SENATE RURAL AND REGIONAL AFFAIRS
AND TRANSPORT COMMITTEE

INQUIRY INTO AUSTRALIA'S FUTURE OIL SUPPLY AND ALTERNATIVE TRANSPORT FUELS

SUBMISSION BY

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PERSONAL BACKGROUND

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Brian is an executive member of the Australian Association for the Study of Peak Oil founded in 2005.

He is a member of the Board of International Advisers to the Oil Depletion Analysis Centre (ODAC), a branch of the London-based Association for the Study of Peak Oil and Gas (ASPO).

He was a member of the WA Minister for Planning and Infrastructure's Transport Energy Strategy Committee in 2003-04.

He is a member of the Sustainable Transport Coalition of W.A. that has a major focus on oil supply futures, transport and land use planning.

He worked for the Water Authority of W.A. and its predecessors for 34 years until his retirement in 1993.

He completed his career managing the operation and maintenance of Perth's water sources, both surface and groundwater.

During the 1980s he represented the Water Authority on national committees on water quality issues and for 8 years was a member of the National Health and Medical Research Council's Water Quality Committee.

His family has been farming in the Avon Valley east of Perth since the early 1830s.

In the late 1970s he was inspired by the work of Nicholas Georgescu-Roegen and Howard T. Odum on economics, environment and energy, with a focus on petroleum issues. Thereafter he widened his understanding of ecological economics and related issues, complemented by his employment in the water industry that was confronting conditions where water resource and environmental constraints to its operations became its central focus.

On retirement he took these issues up publicly and in 1995 wrote a book, *The Decline of the Age of Oil.* He has campaigned on these issues ever since.

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SUMMARY AND RECOMMENDATIONS

It is certain that cheap and available oil will become more and more scarce as the demand for it grows. It is also certain that the cost of preparing too early is nowhere near the cost of not being ready on time.

Alannah MacTiernan, W.A. Minister for Planning and Infrastructure, in her speech opening the W.A. Sustainable Transport Coalition's "Oil: Living With Less" Conference, August 2004

Section 1. Introduction

Cheap petroleum products dominate transport fuels and there are no alternatives emerging to match their performance, including remaining petroleum products. The long-term response must be to progressively reduce the role of contemporary transport, reversing 200 years of development. This structural change will take TIME and the sooner we start adapting the better.

The pioneering work on all-inclusive *community and stakeholder dialogue* to find solutions to complex problems and used in the Department of Planning and Infrastructure in Western Australia gives a lead that needs extending and developing everywhere.

> **Recommendation:** *Processes for inclusive community and stakeholder dialogue based on democratic participation with attention to social justice* ***are essential*** *for a successful transition to a world 'beyond oil'.*

Section 3. Energy Quality and Economics

A dialogue is urgently needed between neo classical economics and ecological economics to give energy its due place in the discipline. There is an urgent need for studies to determine and make public the embodied energy in goods and services, including for energy sources themselves, their energy profit ratio. *A dialogue to raise the standard of such studies is needed.* Such information is vital to make the right choices for the future.

> **Recommendation:** *That research is promoted to assess the embodied energy in important goods and services in Australia, and the energy profit ratios of energy sources with the results made public.*

Section 4. World Oil

The "pessimists", such as the Association for the Study of Peak Oil, are winning the debate on the timing of peak oil production against the "optimists"—more strictly a plateau. Production comes from ageing giant oilfields and exceeds the discovery rate. New discovery is limited and in hostile, expensive and politically unstable locations. Production outside the former Soviet Union (FSU) and the Middle East has plateaued. Russia has reached the limits of oil export capacity that limits its future. Published reserve data and performance lacks transparency and cannot be trusted, especially in the FSU and Middle East. It is a source of market uncertainty.

> **Recommendation:** *That Australia require mandatory transparent reporting by companies of field-by-field reserves and production data, and subject these to public audit for original oil-in-place, the ultimate recoverable and cumulative production.*

Such a requirement is unlikely to cause too much difficulty for companies operating in Australia. But it will set an example for the world to emulate.

Section 5. World Natural Gas

Natural gas production is in decline in North America and imminent in Europe—46 per cent of world consumption. UK production is in rapid decline. *See Appendix 3.* Russia and the Middle East dominate reserves*. Due to the high cost of transporting natural there will be a series of regional natural gas peaks rather than a world peak*. A boom in LNG development for export is occurring. *Natural gas prices will rise.*

> **Recommendation:** *That more attention needs to be given to the long-term economic risks of exporting LNG to the USA and its ability to pay for these given the acute supply crises occuring in both US oil and gas.*

Section 6. Australian Oil and Gas

Australian oil production comes from declining small fields with future discovery uncertain and may be mostly from deep water offshore. Imports are increasing and vulnerable to disruption for a small player like Australia. Natural gas is more plentiful, but most is offshore from the

North West coast and distant from local markets. But it can be a potential transition transport fuel for a much less transport intensive future. Little attention is being given to this role.

Recommendation: *That a 30-year strategy for domestic Australian oil and natural gas supply be developed focusing on a priority role for natural gas as a transport fuel as against other uses and export as LNG. To be concurrent with similar demand management strategies—see further recommendations below. To be reviewed every five years.*

Recommendation: *That royalties and tax concessions for the upstream oil and gas industry be reviewed. Any further tax concessions and subsidies to the industry to have a lower priority than introduction of demand management initiatives to reduce consumption of oil and gas as these will be of more immediate benefit.*

Section 7. Effectiveness of Transport Fuels

There are no transport fuels in sight that can replace petroleum products as we now use them. Therefore the prime response to 'peak oil' must be demand management—to reduce the scale and extent of fuel driven transport at all levels from the local to the global. *This will take several decades to achieve.* This must have immediate high priority regardless of when the global peak of world oil production is expected to occur. Biofuels such as ethanol and biodiesel cannot replace petrol and diesel on any scale because of supply conflicts with grain for food. The present World Trade Organisation (WTO) strategy on trade implies the endless growth of cheap transport, an era about to end.

Recommendation: *That a 30-year broadly based transport demand management strategy be prepared for petroleum-based transport fuels to reduce their consumption at a rate consistent with the likely declining availability of these fuels.*

Recommendation: *That biofuels for transport should not be promoted or subsidised except possibly for biodiesel on a limited farm scale for local use.*

Recommendation: *Explore using LNG as a transition fuel for trucks and locomotives in lieu of diesel. The alternative of gas-to-liquids is likely to have an inferior net energy yield.*

Recommendation: *The WTO strategic direction on free trade is becoming obsolete. Australia should promote reform to reverse the strategy towards a transition that focuses on greater local production of goods and services and reduced long-distance trade*.

Section 8: Agriculture and the Food Chain

Modern agriculture is the use of land to convert petroleum into food, a description that particularly applies to Australia with its poor soils and rainfall. *The first priority for remaining cheap oil and gas must be for food production while a sustained effort is made to reduce world population to levels not dependent on these fuels.* The major energy inputs to the food chain occur post-farms, with significant inputs for transport, processing, packaging and retail.

Recommendation: *Governments should sponsor NOW embodied energy studies of the food chain from farm inputs to homes so that the priority areas for reducing energy inputs can be defined for energy demand management. A high priority is likely to be reducing and even eliminating the need for car travel to and from large centralised super markets.*

Recommendation: *In the transition period such localisation strategies for the food chain must be balanced against maintaining appropriate food exports until the countries and regions absolutely dependent on food imports have reduced their populations to levels of sustainable food self-sufficiency.*

Recommendation: These strategies should incorporate revitalisation of rural and local communities and the tackling of land degradation.

Section 9. Road and Rail Transport

Car-dependence has increased personal travel costs in our cities at the expense of much cheaper public transport, cycling and walking. Crash, pollution and congestion costs are huge. The provision of other services suffers as a consequence. Urban sprawl is promoted that separates residences from workplaces forcing long commuter journeys, especially in the outer suburbs where public transport is poor. Funding from taxes favours roads. Local production can reduce the need for freight transport that also needs to shift to more energy efficient rail as far as possible. Road freight does not cover the cost of 'externalities'. Perverse taxes and charges reinforce these impacts.

Recommendation: *Cease funding of freeways and road tunnels in cities and restructure financing to give priority to public transport walking and cycling built around core electric rail transit.*

Recommendation: *Integrate land use planning with transport with a focus on quality higher density development and good services, minimising oil dependence, localising employment and enhancing urban living.*

Recommendation: *Require transport impact studies for ALL significant developments to reduce petroleum fuel consumption that keeps pace with declining oil supply*.

Recommendation: *Use democratic dialogue processes as outlined in Section 1 to implement these strategies, including where job changes occur due to reduced car use*.

Recommendation: *Concurrently, with dialogue processes, review perverse tax and charges regimes that work against the above reform strategies and progressively implement reforms to consistently reinforce the new direction.*

Section 10. China and India

China, and to a lesser extent India, are undergoing unprecedented urban and industrial development, including cars. *China is the main driver of oil consumption growth*. Chinese demand for minerals is responsible for the commodities-driven economic boom in Australia. This development in China is at the expense of agricultural land that is compromising grain production. Water shortages are aggravating the situation. *Soon China may be forced to import grain at a rate the world cannot meet.* The Western industrial economic model is not an option for China. There are serious consequences for Australia not being addressed by governments, business and economists.

Recommendation: *Governments and the community must investigate urgently the unsustainable nature of Chinese and Indian economic development and enter into a dialogue on the consequences and how to respond.*

Section 11. Greenhouse Gas Emissions and Climate Change

The Australian Bureau of Agricultural and Resource Economics (ABARE) released a report in January 2006 for the inaugural meeting of the Asia Pacific Partnership on Clean Development and Climate (APPCDC) responding to the six countries growing emissions of Greenhouse gases. The report projected these countries business-as-usual fossil fuel scenarios to 2050 as well as reduced ones for demand management and sequestering of carbon dioxide. *ABARE did not address AT ALL the issue of the impending decline in world oil production, or other resource constraints.* Under the best scenario all six countries significantly increased their oil consumption to 2050 that implied world consumption in 2050 two and a half times that predicted by the Association for the Study of Peak Oil and Gas (ASPO).

Recommendation: *That all governments insist that reports make informed reference to the debate on the imminent peaking of oil production where the subject is relevant to the report.*

The Intergovernmental Panel on Climate Change (IPCC) published in 2000 an update of its 40 scenarios for fossil fuel production from 1990 to 2100. These scenarios are the basis for projections of possible greenhouse gas emissions from burning fossil fuels under a range of circumstances. For oil and gas these range from five times current use in 2100 to near zero. *The IPCC does not attach probabilities to these scenarios.* The ASPO estimates for oil and gas are based on probability estimates and are at the bottom of the IPCC scenarios. IPCC is currently reviewing its scenario package through 2007 and will include a discussion on their probabilities.

