

Energy for life - what can national academies do?

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Abstract

This paper reviews the historical growth of energy demand and the factors driving that demand including the mix of fuels used. It also provides some commentary on current production rates versus usage of the fuel and considers the constraints arising from climate change. The author suggests areas where national academies might advise their governments on energy strategy and also how future generations might be encouraged to become engineers and tackle these kinds of issues.

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Introduction

This paper considers:

- Energy demand, energy supply and impact on the environment over the working career of an engineer
- What will the energy scene look like for the next generation of engineers?
- What can national academies do to influence governments and steer a change in direction on energy?

Energy Demand

Pre the industrial revolution energy demand was reasonably stable and was primarily from biomass. In 1850 demand was 200 million Tonnes Oil Equivalent (MTOE). In 1950 energy demand had risen 10 fold and in 2000 nearly 50 fold from the 1850 level.

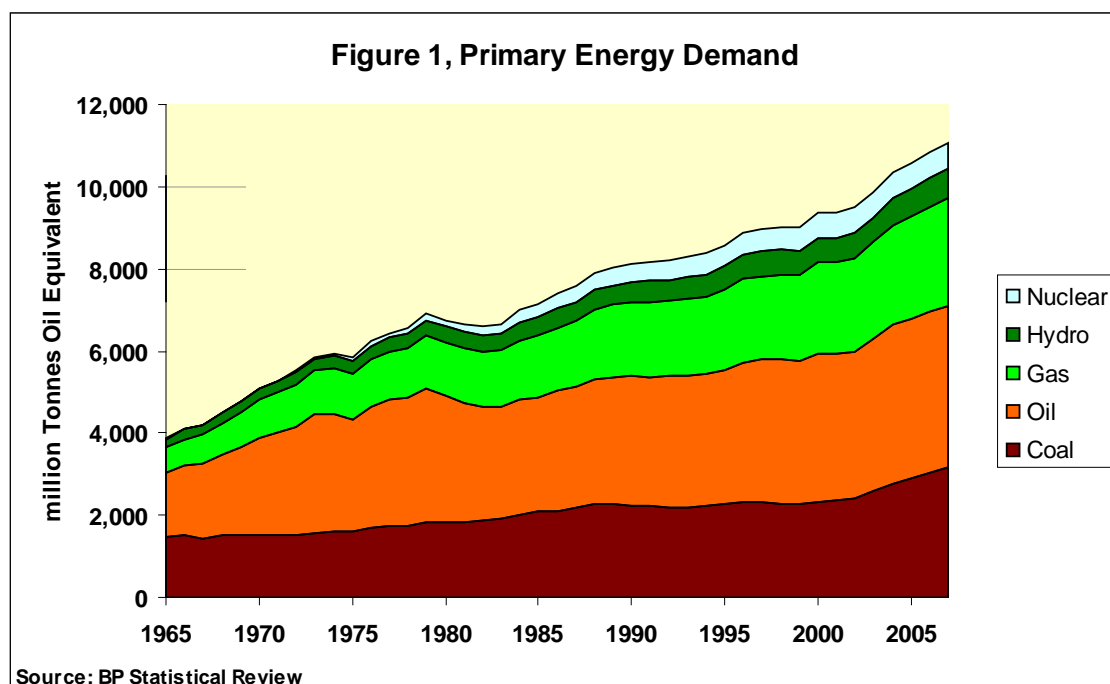
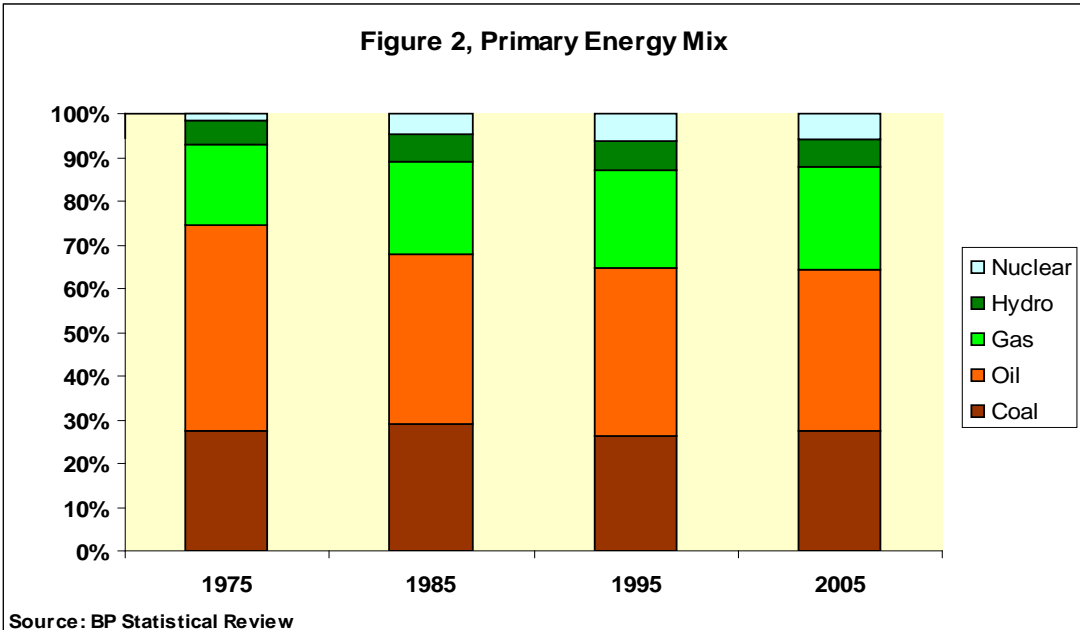
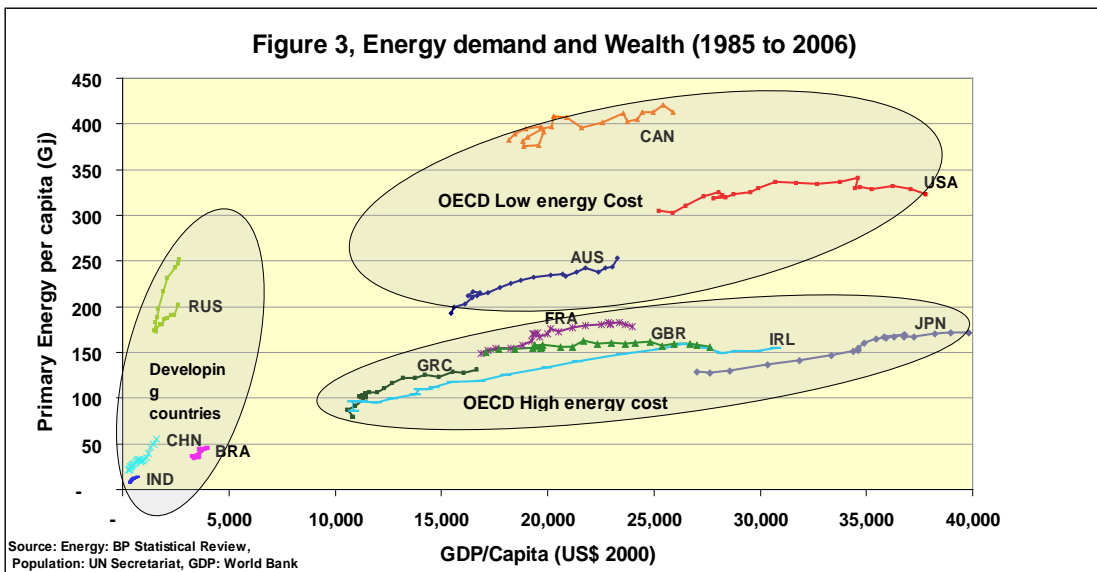


Figure 1 shows the change in primary energy demand over 40 years. There are some disturbances with oil price shocks and economic recession but the rise in demand continues apace. Apart from nuclear energy, it would appear that little has changed in the energy mix over the last 40 years. If we look in more detail at four snapshots in time (Figure 2) we see some subtle changes with an increased share for nuclear and gas, largely at the expense of oil. However, considering the time span the change is very small.



