ENERGY QUALITY
and
ECONOMIC EFFECTIVENESS

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All fuels are equal but some
are more equal than others
--- after George Orwell

1. INTRODUCTION

It is a truism that energy drives everything in this world. Nothing happens, nothing is created, without the irreversible dissipation of high grade energy into degraded and unusable forms. However, there is no loss of energy involved. During its use it is just dissipated as waste heat into the environment. This is the essence of the first and second laws of thermodynamics, the most economic of all the physical laws.

Economic activity is driven by such expenditure of energy, whether it is by human energy in the form of labour, or by that labour amplified using external energy sources, such as fossil fuels, wind, water power and their derivatives. Energy sources are unique as energy cannot be recycled, a piece of coal can only be burnt once. *These are the first important aspects of energy quality, where it differs from matter which can be recycled, but only some of it within a human time frame.*

Our dependence on energy applies to energy sources as well. We have to use energy to both extract primary energy from natural sources and transform these into more convenient and useable forms. It is not possible to transform one energy form into another without dissipating some of the energy. We have to spend energy to get useful energy resources. How much energy we need to transform primary energy into useful energy is a critical economic issue. It is the net energy yield that matters – the difference between gross energy output from a source and the energy spent extracting and converting it into a useable form in locations where it is needed. The higher the net energy yield the more economically effective is the fuel or energy source. *The energy cost of obtaining useful energy is the second important aspect of energy quality.*

In addition the different physical characteristics of fuels affects their usefulness and quality. For example, we are never likely to see coal powered aeroplanes. However, we do have ones fuelled by liquid petroleum products. Electricity is perhaps the most versatile, useful and economically effective form of energy. That is why we prefer to burn coal in thermal power stations to generate electricity, even though half the heat energy is dissipated as hot gases up the chimney and as warm water from the steam condensers. *This is the third important aspect of energy quality, their differing physical forms that affect their usefulness, even when they may have the same net energy yield*

Finally, human use of fossil fuels – the stored solar energy from millions of years ago – has significantly amplified human capacity to transform and use the mineral and biological resources of the earth to serve human ends. These have made possible the huge human population increase since the 17th century, and the accompanying increase in per capita material consumption.

The limited resource-base of high grade minerals and fossil fuels are mined first and transformed to metals and useable fuels. As these are exhausted progressively lower grades are mined that require more energy per tonne of final product, unless technology can counter the trend. But eventually, with the need to mine ever lower grade ores, the sheer volume that has to be mined overwhelms technology. And it is not possible to have 100 per cent recycling - this is an energy intensive process too. The volume of wastes to dispose of increases and overwhelms the capacity of biological and environmental systems to absorb and adapt to the impact. The use of energy to produce high quality goods and services for humans *necessarily* has a complementary degrading and disordering impact on the environment. *This is the fourth important aspect of energy quality, its use to meet human needs necessarily disorders the environment.*

These ideas hold an important place in the rapidly growing field of Ecological Economics. This paper will summarise a few of the key conclusions reached on subjects such as:

- the relationship between energy consumption and gross domestic product (GDP);
- the consequences of historical changes in fuel type on this relationship;
- the net energy yield of various fuels and some of the factors that influence this, with a focus on transport;
- comparisons between petroleum-based fuels and alternatives to these for transport; and
- the implications for Australia when assessing the strategic futures for transport fuels

Most of the quantitative information in this paper will be based on work done in the USA since the 1970s, with comment on its relevance for Australia and the urgent need for similar studies here. A rapid decline in Australia's oil self-sufficiency is occurring when the world is approaching the peak of oil production. These issues of energy quality are central to evaluation of alternative transport fuels, and as an aid to assessing how we can most effectively respond to this historic event.

FIGURE 1 shows primary energy use in the USA to illustrate the changing composition of energy quality there since 1800 (Cleveland 2000). Electricity includes only the primary sources from hydropower, nuclear, geothermal, and solar. Similar patterns would apply to Australia, minus nuclear and geothermal.

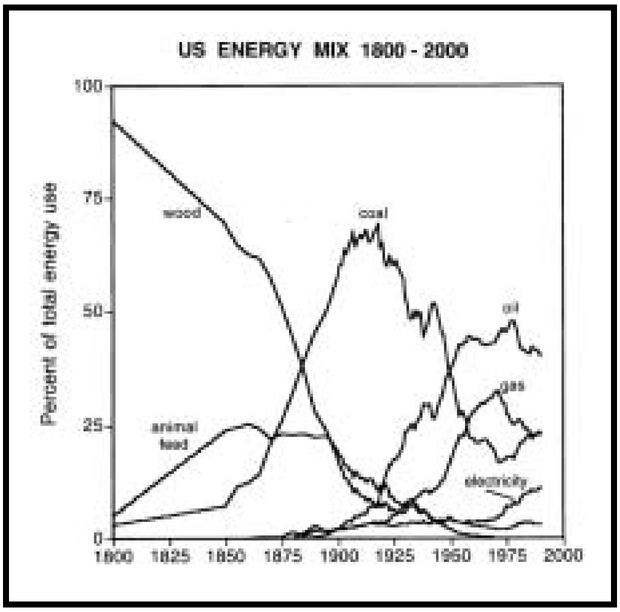

Figure 1

2. ECONOMIC APPROACHES TO ENERGY QUALITY

2.1 Energy Quality

Aggregating the vast numbers of inputs and outputs in the economy makes it easier to recognise patterns in the data. For energy the simplest form of aggregation is to add up the individual variables according to their thermal equivalents, e.g. joules, or joules per unit volume or mass. This approach underlines most methods of aggregation in economics, as well as in ecology. For example, the gross domestic product/energy relation (GDP/E) and most net energy analyses. However, aggregating energy in this way embraces a serious flaw: it ignores qualitative differences among energy vectors. Energy quality here refers to the relative economic usefulness per heat equivalent unit of different fuels and electricity. The general shift to higher quality fuels (*Figure 1*) affects how much energy is required to produce GDP.

The concept of energy quality needs to be distinguished from that of resource quality. Petroleum and coal deposits may be identified as high quality because they provide a very high energy surplus relative to the amount of energy required to extract the fuel. On the other hand, some forms of solar electricity may be characterised as a low quality source because they have a lower energy return on investment, as measured by energy profit ratio – see further discussion below. However, the latter energy source may have energy of higher quality (electricity) because it can generate more useful economic work than one equivalent heat unit of coal or petroleum.

Taking energy quality into account in energy aggregation requires more advanced forms of aggregation.

