Proceedings of the International Symposium on Engineering Lessons Learned from
the 2011 Great East Japan Earthquake, March 1-4, 2012, Tokyo, Japan

THE ENERGY HIERARCHY APPROACH TO OPTIMUM USE OF ENERGY INFRASTRUCTURE - SHARING IDEAS FROM THE UK AND OTHER PARTS OF EUROPE -

Ian M. ARBON[1]

[1] EurIng Prof Ian M. Arbon MSc, MBA, CEng, CEnv
FIMechE, FASME, FEI, FInstR, FIES

Sustainable Energy Consultant, Engineered Solutions, Girvan, Scotland, UK,
Immediate Past Chairman, Energy, Environment & Sustainability Group,
Institution of Mechanical Engineers
ian.arbon@engineered-solutions.co.uk

ABSTRACT: This paper focuses on how the Energy Hierarchy could be used to guide new energy infrastructure policies in Japan, in the context of the 2011 earthquake, examining parallels with Europe, particularly the UK. The Hierarchy approach considers pragmatic pathways towards a sustainable energy future for Japan with reference to all forms of energy, not just electricity. Although engineering solutions are crucial, the Hierarchy recognises that a primary influence on energy consumption is human behaviour.

INTRODUCTION

The stated aim of The Institution of Mechanical Engineers (IMechE) is “Improving the world through engineering”. There are 100,000 IMechE members, and a large number of those have signed up to the Energy, Environment and Sustainability Group (EESG). IMechE, specifically EESG, was instrumental in formulating the “Energy Hierarchy”, a sustainability framework for advocating the prioritisation of energy-saving as the most important step in a whole-system energy strategy (followed by energy efficiency and renewable energy) to provide a logical framework for the development of technically coherent sustainable energy policies. This was launched internationally at ICOMES in 2007 and has gained acceptance across many of the world’s engineering societies. Our idea is that the addition of more minds to the challenge of a new national energy strategy in Japan, led by Japanese engineers, could be helpful for both Japan and the UK. Such an “energy saving” approach to national energy strategy is needed worldwide, so the potential to share learning in this area is significant. Traditionally, engineers have focused on energy supply, rather than demand. However, energy supply exists only to meet demand, so engineers must learn to focus on managing and reducing energy demand to deliver more sustainable solutions in the future i.e. they need to provide the capacity for continuity.

EXPLANATION OF THE ENERGY HIERARCHY CONCEPT

Definitions for Energy

It is important to understand that the subject being dealt with here is 'energy' and that it is not synonymous with 'electricity'. The confusion of 'energy' and 'electricity' appears very frequently in the press and broadcast media, as well as in many government communications.

Technically, 'energy' is regarded as the actual amount of energy produced (or consumed) and is typically expressed in *joule* (J), whereas 'electricity' is generally considered in terms of 'power' which is measured in *watt* (W); there is a time relationship between the two in that power is a measure of energy generated/consumed per unit time (1W = 1 J/s). In the energy industry, it has (unfortunately) become customary for the term 'power' to be used to mean 'electricity' while 'energy' is generally used to refer to the non-electrical sector, e.g. 'heat energy'.

When statements are made concerning 'power' or 'energy', it is of crucial importance that the differences between 'installed generation capacity', usually measured in 'megawatt' (Million Watts), MW, 'gigawatt' (Billion Watts), GW, or 'terawatt' (Trillion Watts), TW, and the actual amount of energy produced or consumed (in GWh, gigawatthour, or TWh, terawatthour) is clearly understood. For example, the 'installed capacity' of an electricity generating plant is generally the maximum power output that the plant can produce, rather than the actual energy output over an extended period of time, e.g. GWh/y.

Similarly, much focus by governments in the developed world is on electricity production, even though this is not necessarily the largest area of energy demand. In the United Kingdom, for example, the proportion of total energy demand which is consumed as electricity is just 24%, compared with 38% for heat and 38% for the transport sector's demand (DECC 2009). This is shown graphically in Fig.1. Corresponding figures for Japan were not available before submitting this paper.