Why does energy demand continue to grow at such a pace and what can be done to reduce or stabilise demand? As nations become wealthier their demand for energy increases or conversely, access to energy enables economic growth. Whilst increasing prosperity partly explains the growth, there are some dramatic differences throughout the world shown in Figure 3. The trends are characterised by three broad groups, OECD low energy cost, OECD high energy cost and developing countries. Whilst this is a generalisation and takes no account of geography, population density and local climate, it does show trends. The developing countries (BRICs) whilst in the lower left of the diagram, currently account for nearly 30% of primary energy consumption. Over the last 5 years their compound growth in energy demand/capita has been 3.5% with a corresponding rise in GDP/capita of 5%.



Predicting the future of energy demand is an impossible task. However, looking at the historical trend unless there is a dramatic global event it seems likely that demand will continue to grow steadily.

Energy Supply

Over the last 40 years we have heard many predictions that we will run out of oil and gas; the latest pundits talk about “peak oil”. It hasn’t happened so far!

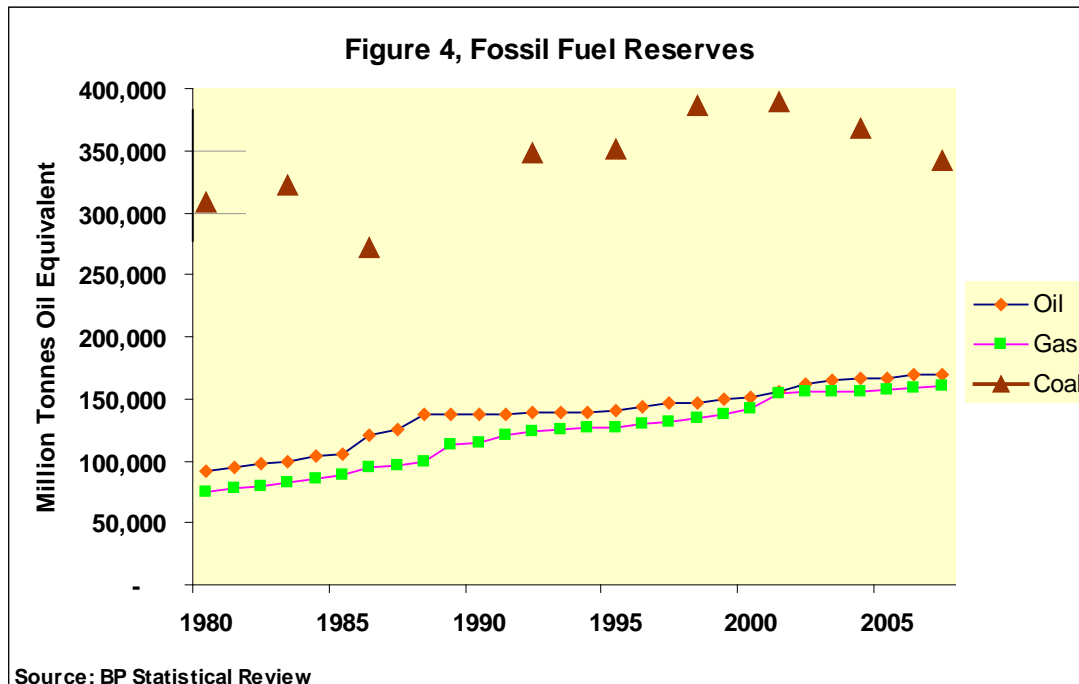
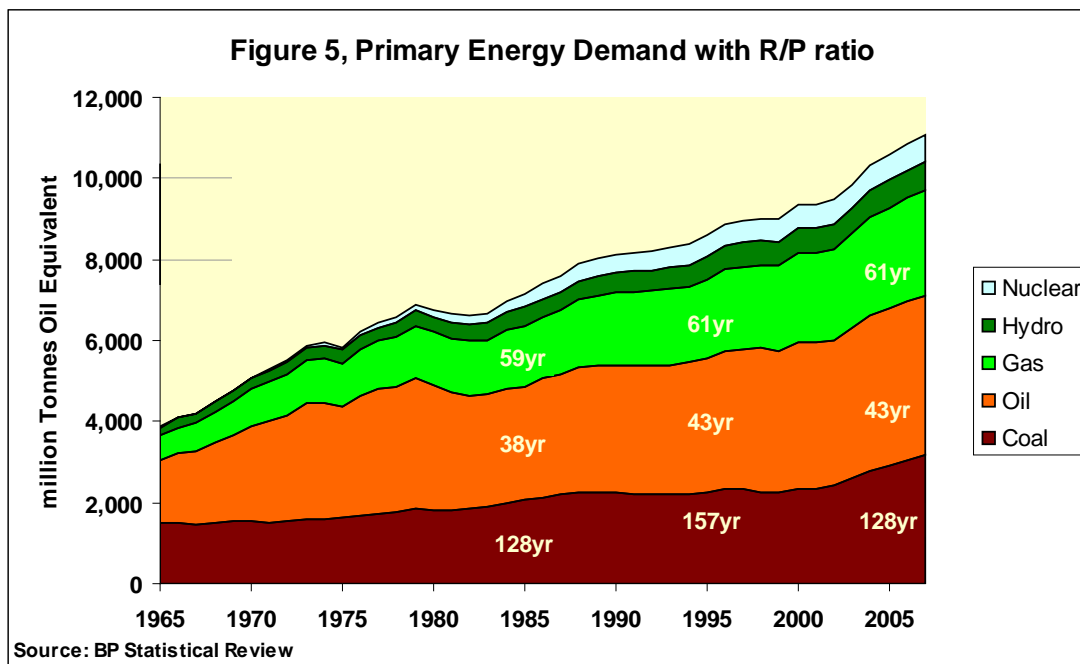