2.2 Market Approaches

From a neo-classical economic perspective, the value of a heat equivalent of fuel (e.g. joules per unit volume or mass) is determined by its price. Theory says price-taking consumers and producers set marginal utilities and products of the different energy vectors each equal to their market prices. These prices and their marginal productivities and utilities are set *simultaneously* in general equilibrium[11]. The value of the marginal product of a fuel in production processes is the marginal increase in quantity of a good or service produced by the use of one additional heat unit of fuel multiplied by the price of that good or service.

Cleveland (2000) says government policy, regulations, cartels also explain some of the price differentials among fuels, but certainly not the substantial range that exists. More fundamentally, price differentials are explained *in part* by a complex set of attributes unique to each fuel such as physical scarcity, capacity to do useful work, energy density, cleanliness, amenability to storage, safety, flexibility of use, cost of conversion, and so on. But the marginal product is not *uniquely* fixed by these attributes. Rather, the energy vector's marginal product varies according to the activities in which it is used, the form and quantity of capital, labour, and materials that are used in conjunction with the quantity of energy used in each application. When capital stocks have to be adjusted these responses may be sluggish and leading to lags between price changes and changes in the value of marginal product. It is a dynamic environment where all the attributes and vectors adjust to variations in any one of them.

Consistent with this perspective, the price per heat equivalent of fuel varies substantially among fuel types. The various fuels and electricity are therefore less than perfectly substitutable among energy types.

Cleveland (2000) summarises attempts by others to quantify in US energy markets some of these relationships concerning *quality differences between energy types* and energy prices. He asks the question; do market signals (i.e. prices) accurately reflect the marginal product of inputs? The results indicate that there is a *long-run* relation between relative marginal product and relative price, and that several years of adjustment are needed to bring this relation into equilibrium – *see also footnote 1*. This suggests that *over time* prices do reflect the marginal product when differences in energy quality are taken in to account – and hence also the economic usefulness of fuels.

He says other analysts, using models of industrial output as a function of fuel use, have calculated the average product of fuels, which is a close proxy for marginal product. This is the impact on gross domestic product (GDP) of using the thermal equivalent of these fuels. These show that in seven European economies from 1950 to 1962 petroleum was 1.6 to 2.7 times more productive per unit of thermal equivalent than coal in producing industrial output, while electricity was 2.7-14.3 times more productive than coal. The range of values arises because some fuels are more effective in some uses than in others. Corresponding US quality factors relative to coal are 1.9 for petroleum and 18.3 for electricity.

If marginal product is related to price, some people have suggested that energy quality can be measured by using the price of fuels to weight their heat equivalents. In the simplest case a weighting index is constructed by comparing the price of a fuel per thermal equivalent to that of a reference fuel. However, this approach has problems. Such an index embodies a restrictive assumption that all fuels are perfect substitutes one for the other, and it is also sensitive to the choice of reference fuel. Alternative approaches to overcome these problems have had limited success and have increased complexity.

These problems lead to doubts on the usefulness of price as a *sufficient* basis for any indicator of sustainability.

[11] Absurd assumptions are needed for all markets to reach equilibrium simultaneously. In fact modern thinking queries the very possibility of markets *ever* reaching equilibrium. Equilibrium is a static concept, markets are dynamic. They behave 'chaotically' in the sense of so-called chaos theory. Equilibrium implies only negative feedbacks are at work in markets, such systems cannot evolve. See Steve Keen, *Debunking Economics Ch. 8, www.debunking-economics.com.*

He says a further limit on the use of prices is that these generally do not exist for wastes. It is impossible to construct an index of waste flows within the neo-classical economic framework. The role of the environment is not organically linked to its model of the market place. It is an 'externality' outside the market place.

Such complexity cannot be embraced in a single index. However, some indices can help us understand the complexity when these are put into their context.

Marginal product also depends on the state of technology, the level of other inputs, and other factors. Consistent with this perspective, the price per heat equivalent of fuel varies substantially among fuel types. The heat equivalent of a fuel is just one of its attributes and ignores the context in which it is used, and thus cannot explain why a thermal equivalent of oil is more useful in many tasks than is a heat equivalent of coal. These variations in attributes among energy types means the various fuels and electricity are not equally substitutable one for the other. Users are interested as well in attributes other than heat content.

3. NET ENERGY YIELD AND ENERGY TYPE VARIATION ENERGY PROFIT RATIO

Net energy analysis is one way of evaluating the productivity of energy systems It compares the quantity of energy delivered to society by an energy system to the energy used directly and indirectly in the delivery process. Cottrell (1955), Odum (1971) and Odum and Odum (1976) were the first to identify its economic importance. There has been a long debate about the relative strengths and weaknesses of net energy analysis. One restriction on its ability to deliver the insights it promises is its treatment of energy quality. In most net energy analyses, inputs and outputs of different types of energy are aggregated by their thermal equivalents. Cleveland (2000) summarises a study he did in 1992 to illustrate the limitations of this approach for the USA (Cleveland 1992). His assumptions and conclusions for US petroleum extraction from 1954 to 1992 are summarised below.

He obtained an index for net energy called energy return on investment (EROI) by dividing the energy output of a fuel by the aggregated direct and indirect energy inputs. This index is sometimes called energy profit ratio (EPR), the term this paper will use. He compared EPR's for US petroleum extraction obtained by aggregation of thermal equivalents with those using an energy quality correction factor for both the numerator and denominator, with the latter result called the Divisia EPR. Key points in the calculations are:

- Only industrial energy direct and indirect inputs were used - fossil fuels and electricity;
- The costs only include those energies used to locate and extract oil and natural gas and to prepare them for shipment from the wellhead;
- Transport and refining costs were excluded;
- Output was the sum of the marketed production of crude oil, natural gas, and natural gas liquids;
- Application of the direct energy cost of petroleum and electricity used in oil and gas fields;
- Indirect energy costs include the energy used to produce material inputs and to produce and maintain the capital used to extract petroleum; and
- The energy intensity of capital and materials was measured by the quantity of energy used to produce a dollar's worth of output in the industrial sector of the US economy, the ratio of fossil fuel and electricity used to real GDP, as produced by industry.

The thermal equivalent and quality corrected Divisia EPR's for petroleum extraction show significant diverging differences from 1954, *Figure 2*. The quality corrected Divisia EPR declines faster than the thermal equivalent EPR. This difference is driven largely by changes in the mix of fuel qualities in energy inputs. Electricity, the highest quality fuel, is among the energy inputs but is not an energy output. Its share of total energy use rises from 2 to 12% over the period; its cost share from 20 to 30%. Thus, the two highest quality fuels, electricity and refined oil products, comprise a large and growing fraction of the denominator in the Divisia EPR compared to the heat equivalent EPR, causing EPR to decline faster in the former case.