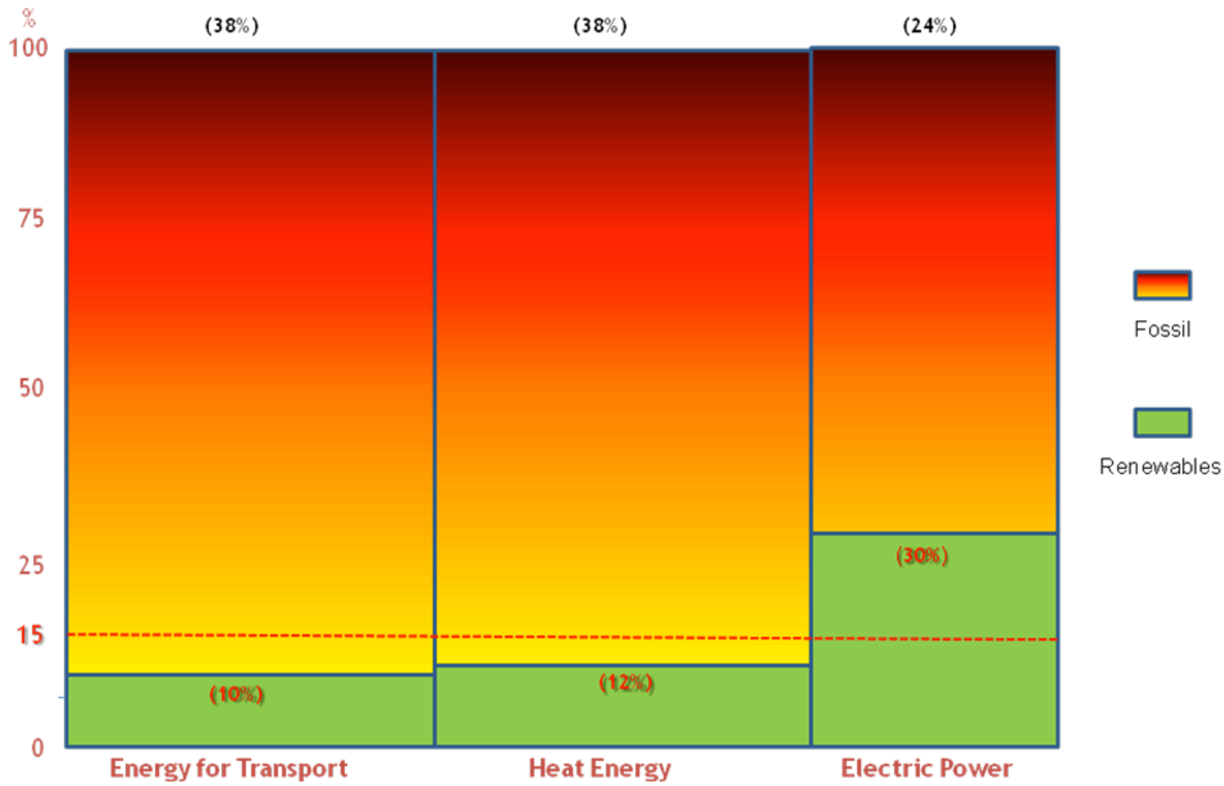

Fig.1 UK Energy Commitment for 2020 (15% overall Renewable Energy Target)

Renewable Energy Targets

Much has been written on the subject of 'renewable' energy and many countries have set challenging renewable energy targets to be achieved over the next decade or two. The European Union (EU) has legislated (in Directive 2009/28/EC) to achieve the targets, by the end of 2020, averaged across the 27 member states, of:

- 20% of all energy (heat, transport and electricity) to be produced from renewable sources;
- 20% improvement in energy efficiency;
- 20% reduction in greenhouse gas emissions, over 1990 levels.