Figure 4 shows that over the last 25 years, where there are reliable data on reserves, oil and gas reserves have nearly doubled despite the growing demand over this period. In the oil and gas industry reserves have a specific definition, “those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.” The data for coal reserves are less reliable. This definition of reserves has some important implications, particularly “under existing economic and operating conditions”. As the price increases, supply demand economics drives further exploration with increasing reserves recoverable at the revised economic conditions. A good short term indicator is the Baker Hughes monthly oil and gas rig count although this correlates more with production rather than exploration. In 2008 when prices were high, the world rig count peaked at around 3500, whereas currently with lower prices the rig count is 2000.

Developments in technology and enterprise of engineers in applying the new technology lead to both a better understanding of reserves and improvement in operating conditions. There have been dramatic improvements in seismic surveying, the analysis of seismic data and understanding of reservoir performance. The unit cost of drilling wells has reduced so we are economically able to drill deeper wells in more hostile environments. In the 1970s wells were drilled in 100m of water on the continental shelf, nowadays wells are drilled producing oil and gas in over 2000m of water.

A key measure is the Reserves/Production ratio; this is the number of years of remaining reserves at the current production level. Looking again at the energy demand graph (Figure 5), despite the continuing demand for energy the R/P ratio has remained pretty static over the last 30 years.



So despite economic and significant technological growth little has changed in the mix of energy sources or in the remaining years of fossil fuel reserves over the last 30 years. What will it take for there to be a significantly different picture in 30 years time?