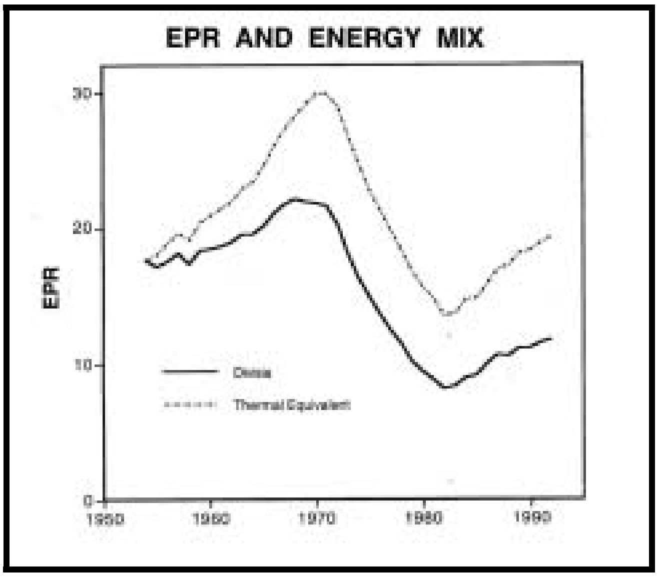

Figure 2

When comparing EPR’s for a fuel or energy source *over time* changes in the quality of energy inputs should be accounted for.

4. GROSS DOMESTIC PRODUCT and ENERGY RELATIONSHIPS

Gross domestic product (GDP) during a given period is the total monetary value of all the goods and services produced in a nation without deductions for depreciation or other business expenses, minus the net payments on foreign investments. It has come to be regarded as a general measure of welfare. However, its critics say this interpretation is seriously deficient as it does not account for the benefits from extensive unpaid community activity, and gives no regard as to whether the goods and services add to or detract from welfare, nor lead to environmental degradation. For example, the dollar costs of fighting, cleaning up and restoration after recent bushfires in Australia adds to GDP. Alternative indices have been proposed to accommodate these deficiencies. The Australia Institute (1997) has attempted to do this with its General Progress Indicator. This paper does not address these issues.

Cleveland (2000) says some analysts have used statistical methods to evaluate whether energy use or energy prices determine economic growth, or whether the level of output in the US and other economies determine energy use or energy prices. Generally the results are inconclusive. Many of these studies aggregated energy use according to thermal energy equivalents without taking into account differences in energy quality according to energy type, as discussed above. In recent decades GDP has been growing at a faster rate than such energy use aggregated by thermal equivalents.

He says some economists have claimed this shows that economic growth, as measured by GDP, has become 'decoupled' from energy use since 1950. Biophysical economists have disputed this interpretation because many analyses of the GDP/E ratio ignore the effect of changes in energy quality over time.

Cleveland quotes one study by Stern (1993) for the US from 1947 to 1990 that did account for differences in energy quality. This showed there is much less decoupling between GDP and energy use when the aggregate measure for energy use accounts for qualitative differences, as shown in *Figure 3*.

Stern tested for causality between GDP and energy use in a multivariate setting using a model of GDP, energy use, capital and labour inputs. He measured energy by both its thermal inputs and by the Divisia aggregation method discussed above. The model took account of changes in energy use being countered by substitution with labour and/or capital. Weighting for changes in energy composition showed that a large part of the economic growth effects of energy were due to the substitution of higher quality energy sources such as electricity for lower quality energy sources such as coal (see *Figure 1*). Adjusting for energy quality is as important as considering the context within which energy use is occurring.

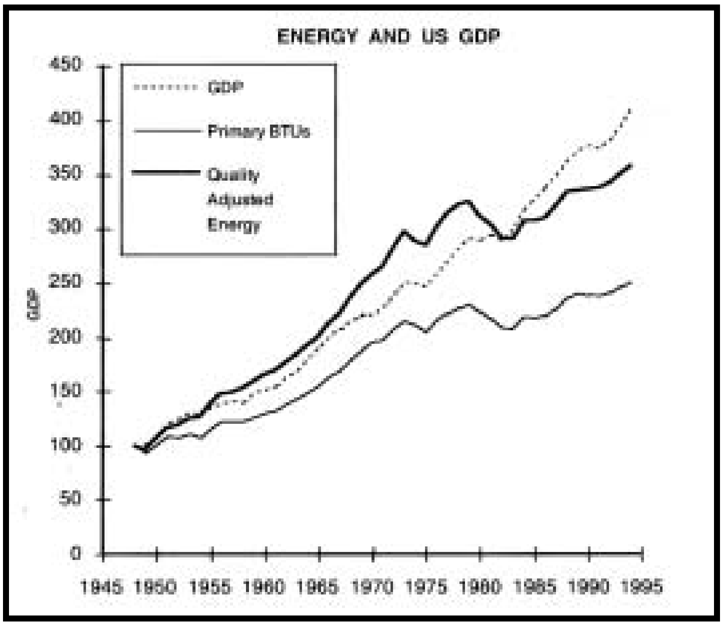

Figure 3

These studies taking account of energy quality and testing for the causal relationship between growth and energy use showed there is *a statistically significant relation* between energy use and GDP, but that the direction of causality runs from economic activity to energy use. However, this correlation alone does not prove causality. But the implications for the importance of energy in the economy are quite significant.

The rate at which an increase in the use of natural gas, oil, or primary electricity increases the real GDP/E ratio is variable. For example, petroleum can provide more motive power in transport per heat unit of coal, but this advantage nearly disappears if petroleum is used as a source of heat.

From an economic perspective, *the law of diminishing returns* implies that the first uses of high quality energies are directed at tasks best able to make use of the physical, technical, and economic aspects of an energy type. See the data at the end of paragraph 2.2. As the use of a high quality energy source expands, it is progressively used for tasks less able to make use of the attributes that confer high quality. This implies that the amount of economic activity generated per heat unit diminishes as the use of high quality energy expands. *The first uses of high quality energy increase the real GDP/E ratio faster than the last uses.*

Cleveland (2000) reports that the regression results for the real E/GDP relationship for France, Germany, Japan, and the UK during the post war period, and for the US since 1929 (*Figure 4)*, show that changes in the energy mix can account for most of the downward trend in this ratio. Note that *Figure 4* plots are for the energy/GDP ratio, not the E/GDP. One is the inverse of the other. For the USA, changes in the fuel mix from 1929 to 1972 explain about 72% of the change in the real GDP/E ratio (Gever et al. 1991, p.88).