These targets are often summarised as "20/20/20 by 2020".

Although it is often stated that renewable energy targets are set as part of a strategy to reduce greenhouse gas (GHG) emissions, there is evidence that the extent of reduction depends on the method of integration to match the energy demand profile. For example, many forms of generating electricity from renewable resources, such as wind, are 'intermittent' in their output, which gives rise to the need for different forms of 'back-up' generating capacity, often from fossil fuels. The extent of the nature of back-up depends on the context of demand profile and transmission characteristics and this can have a significant impact on the actual reduction in GHG emissions.

This does not imply that renewable energy is not worthwhile or will not have an important environmental and societal impact but rather that each type of renewable energy source and conversion technology needs to be examined in terms of its true 'sustainability'.

Energy sustainability

Traditionally, the priorities in energy production have largely been based on cost and fuel availability, with little regard for impacts on the environment and even society. Nowadays, there is a growing understanding of environmental/societal issues such as Climate Change, the finite nature of fossil fuels and rapidly increasing global population. This has made the 'sustainability' of any form or conversion method of energy a mandatory consideration.

In September 2005, the UK's Royal Academy of Engineering produced its "Engineering for Sustainable Development: Guiding Principles". This built on previous definitions of sustainability and stated: "Sustainable development is the process of moving human activities to a pattern that can be sustained in perpetuity. It is an approach to environmental and development issues that seeks to reconcile human needs with the capacity of the planet to cope with the consequences of human activities. It is useful to represent the constraints that make sustainable development an imperative in the form of a simple Venn diagram" (Fig.2):

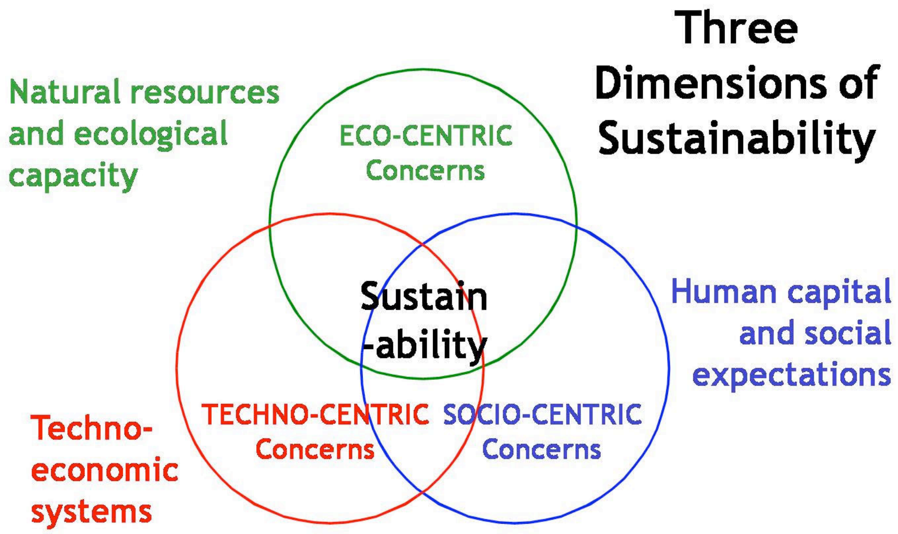

Fig.2 'Sustainability Diagram [RAE]

The term 'Three Dimensions of Sustainability', used in Fig.2, is often expressed nowadays as the 'Triple Bottom Line'. The expression 'bottom line' derives from the Profit & Loss (or Income) Statement which, along with the Balance Sheet, is the main document used in the day-to-day running of a business. The P&L Statement is, in effect, a spreadsheet, where the first row ('top line') shows the total turnover or revenue coming into the business; from this, the material, labour, overhead costs and other expenses are deducted to show what is retained by the company, i.e. its 'profit'; this is traditionally shown on the last row of the spreadsheet, or, the 'bottom line'. So, 'what's the bottom line?' has come to express the whole purpose of being in business in the first place. This expression has now entered into the English language.

