is that members of society support the aims and objectives of a particular project or development, as long as it is not located in their immediate area.

Four common elements to groups that oppose development on this basis have been identified (Yarzebinski 1992) being: -

1. Fear – the general fear of change, whether this is a change in the environment or the composition of the community. The result being that group members promote maintaining the status quo and highlight the negative aspects of the proposed development.

2. Meetings – opponents rely on a show of numbers to community meetings to reinforce the opinions of that group as being representative of society as a whole as being opposed to the development.

3. Emotions – the emotive pleas of those most closely affected by the development are highlighted, hoping that it will force the development to be relocated.

4. Politics – which side of the debate that has the greatest support from members of society will generally also have the support of local politicians (particularly if there is an election looming). There are many politicians who have been elected (or defeated) based on their support or rejection of a contentious issue.

It is those communities that have the greatest political and economic resources that are able to prevent unwanted development. In considering these developments the initial question that will be asked by the community is 'why is this development needed?' The value of the development to the community will extend past the value of the energy generated, creation of jobs, effect on electricity prices, sustainability of resources or localised control and will include external effects such as (Bergmann, Hanley & Wright 2006): -

- Projects must be aesthetically pleasing;
- Renewable energy projects must have a low environmental impact;
- Wildlife should not be harmed.

Irrespective of the community's initial attitude, how the costs and benefits of any proposed development are explained and queries dealt with, will determine much of the community's ultimate reaction to the proposal (Wolsink 2006).

There have been many papers which have discussed the implications of local governments and communities on the siting of renewable energy generators. In addition to the external effects noted above, surveys have shown that the public has (Upham & Shackley 2006): -

- A distinct distrust of developers, including their description of the proposed project and its effects (in an English survey (75.7% believed that the information provided by the developer was either wholly or somewhat inaccurate, 15% believed it was neutral and only 7.3% believed it was accurate).
- The perception that public organisations did not provide satisfactory responses to questions raised.
- The perception that environmental impact statements obtained were not independent. These environmental reports were generally limited by the scoping brief, which local communities believe should be prepared through public consultation.
- That whilst many developers hold public meetings, this consultative process generally occurs after many of the decisions have already been made. It is believed that there is a lack of early involvement in the planning process.
- That many of the planning processes involve reviews by a number of government departments, at all levels (Federal, State and Local), however the perception is that these reviews are unable to be scrutinised or held to public account.

It is important that the IChemE, when attempting to influence policy in the direction of the goals of the roadmap, avoid spokespeople with conflicts of interest, gives objective assessments of projects and policies and makes their expertise available to all parties. It is only through being seen as a disinterested party acting for the common weal that the Institution can be effective.

Economics

It seems apparent that Australia will have a carbon Emissions Trading Scheme (ETS) which will be introduced in 2010. This has been welcomed by most, if not all, major players in the energy sector as it has lowered the uncertainty that existed up to the election of the Rudd government. Full details of the scheme are not available at the time of writing (the final Garnaut review report detailing the recommended scheme is due to be published on 30 September 2008). Australia is well placed to avoid the over allocation of permits that occurred in the first two phases of the European ETS and will no doubt eliminate windfall profits that accrued to the European power generators who were allocated free permits and proceeded to include the value of the permits in pricing decisions.

Emission trading schemes have been widely discussed since first considered as an economic instrument over 40 years ago. They have been most widely used in the USA given the political aversion to the introduction of any new taxation (Solomon 1999), a weighty consideration given the Australian political environment when this measure was proposed. In addition, emission trading schemes confer property rights on the permit owners compared to a carbon tax which implies government ownership of the property right (Bandyopadhyay, Bagheri & Mann 2007).

Solomon (1999) conducted a survey of the six emission trading schemes that had been operating in the US noting that the four 'cap-and-trade' systems, similar to that proposed in Australia, had the lowest transaction costs compared to the 'offset' programmes. It was also noted that these programmes enjoyed a moderate to high market participation rate.

Based on the results of the above survey combined with a review of possible new applications, Solomon arrived at a number of predictions (Solomon 1999) comparing the cap-and-trade system to an offset system, the following which have relevance to the Australian position, being: -

- In an organisational environment with ample training and experience in emission trading schemes, a cap-and-trade system will be more cost effective but slower to implement;

- In an emissions market with low transaction costs a cap-and-trade system will be more cost-effective; and

- In an emissions market with stringent environmental goals, the cap-and-trade system will result in greater emission reductions.