After the 1970s oil shocks the fraction of total energy use from petroleum was steady or declined slightly in the European nations and the US. However, the fraction of primary energy use from primary electricity rose steadily, offsetting the relative decline from petroleum that occurred. In Japan the effect of changes in energy mix on the real E/GDP ratio showed a different trend over time. The fraction of total energy consumption supplied by primary electricity fell during the early 1970s and increased steadily thereafter, offsetting the steady increase in the fraction of total energy use from petroleum that occurred prior to 1973. After the 1970s oil crises Japan abandoned aluminium smelting and shifted from oil to coal for electricity generation, and later still to nuclear and natural gas.

These results indicate that the historical increases in the real GDP/E ratio are associated with shifts in the type of energies used and the types of goods and services consumed and produced.

International comparisons of GDP per capita using this approach show a distinct positive correlation with per capita energy use.

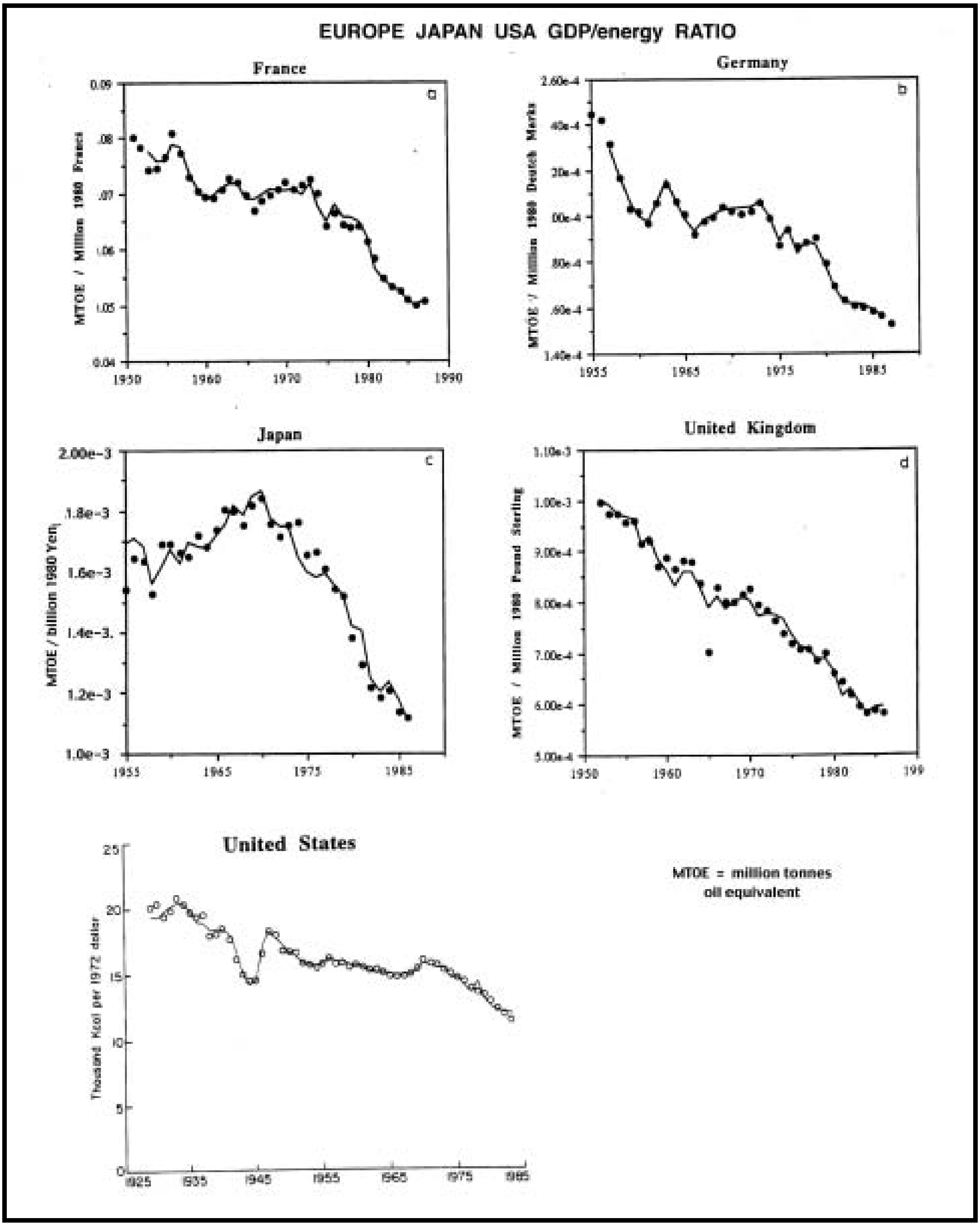

Figure 4

Diminishing returns to high quality energies and the continued consumption of goods from energy-intensive sectors such as manufacturing imply that there is limited scope for further changes in the composition of inputs and outputs to further increase the real GDP/E ratio.

5. TECHNOLOGY, LABOUR, ENERGY QUALITY AND GDP ECONOMIC POLICY

5.1 Technology

The energy surplus delivered by petroleum extraction in the USA is smaller than indicated by unadjusted EPR (paragraph 3). This result, together with the corrected relationship for the real GDP/E ratio, suggest that accounting for energy quality *reveals a strong relationship between energy use and economic output.* This runs counter to the conventional wisdom that technical improvements and structural change have decoupled energy use from economic performance.

Cleveland (2000) says to a large degree, technical change and substitution has increased the use of higher quality energy and reduced use of lower quality energy. In economic terms this means that technical change has been 'embodied' in the fuels and their associated energy converters. These changes have increased energy efficiency in energy extraction processes, and allowed an *apparent* 'decoupling' between energy use and economic output, and has thereby been a major factor increasing energy efficiency in the production of output. Most of the technology innovations were directed at applying the new fuels.

The ability of technical change to increase the goods and services produced from the same amount of and mix of fuels is much smaller than most economists claim (Gever et al. 1991). There are several reasons for this, including:

- Analysts who ignore the important changes to the kinds of fuel used in the economy and their division between households and intermediate sectors.
- Assuming that results obtained from studies of individual sectors can be extrapolated to the entire economy – i.e. that fuel, labour and capital are *independent* inputs, ignoring the fuel used elsewhere in the economy to produce and support the additional capital and labour that ensures a high degree of *inter-dependence.*
- *Deindustrialisation:* that the shift from smokestack industries to light manufacturing, information technology and services is increasing the real GDP/E ratio and will continue to do so – these hypotheses have not been supported with hard data..
- Changes due to fuel type have been mistakenly attributed to technology. *We must distinguish between fuel efficiency and energy efficiency.* The well known Amory Lovins makes these mistakes.

If decoupling is largely illusory, any rise in the cost of producing high quality energy vectors could have important economic impacts. Such an impact might occur if use of low cost coal to generate electricity is restricted on environmental grounds, in particular for climate change reasons. Three factors might limit future substitution to higher quality energy.