Constraints

If the pattern of energy use is to change significantly then a major event is needed to upset the status quo. The energy demand figure shows that in 1974 demand

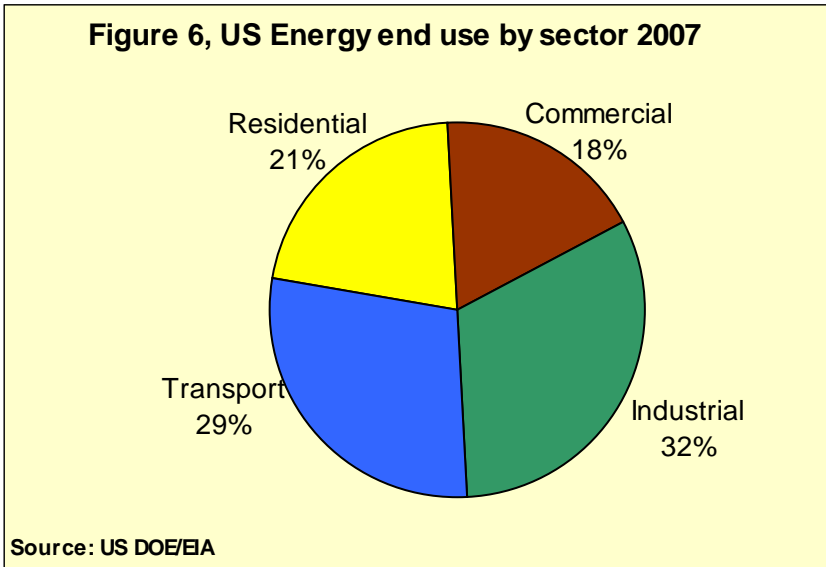
dropped mainly as a result of the Yom Kippur war when oil price jumped from \$15/bbl to \$50/bbl (2007 US dollars). Demand recovered without a drop in price until the early eighties with another price hike to \$90/bbl. Again more recently oil prices have peaked at \$147/bbl. Price driven by supply/demand imbalance or uncertainty in the market affects demand but typically it is not sustained over a long period of time.

Probably the most significant other influence is climate change resulting from greenhouse gas emissions and it is generally recognised that anthropogenic CO₂ emissions are leading to an increase in global temperatures. The IPCC have revised their estimates upwards and with greater certainty with each successive assessment report. Unlike other pollutants such as particulates and NO_x, which tend to be more local with their impacts more immediately apparent, CO₂ is a global issue which will impact future generations. If we stopped emitting CO₂ immediately the concentration in the atmosphere would continue to increase for many years. Global action is required at least from the major current and potential emitters of CO₂.

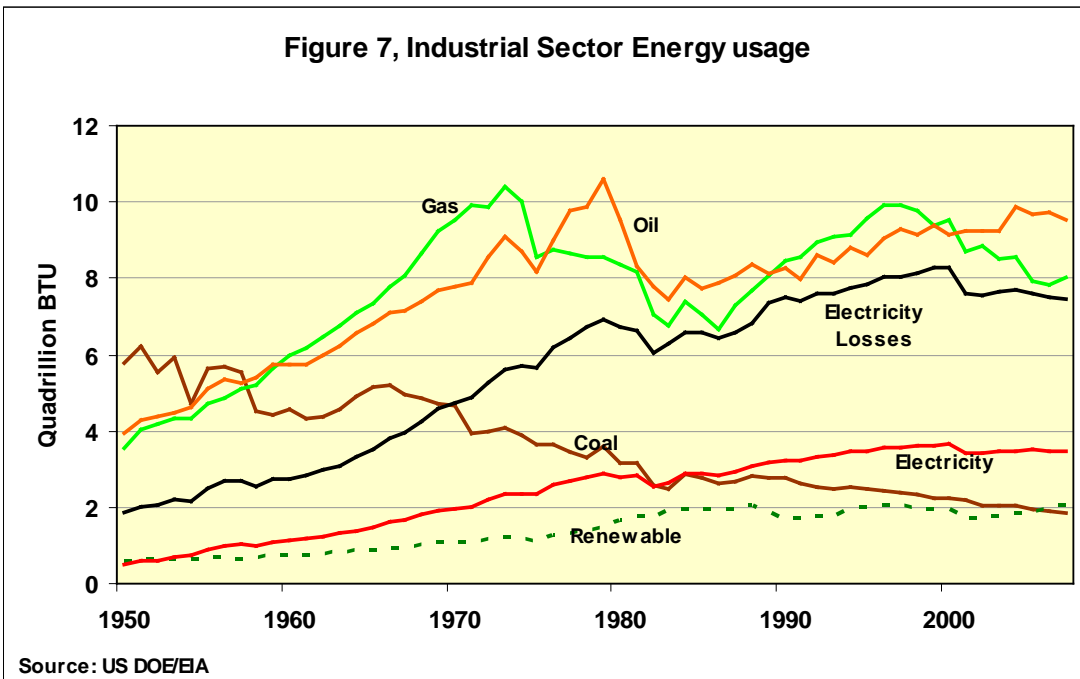
It seems likely that the 'price of carbon' either through taxes or a 'cap and trade' scheme will be a feature in future energy investments. This is likely to have an impact on fossil fuel demand unless 'carbon capture and storage' can be developed which overcomes the regulatory issues, public concerns and the economic challenges.