Recommendation: *That the Federal government initiate a public critique of the 40 IPCC scenario probabilities as part of the current IPCC scenario review.*

Recommendation: *That strategies responding to anthropomorphic climate change from fossil fuel consumption be merged with those responding to the impending decline in oil production.*

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1. INTRODUCTION

Ride the Whirlpool

"I have seized on the metaphor of the boat in the whirlpool to emphasise the point that the chaos into which we are moving is a natural thing, far more natural than linear stability and order. We ride the whirlpool in many forms in nature, and we evolve personally and socially to do so. The individuals and organisations that will be successful in this will be the ones that unleash the creative genius of their people. This is the essence of modern leadership."

Lieutenant General Dr John Sanderson, AC ex-Governor of Western Australia
on his choice of name for the book of his speeches while Governor, *UWA Press 2005.*

The decline of cheap oil will be the climax of the fossil fuel age, given the role of petroleum and petrochemicals in our civilisation. It is the greatest adaptive challenge that *homosapiens* has ever faced. Everyone will undergo a cultural transformation, have to make major concessions and give up old ways of living for new ones in an incredibly short time frame. The experience will appear to be chaotic with perpetual change. But as our ex-Governor says this is a natural thing and can be a powerful and creative experience with the right leadership.

Positive change can only occur rapidly *if everyone* can participate in an informed way and respect the views of others, be confident that there is all-round fairness, and if government and other authorities are genuinely committed to embracing the outcomes of the process. The magnitude, multiplicity and complexity of the changes means no one can know in advance what a satisfactory outcome will be—an important conclusion from complex system theory. Satisfactory outcomes can only emerge through active democratic participation that weaves citizens more deeply into decision-making. Participative democratic processes are essential for success.

This approach has been successfully used in Western Australia by the Department of Planning and Infrastructure on the initiative of the Minister, Alannah Mactiernan, to progress a range of complex planning and transport issues, including ones where there are many conflicting interests. The following principles apply:

- Government must genuinely listen to divergent voices.
- Stakeholders are to listen to others in the same way.
- Governments must ensure the engagement is reflective of the community—that the aspirations of special interest groups are calibrated against a broad cross section of the community.
- Governments to be open with the process of engagement and with its sharing of information.
- Governments to be genuinely committed to embracing the outcomes of the process.
- Establish continuous feedback links with participants to ensure the broader community stays engaged.
- Leadership must reflect and implement these principles.

This process has been successfully used in Western Australia at local and regional levels and in the lead up to the *Network City* plan for the Perth Region (**WAPC 2004)**. A highlight was the *Dialogue with the City Forum* in 2003 where 1,400 people participated in an interactive forum, eight people at a table each with a facilitator for face-to-face deliberation and a networked computer. The computers enabled common themes to be collected and broadcast to the forum in real time. The outcome provided the basis for the development of the draft *Network City* Plan in 2004. A more comprehensive exposition on the principles involved is in the book *Gaian Democracies* **(Madron & Jopling 2003).**

The process fosters attitudes of cooperating for the common good, while retaining the beneficial sides of competition. Cooperation and competition processes in human affairs complement each other. They are not mutually exclusive.

Developed further, this pioneering approach can be a powerful tool for coping with the changes arising from declining oil supply, indeed the only way.

Finding out what the problems are and how they interact, what options there are, what needs to be 'done' and how to do it can only arise from such participatory processes. The Recommendations in my submission will have few specific 'solutions' to issues raised, rather they will point to broad issues that need addressing in the way described above. Many of the problem areas have already been analysed and described in great detail, there is already a great deal of factual information.

2. SUBMISSION STRUCTURE

The submission will cover a wide arrange of topics with some of the more important issues explained in depth in eight Appendices. This will enable readers to cover the issues briefly and grasp the essence of the arguments without being submerged in too much detail.

The submission will address the following issues.

- The necessity for inclusive, democratic and socially just practices for implementing adaptation and change strategies, with an emphasis on the need to simultaneously integrate cooperation and competition—as discussed above.
- Outline an ecological economics critique of economics focusing on the energy cost of producing energy as a central theme. Introducing the concept of energy profit ratio.
- Outline the position of the Association for Peak Oil and Gas (ASPO) on the future of oil production and compare its views with the position of one more optimistic viewpoint.
- Discuss the imminent peaking of North American and European natural gas production.
- Outline the Australian position on oil and natural gas supply in this global context.
- Compare transport fuel options from an ecological economics viewpoint, concluding that the scope for alternative fuels to match the performance of petroleum products are limited.
- *Industrial agriculture is a way of converting petroleum into food*—the food chain and population issues.
- The consequences for urban areas and development and the need for reform of transport infrastructure financing, the tax system and current government subsidies.
- China's urban/industrial development is at the expense of agricultural land and grain production. It is unsustainable in the near term. Implications for Australia and the world.
- Outline the need to merge policies responding to the peaking of cheap oil and climate change arising from human-induced greenhouse gas emissions. Critiques of ABARE's report 06-1 for the Asia Pacific Partnership on Clean Development and Climate, and of the Intergovernmental Panel on Climate Change scenarios for oil and natural gas consumption to 2100.

3. ENERGY QUALITY AND ECONOMIC EFFECTIVENESS

Neo classical economics regards energy as *'just another commodity'.* By contrast energy occupies a central place in the more recent discipline of ecological economics. Economic systems theory must be consistent with the first and second laws thermodynamics[1]. Appendix 1 (14 p.) discusses the relevant issues—these are summarised below.

- *The 'economy' is a sub-system embedded in the environment* and draws high quality material and energy sustenance from it, discharging wastes and low quality energy to the environment. Energy cannot be recycled—a consequence arising from the second law of thermodynamics.
- *Energy drives the energy industry*. Some commercial energy must be used to extract and convert energy sources from nature into useful forms. *The critical issue is 'how much'.* Energy Profit Ratio (EPR) is one measure of energy quality and a pivotal index for assessing the economic performance of fuels. Both the direct and indirect energy inputs embodied in goods and services must be included in the denominator.

$$\text{EPR} = \frac{\text{energy output}}{\text{energy input}}$$

- *Energy sources have different qualities* that affect their usefulness and economic performance, as measured by gross domestic product per unit energy input (GDP/E). We are never likely to have coal-fired aeroplanes. GDP is a deficient index of welfare.
- *The different end-uses of energy sources* also affect their quality and contribution to GDP/E. In the USA oil is 1.6 to 2.7 times more effective economically than the direct use of coal, and electricity 2.7 to 14.3 more effective. Similar relations apply for Europe and Japan.
- For the USA 72 per cent of the increase in the GDP/E ratio since 1920 can be explained by change of fuel type—the shift to oil and electricity. Another 24 per cent can be explained by changes in direct use of energy by households—fuel for vehicles and heating.
- *Technology development* is about using energy sources effectively—and consumes energy in the process.
- *Government, financial and other services* are significant users of commercial energy.
- *Given these factors* there are direct but complex relations between energy consumption, money, economic activity and inflation, and the quality, availability and types of energy.

Most of the world's oil production is refined into petroleum products for transport. In this role it is superior to any alternative fuels and has mostly had a particularly high EPR. Remaining oil production will have reduced economic performance as the best deposits from the past are depleted and the cost of discovery and extraction increases in both dollar and energy terms. Alternative transport fuels cannot match the historical performance of petroleum products.

Figure 1 shows the variation in EPR for Louisiana USA oil and natural gas over the production life cycle. Note that the highest EPR's occur in the middle of the production cycle. In the early years both the volume and economic effectiveness of the output is expanding. In the final years the reverse is the case. Similar relationships would apply for other petroleum provinces, but not necessarily the simple profile for Louisiana. *This relationship should be borne in mind in the subsequent discussion below.*

4. IS WORLD OIL PRODUCTION ABOUT TO PEAK?

This topic raises its head periodically. Surging consumption over the last three years, driven mainly by China, has caused demand to press against supply for the first time since the 1970s, forcing up oil prices. Debate on the timing of peak oil production has gathered pace since the mid-1990s, initiated mainly by the work of two retired petroleum geologists, Colin Campbell and

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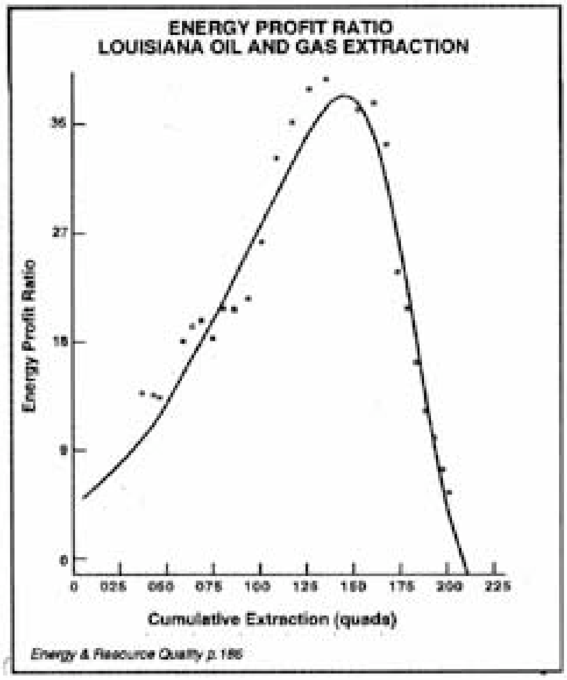
1 The first law of thermodynamics says energy can neither be created nor destroyed but may be transformed from one state to another. The second law says: without compensating change elsewhere, heat can only flow from a hotter body to a colder body, introducing the concept of irreversible processes

Jean Laherrére. In the 1990s they had privileged access to Geneva-based Petroconsultants' extensive database on oilfield exploration, development and performance in the 1990s, the only one for countries outside of North America. Their initial work was published by Petroconsultants, and subsequently in many books, magazines and industry journals.

Figure 1
Louisiana USA EPR Profile



By 2001 rising interest led to the formation of the mainly European-based Association for the Study of Peak Oil and Gas (ASPO) and comprised petroleum industry professionals, academics and other interested people, including Campbell and Laherrére. In late 2001 ASPO formed its research arm, the Oil Depletion Analysis Centre (ODAC), and has held annual conferences since 2002. It publishes a monthly Newsletter and its members are extensively involved in conferences, media and publicity on peak oil (**ASPO 2005).**

People often ask; *"are we running out of oil".* This is the wrong question. In the absence of political and other disturbing factors, production from petroleum provinces rises to a peak and then declines as continued oil extraction becomes progressively more difficult. In these circumstances the peak usually occurs when about half the ultimately extractable oil has been produced. The crucial question is; *"when is production going to peak and decline begin".* Ultimately production ceases when it is no longer economic to continue pumping—but there will still be large amounts of oil left in the oilfields. Some heavy viscous oil and that derived from solid hydrocarbons, such as Canadian tar sands, have different production profiles.