- There are limits to the substitution process. Eventually all energy would be of the highest quality – electricity - and no further substitution could occur. Discovery of as-yet-unknown higher quality energy sources is most unlikely.
- Different energy sources are not perfect substitutes. The substitution process could have economic limits that will prevent full substitution;
- The decline of petroleum supplies in the near future – petroleum is of higher quality than coal.

Gever et al. (1991, p. 104-5) compared the dollar output for various US industries with their direct fuel use only, which showed a near random scattering of points. But by including as well the *indirect energy costs of capital, labour, <u>and government services</u>* the points were compressed into a neat line. The total energy cost of a dollar's worth of financial and insurance services, for example, was nearly identical to the energy needed to produce a dollar's worth of primary non-ferrous metal products.

Decisions regarding substitutions among labour, capital and fuel, in the hope of achieving energy savings via technology, <u>mus</u>t include all the energy costs associated with the technology.

These conclusions do not imply that one-dimensional and/or physical indicators are universally inferior to the multi-dimensional economic indexing approaches described above. We cannot ignore Leibig's law of the minimum in which the growth or sustainability of a system is constrained by that single critical element in least supply. *We must be constantly on the alert for such constraints.*

5.2 Labour

Gever et al. (1991, Ch. 3) report that 72% of the change in the real GDP/E ratio in the US from 1929 to 1972 can be explained by change of fuel type, as discussed above. *A further 24% was due to changes in direct fuel use by households* (of petroleum and electricity) versus their use in other sectors such as manufacturing. Because a labour pool consists of human beings, energy is required for its continued existence. Workers need to use energy at home as well as to work in order to be productive. The fuel bought *directly* by workers and their families can be considered the *direct energy cost of labour*, and this can vary widely. A worker who rides a bicycle, walks or uses public transport, rather than a car, will make low direct fuel purchases.

Imagine two companies making identical products with identical methods. However, one firm's labour consists entirely of workers who ride bicycles and live in unheated flats, while the other firm employs only Jaguar drivers. Each company uses 1,000 kcal of fuel and pays its workers one dollar to produce a 100 dollars' worth of output. A complete accounting of the energy cost of a hundred dollars of output must include the energy equivalent of a dollar's worth of labour – that is, the fuel purchased by workers from a dollar in wages – as well as the 1,000 kcal of direct fuel use. If the bike riders buys an average of 50 kcal of direct fuel from each dollar of their wages, while the Jaguar drivers buy 500 kcal, the first firm will "use" 1,050 kcal to produce a 100 dollars in output, while the second firm "uses" 1,500 kcal. Clearly, the *economy* receives more output per kcal of total energy from the first firm than from the second.

It is worth noting here that GDP is an aggregated index that takes no account of variations in income distribution within the population.

In the USA variation in fuel prices accounted for less than one per cent of the variation in real E/GDP between 1929 and 1983, contrary to the conventional wisdom. However, fuel prices were relatively stable up to the early 1970s. They became considerably more important after the 1970s oil crises, but have not weakened significantly the linkage between the real GDP/E ratio and the fuel mix and household fuel consumption. (Gever et al. 1991).

The same applies to entire nations. Internationally, *differing* household energy consumption patterns explain 57% of the variation in real GDP/E ratios among nations (Gever et al. 1991, p. 90). There was a sharp rise in this ratio in the USA during World War II due to gasoline rationing and voluntary cutbacks for the war effort.

The pre-1972 period for the USA saw two sustained trends that made rising productivity through increasing fuel subsidies economically feasible: rising fuel supplies with falling fuel prices relative to the cost of labour. Similar trends, with variations, applied in other developed countries.

5.3 Economic Policy

Despite the abundant supply of high quality fuel prior to the 1970s, the performance of economies have had their ups and downs, the Great Depression of the 1930s being an example. Starting from that time, partly under the influence of the theories of John Maynard Keynes, governments responded to economic downturns by increasing the money supply (monetary policy) and/or by government spending (fiscal policy). By putting more money in people's pockets or by having the government buy goods and services directly, these policies spurred demand and got the economy growing again. *They were successful prior to the 1970s because the high quality energy needed to meet the stimulated demand was easily available to match the increased money supply (Gever et al 1991, p. 96-101).*

But in the US domestic oil production peaked in the early 1970s and has since declined to nearly half its peak rate, while demand continued to grow. Since then the EPR of domestic fuels has fallen significantly, as has the EPR of imported oil during periods of high oil prices. The 1970s oil crises followed because the USA, *for the first time*, became vulnerable to the market power of the Organisation of Petroleum Exporting Countries (OPEC). In addition most new US electric power has come from nuclear reactors with a low EPR. The Keynsian formula no longer worked as well as beforehand. The high quality cheap fuels and energy was not so readily available to match the increased money supply. Economic stagnation and high unemployment accompanied high inflation, a phenomenon neo-classical economics was unable to explain.

Cleveland et al. (1984) say all inflationary periods (in the USA) can be explained when demand (money supply) increased faster than supply (energy use). They could account for almost all the variation in prices since 1890 by correlating changes in the ratio of money supply to energy consumption with the consumer price index. However, not all inflationary periods have been caused by tight energy fuel supplies: in the past, inadequate industrial capacity or insufficient labour were probably the main factors that kept output (energy use) from growing as fast as the money supply. However, limits to high quality energy supply are now becoming high on the agenda everywhere.

They say increased government buying won't stimulate sustained growth when high quality fuels can no longer be drawn *without limit* from the environment. Such spending crowds out other sectors, perhaps one reason why large federal budget deficits can now have such a strong impact on interest rates. By the same token, increased energy use by the private sector means less energy is available for educating our children, delivering our mail, public health, or providing other government services upon which we depend.

Expenditure by governments on the military is now a huge drain on the public purse, especially in the USA. It is expenditure on destruction. Modern day high-tech armaments and military operations are also *very energy intensive*. Davis (2003) in the Wall Street Journal, commenting on increased US defence expenditure for Gulf War II, compares the increase in US wartime spending as a percentage of GDP with the per cent of inflation adjusted GDP growth for World War II (1939-44), the Korean War (7/1950-3/1957), Vietnam War (7/1965-3/1967) and the Gulf War 1990-91 (8/1990-3/1991), *Table 1*.