Of course, the 'bottom line' purely measures the financial performance of the company which, in any modern business, is only one of the key performance indicators (KPIs) which is necessary to run a business successfully. Any business now has to consider the broader impacts of its operation, including the societal and environmental impacts and these same impacts must be assessed for any sustainable energy project or development. This has become known as the 'Triple Bottom Line' (TBL). In order to be truly competent, a TBL analysis should also form an integral part of any national or international energy policy.

It should also be noted that a serious limitation of the 'single bottom line' approach is the difficulty of including all of the 'externalities' in establishing, for example, a $/MW cost of different types of power generation. Examples of these 'externalities' are: not including the full cost of decommissioning and remediation for nuclear power stations, not including the full cost of the damage caused by fossil fuel combustion emissions or not including the true cost of 'back-up' generating capacity for 'intermittent' renewables such as wind.

Definition of the Energy Hierarchy

The concept of the 'Energy Hierarchy' is a simple one, although it has profound implications for energy strategy or policy; it states that a competent energy policy must start with energy demand reduction and then with improving energy efficiency before different types of energy supply are considered. It has five main tiers of priorities (as shown in Fig 3), although obviously the 5^{th} tier does not represent any advantage. For the sake of clarity, there is no suggestion that one tier has to be 'completed' before moving to another; indeed, the concept is that all tiers will be being put into practice at the same time, but there has to be some value basis on which there is change in focus between stages.

Fig.3 'The Energy Hierarchy [IMechE 2011]

Energy conservation is about eliminating the need for the energy demand in the first place. The concept is simply that a kilowatt saved (or not used) is much more valuable than a kilowatt supplied, no matter what the source. Energy conservation can often be achieved through behavioural changes; for example, not making a journey and conducting a meeting by teleconference instead. Nevertheless, engineering solutions such as smart meters and real-time displays also have an important role to play in energy conservation, though how much they will actually influence behaviour change remains to be seen.

The second tier of the hierarchy, 'energy efficiency', affects both energy demand and energy supply. On the demand side, enormous savings can be made by the use of more efficient domestic appliances, more efficient vehicles, more efficient heat delivery systems, and so on. However, it is on the supply side that energy efficiency can significantly affect most country's future choices.

In a modern fossil-fuelled power station for example, the steam turbine generator system can have its efficiency significantly increased by the use of supercritical or ultra-supercritical steam, which gives a much larger power output from the same quantity of fuel. Further, if the waste heat energy produced by the plant is harnessed and utilised, as is commonplace in most other European countries, the overall efficiency of the power plant is greatly increased; the heat energy is provided from the same amount of fuel that would have been used to generate the electricity in the first place, thereby leading to an efficiency gain. .

The other three tiers of the Hierarchy are concerned with the supply-side for energy and assume that demand reduction and efficiency have already been considered and implemented. The 3rd tier is about the utilisation of renewable, sustainable resources to supply energy in many forms, not solely electricity. The latter is the focus of many national governments' view on energy provision and clearly this misses the contribution to be made by delivery of renewable energy in other forms, such as heat, and from other tiers in the Hierarchy.

The 4th tier concerns the utilisation of low-GHG-emitting resources; a good example of this is the use of nuclear generation for base-load electricity, as is currently the case in many countries. Although nuclear power is not accepted by some as a sustainable technology, if an important objective of an energy strategy is to support a reduction in GHG emissions from electricity generating plant, this is a much more sustainable option to include than some other conventional methods.

Another example of a tier 4 approach is utilisation of a Carbon dioxide Capture and Storage (CCS) system to reduce CO_2 emissions from conventional fossil fuel plant, though it should be noted that the application of this method will reduce the plant's energy efficiency and may offend the 2nd tier of the Hierarchy.