ASPO is the leading *'pessimist'* school—holding that the world peak may only be 5-10 years away. There are *'optimists'* who say this may be 20-30 years away. I will outline the essential features of the ASPO school and their rationale, and describe key differences with the 'optimist' school and why I think this perspective is not valid.

4.1 The ASPO viewpoint

Below is a summary of the ASPO model for past and expected future oil discovery and production, (**ASPO 2005).** ASPO defines *regular oil* as the majority of oil that is produced easily and relatively cheaply from oil fields in favourable locations. *Non-regular* oil comes from a variety of difficult-to-produce and expensive sources such as heavy oil (very viscous and solid hydrocarbons), from deep water offshore, in polar regions (e.g. Alaska), as well as liquids extracted from natural gas (NGL). *Table 1 shows ASPO's past and expected future production for regular and non-regular oil.*

Table 2 shows ASPO's expected production rate in million barrels per day for the major *regular oil* producing regions to 2050, plus expected ultimate production in gigabarrels, and as well for the categories of *non-regular oil*. ASPO's expectations for the peak years are shown.

Table 1
ASPO Future Production by Category
Gigabarrels Gb

Regular Oil Gb				
	To 2004	**Future**		**Total**
		Known Fields	New	
		758	123	
	968	**882**		**1850**
Non-Regular Oil Gb				
Heavy Oil				151
Deep Water				69
Polar				52
NGL				276
Total	**106**	**444**		**550**
All Liquids Gb				
Total	**1074**	**1326**		**2400**

Table 2
ASPO Future Production 2005 to 2050
Million barrels/day and Gigabarrels

Regular Oil							
Region	**2005**	**2010**	**2015**	**2020**	**2050**	**Total Gb**	**Peak Year**
US-48	3.6	2.8	2.2	1.7	0.4	200	1971
Europe	5.2	3.6	2.5	1.7	0.2	75	2000
Russia	9.2	8.4	6.8	5.5	1.5	220	1987
M.E.Gulf	20	20	20	20	11	680	1974
Other	29	26	22	18	7	675	2005
World	**67**	**61**	**54**	**47**	**21**	**1850**	**2005**
Non-Regular Oil							
Heavy Oil	2.3	3	4	4	4	151	2021
Deepwater	3.6	12	11	6	4	69	2011
Polar	0.9	1	1	2	0	52	2030
NGL	6.9	9	9	10	8	276	2035
Total	**13.7**	**25**	**25**	**22**	**16**	**550**	
TOTAL	**81**	**86**	**80**	**70**	**35**	**2400**	**2010**

Figure 2 shows the existing ASPO production profiles to 2004 and those projected to 2050 for its categories of regular and non-regular oil and natural gas liquids.

A few giant oilfields dominate. There are over 10,000 producing oilfields in the world. However, a small number of giants have always dominated supply with 116 giants producing 48 per cent of world production[2]. Of these, 16 produce 21 per cent and four 11 per cent **(Simmons 2001).**

[2] Giant oil fields are those producing over 100,000 barrels/day, or sometimes regarded as those with 500,000 barrels of extractable oil on discovery.

They are usually found first because they are large, easy to find, and produce the cheapest oil. They have long lives, 40-50 years and more. Many are ageing and already in decline.

Figure 3 is from a paper by **Longwell (2002),** Executive Vice President of Exxon-Mobil. It shows the discovery and production profiles for oil and gas from 1900 to 2000 and his consumption projections to 2020—the latter conditional on a large increase in investment.

Figure 2
ASPO Oil Production Profiles 2004
Billion barrels per year

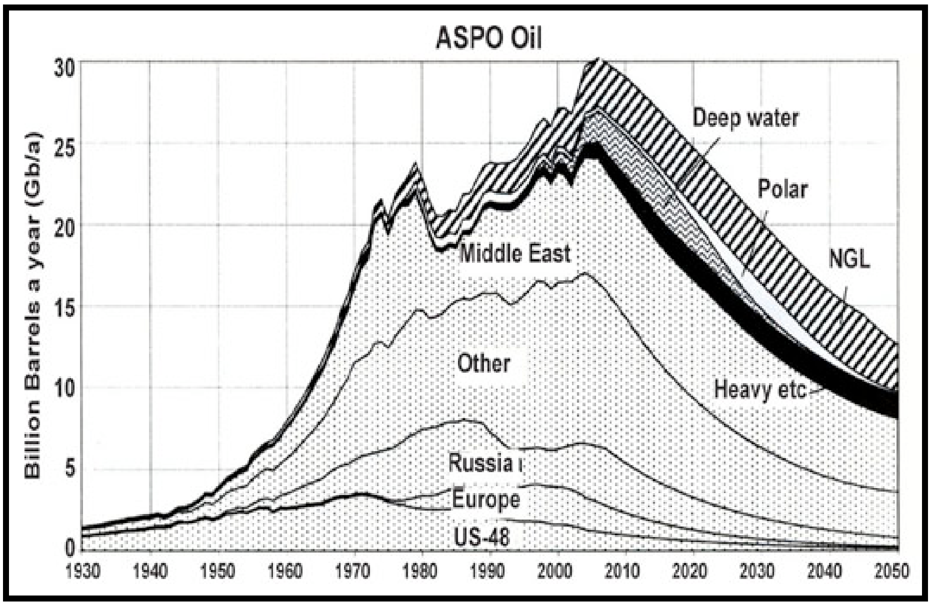
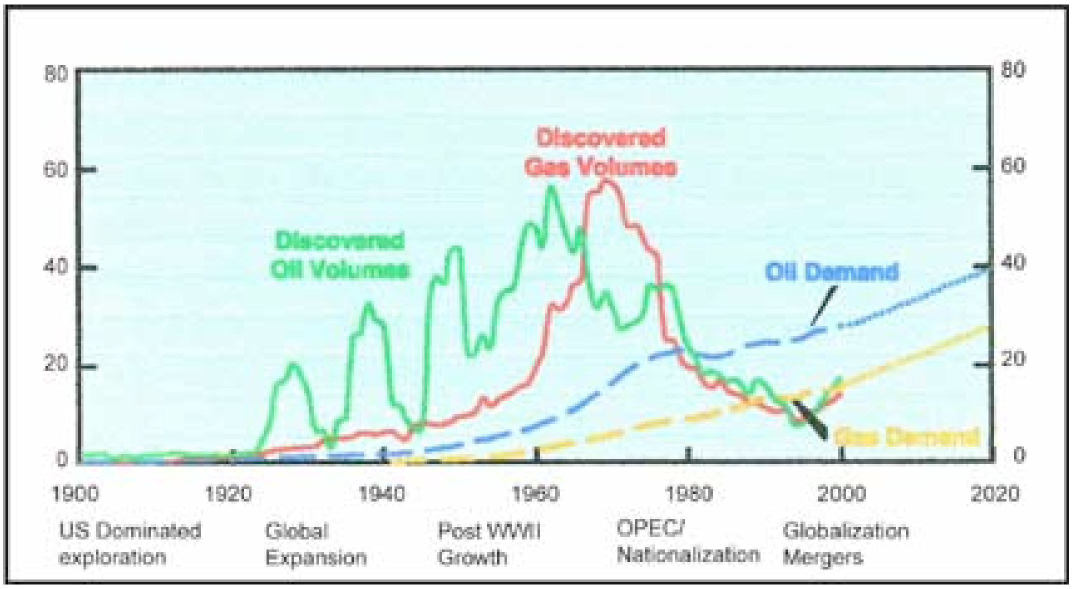


Figure 3
World Oil and Gas Discovery/Production
Longwell: Exxon Mobil
Billion barrels oil-equivalent



The discovery peaks for oil represent episodes of giant and super giant oilfield discovery starting with Venezuela in the 1920s, Texas, Iraq and Iran in the 1930s, the Middle East and Africa in the 1950s continuing into the 1960s with the former Soviet Union, Alaska and the

North Sea as well[3]. The secondary peak in the 1970s covered most areas and offshore exploration. *The discovery rate has been in decline for over 40 years*. An upturn has occurred in the 1990s with exploration offshore in the Caspian Sea and deep water offshore (>300m.).

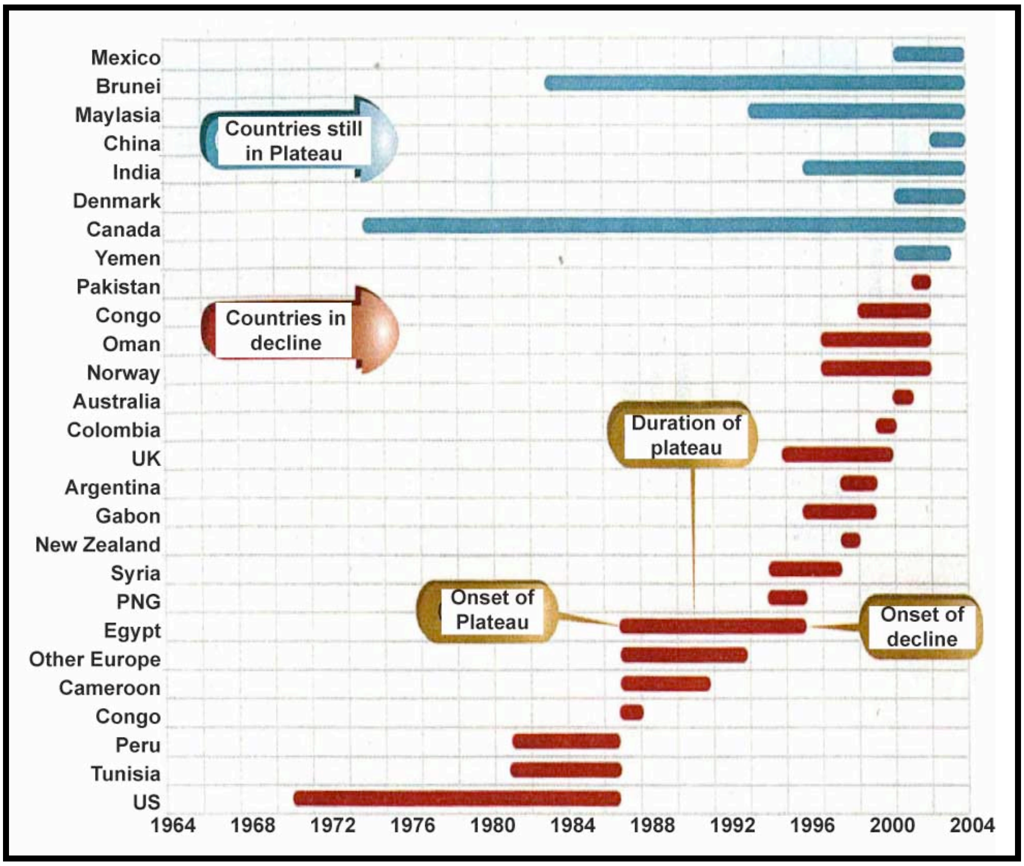
Oil production has exceeded discovery since 1980 and is now about 3-4 times the discovery rate. Very few giant oilfields are being found. Longwell says discoveries are increasingly being made at greater depths on land, in deeper water at sea, and at more distances from consuming markets, especially for natural gas.