Living with the constraints

When the issue of carbon emissions is raised there seems to be a high level of focus on the transport sector, probably because it is closest to home and changing behaviours would have the most immediate impact on people's lifestyles. In the US, where energy usage for transport is generally a higher proportion than for most of the world, transport still only accounts for a little over a quarter of primary energy consumption Figure 6. Energy end use in the other sectors probably warrants more focus than at present if we are to have a material impact on carbon emissions.



The pattern of energy use is similar within the other three sectors and an example is shown in Figure 7 for the industrial sector. This diagram also includes electricity produced from a number of the primary energy sources. Whilst there is a significant fall in high carbon fuels and increasing renewable energy, the most striking factor is increase in electricity usage combined with consequential losses in conversion and transmission.



For the US, the overall efficiency from primary energy to useful electricity at the customers site has remained virtually static at 31% for the last 40 years, although

carbon emissions per megawatt-hour are reducing due to the increase in nuclear and renewable energy in the primary energy mix.

The Institution of Mechanical Engineers in the UK as part of its input to the UK government on energy policy has identified five priorities

Figure 8, IMechE Energy Priorities

- **Priority 1:** Energy Conservation – changing wasteful behaviour to reduce demand
- **Priority 2:** Energy Efficiency – using technology to reduce demand and eliminate waste
- **Priority 3:** Exploitation of renewable, sustainable resources
- **Priority 4:** Exploitation of non-sustainable resources using low- carbon technologies
- **Priority 5:** Exploitation of conventional resources as we do now

Considering these priorities each has its own challenges.

The convenience of electricity, there at the touch of a switch, tends to make us wasteful. How many office buildings are left over the weekend with lights blazing and air conditioning running? The wasteful behaviour is something that is difficult to change unless there is a close link between the behaviour and consequence, clearly the consequence of climate change is unlikely to have much impact. The price of electricity is a much closer link but even then the effect tends to be short lived. Real time metering and display of cost of use, at the point of use, provides a closer linkage.

The conversion to electricity and losses of electrical transmission is an area with a huge prize. Combine heat and power with local generation and use of 'waste heat' are very efficient but the regulatory regime has often penalised or put significant barriers in the way of such schemes. A Combined Cycle Gas Turbine (CCGT) can have thermal efficiencies of 54% compared with a conventional sub critical steam plant of 34%. Taking account of the carbon content of the fuel the gas fired CCGT emits about half the CO₂ of a conventional sub critical coal plant for the same electrical output. Currently, most converters of primary energy to useful work are

sized for peak capacity, whether it be, electrical generation, the automobile or domestic heating systems. An economic and efficient process for storing energy at large scale would be an enabler for more renewable energy sources and would enable conventional power generation to be optimised for continuous base load operation. Despite extensive research around the world such a process has not yet been delivered.