The 5th tier of the Hierarchy, namely the utilisation of conventional resources as we do now is clearly the least sustainable option and is unlikely to form any part of a future sustainable energy strategy.

The main purpose of the Energy Hierarchy is as a tool that can guide policy-makers towards the most sustainable solutions for future energy needs. Each policy development must however be considered on its own merits; for example, a policy that is based on using only one type of intermittent resource, no matter how renewable, to provide all of its energy, or even electricity, needs is extremely unlikely to be sustainable in overall terms.

It should also be noted that the Energy Hierarchy is not a route to finding the cheapest available option; in the author's experience, the most sustainable solution is rarely the cheapest. However, it has to be accepted that the current unsustainable state of the worldwide energy market has resulted from a sole focus on the traditional 'single bottom line' analysis; only by taking new measures such as the Triple Bottom Line approach can a truly sustainable solution be found.

APPLICATION OF ENERGY HIERARCHY – LESSONS LEARNED IN UK/EU

Challenges

There are four main challenges that are generally considered in the determination of sustainable energy systems:

1) Rapidly growing global population and even faster growth of global energy demand;
2) Decline of availability of 'cheap' fossil fuels;
3) Security of national energy supplies;
4) Impacts on climate change.

The Energy Hierarchy can be used to consider any of the foregoing challenges and resultant policies will lead to a reduction in fossil fuel consumption; this to some degree also mitigates the concerns of such concepts as 'peak oil' which refers to the accessibility of extraction of oil becoming increasingly difficult either from this point onwards or at some point in the near future. While the transition from the use of oil may be either due to physical limits or alternatives becoming economically preferable, it is suggested that energy prices will become increasingly volatile. Applying the Energy Hierarchy can increase a nation's resilience to energy price shocks and reduce its vulnerability.

1st Tier of Energy Hierarchy – Energy Conservation

In most developed countries, the 1st tier of the Energy Hierarchy has been the most overlooked and is where most engineering challenges in the future are likely to be. Avoiding the use of energy in many cases requires a change in behaviour and there can be resistance to this on both a cultural and personal level. For example there may need to be a change in work practice with people travelling less and working at local hubs, compensating for the lack of personal interaction with colleagues through advanced audio-visual communication systems. Such workplaces are already being established in the UK and are becoming more popular as people seek more flexible ways of working. Getting people to accept sacrifices in comfort however is difficult and the more engineering can be used to avoid this requirement without excessive cost or complexity the swifter progress in avoiding energy consumption is likely to be. For example it is challenging to get people to accept reduced internal temperatures in the winter when they are used to warm rooms, even if they can compensate for this by wearing warmer clothes. However the avoidance of heating the rooms that are not occupied at a given time can be achieved through the engineering of 'smart' building management systems with occupancy sensors and occupancy pattern feedback.

2nd Tier of Energy Hierarchy – Energy Efficiency

Japan has for many years been at the forefront of design and manufacture of energy efficient products and it is understood that there is a mandatory 'Energy Saving Label Program' to allow consumers to compare products. This is stricter than the European Union equivalent. However even in Europe energy labelling has been successful in stopping the sale of inefficient appliances. Energy efficiency is given high priority in the Energy Hierarchy, but caution needs to be applied to the extent to which energy efficient products are procured and used. Reference may be made to the Jevons Paradox. At the time of the Industrial Revolution, Jevons argued that the increasing the efficiency of use of coal would increase the demand for coal and not result in the reduction in rate of depletion of this resource. In the modern context people who experience reduced energy consumption through more efficient appliances offset these savings through expending energy in other ways. For example they may buy further energy consuming appliances. This is often known as the 'rebound effect'. One way of addressing this, which has not yet been put into practice in Europe, is to cap the energy use of people or organisations through the introduction of a carbon dioxide allowance, constraining their equivalent carbon dioxide emissions in the same way that their economic budget is constrained. They can then decide on what they expend their allowance. Whilst this might be perceived as a vehicle for abating climate change, the outcome is a reduction in energy consumption, with electricity and heat being measured in terms of carbon dioxide equivalent. In fact Europe has something to learn from Japan in this regard with Tokyo becoming the first cap-and-trade city for companies in the world. It is understood, at least in 2010, that the energy usage reporting system was superior to that in Europe in accordance with the European Emissions Trading scheme (EU ETS). With economic conditions being severe both in Japan, the UK and other parts of Europe, it is difficult to bring in such a scheme on a domestic level. However in the longer term such a system can help regenerate the economy through the introduction of stimulation of production and installation of new technologies.