Natural gas discovery peaked in the 1970s with major discoveries between 1960 and 1980 in Russia, the Middle East, North Sea and Indonesia. A minor upturn occurred in the 1990s from deepwater offshore exploration. Gas production has started to exceed discovery since 2000, some 20-25 years later than for oil, *Figure 3*.

4.2 Non OPEC production

Rodgers (2004), from PFC Energy, Washington DC, in a detailed analysis of production excluding OPEC and the former Soviet Union (FSU), says oil production in these countries has exceeded reserves addition by 12-15 billion barrels per year since the mid-1980s and production has reached a plateau since the mid 1990s. At least 20 of these countries (currently 19 million barrels a day) have passed their peak and are in decline, after producing 50-60 per cent of their reserve base. Their production declines by one million barrels a day. Another eight have reached a plateau at 13 million barrels a day and would all peak by 2010, Mexico and Yemen in 2006. *Figure 4* shows the detail. **New supply has to meet both production decline and consumption growth.**

Figure 4
Non-OPEC Countries in Decline or Plateau



[3] Super giants are those oilfields with over five billion barrels of extractable oil on discovery.

Skebrowski (2004) says mega projects on new giant fields are the main source of new supply and there is normally a six year lag between discovery and first production. He says several such projects have come on stream since 2003 with further projects well covered to 2007. But beyond 2007 looks bleak due to a decline in giant field discoveries from 2002. None were discovered in 2003 and only two in 2005. *That leaves the Middle East and the former Soviet Union as the main areas for growth.*

4.3 Former Soviet Union (FSU)

There was a steep FSU production decline from 12 to 7 million barrels a day between 1989 and 1998 consequent upon neglect of investment in petroleum infrastructure and the collapse of the Soviet Union, *Figure 2*. Some fields also peaked. Production has significantly improved since Putin became Russian President in 2000 and reached over 11 million barrels a day in 2005, 9.3 million barrels a day from Russia. Some of the recovery was due to commissioning giant offshore discoveries in the Caspian Sea and commissioning of a new pipeline in 2005 to the Turkish port of Ceyhan. The new Caspian oil is of poor quality—heavy 'sour' oil—and political instability is slowing progress. Not all refineries can process heavy sour oil. Higher oil prices together with the return of political and economic stability contributed to Russia's recovery. Much needed investment was possible.

However, Russia has reached the limits of export capacity and export growth will slow down. The main fields are in the Ob River basin in Siberia. New large pipelines would be expensive and need operation at near capacity for 20 years to justify projects. Furthermore, **Jean Laherrére (2003)** says Russian reserves are overstated by 30 per cent compared to the rest of the world as their definition of reserves takes an optimistic low probability view that ignores constraints to development. *The Russian production peak could be imminent.* The Russian government prohibits publication of the relevant performance data that would allow an independent audit.

4.4 Middle East production

Table 3 shows current and sustainable production and reserves of the Middle East OPEC countries. The run-down state of Iraq's oil infrastructure and the insurgency has kept oil production well below its current 'sustainable' capacity. The Middle East produces two-thirds of OPEC oil and the rest of OPEC[4] has negligible spare capacity as well. By the end of 2005 virtually the only spare production capacity in the world was in Saudi Arabia—and that was heavy sour oil (high sulphur content) when refinery capacity for such oils was fully committed.

Table 3
OPEC Middle East
Million barrels a day

Country	Production Sept. 2004	Sustainable production	Reserves Gigabarrels
Saudi Arabia	9.56	10.5	263
Iran	3.97	4.1	133
Kuwait	2.46	2.5	99
United Arab Emirates	2.52	2.55	98
Qatar	0.81	0.83	15
Iraq	*1.97*	*2.5?*	*115*
Total	**21.3**	**23**	**723**

However, ASPO and others question the validity of OPEC's figures for reserves. All these countries substantially increased reserves in the late 1980s without published justification—a doubling by Iran and Iraq, 50 per cent by Saudi Arabia. Oil prices had collapsed following the

4 Libya, Algeria, Nigeria, Venezuela and Indonesia. Indonesia became an oil importer in 2005.

1970s oil crises and OPEC was trying to enforce production quotas on its members to support prices. The size of reserves was a factor in calculating these quotas and boosting oil reserves increased your quota. There may have been a case for some increase but not of that magnitude. Major oil companies do not publicly question these figures as it may compromise their chances for a return to these countries.

Saudi Arabia dominates at 10.5 million barrels a day. One super giant field, Ghawar, produces nearly 60 per cent of Saudi oil. Saudi ARAMCO spokesperson's say they can expand oil production to 15 million barrels a day and maintain this to 2050 (**Darley 2005).** This claim was a response to an in-depth study on Saudi oil by Matthew Simmons in his book *Twilight in the Desert*. He studied over 200 technical papers published by the Society of Petroleum Engineers since the early 1960s **(Simmons 2005)[5].** His suspicions were aroused by public Saudi statements that did not match what he observed on a visit to their oil installations in 2003.

Simmons essential conclusions on Ghawar are summarised below.

- Ghawar is the world's biggest oil field with complex geology that continually reveals surprises and problems that require *continuous* sophisticated exploration and development with the most advanced computer modeling and technology.
- Production is concentrated in the northern high-yielding part—the rest has poor geology with limited capacity to produce oil, in sharp contrast to the northern part.
- The complex heterogeneous geology constantly reveals pockets of 'stranded' oil needing many new wells to tap it and maintain production levels.
- Massive water injection systems are used to push the oil to producing wells—on average 1.4 times the oil produced, and is one of the most complex such systems in the world.
- Consequently, and due to the *uneven* geology, there are significant water cuts with the oil that must be removed. In addition underlying water is *up-coning unevenly* to wells.
- To overcome these problems 200 horizontal wells have been drilled, and more are planned. Simmons asks; *"what happens when the rising water reaches these wells"*?

Simmons says these are the signs of a *mature oil field* approaching its climax, when comparisons are made with the history of other giant fields that have begun production decline.

His book also covers the other Saudi oil fields where similar problems exist. He says technical papers reveal the Saudi's have recently explored the rest of their country with limited success.

He concludes on the basis of these quality technical papers that Ghawar, and hence Saudi Arabia, is at a mature stage of oil depletion and that production decline may be near at hand. The true situation could only be confirmed if the Saudi's were to publish the historical performance data for ALL their oil fields for independent audit. The Saudi's counter claims lack credibility.

Powerpoint presentations by Simmons on these and related issues are available on his company's website **(Simmons).**

Iraqi producing oil fields are in a run-down clapped out state after 25 years neglect since the beginning of the Iran-Iraq war in 1980 and following the era of sanctions after Gulf War I. Production has been flying 'blind'—failed and obsolete instrumentation—with a real risk that oil extraction may be permanently damaging the oil reservoirs. Water injection has become necessary. Massive investment is needed in these mature fields to upgrade facilities to a similar operational standard as in Saudi Arabia. Iraq may be the only Middle East country with significant discovered undeveloped oil fields capable of significant new production **(Djamarani**

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5 Simmons is the founder and head of Simmons & Company International, a Houston Texas based financial services company that specialises in the energy industry. He is a member of the National Petroleum Council and the Council of Foreign Relations, and is an active member of ASPO.

2000). It is unlikely to happen on a sufficient scale while the insurgency continues and before other war-damaged infrastructure in Iraq is restored and a more stable social climate exists. **Gulf War II has severely compromised the future of Iraq's oil production prospects.**

Similar oil development problems arising from sanctions and the 1980s Iraq-Iranian war confront Iran, but not on the scale of Iraq.

These are the principal reasons why ASPO does not expect Middle East oil production to increase much beyond its present level, before declining about 2020.

4.5 US Geological Survey World Petroleum Assessment 2000 Description and Results. *An 'optimist' example*

The US Geological Survey (USGS) published this assessment in 2000. A criticism is given below of the USGS projections for oil discovery to 2025 based on a review by **Laherrére (2000).** It does not attempt a comprehensive coverage, focusing on undiscovered oil and reserve growth from 1995 to 2025—what might be added to the resource base. The USGS Report discusses both oil and natural gas; this review covers oil and natural gas liquids (NGL).

Table 4 gives the USGS Report's mean *(i.e. statistically close to the most likely)* estimates for *new discovery* and reserve growth *for conventional oil* from 1995 to 2025. Adding the already discovered and produced-to-date gives a figure for the most likely ultimate production. Unconventional oil and reserve growth are discussed below. Laherrére discusses the assessments from their inconsistent application of statistical theory, the inadequate and inconsistent nature of definitions of conventional and unconventional oil, the poor statistical database generally and the unreliability of published figures for reserves. He says the USGS does not adequately discuss these issues to justify many of their conclusions. Furthermore, he says the definitions the USGS uses discount environmental, political and access constraints to potential oil extraction that always limit development and are a central feature of ASPO assessments. **The USGS 2000 estimates are optimistic low probability ones, not the most likely. They represent an upper bound.**

Table 4
USGS Assessment—Conventional Oil 1995-2025
Additions to Reserves
Gigabarrels—Gb

Category	Yet to discover	Reserve growth	Total
Oil outside USA	649	612	1,261
NGL outside USA	207	42	249
Sub-total outside USA	**856**	**654**	**1,510**
Inside USA	83	76	159
World total 1995-2025	**939**	**730**	**1,669**
World reserves 1995			959
Cumulative Prod. to 1995			717
Mean ultimate estimate			**3,345**

This compares with the ASPO ultimate estimate from Table 1 of 2,250 Gb, excluding heavy oil, the main component of unconventional oil. It implies a mean addition to reserves of over 50 Gb/year for 30 years. By contrast the peak discovery rate was about 60 Gb in 1962-3 *(Figure 3). It implies a sustained fivefold increase in the discovery rate that would require a return to significant discovery of giant oilfields, rather than the near cessation that has occurred.*
If reserve growth is excluded the USGS ultimate is about 2,600 Gb, much closer to the ASPO figure of 2,250 Gb—even closer if the optimistic nature of the USGS estimate is considered. We will now discuss reserve growth.

Reserve growth is a distinctly US phenomenon arising from the rules of the Securities and Exchange Commission (SEC). An orgy of speculation, dubious reporting and fraud followed the big discoveries in Texas in the 1930s. The SEC introduced company-reporting rules that limited reserves to the "proved" category—the oil that could be drained to a *producing* oil well. In the days of large oil fields this meant companies listed on US Stock Exchanges were compelled to under-report their reserves. Of course, as these fields were developed *and drilled up*, "reserve growth" naturally occurred. Over time much of this became falsely attributed to new technology. By contrast, in the rest of the world with good reporting legislation, companies reported "proved" plus "probable"—much closer to the statistically most likely. Reserve growth was much less than in the USA.