Transaction costs are expected to be low due to the structure of the market and current societal opinions are demanding stringent environmental controls. The economic impact of such a scheme, in the case of Australia, is currently being analysed by Garnaut, with the discussion document noting three possible short-term changes, being (Garnaut 2008): -

- Energy efficiency measures within existing operations;
- Fuel substitution, most likely gas for coal where feasible; and
- A shift in base load generation from coal to gas using those facilities that are already in existence.

This change in production for some of the coal generation plant, particularly those nearing the end of the useful life may see if become more economic to close them down. (Garnaut 2008) This together with the economics of utilising low emission plant for new base load generating requirements will see a gradual move away from coal plant (until carbon capture and sequestration becomes viable).

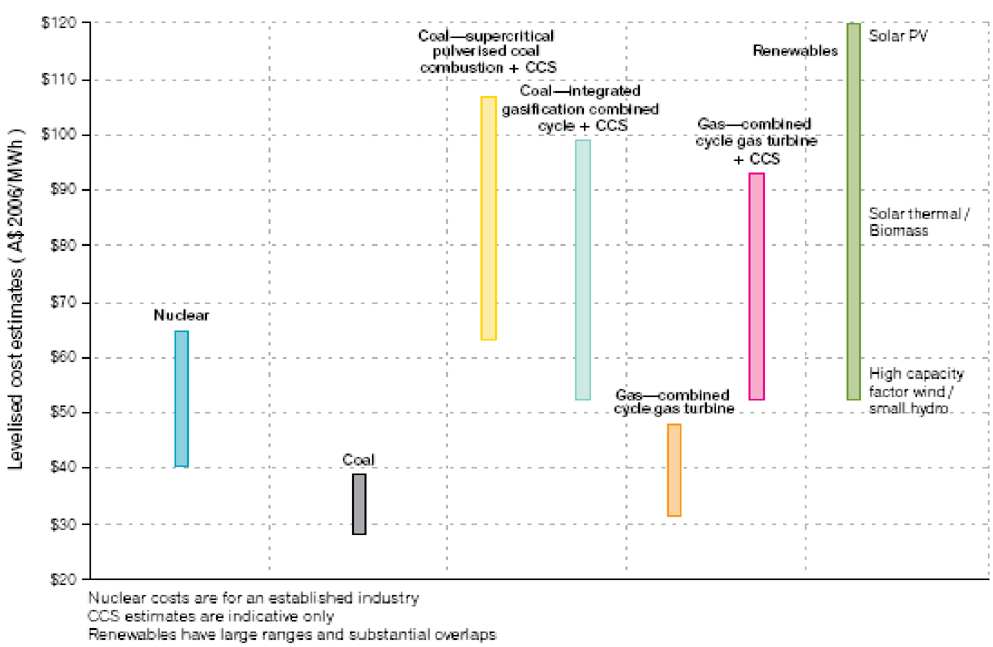

Figure 3 Cost of energy including externalities (Source: Office of the Prime Minister and Cabinet).

Accurate economic comparison of different sources of stationery energy means that their true cost (i.e. their production cost plus the external costs to the environment and society need to be compared (Figure 3). This comparison shoes that most renewable are comparable in price (once externailites are computed) to coal with sequestration and that wind is of the same order of cost as nuclear. The most recent report by the ExternE program was published in 2005 shows the external costs per kWh for both current and advanced electricity systems (Figure 4). It differentiates between the actual costs of power plant and the balance of the energy chain (Rabl & Spadaro 2005). The costs that have been calculated have included environmental impacts that occur either upstream or downstream of the power plant. It has also excluded any of these impacts if they have already been internalised through an optimal pollution tax. If the cost is accounted for through tradeable permits that are issued at no cost, those costs are included as they have not been paid by the polluters (Rabl & Spadaro 2005). It can be readily seen that the external costs of traditional fuels represent a vast subsidy of these fuel types. Recognising these subsidies and applying the proceeds of a carbon tax to fledging renewable industries will greatly accelerate their development.