3rd Tier of Energy Hierarchy – Renewable Energy

There are certain geographical similarities between the UK and Japan with their both being island nations and with the latitude of Hokkaido not being dissimilar to southern England. However, it could be argued that Japan has even greater energy challenges than the UK for the following reasons:

1) The wave and tidal resource is less;
2) Japan is a very mountainous with higher densities of population on the flatter ground that may be more suitable for wind turbines – this appears to be particularly the case on the main island of Honshu, where the plains are extensively populated.

There is however more potential for solar energy in Japan than in the UK and what needs to be determined is how the annual solar resource profile matches the consumption profile. In northern European countries such as the UK and Germany there is a mismatch in this respect, in that there is a higher level of solar resource in the summer than winter but greater energy demand in the winter – inter-seasonal energy demand spreading and storage remains a major challenge. The balance in Japan would be expected to be somewhat different given that summers are generally hotter and more air conditioning is used.

These constraints on renewable energy generation bring into sharp focus the pressing need to reduce consumption. In the UK, behavioural change has been slow and the greatest progress has been in terms of regulation. This is notable in the building sector where building regulations have been tightened considerably over the last few years. It is understood that at the current time Japanese building regulations are less stringent than those in a number of European countries and that much could be gained through adoption of an ambitious system of mandatory u-values. While traditional buildings in Japan have been designed to give comfort in high summer temperatures with shading and natural ventilation, modern buildings to a large extent have become dependent on air conditioning. While it is recognised that natural ventilation on tall buildings in urban centres is challenging, there is much that can be done through building regulations to facilitate building design that minimises the need for air conditioning, which is a significant energy load.

Energy Infrastructure

Energy infrastructure covers generation plant, energy storage and energy distribution. It is important to get the right balance between these for the most effective application of the Energy Hierarchy. A balance has to be explored between the introduction of new energy infrastructure and more effective utilisation of existing energy infrastructure. The Energy Hierarchy can be applied to the development of pragmatic pathways towards a sustainable energy future for Japan, as with Europe, with the appropriate balance at each stage between investment in renewable, sustainable, energy and more efficient (or lower greenhouse gas emitting) supply of non-renewable energy, for example through combined heat and power (CHP) or even 'heat only' plant (the latter generally being both more energy-efficient and more cost-effective). The way in which the Energy Hierarchy influences the implementation of non-electrical infrastructure solutions and their interrelationships also needs to be considered - for example heat distribution, biogas injection into the gas mains, transport (considering energy sources and energy vectors) and waste infrastructure. The appropriate extent of heat distribution infrastructure should not only be determined by the application of the energy hierarchy to assess the most efficient mode of energy supply, but it will also be determined by the availability of sustainable resource to produce heat, in particular biomass. Although electric heating, in the form of heat pumps, may have a role to play this may also be centralised in an area with heat distribution to give potentially greater efficiency and ease of control and maintenance by an energy service company. It can be seen therefore that the form commercial delivery vehicle (energy service company or utility) may affect the type of infrastructure chosen. Injection of biogas into the mains, a practice that is becoming more prevalent in both Spain and Germany and which is being explored in the UK, gives a more sustainable use of existing gas infrastructure and also has a link to waste management infrastructure. Developments are also underway in Europe, and perhaps also in Japan, on the synthesis of hydrocarbon fuel from electricity. This and direct electrical transportation allow buffering of intermittent renewable energy thereby giving more efficient energy supply in line with the Energy Hierarchy.