Laherrére (2000) says over the previous 20 years only six per cent of reserve growth in the USA was due to new discoveries. But the scope for reserve growth diminishes as oil fields age. With the size of new discoveries declining, and these increasingly offshore, companies can no longer afford to indulge in such under-reporting. *The USGS' extension of the US reserve growth pattern into the future and extending these to non-US countries cannot be justified.*

4.6 Tar sands and shale oil

Tar sands are solid bitumen-like hydrocarbons embedded in porous sandy formations. There are large deposits in Canada and Venezuela. So-called shale oil occurs in hydrocarbon-rich formations containing kerogen, a precursor to oil that has not yet been subject to the pressure and heat needed to transform it into crude oil. It occurs extensively in the upper Colorado River basin in the USA, Brazil, Scotland, China and Australia. The potential resource base for forms of crude oil is very large. Appendix 2 (3p.) has a detailed description of both, and describes their limited potential as future sources of oil—probably nil for shale oil.

After decades of development costing billions of dollars and huge government subsidies oil is finally being produced from Canadian tar sands in Alberta at a rate approaching one million barrels a day. *An energy input equivalent to two barrels of oil (natural gas) is needed for every three barrels of product (EPR 1.5).* However, a crisis is impending as North American natural gas production is poised to decline—*see further comment below.* The environmental damage is huge as are the greenhouse gas emissions.

In summary, two or more tonnes of tar sands or shale must be mined and processed with water using heat to produce one barrel of heavy oil. To produce four million barrels of oil a day requires *mining and processing three billion tonnes a year* to yield products requiring further processing to produce the equivalent of crude oil. Oil from tar sands consumes large quantities of water that require large-scale treatment before discharge to the Mackenzie River.

Several attempts at getting oil from shale have been made since the 1920s. All have failed at a cost of billions of dollars, the latest in Australia.

These are the reasons ASPO sees a limited future for oil from these sources. *Oil from shale has been described as the fuel for the future—and always will be.*

4.7 Conclusions

The ASPO viewpoint on the future of oil production has been developed, publicised and criticised since 2001. So far it has withstood the challenges while also responding to new information and its critics as events unfold. We will next address the status of world natural gas, then Australian oil and gas supply.

5. WORLD NATURAL GAS

The database for natural gas is less reliable than for oil. Until recently natural gas did not receive the attention that has been given to oil. In the early years it was regarded as a waste product from oil production and flared at oil wells. Natural gas is also re-injected into oil fields to sustain oil production, often for later extraction as a marketable fuel. It is also used as a fuel in oil field operations. Consequently the data on past production is poor leading to more uncertainty in the statistics for discovered natural gas than for oil.

The cost of transporting natural gas any distance is 6-10 times greater than for oil—because it is a gas. Consequently there will tend to be regional gas production peaks rather than a global peak. Gas can flow more freely in geological formations and more of the gas-in-place can be extracted than is the case for oil—up to 80 per cent. These factors make infrastructure for natural gas expensive compared to oil, especially offshore. Consequently, the peak production profiles typical of oil tend to be more like extended plateaus for gas. As much as 80-85 per cent of the extractable gas can be extracted before production decline begins. When decline begins it can be steep.

Table 5 shows natural gas statistics for 2004 **(BP 2005).** The difference between exports and imports is probably due to natural gas consumed in transporting gas. There is significant export and import of gas within the regions as well.

Table 5
World Natural Gas 2004
Billion cubic metres

Region	Reserves	Production	Consumption	Imports	Exports
	Billion cubic metres				
Nth America	7,300	763	784	19	0
S&C America	7,100	129	118	0	14
Europe	5,400	300	491	188	0
FSU	58,700	751	580	5	154
Middle East	72,800	280	238	5	44
Africa	14,100	145	69	0	74
Asia Pacific	14,200	323	368	35	1
Total	**180,000**	**2,692**	**2,689**	**251**	**287**
Australia	2,500	35	25	0	12

North America produces 28 per cent of world gas but only has four per cent of reserves. Over 80 per cent of the discovered gas has been consumed and production is declining and natural gas prices undergoing a dramatic increase. The subject is fully covered in Appendix 3 (8p.).

*Europe consumes 18 per cent of world production but only has three per cent of gas reserves. Consumption of discovered gas is approaching 80 per cent and UK production is declining rapidly. Gas from Algeria and Russia is piped to Europe and LNG imports are increasing **(BP 2005**). The Russian gas comes mainly from the Ob River basin. Cold weather this winter has stretched the Russian pipeline capacity to its limits. European gas production should be in decline by 2010—it comes mainly from North Sea gas fields.*

About 60 per cent of Middle East gas reserves are reputedly in one super giant gas field straddling the Persian Gulf between Qatar and Iran—about 20 per cent of world reserves. *Its location has profound geopolitical and security implications for the future of natural gas and the resource is the least developed in the world.* Will this field exhibit similar characteristics to Saudi Arabia's Ghawar oil field when serious development begins? Can we trust published figures for Middle East gas reserves?

The gas shortage in North America and Europe is generating a boom in liquid natural gas (LNG) development to compensate. China and India are also planning to increase their LNG imports. *More details on world LNG supply are in Appendix 3.*

European and North American gas will go into decline about the same time as world oil production peaks. There is less uncertainty about this conclusion than for world oil. Europe and North America consume 46 per cent of world gas production, but only have seven per cent of gas reserves. **We can expect natural gas prices to rise in the immediate future.**

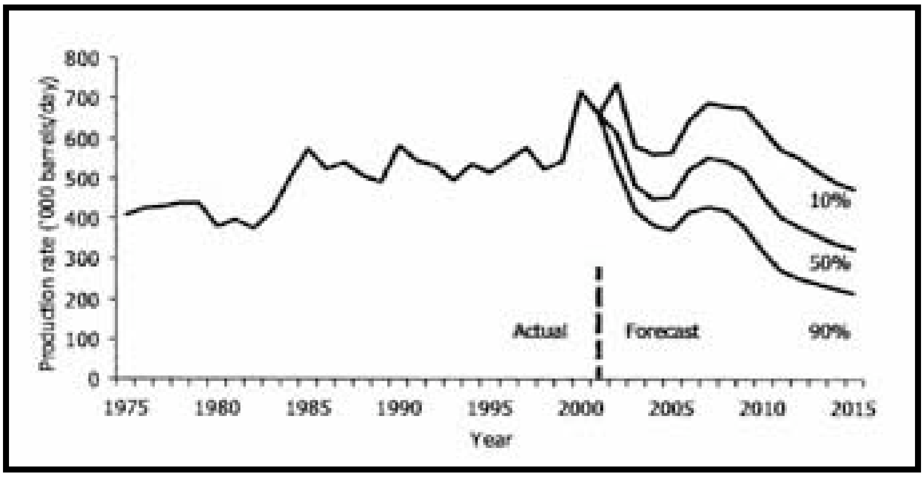
6. AUSTRALIAN OIL AND GAS

Australia is a small player in oil and gas production. Production of both began about 1970 after discoveries offshore in Bass Strait, Central Australia and Western Australia. More natural gas has been found than oil and most of it offshore. Geoscience Australia publishes regular reports on Australian oil and gas resources

6.1 Oil and natural gas liquids

Only three minor giant oil fields have been found, all offshore in Bass Strait around 1970, and their production has been declining since 1987. Subsequent small field discoveries have been developed offshore on the North West Shelf and in the Timor Sea. Central Australian oilfields are at a mature stage and elsewhere oil discoveries are erratic and small with liquids production increasingly dependent on natural gas liquids from the North West Shelf project. *Figure 5* shows Australian liquids production and estimates of future production to 2025 **(Geoscience Australia 2005).** Production has been declining since 2000 with a secondary peak expected about 2006-7 following minor offshore discoveries mostly on the NW Shelf. *Net oil production was equal to consumption in 2000.* The size of oil discoveries is declining.

Figure 5
Australian Crude Oil & Condensate Production
Actual 1975-2001, Forecast 2002-2015
Thousand barrels per day



Governments have been unable to interest companies exploring in the Canning and Officer Basins as these remote land locations have so far been regarded as having low prospects due to their location and geological history[6]. *Figure 6* shows Australian production by oilfield, including the post 2000 contribution from gas condensate **(Powell 2001)**. It illustrates the relatively long life of the three Bass Strait giant fields and their subsequent replacement by many small fields that are *'here today and gone tomorrow'*. A similar pattern is emerging on the global scale.

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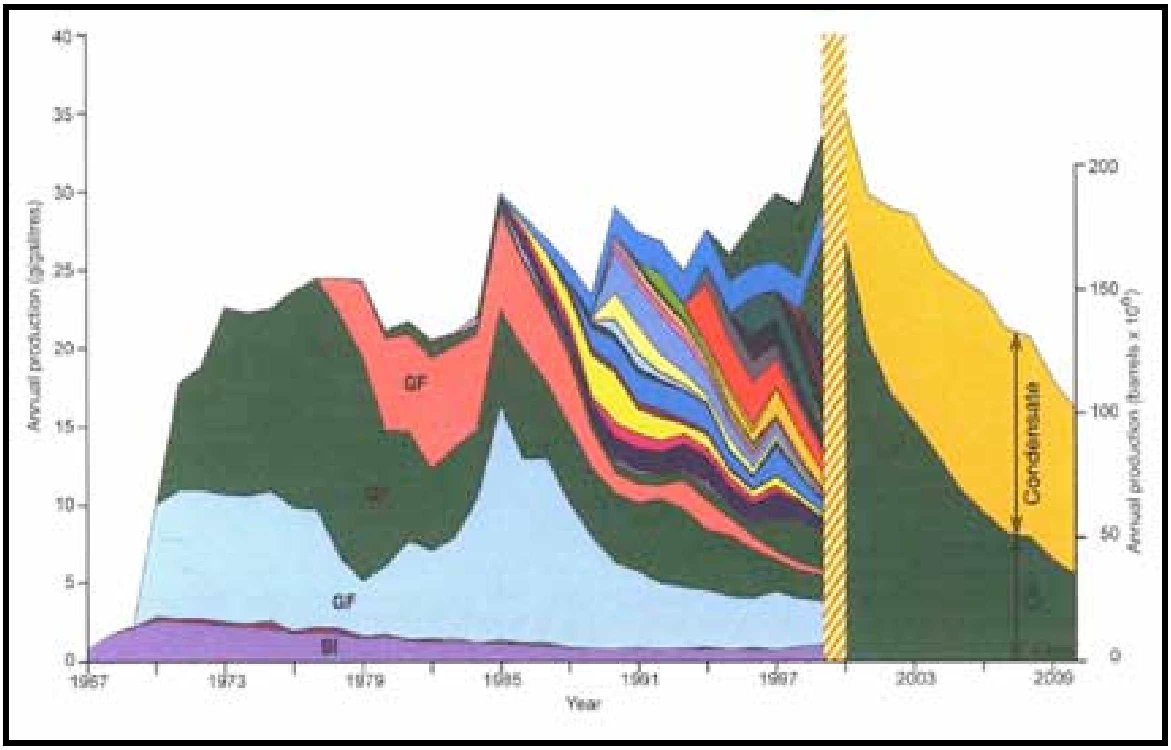
6 The Canning basin is onshore from the coast between Port Hedland and Broome to the border of Western Australia. The Officer basin is north of the Nullarbor Plain.