TABLE 1
US MILITARY SPENDING AND GDP

	World War II	**Korean War**	**Vietnam**	**Gulf War '90/91**
GDP increase – per cent	69.1	10.5	9.7	**-1.3**
Military spending rise as a per cent of GDP	41.4	8.0	1.9	0.3

Davis says: *"Military expenditure is one of the few bright spots in a weak US economy but an Iraqi war won't provide the stimulative jolt that conflicts once did…..The harmful effects of war – sharply reduced consumer confidence, a sagging stock market and reluctance by business to invest – now overshadow any gains from military expenditure."* There is now almost certainly *a very high opportunity cost* involved in diverting more of the USA's declining high quality fuels to the military. The same can be said for NASA, highlighted by the recent crash of the space shuttle, Columbia.

No country *can afford any more to sustain high technology military establishments on a significant scale.*

5.4 Energy efficiency and conservation

We must distinguish between efficiency and curtailment in the use of energy. Setting the thermostat at a different level, whether it be for warming or cooling, is curtailment. Energy efficiency is using more energy efficient appliances and equipment, or designing and modifying buildings to adapt to solar energy rather than by using heating or cooling devices. Another way is designing urban areas to minimise powered transport use. And it takes time to change the structure of cities and buildings, and to introduce more energy efficient systems and products.

Another conservation strategy is demand management. Simply eliminating some energy consuming activities for alternatives that do not use high quality energy. The W.A. Department of Planning and Infrastructure's Travelsmart Dialogue Marketing program is an example (Transport 2000). It aims to convince Perth residents of the advantages of walking, cycling and public transport as alternatives to using cars for short journeys.

But there is an energy cost involved in improving *energy efficiency* in these ways. We must be sure that the energy saved by conservation exceeds the energy spent achieving the saving. Here it is vital to include the indirect as well as the direct costs, as emphasised in this paper. The former can often be larger than the latter. This is often over-looked and leads people to believe that many efficiency improvements can achieve more than is possible.

6. TRANSPORT FUELS AND ENERGY QUALITY

6.1 Background

Powered land transport is dominated by petroleum products with a minor role for electric rail traffic. Commercial shipping and aviation are almost exclusively petroleum powered. 60% of world oil supply is used to fuel transport, and the proportion is slightly higher in Australia. Most petroleum products are used for land transport, followed by aviation. The following qualities have led to petroleum products dominating as transport fuels:

- their abundant availability at widely dispersed locations;
- high energy profit ratios, EPR's, especially for oil from giant oil fields;
- high power-weight and power-volume ratios;
- consequently easy transport. storage and portability characteristics;
- a capacity for precise fine control and flexibility in compact engines;
- low environmental impact from production to end use compared to coal; and
- efficient, flexible and responsive transformation of fuel energy into vehicle motion.

It is unlikely that any alternative transport fuels will be able to fully match all these favourable characteristics of petroleum products.

Unfortunately we face, perhaps around 2010, the beginning of world oil production decline as the best oil fields reach their prime (Campbell 2003). Laherrérre (2001) also gives a comprehensive overview. Discovery peaked 40 years ago, has been declining ever since, and is now only one quarter of consumption which has exceeded discovery since 1980, *Figure 5*. Furthermore, the bulk of oil supply comes from a very small number of giant oil fields. These are fields with over 500 million barrels (80 GL) of extractable oil on discovery. *Figure 6* shows the discovery profile of giant oil fields (Campbell 1997).

Perhaps 40,000 oil fields have produced oil and around 30,000 still do, but just 360 giant fields produce around 60% of oil production. But nearly half the oil comes from just 120 giant fields, 14 of these produce 20% and four fields produce 11% (Simmons 2002). Giant fields are usually easy to find, are therefore found first, and produce the cheapest oil for a long time (i.e. generally have a high EPR). Discovery of giants has almost ceased, existing ones are ageing and many are in decline.

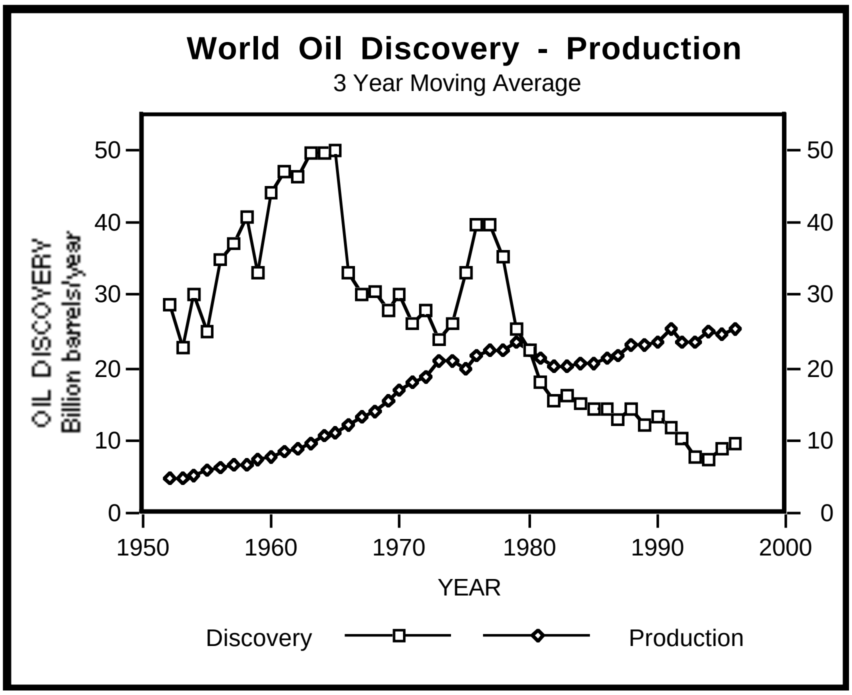

Figure 5

Figure 7 shows the EPR profile for Louisiana USA oil and gas production plotted against cumulative production (Hall et al. 1986, p. 186). In this case there has been no correction of energy inputs for energy quality over time in the terms discussed above. Note that the highest EPR's were in the middle range of the production cycle and declined after about two-thirds of the petroleum had been extracted. In *Figure 7* small and large field performance is aggregated for both oil and natural gas. The EPR performance of the Louisiana *giant oil fields* would have higher EPRs than shown. *On the downside of petroleum production net* *energy yield declines faster than gross output.* It is the net energy yield that counts, the energy we use to do useful things. Not all oil producing regions would have such a simple EPR profile.