The main challenge for renewable energy is the intermittent nature of supply, hydro has a seasonal cycle, solar a diurnal cycle and wind is unpredictable. The scope for further large scale hydro power generation is limited. Tidal energy schemes are gaining interest but large scale schemes such the Severn Estuary or the Bay of Fundy where extremes of tidal range would provide a large source of energy will probably take some considerable time to permit and build. Tidal current turbines whilst of much smaller scale are in commercial operation but they will suffer from some of the problems that wind generation does, however, their significant advantage is they follow the lunar cycle which is highly predictable. Another factor in some countries is current grid system design which tends to favour large scale generators over smaller niche players.

Carbon capture and geological storage probably offers the best short term option for 'low carbon' large scale electricity generation. Whilst the technology of most aspects of the concept have been demonstrated there has been no full scale plant built and operated which integrates all the technologies from raw fuel to CO₂ storage. There is little incentive to apply carbon capture and storage technology if electricity has to compete in the market place. There are also the long term liability and ownership of the CO₂ once stored underground. Whilst there are still technology challenges which will improve the economics, current barriers are policy and funding for demonstration projects.

Latest generation nuclear plants, whether light water or advanced gas cooled reactors offer promise of decarbonised electricity and many of the safety or proliferation challenges have been resolved. There are still issues of public perception particularly the long term storage of nuclear waste. Planning and

permitting of new nuclear plants are probably the greatest barriers to the next generation of large scale power generation.

Role of National Academies

The energy sector is a long term business which requires infrastructure to be planned and invested in over many years, with technology barriers to be overcome and also policy issues that have to be resolved.

What is required to achieve this?

- Mechanisms to motivate and inspire people to enter engineering and science.
- Educated, trained and competent scientists, engineers and technicians
- Fundamental science and engineering research leading to practical solutions
- Informed and unbiased advice to governments on science and engineering.
- A stable policy and fiscal regime to allow long term investment.

In developed countries it has become fashionable not to pursue an engineering career which might explain how little the energy mix to power our society has changed over the past four decades.

In the UK we have many engineering institutions organised by discipline all of which serve their individual members needs. However, when it comes to advice to the Government each has its own focus which not surprisingly creates some confusion with non technical people in government. A recent parliamentary Select Committee recommended that the Royal Academy of Engineering should take a lead in cross disciplinary debate and formulation of the engineering advice to government.

The strategic priorities for the Academy are:

- Enhancing national capabilities
- Recognising excellence and inspiring the next generation
- Leading debate by guiding informed thinking and influencing public policy

The following are a few examples of how the Academy is turning these strategic priorities into tangible actions.

- The 'Best' programme encourages the brightest and most motivated young people to take up engineering. The Academy has provided strong support for the development and delivery of the pilot 14-19 diploma in engineering, and has taken the lead in enhancing the mathematics content of the advanced diploma.
- A steering group of experts has been established to review current approaches to engineering education and to develop an experience-led engineering degree which integrates technical, operational and business skills.
- Engagement with the UK Department of Energy and Climate Change in the development of its energy strategy, both in providing direct policy advice and helping to guide the production of consultations and policy statements at the formative stage.
- Production of detailed responses to 14 UK Government and EU energy consultations, including responses on offshore wind and other renewable energy generation technologies, the role of nuclear power in a low-carbon economy, nuclear waste management, the Climate Change Bill, and contributed to the Royal Commission of Environmental Pollution's study on "Adapting the UK to Climate Change".

This is the approach adopted by the Academy in the UK - it is not to say this is the right approach for every country, but it is seen to be working in the UK context. Whatever approach is taken national academies clearly have a role to play in changing the future direction for energy supply and usage in their own country and globally.

Summary

Energy supply and demand data over several decades suggest that little has changed with the mix of energy, the R/P ratio and the efficiency of electricity generation and transmission. This is not a completely accurate conclusion. A great deal has changed driven largely by technology and engineering application, however, such dramatic changes at a micro level have not significantly influenced the global energy supply and demand scene.

The 'new' issue and constraint is carbon emissions. History has shown how hard it has been to change the overall energy demand pattern, therefore carbon emissions present a challenge that will require enormous levels of commitment and sacrifice if the world is to limit the concentration of greenhouse gases in our environment. National academies have a clear role to play providing consistent informed advice to their governments.