Figure 6
Australian Oil & Condensate Production by Field
Actual 1967 to 2000 Estimated Post 2000



Geoscience Australia is investigating the potential for petroleum discovery in deep water offshore (>3-500m.). The high cost, exploration risk and remoteness of these locations are obstacles as there are only a limited number of the rigs needed. These are committed to more favourable sites in the northern hemisphere. If exploration does take place and commercial discoveries are made then production is unlikely until around 2020 **(Powell 2001)**. *The fact that Geoscience Australia sees these sites as the new frontier for exploration speaks volumes.*

The USGS Assessment 1995-2025 estimated a mean undiscovered for oil from 1995 to 2025 of 5,032 million barrels for the Bonaparte, Browse, Carnarvon and Gippsland Basins. So far this is not being achieved.

Australia's self-sufficiency in oil is declining rapidly and is likely to continue. Reversal of this trend requires heroic discoveries in heroic locations with high risk attached—the oil will be very expensive to produce. Therefore a high priority needs to be given to reducing our dependence on petroleum-based fuels, especially for transport.

6.2 Australian Natural Gas

Table 6 shows the mean reserves at end 2003, production and discovery to 2003 and production in 2003 for the principal gas basins in Australia[7]. All the basins except the Cooper-Eromonga are offshore. Over 90 per cent of gas reserves are offshore between Carnarvon and Darwin **(Geoscience Australia 2005).** Sydney and Adelaide were connected to the Gippsland/Otway Basins in 2003 and 2004 to supplement their supply from the Cooper-Eromonga Basins. By 2005 over 80 per cent of discovered gas has been extracted from that basin which also supplies some gas to Darwin and Queensland. Decline has commenced. By 2005 some 55 per cent of the discovered Gippsland Basin gas will have been extracted and could reach 80 per cent by 2015. Gas exploration in the Otway Basin has so far not been very

[7] The Browse basin is off the Kimberley coast, Bonaparte basin in the Timor Sea, Otway basin west of the Gippsland basin and Cooper-Eromonga basin in Central Australia.

successful. Woodside Energy made a major natural gas discovery (Pluto) in the Carnarvon Basin in 2005 and is fast-tracking its development while confirming its size **(Clark 2005).**

The Bayu/Undan gas field in the Bonaparte Basin will come into production in 2006, including an LNG plant at Darwin. A 430 billion cubic metre gas field is under development in Papua New Guinea along with a pipeline to deliver gas down the Queensland coast to Gladstone **(Williamson 2005**).

The impending depletion of Gippsland and Cooper-Eromonga Basins has stimulated development of methane from coal seams in NSW and Queensland for local use. It is more expensive than gas field supply but cheaper than gas transported from the other side of the continent. Some residents in NSW are resisting coal seam development in their area on environmental grounds. It is too early to judge its future role, but it may be significant.

Table 6
Australian Natural Gas 2003
Reserves, Discovered & Production
Billion cubic metres

Basin	Reserves 2003 Mean est.	Production to 2003	Discovery to 2003	Production 2003
Carnarvon	2,368	247	2,615	20.5
Browse	733	-	733	-
Bonaparte	538	3	541	-
Gippsland	162	170	332	5.8
Sub-total	**3,801**	**420**	**4,221**	**26.3**
Otway	14	3	17	0.8
Cooper-Eromonga	54	151	205	7.3
Other	52	47	99	1.6
TOTAL	**3,921**	**621**	**4,542**	**33.5**

Table 7 shows the USGS World Petroleum Assessment 2000 estimate for mean gas discovery from 1995 to 2025 through new discovery and reserve growth for the Bonaparte, Browse, Carnarvon and Gippsland Basins, together with reserves and the produced-to-date in 1995, plus the estimated ultimate for 2025 **(Geoscience Australia 2001)**. Discoveries in the Carnarvon and Browse Basins have more than doubled since 1995 and increased in the Bonaparte Basin, but are static in Gippsland. The USGS estimate for Carnarvon will certainly be exceeded and the same is possible for the Bonaparte and Browse Basins, given the scope for more exploration, but this is unlikely for the Gippsland Basin. *However, most new discoveries are likely to be in deep water offshore.*

Geoscience Australia's method for estimating likely discovery prior to 2000 was based on a limited 10-15 year horizon. It was focused on what investment the industry was likely to make, not so much on what the potential might be and generally gave a low priority to deep water offshore. Therefore the USGS estimates for the first three basins for 2025 may be valid, certainly for the Carnarvon Basin.

The tsunami off Sumatra in December 2004 has focused attention on the risks to offshore petroleum infrastructure on the North West coast. Geoscience Australia and Woodside Energy are reviewing the risks. The severe damage to offshore rigs and pipelines in the Mexican Gulf from hurricane Katrina in 2005, especially for those in deep water, has called in question the current engineering standards for these structures. New standards are likely that will increase the cost of deepwater operations. Category five cyclones (winds >250 km/hour) can be expected on the northwest and Northern Territory coasts.

Table 7
USGS Assessment 1995-2025
Australian Natural Gas Discovery
Billion cubic metres

Basin	Reserves 1995	Production to 1995	Discovered to 1995	USGS mean discovery est.	
				1995-2025	Ultimate 2025
Carnarvon	1,161	79	1,240	1,832	3,072
Browse	625	0	625	569	1,194
Bonaparte	216	0	216	674	890
Gippsland	207	115	322	160	482
Total	**2,209**	**194**	**2,403**	**3,235**	**5,638**

It is possible another three LNG trains will be commissioned in the Carnarvon Basin by 2010—No. 5 on the North Shelf Joint Venture, stage 1 of the Gorgon project and Woodside Energy's new Pluto project. Together with other expanding uses of natural gas annual production of natural gas (e.g. chemicals and electric power) in the Carnarvon Basin could reach 45 billion cubic metres per year by 2010. Further LNG expansion could increase this to 60 bcm by 2015. There is scope for petrochemical plants as well.

6.3 Summary

Australia faces declining self-sufficiency in oil at a time when world oil production is approaching its peak. Most oil is used for transport fuels. There is much uncertainty about the potential for sustained oil discovery—Australia seems to be a gas prone region.

Barry Jones (2003), Executive Director of the Australian Petroleum Producers and Exploration Association (APPEA), has commented in their journal *Flowline* saying Australian governments need to give prominent strategic direction on this issue which he regarded as *far more important* than electric power reform. He said transport was most at risk, and required demand management initiatives with a priority for public transport. He also supported increased use of natural gas as a transport fuel and tax reform for the upstream oil industry.

Since 2000 petroleum development, and to a lesser extent exploration, has expanded, especially in natural gas, but for oil in smaller fields in more difficult locations. It may be difficult to sustain this level of activity due to a world shortage of petroleum geologists and engineers and other skilled staff. At the peak in 1981 the large companies employed 1.4 million employees world wide, compared with 900,000 in 1974. When oil prices fell in the mid-1980s staff were shed and employment fell to 600,000 in 1995 **(Smith 2005).** There has been a corresponding fall in students enrolled in these courses. *Current skilled staff are ageing and approaching retirement.*

Eric Sreitberg (2005), Managing Director of Arc Energy Ltd, reports that a straw poll taken at the 2005 APPEA Annual Conference demonstrated a belief that we have passed the oil peak. He says a telling statistic is that *over the last decade the percentage of capital devoted to exploration has declined from 30 per cent to 10 per cent.* He also says that the industry is greying and student enrolments are low and the median age of industry employees will be 56 in 2008. *There are shortages of equipment, such as drilling rigs, especially for offshore.*

These are reflections of the increasing energy cost of extracting oil and transforming it into useable fuels for human use—a declining net energy yield with reduced capacity for economic activity as we have known it. We will now shift our focus to the consequences for transport.

7. PETROLEUM AND TRANSPORT FUELS

Petroleum products dominate transport fuels with a minor role for electric rail traffic. Commercial shipping, and especially aviation, is almost exclusively petroleum powered. 60 per cent of the world's oil fuels transport. Land transport uses 65 per cent of Australian petroleum product consumption and nine per cent is used for aviation. *The following qualities have led to the domination of petroleum products as transport fuels.*

- They are liquid and available at convenient locations.
- They have high energy profit ratios, especially for oil from giant oil fields (see the discussion below).
- They have compact and cheap fuel storage characteristics—high power-weight and power-volume ratios;
- They have good storage and portability characteristics;
- Fine control is possible in compact responsive engines;
- The environmental impact from production to end-use is low compared to coal.
- Flexible responses to vehicle motion are possible.

It is most unlikely that alternative transport fuels and remaining petroleum can fully meet all these favourable characteristics. This section discusses criteria for comparing the quality and effectiveness of transport fuels. *Appendix 4 (6 p.) compares a range of land transport fuels based on the above criteria in more detail. Table 8* gives a snapshot of Australian refined petroleum products and shows the increasing volume and cost of net imports **(ABARE 2005)**.

Table 8
Australian Refined Products
Megalitres ML

Year	Production ML	Consumption ML	Imports		Exports	
			ML	$million	ML	$million
1974-75	34,066	36,637	4.063	247	1,954	146
1984-85	35,924	37,204	2,823	683	2,207	641
1994-95	44,421	46,746	3,479	676	3,289	719
2000-01	47,690	50,010	4,746	1,896	4.564	1,844
2004-05	44,555	53,909	11,200	5,127	1,847	844

Consumption of refined products in 2004-05 is listed below in megalitres **(ABARE 2005)**.

- Refinery input 40,334
- *Auto gasoline 19,876*
- *Auto diesel 15,185*
- *Aviation turbine 4,730*
- Liquid petroleum gas 4,700
- Fuel oil 1,595
- Other diesel 15 —industrial and marine
- Bitumen 812
- Lubricants 470
- *Aviation gasoline 91*
- Heating oil 34
- Other 5,200 —includes industrial feedstock and refinery fuel.
- **Total 57,707 ML**

7.1 Net energy and energy profit ratio

Net energy analysis is one way of evaluating the productivity of energy systems. Some of the commercial energy obtained from nature must be used to extract and convert it into useful forms. A crucial economic issue is what proportion should be so used. Net energy compares the quantity of energy delivered to society by an energy system to the energy consumed *directly and indirectly* in extraction, conversion and delivery processes. It can be measured by *energy profit ratio (EPR),* sometimes called *energy return on investment (EROI)*.

$$\text{EPR} = \frac{\text{energy output}}{\text{energy input}}$$

Not all energy sources with the same EPR have equivalent performance in specific end uses, e.g. as transport fuels. Other qualities impact on the usefulness and economic merit of fuels, such as those listed above for transport. In most net energy analyses, inputs and outputs of different types of energy are aggregated by their thermal equivalents and disregard other aspects of energy quality. To paraphrase George Orwell from his famous book, *Animal Farm,* '*all fuels are equal but some are more equal than others'*.