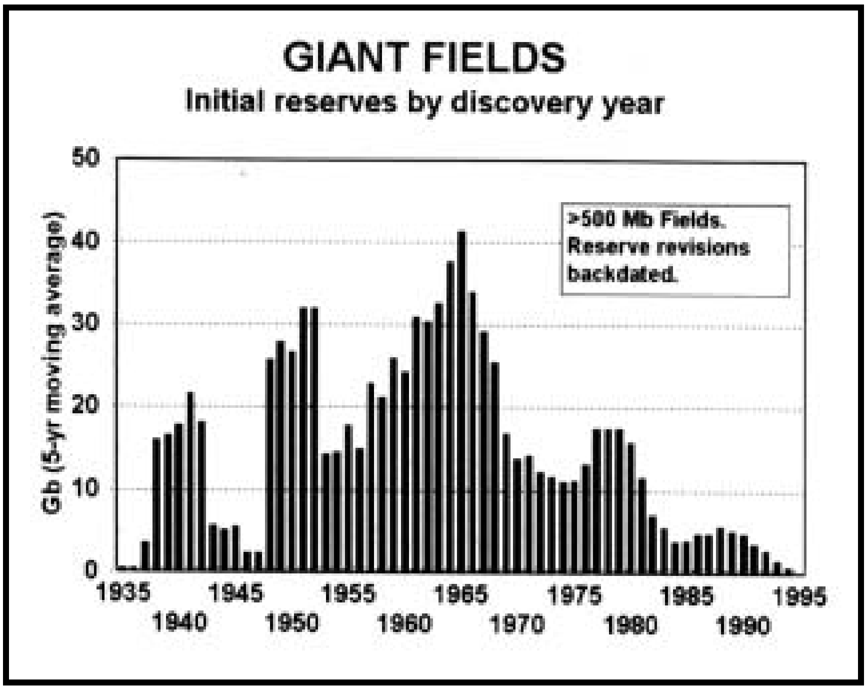

Figure 6

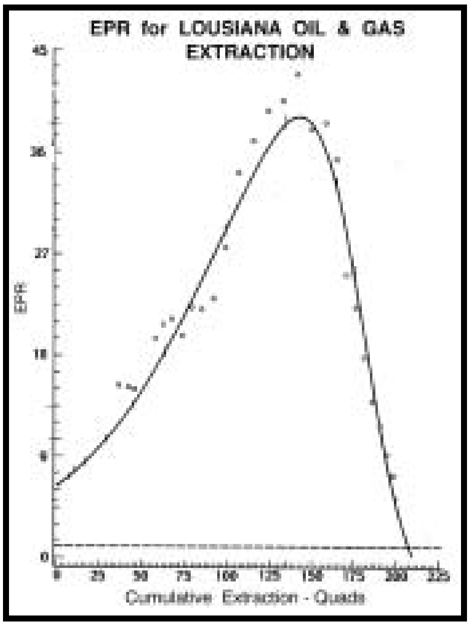

Figure 7

6.2 Alternative transport fuels compared

Figure 8 compares important quality characteristics of some transport fuels. Their EPR's are listed on the vertical axis and they are *ranked* on the horizontal axis according to other quality characteristics. The EPR data is mostly for the USA and taken from Cleveland et al (1984), also shown in Gever et al (1991, p.70) and Hall et al (1986, p.48). What *Figure 8* shows is the unique role that oil from giant oil fields has played, ranked well above all alternatives. But their best years are now mainly in the past.

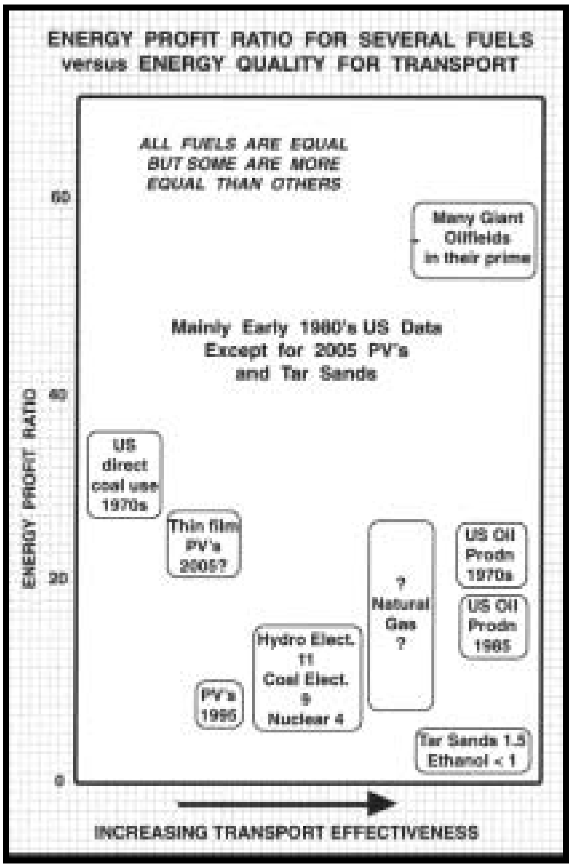

Figure 8

Liquid fuels are listed on the right because they are the most convenient and adaptable transport fuels and the technology for their use is well developed. Natural gas is to the left of liquids because it is more difficult to store and transport, but it can be used in existing internal combustion engines and the basics of a distribution system exist. EPR's for natural gas have not been published to my knowledge. Natural gas is the only fuel immediately able to substitute for petroleum products in land and sea transport.

Oil from Canadian tar sands has an EPR of 1.5, Youngquist (1999). *Large-scale* biofuel production (such as ethanol and biodiesel), according to studies embracing several countries by Giampietro, Uligiati and Pimentel (1997), *"is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it."* Using the net energy approach and including both direct and indirect inputs as outlined above, they found that the energy inputs exceeded the output – there was a net energy LOSS. Also the area of land required to grow the crops made serious and unacceptable in-roads on land needed for food production, along with major environmental problems.

Electricity is perhaps the most effective energy source for transport. Unfortunately it has to be manufactured from other fuels with attendant energy losses that attenuate EPR's, and it cannot be economically stored. Four litres of petrol has the same energy content as a one tonne lead acid battery, the reason why battery operated cars have never gained a large market (Youngquist 1999). However, electric assisted bicycles are already viable – you do not need power to transport a heavy vehicle and battery. Electric power is therefore to the left of natural gas.

Photovoltaics for electricity have the additional disadvantage of only generating electricity while the sun is shining. The EPR expectations of researchers for thin film silicon technology have to be realised before photovoltaics could be a serious contender for a role in transport, say for electrolysis of water for hydrogen – see below. Nearly all the energy input for photovoltaics occurs in the initial construction of the facilities, an energy call on existing commercial energy supply. This requirement limits the rate at which this technology can be introduced. The call on existing high quality energy supply is at the expense of existing uses.

The EPR for nuclear energy is for the early 1980s in the USA. It is based on the original very electric power intensive gaseous diffusion process for uranium enrichment, now superseded by the less energy intensive centrifugal process. However, the EPR does not include the energy cost of decommissioning nuclear plants and the disposal of nuclear wastes – unknown costs much of which will occur AFTER the plants are decommissioned. It is difficult when assessing the economic merits of nuclear power to disentangle the power industry from its connections with the nuclear weapons issue – indeed that is not possible.