Establishing constraints and targets

In formulating policy recommendations, IMechE has recognised, for a number of years, that there is a need to take care with the practical application of international or national energy or GHG emissions reduction policy to ensure that the impacts are optimised. For example, deploying a large percentage of intermittent 'renewable' energy sources in a system for electricity generation with the current energy infrastructure might be accompanied by the provision of back-up capacity in the form of fossil fuel fired plant, such as gas turbine power generation, which reduces the potential overall emissions reduction and contribution to security of energy supply. Care must therefore be taken in this regard when developing plans to deliver GHG-reduction targets, in particular that there is not an assumption that new, for example renewable, measures will not just plug into the existing system. Rather, what is required is an overall view of the energy system harmonising supply and demand variations. For integration of renewable energy load there needs to be control of loads for which timing of demand is not critical (such as electric heating via heat pumps), energy storage and greater interconnectivity of loads to balance the intermittency.

Mallon [2006] introduced the concept of 'cross-cutting objectives' as one of the major 'pitfalls' in developing a competent energy policy: "sometimes apparently mutually supportive objectives can clash in practice". This applies when considering the interaction between different tiers of the energy hierarchy and the choice of different energy vectors (such as heat, electricity and liquid fuel) needs to be worked out in conjunction with available forms of energy supply.

The March 2011 edition of DECC's UK 'Energy Trends' provides an illustration of how the reality can be different from expectations. The data presented showed that the penetration of renewables in UK electricity generation actually fell slightly from 7.0% in 2009 to 6.9% in 2010, despite a very large number of new wind-farms having been built over the same period. However, leaving aside the fact that 6.9% is significantly short of the 10% target for 2010, it must be noted that power generation from nuclear reduced from 17.6% to 15.6% and coal-fired power generation increased from 27.8% to 28.4%. This means that, as well as the below target trends in the proportion of renewable electricity, the decrease in the type of power generation from the lowest GHG-emitting generator and the increase in the highest GHG-emitting generator, inevitably means that there will have been a large increase in GHG emissions over the year in question. Therefore, in setting targets in one sector (e.g. renewable energy) there needs to be accompanying targets or measures in other sectors (e.g. aspects of energy consumption) to ensure compatibility of measures and arrival at the intended results.

Policy Measures and Commercial Conditions

The question of whether the Energy Hierarchy approach might be introduced through legislation, economic incentives, awareness raising or a combination of these needs to be addressed. While the focus of the paper is on engineering solutions, it cannot be ignored that a primary influence on energy consumption is human behaviour and therefore policy measures need to be introduced to allow people to be both empowered and to gain a better understanding of their energy use such they can contribute towards effective delivery of the Energy Hierarchy.

In implementing the Energy Hierarchy, the appropriate commercial structure and incentives need to be shaped to facilitate the effective delivery of the intended measures. Under the current system, even if a measure is more cost-effective in lifecycle terms, it may not be commercially attractive to the key stakeholders, since the party that benefits from the operational savings may not be the one that has to accommodate a potentially higher initial capital expenditure ('single-bottom line' thinking). This is the case with building developers in the UK, where operational energy savings are still not a strong determinant in choice of building on the part of the buyer – the developers are generally inclined towards developing lower cost buildings that are not as energy-efficient. The same principle applies to energy utilities whose business has traditionally been geared around selling as much energy as possible rather than encouraging reduced consumption. Therefore, there is a need to spread incentives across stakeholders to ensure delivery of the Energy Hierarchy at all stages of the development lifecycle. This can in part be achieved through revised organisational structures and regulation.