For petroleum the EPR varies over the life cycle of oilfields. The highest net energy yield usually comes in the middle of the production cycle, *Figure 1*. On the downside, as production declines, an increasing energy input is required. Remaining oil production will not be as useful as it was on the production upside. These aspects are discussed in depth in Appendix 4 (6 p.).

7.2 Comparing effectiveness of transport fuels

Figure 7 compares a range of land transport fuels according to typical EPR's on the vertical scale and increasing transport effectiveness from left to right on the horizontal scale. Appendix 4 discusses the rationale for these rankings. Some brief comments.

The exceptional quality of transport fuels based on oil from giant oilfields in their prime is apparent—a phase now retreating into history. Electricity is an excellent transport fuel, but unfortunately it cannot be cheaply stored in bulk. Five litres of petrol has an energy potential equivalent to a one tonne lead acid battery. Hydrogen fuel cells are technically feasible. But hydrogen must be manufactured from other fuels and its storage in vehicles is bulky and expensive. The lack of a hydrogen distribution system is a major barrier to mass marketing of hydrogen-powered vehicles.

Biofuels, such as ethanol and biodiesel, are technically and commercially feasible (but still with subsidies). However, it is misleading advertising to call these 'renewable energy'. There is a significant fossil fuel input to growing and harvesting the crops, and for ethanol to achieve an anhydrous product after fermentation. This energy input can exceed the energy content of the ethanol obtained. *There is some disagreement on the methodology for making energy input/output analyses that need resolving.*

LNG may be an option *as a transition stage* to replace diesel in trucks, locomotives and mine dump trucks. Some freight trucking companies in Western Australia are already using LNG.

If all of Australia's wheat crop, net of domestic consumption, were converted to anhydrous ethanol its energy content would be equal to 23 per cent of that from our annual auto gasoline consumption, declining to 7 per cent in drought years such as 2002/03. *Table 9* compares the potential ethanol output from wheat and sugar with Australian oil consumption, all in gigajoules. Regardless of the net energy yield *there is no possible way that biofuels can replace petrol and diesel as transport fuels on a significant scale*. Australia produces enough wheat to feed 80 million people—about equal to the annual increase in world population. It would be a fatal mistake to go down this biofuel pathway. Appendix 5 (2 p.) has more detail.

There may be a case for on-farm production of biodiesel *for immediate local use* as a transition step in the adaptation to declining oil supply. This option needs further investigation.

There are no transport fuels in sight that can replace petroleum products as we now use them. Therefore the prime response to 'peak oil' must be demand management—to reduce the scale and extent of transport at all levels from the local to the global. This will take several decades to achieve.

Figure 7
Comparisons of Transport Fuel Effectiveness

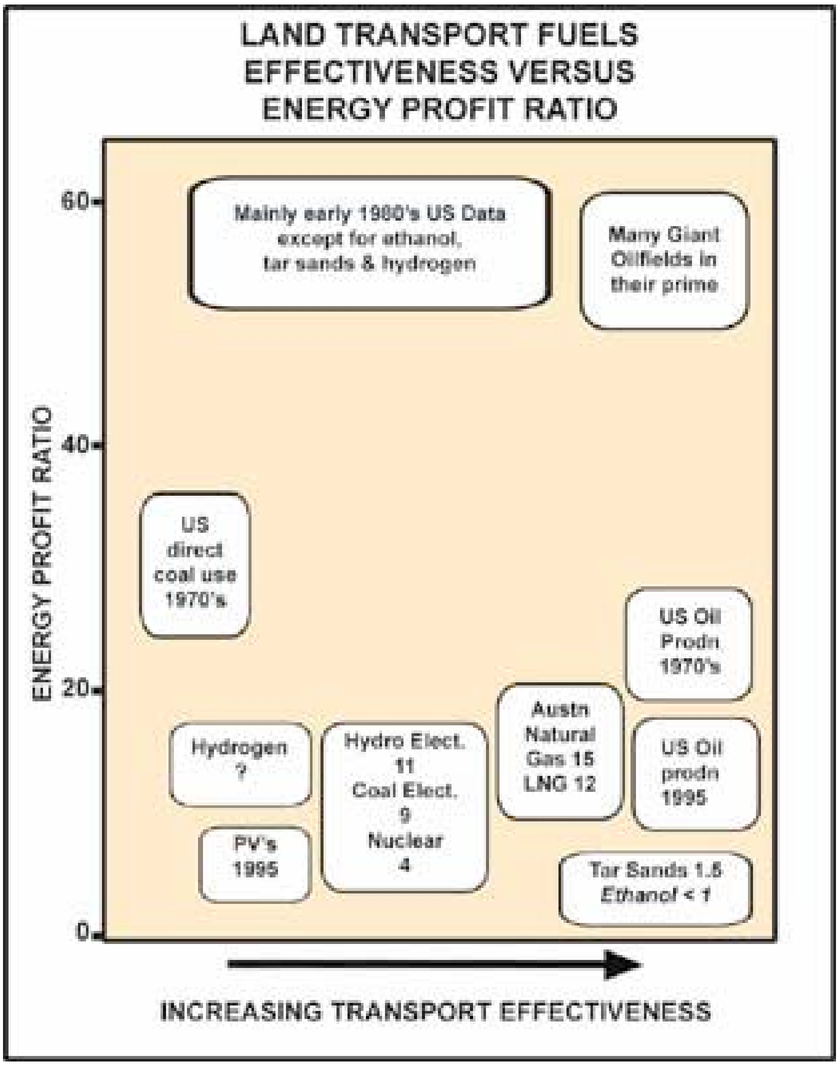


Table 9
Potential Maximum Annual Ethanol Energy Output
Compared to Annual Petroleum Consumption

Annual Petroleum Products GJ x10^6/yr		Wheat $161x10^6$GJ/yr Good year	Wheat $47x10^6$GJ Drought	Sugar $57x10^6$ GJ/yr Good year
		Per cent of petroleum consumption		
Gasoline	688	23%	7%	8%
Diesel	586	27%	8%	10%
Gasoline+diesel	1,274	12.5%	3.5%	4.5%
Crude oil	1,630	10%	3%	3.5%

8. INDUSTRIAL AGRICULTURE—THE FOOD CHAIN

"Modern agriculture is the use of land to convert petroleum into food".
Prof. Alan Bartlett University of Colorado 1978.

Australia has a dry climate and the most nutrient deficient soils in the world. Crop production and horticulture did not really develop until fertilisers and farm machinery were introduced 100 years ago and affordable rail networks became available to transport farm inputs and products to markets. The main expansion began after World War I when petroleum-powered transport and tractors became available, intensifying after World War II. Petroleum products enabled European style agriculture to be imposed on a vastly different Australian environment and has led to severe land degradation—e.g. soil erosion and impoverishment, salinity and polluted rivers, loss of biodiversity. The high labour productivity arising from petroleum-fuelled mechanisation is depopulating rural communities that are now struggling to survive, making possible the growth of cities. *Prof. Alan Bartlett's description of modern agriculture applies to Australia more than anywhere else in the world.*

8.1 Fertilisers

The biggest single fossil energy input to Australian agriculture is probably the embodied energy in nitrogen fertilisers whose use has expanded rapidly since 1990. *The global background to nitrogen fertilisers is in Appendix 6 (4p.).* Nitrogen fertilisers (the Green Revolution), coupled with cheap petroleum-fuelled transport, made possible the doubling of world population since 1960 and the subsequent growth in urban populations and the "factory farming" of animals. Natural gas is the principal input to nitrogen fertiliser manufacture via the synthesis of ammonia from hydrogen and nitrogen. China is now the world's biggest manufacturer of fertilisers followed by the USA, India, Russia and Canada. The biggest consumer is China followed by the USA, India, Brazil and France. *Table 10* shows world fertiliser production. China is importing soybean from Brazil and the USA for aquaculture to minimise the use of nitrogen fertilised grains at factory animal farms.

Table 10
World Fertiliser Production
Million tonnes

Fertiliser	Production		
	1980/81	1990/91	2002/2003
Nitrogen	63	82	87
Phosphate	35	39	34
Potash	27	27	26
Total	**125**	**148**	**147**

Table 11 lists recent Australian fertliser consumption and imports (**ABARE 2005)**. Phosphate rock is imported from Morocco, China and Togo. Production has virtually ceased at Nauru and Christmas Island. These fertilisers contribute to soil acidification requiring massive inputs of lime in Western Australia, s*ee Appendix 7 (3p.)*.

Table 12 lists lime, dolomite and gypsum used in Australia as soil conditioners **(ABS 2001-02)**. In Western Australia nearly 2.5 million tonnes of fertilisers and lime is transported by road to farms, the majority to wheatbelt farms, or some 600 million tonne-km per year. It consumes about 20 ML of diesel fuel and causes significant damage to roads. Petrochemicals in the form of herbicides and pesticides are widely used to control weeds and insect pests.

ABARE (2005a) reports Australian agriculture sector primary energy consumption at 94.3 PJ for 2004/05. This would cover *direct use on farms* of which about 90 per cent would be petroleum products, equivalent to about 100,000 ML as diesel and petrol. This would not include the energy embodied in fertilisers, manufacturing machinery and petrochemicals, nor transport external to farms. *The statistical category of 'agriculture' understates the dependence of agriculture and food supply on petroleum products*

Table 11
Australian Fertiliser Consumption & Imports
Thousand tonnes

Year	Consumption			Imports		
	Phosphate P_2O_5	Nitrogen N	Potash K_2O	Phosphate P_2O_5	Nitrogen N	Potash K_2O
1985-86	726	340	130	150	121	117
1990-91	580	439	145	306	270	147
1995-96	977	671	219	604	469	219
2000-01	1,097	1,002	203	637	705	203
2004-05	1,185	1,105	298	706	796	298

Table 12
Agricultural Lime & Gypsum in Australia
Thousand tonnes

Lime & Gypsum	Australia		W. Australia
	2001	2002	2002
Lime—acidity control	1,745	2.353	785
Dolomite	155	197	78
Gypsum—soil cond.	1.376	1,715	228
Total	**3,277**	**4,266**	**1,091**

8.2 Energy used in the food chain

The food chain covers farm inputs, on-farm, transport, food processing, packaging, retail, customer travel and home energy use. The last study in Australia that I know of was for 1975 by **Muriel Watt (1982)** at Murdoch University—the food chain has become more energy intensive since then. **Brown (2005)** has published statistics for the USA that are summarised in *Table 13* below and would reflect a pattern applicable to Australia—we are possibly less energy intensive than the USA. The US uses a lot of fuel to dry corn, its biggest crop.