Finally, direct use of coal as a fuel for transport has the real disadvantage of it being a solid and dirty fuel.

Hydrogen is not shown on Figure 8 . It is being widely promoted as a transport fuel in conjunction with fuel cells to generate electricity. But hydrogen has to be manufactured using some other fuels or energy sources. Hydrogen is an energy *carrier,* like electricity, not an energy source. The fuel cell technology is still under development. At least two energy transformation processes are involved to obtain electricity, with their attendant energy losses and embodied energies incorporated in the processes involved. However, there are many possible primary energy sources that can be used to manufacture hydrogen, one reason for it being favoured as a potential transport fuel.

But hydrogen is a gas and is the lightest of all the elements. Even compressed, its energy per unit volume is very low compared to all liquid and gaseous alternatives so that the storage and transport costs of hydrogen are very high by comparison. Likewise the proportion of its energy content needed for these tasks is also very high..

One option is to manufacture methanol, a volatile liquid, which can be used directly in some fuel cells to generate electricity. It does not have the transport and storage problems of hydrogen. Methanol can be manufactured from natural gas and from biomass. But natural gas is also a limited non-renewable resource and the biomass route has the same limitations as does ethanol and biodiesel.

Hydrogen will most likely be positioned around electric power on *Figure 8*, perhaps to the left of it.

Given these problems and the steps needed to get from a primary fuel to manufacture of hydrogen, then to electricity in a vehicle, it is extremely unlikely that it will have the convenience nor the EPR performance of historical petroleum products for transport. The net energy approach outlined in this paper is critical to evaluation of the transport potential of hydrogen.

After years of research the only efficient catalyst found for fuel cells is platinum, a very rare element. Will platinum become a limiting factor – Liebig’s law of the minimum?

6.3 Agriculture and mining

These are both important Australian industries and their products dominate our exports. Both are critically dependent on transport, both on farms and at mines, and for exporting their products to market and for accessing the many input products. In addition petroleum products play an important part in their production processes.

The limits of good agricultural land in the world were reached 50 years ago. Much agricultural land developed since is not suited for agriculture and is degrading rapidly, including in Australia. Since the 1950s crop yields per hectare have more than doubled to feed a doubling of world population (Brown 1999). Mechanisation, petrochemicals, fertilisers and use of high yield hybrid grain varieties have combined to produce the so-called Green revolution in Asia, *with the first three factors fuelled by oil and natural gas. Modern agriculture has been described as the use of land to convert petroleum into food (Youngquist 1999a).*

Approximately 90 per cent of the direct and indirect energy used in crop production is oil and natural gas. About one-third is used to achieve a hundred fold reduction in the labour input per hectare in the USA, Canada, Europe, Australia and Argentina, the principle grain exporters. The countryside has been depopulated and urban populations have soared. The remaining energy is used for production, of which about two-thirds is for fertilisers alone. The emphasis in the rest of the world is more to petroleum based fertilisers than mechanisation, with some variation. Africa has the least dependence on petroleum products for agriculture (Conforti & Giampietro 1997).

A critical role is played by nitrogen fertilisers. The starting off point is the synthesis of ammonia using atmospheric nitrogen and hydrogen obtained from natural gas subjected to high pressures and temperatures in the presence of catalysts. According to Vaclav Smil, around 1960 the world reached the limits of providing an adequate protein diet by using legumes and animal manures in crop production. Since 1960 an adequate protein diet for a doubling of world population to six billion people has been achieved through enhanced crop yields in which nitrogen fertilisers have played a key role. From 1960 to 1990 world nitrogen fertiliser production increased from 10 to 85 million tonnes as nitrogen, with two-thirds of the increase used in Asia (Smil 1993 & 1997). These fertilisers made the so-called Asian Green revolution possible. Two petrochemical plants proposed for the Burrup Peninsula are for the manufacture of nitrogen fertilisers. One is based on export of 700,000 tonnes of urea to India per year. Nitrogen fertilisers now play a significant role in most Australian agriculture.

How can the world manage a reduction and re-distribution of population over the next century to levels that can be fed without the need for a petroleum input to agriculture? A major issue is solving the population problems of the Persian Gulf countries who have over half the world's remaining conventional oil and close to one-third of its conventional natural gas. These issues underlie the growing refugee problems in the world.

This food supply agenda must have first call on the world's remaining oil and natural gas.

7. CONCLUSIONS

One can only conclude that there are no alternative transport fuels in sight that can replace the performance of petroleum products as we have used them for the past 60 years, nor are these likely to emerge. This era will be seen by future generations as unique, a period created and so far sustained by oil primarily from the giant oil fields. Up-to-date information on EPR's is unlikely to alter the relative relationships of the fuels shown in Figure 8. We have been picking the eyes out of a large hydrocarbon resource base.

Already there are people lobbying for the addition of ethanol to petrol, the use of bio-diesel, and of hydrogen powered fuel cells as alternatives to petroleum products for transport fuels. Others are promoting gas-to-liquids technologies for transport fuels. How do we evaluate these choices and others for their viability? Comparing the different qualities of fuels as has been done in *Figure 8* is crucial. Taking account of differing energy qualities in ways discussed in this paper are essential when comparing fuels and other options. All direct and indirect energy inputs must be taken into account. When this is done the direct relationships between economic performance and energy inputs are starkly revealed, whether at the local or global scales.

7.1 Australia

Most of the information used in this paper relates to the USA. How does Australia compare?

- Firstly. We are well integrated with the rest of the world through trade; we do not live in isolation.
- Secondly, we have high dependence on petroleum products for transport, like the USA.
- Thirdly, we are a net exporter of energy – LNG and the world's largest coal exporter – whereas the USA is a net fuel importer, principally oil and to a lesser extent natural gas. However, our oil self-sufficiency is declining rapidly, and most supply is from small fields offshore.
- Fourthly, we have a smaller population than the USA. But Australia is largely desert, the driest continent, and our soils are among the most nutrient deficient in the world. Our present farming practices are totally dependent on petroleum products.
- Fifthly, the USA is further advanced in depletion of its mineral resources than Australia.

An urgent task in Australia is to determine in a biophysical economics framework the net energy yields of Australian fuels and energies, their EPR profiles and the direction these are heading, as well as other energy-economic statistics like those described in this paper. Some such work may already be done, but more is needed. Without this background information, we cannot successfully steer our way through the challenging times ahead.

Strategies are needed to raise the public, business, economic and other professions understanding of these biophysical economic insights and what they mean for the future directions we now need to follow.

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