Success and Failure

Whilst awareness of the energy hierarchy on the part of Government and energy practitioners, including engineers, is a good first step in the process towards realisation of its benefits, there are usually significant obstacles to be overcome in each country. One of the failures in the UK, and indeed other parts of Europe, is to leave the implementation of energy systems for market forces to settle. Adhering to the energy hierarchy does not necessarily give the most cost-effective solution under current economic conditions. In part this is because the cost under our current economic system of using fossil or nuclear fuel invariably does not take into account the cost of the damage caused by their use and therefore the price of this form of energy is artificially low. This is being redressed step by step through the introduction of economic mechanisms such as carbon dioxide taxation (for example the Carbon Reduction Commitment [CRC] and the Climate Change Levy [CCL] in the UK). Whilst this by definition is focused on the mitigation of climate change, their effect is to reduce sustainable energy practice and give more commercial incentive to adherence to the energy hierarchy. However these measures do not yet go far enough to bring economic equality to fossil fuels, nuclear and renewables and therefore their impact is limited.

As has been identified earlier in the paper a value judgement needs to be applied in determining when to shift focus from one tier of the hierarchy to another. Ideally all energy consumption would be eliminated or if this were not possible then systems using energy should have no losses, in line with the first two steps of the Energy Hierarchy. Of course we know that this is not possible if we are to maintain the functioning of our societies, so how should it be decided when enough has been done on energy efficiency and resources can be directed towards renewable energy, moving to the next step of the hierarchy? Under current economic conditions there comes a point whereby energy efficiency measures may be more expensive than renewable energy supply measures. An example of this is increase in thickness of external thermal insulation when retrofitting an existing building. Increasing the thickness of insulation has diminishing returns in thermal benefit with the associated cost-reducing at a lower rate, such that a thickness will be reached whereby further expenditure would result in lower GHG-emissions displacement than would the same expenditure on renewable energy supply. In this way there may be a conflict between short-term economic benefits and longer term energy savings. The question is how to determine the prioritisation of measures favoured by the energy hierarchy within a practical economic framework.

CONCLUSIONS

With increasing global population, rising material lifestyle expectations and increasingly constrained resources it is becoming ever more apparent that more priority needs to be given to using less energy. In recognition of the major challenges of long term sustainable energy supply globally the Energy Hierarchy has been presented as a framework towards achieving this. Last year's devastating earthquake in Japan has exposed vulnerabilities in the current energy system which has given rise to an opportunity for new approaches to energy supply and consumption. There are not only benefits in Japan drawing from lessons learned in UK and other parts of Europe through applications of the Energy Hierarchy, but as Japan consolidates its new direction, there will no doubt be much for European countries to learn from, as they face similar energy challenges, albeit without the same widespread exposure to the threat of natural disasters. With today's level of global interconnection and interdependency the most effective course of action in addressing what may reasonably be described as a global energy crisis is to work together and combine the very best ideas from each country. This paper has taken the concept of the Energy Hierarchy and through comparison of characteristics of Japan and countries within Europe, in particular the UK, has explored its practical application and given examples of measures that may be adopted to support it.

ACKNOWLEDGEMENTS

Thanks for the support in preparing the paper to Rupert Blackstone (Wattcraft Ltd) and Daniel Kenning (Splendid Engineering), fellow members of the Energy Environment and Sustainability Group (EESG), of the Institution of Mechanical Engineers.

REFERENCES

Royal Academy of Engineering (2005). "Engineering for Sustainable Energy: Guiding Principles".

European Parliament and Council (2009). "Directive 2009/28/EC of the European Parliament and of the Council, on the promotion of the use of energy from renewable sources"; 23 April 2009.

UK Department for Energy and Climate Change (2009). "The UK Renewable Energy Strategy"; The Stationery Office, London UK; July 2009.

Mallon, K (2006). "*Renewable Energy Policy and Politics – a handbook for decision-making*"; Earthscan, London UK and Sterling, VA, USA. ISBN -10: 1-84407-126-X.

Arbon, I et al (2011). "*Scottish Energy Policy?*"; position paper on Scotland's energy policies; Institution of Mechanical Engineers, London UK.