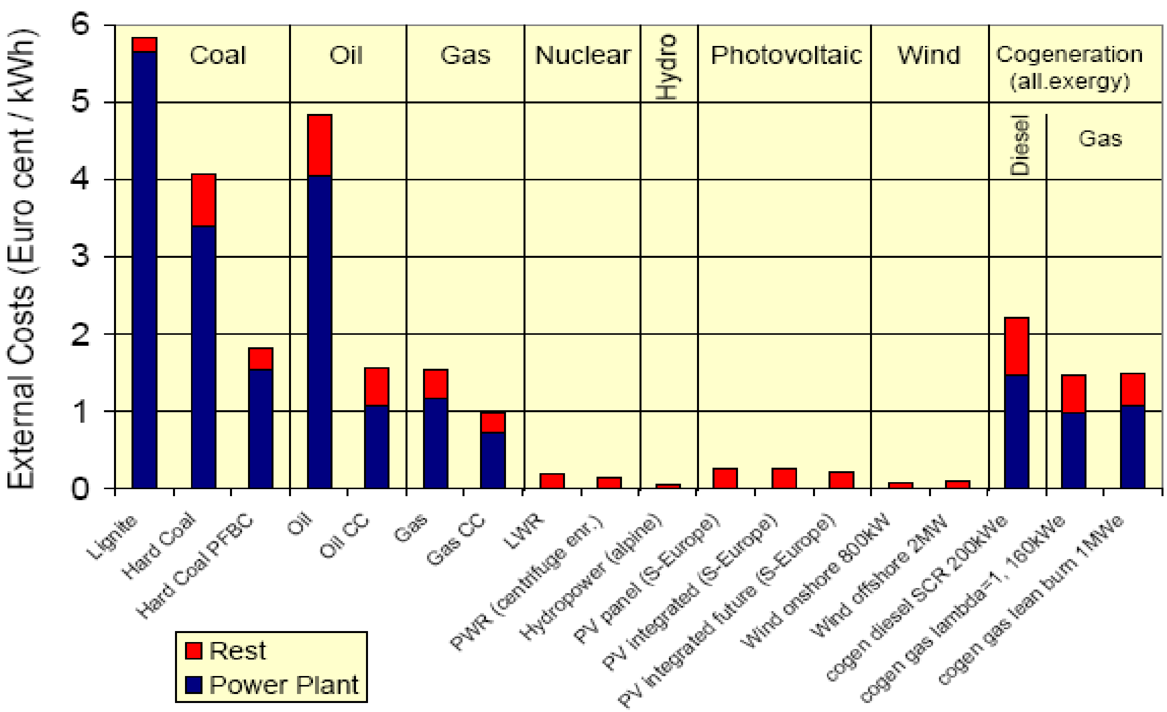

Figure 4 External costs of electricity genreation (Source: Rabl & Spadaro 2005)Source: (Rabl & Spadaro 2005)

<u>Education and professional training</u>

The future of the energy sector is dependent on the ingenuity and skills of the process industries. Not only is there a need to meet a substantial growth in demand estimated at some 40% by 2030, there is also the increasing need to tailor the form of hydrocarbon to the form that enables the efficiency of the user equipment to be optimised with minimal emission.

Establishing an experienced professional workforce to meet this challenge alone is a major takes However, National Petroleum Council report states that over 50% of the work force in the energy industries are due to retire within the next decade. While that is a US figure, it is probably representative of the oil industry worldwide so not only is there a need to replace that part of the skilled workforce but also build and operate the expanding and more complex facilities needed to service future demand.

In addition, the decision making processes required in a climate of emissions trading will be different to the current ones employed by industry. Training of graduate engineers and professional development of practicing engineers will have to occur rapidly if engineering decision making is to reflect the new policy environment. The IChemE, through provision of courses for professional development, sharing of "best practice" tools for project decision making through subject groups and ensuring that universities are equipping graduate with the requisite skills through accreditation, has a duty to ensure that this happens.

CONCLUSIONS

The immediate priorities given by the goals of the Roadmap are sound. The challenges faced by the profession over the coming decades with respect to energy are enormous. Action on developing and implementing appropriate technologies while the price of energy is still cheap enough to make these projects feasible must occur in the next 5-10 years. While this will be difficult enough using the infrastructure within the industrialized world, the profession must consider the industrializing countries (China and India in particular) and developing world as well. The aspirational expectations of the populations of these countries must be met and it is readily apparent that current technologies will not come close to doing this. Development of the energy infrastructure of these countries must take into account the environmental lessons learned by the industrial nations. Chemical engineers need to act to ensure that energy is treated as a scarce resource and work towards ensuring that the technologies that are implemented are sustainable and available to all – not just the rich.