Table 13 does not include customer car travel between homes and supermarkets. Appendix 8 (2p.) investigates this aspect based on a hypothetical transport task for breakfast cereal processed in Sydney and sold in Perth. *Five per cent of the customers' car travel to and from supermarkets is allocated to cereal transport. By far the biggest transport task is between homes and supermarkets, Table 14.*

These estimates are only indicative—they are dependent on the assumptions made. Nevertheless they suggest that car trips by customers to supermarkets dominate the transport task in getting food from farms to households, even when the product is transported from one side of the continent to the other.

There is an urgent need in Australia for new transport/energy assessments of the entire food supply chain from farm inputs to the kitchen table.

The Earth Policy Institute article goes on to say that in industrial countries fruit and vegetables often travel 2,500-4,000 km from farm to store with trucks accounting for the majority. Processed foods now account for three fourths of total world food sales. Food supply has become very dependent on transport worldwide and vulnerable to disruption of fuel supply *The campaign for country-of-origin food labeling in Australia must be assessed from this viewpoint*.

Table 13
Annual Energy Use in the US Food Chain

Food chain	Energy EJ[8]	Per cent	Transport & farm fuel GL
Farms		**Farms**	
Fertiliser	620	28	
Irrigation	150	7	
Farm fuel	750	34	2,850
Grain drying	680	31	
Sub-total	**2,200**	**20**	
Farm to table			
Transport	1,480	14	1,720
Processing	1,700	16	
Packaging	750	7	
Retailing	425	4	
Restaurants	750	7	
Home	3,400	32	
Total	**10,551**	**100**	

Table 14
Cereal Transport—Farms to Perth Homes

TRIPS	Distance km	Load tonnes	Litres fuel	Km per tonne	Litre per tonne
Farm to railway by truck	30	10	10	3	1
Rail to Sydney, 90t hopper car	200	90	90	2.2	1
Road to & from Sydney factory	20	20	8	1	0.4
Rail, Sydney to Kewdale, Perth	3,500	30	800	115	27
Kewdale yard to Supermart	35	15	12	2.3	0.8
Sub-total	-	-	-	***123***	***30***
Home-Supermarket-Home	***400***	***1***	***33***	***400***	***33***
TOTAL	**-**	**-**	**-**	**523**	**63**

The replacement of neighbourhood shops by "super stores" means consumers must drive further to buy their food and hardware and rely more heavily on refrigeration to store food between shopping trips. They cannot walk. Due to their preference for large contracts and homogeneous supply, most grocery chains are reluctant to buy from local or small farms. Instead food is shipped from distant large-scale farms and distributors—adding again to transport, packaging and refrigeration energy needs. The "just-in-time" logistics revolution in freight transport compounds these problems, in effect transferring most of the warehousing function to freight-in-transit. *Any disruption to freight, such as fuel supply, empties supermarket shelves in days.*

Fossil fuel reliance may prove to be the Achilles heel of the modern food system. Oil supply fluctuations and disruptions could send food prices soaring overnight. Decoupling the food system from the oil industry is the key to improving food security.

8.3 Conclusions

The first priority for remaining oil and gas must be to reduce the dependence of food production on petroleum and simultaneously to end world population growth, then reducing it to levels not dependent on nitrogen fertilisers. This will take decades to

8 One EJ = one exajoule = 10^{18}Joules.

achieve and requires unprecedented global cooperation. Progressively reducing the level of processing, packaging and the distance food travels will help free up shrinking oil supply for this task. Likewise, a high priority should be given to rapidly reducing, even eliminating, the need to travel by car to shop for food.

9. ROAD AND RAIL TRANSPORT

It is certain that cheap and available oil will become more and more scarce as the demand for it grows. It is also certain that the cost of preparing too early is nowhere near the cost of not being ready on time.

Alannah MacTiernan, W.A. Minister for Planning and Infrastructure, in her speech opening the W.A. Sustainable Transport Coalition's "Oil: Living With Less" Conference, August 2004.

9.1 Urban Australia

Australian cities have become increasingly car dominated since Word War II to a stage where congestion is acute along with a myriad of other associated social, economic and environmental problems. In regional Australia large urban centres have grown and small ones declined. These urban communities depend heavily on petroleum fuels for internal transport, and for imported food and raw materials as well as for the export of their products. The Institute for Sustainability and Technology Policy at Murdoch University in W.A. is a world authority on cities from these viewpoints. Below is a summary of their studies as presented at the *Beyond Oil* Conference organised by the Sustainable Transport Coalition of W.A. in February 2003 **(Kenworthy 2003).** It is based on a study of 100 large and small cities around the world for 1995 and gives insights on the responses needed for the post-petroleum era.

- *Passenger-km per capita* is by far the highest in the car-dependent cities of the US (18,195), ANZ (11,387) and Canada (8,645), diminishing significantly in Western Europe (6,202) and even less for other world cities. The same pattern exists for freeway length per capita.
- *Energy use per capita* for private and public personal transport follows the same pattern and scale with private energy use by car dominant.
- *Urban density in persons per hectare* showed the reverse pattern—lowest in the US, ANZ and Canadian cities and higher in the rest, for the most part. Auto-dependent cities are invariably low density. Central locations at higher density have much lower energy use than areas far from the city centre and at lower density. Perth represents an extreme case.
- *Transit boardings per capita* were lowest in the car dependent cities.
- *Bus-only cities* tend to languish in public transport patronage. Buses stuck in traffic cannot compete with cars.
- *Energy consumption per passenger-km* for rail transit was less than half that for buses in nearly all cities. Rail transit is almost all electric powered, not by petroleum products.
- *The proportion of trips by walking and cycling* in transit-oriented cities were several times higher than in car dependent cities.
- Centrality, density, mixed use of land, transit access and permeability of the urban environment are all factors that improve from the fringe to the centre.

Kenworthy concluded that there are some confronting, but ultimately optimistic conclusions:

- The whole problem of automobile dependence and high transport energy use must be tackled systematically through better technologies, better pricing and better urban and transport planning.
- The problems of energy use in transport cannot be solved by technology alone.
- The kind of urban planning principles we use, and the transport infrastructure priorities we have, will significantly determine how we cope with the post-petroleum era.
- Reducing our built-in energy dependence will, however, have enormous positive spin-offs in the overall sustainability and livability of the city.
- *Step 1*; Better public transport.
- *Step 2*; more use of non-motorised modes and better conditions for pedestrians and cyclists.

- *Step3*; compact, mixed use urban planning integrated with public transport.

In addition ***Laird et. al (2001)*** *show that car dependent cities spend almost double their wealth per capita on personal transport than those with a strong public transport focus and have a much higher incidence of deaths and injuries from transport accidents. Likewise fares in transit based cities recover a much higher proportion of the cost of public transport.*

In Perth there has been a growing imbalance between the city residences and employment locations leading to increased commuting from outer to inner suburbs for work, *Table 15* **(WAPC 2004)**. The outer suburbs are poorly served by public transport and people with low incomes and insecure employment prevail. Escalating urban land prices are increasing the adverse impacts of these trends. *These people, the unemployed and their communities are those most vulnerable to rising fuel costs. Similar patterns would exist in other cities*.

Roads are financed by government taxes (akin to a subsidy) supported by a powerful transport lobby whereas public transport infrastructure is mostly financed by loans in a climate where government borrowings have been frowned upon. This imbalance has been a major factor leading to car-dependent cities in Australia. **The trend to privately owned billion dollar toll roads since the mid 1990s and neglect of rail public transport is the most disastrous infrastructure investment strategy ever pursued in this country.**

New suburban infrastructure is partly subsidised as well, reinforcing the trend to low-density urban sprawl. Developers fund the local roads and water service infrastructure on Greenfield sites, but not the macro linking components. The marginal cost of urban sprawl is escalating.

Table 15
Population & Employment Shares in Perth 1971-2001

Region	1971	1981	1991	2001
Per Cent of Metropolitan Population				
Inner city	31.8	21.7	15.5	13.8
Middle	45.7	39.8	36.0	32.4
Outer	22.5	38.5	48.6	53.9
Per Cent Metropolitan Employment Share				
City of Perth	31.2	24.4	20.7	18.1
Inner city	29.6	25.2	22.8	20.6
Middle	26.1	32.0	33.1	31.8
Outer	14.1	18.4	23.4	29.4

9.2 The road deficit

The 'externality' costs for road transport are very high, revenue does not cover costs—there is a large road deficit. The principal items are listed in *Table 16* from **Laird et. al (2001).** The deficit would now be much larger due to ending of fuel excise indexing and other concessions, and much larger congestion costs. *The total costs of road transport were broadly estimated at some $80 billion in 1992-93 and could now be $130-150 billion.*

9.3 Freight Transport

What road system costs are attributable to the operation of heavy trucks is contentious and sensitive to assumptions and data limitations. There is significant under-recovery of road system costs from heavy articulated trucks and road trains that haul long annual distances—up to 80 per cent on long hauls[9]. Australia now has the highest road freight per capita in the world. *Table 17* summarises the situation for 1997-98 and shows a shortfall of over $2 billion including environmental and road crash costs **(Laird et. al 2001)**.

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[9] The cost of damage to roads from vehicles varies as the fourth power of axle load.

Federal concessions on diesel excise in 2000 have increased the freight deficit by well over $620 million per year. Improvements in rail freight have eliminated rail deficits since the mid 1990s. Rail freight over medium-long distances is at least three times as fuel-efficient as road freight. There is a growing effort by Federal and State governments under the *Austrans* program to upgrade, integrate and standardise rail freight systems to increase the proportion of freight carried by rail. However, there is a huge investment backlog, especially in NSW and Victoria. Federal-state conflicts on strategy and financing are another problem. Proposals to progressively introduce mass-distance charges for road freight are being proposed as rail systems become improved to reduce the large subsidies to long-distance articulated trucks.

Table 16
Australia's Road Deficit 1997-98
$ billion

Road system costs	7.0
Total cost of road crashes	15.0
Other health impacts	3.0
Net refunds for vehicle use	2.8
Queensland fuel subsidy	0.5
Total costs	**28.3**
Federal excises from road vehicles	8.5
Annual registration fees etc	3.8
Insurance premiums for road crashes	8.0
Total revenue	**20.3**
Net road deficit—no congestion	**8.0**
Road congestion in major cities	11.0
Net road deficit with congestion	**19.0**

Table 17
Australia's Road Freight Deficit 1997-98
Million dollars

	Articulated trucks	Rigid trucks	All trucks
Attributable road system costs	1,955	545	2,500
Road user charges	720	495	1,215
Net road system costs	**1,235**	**50**	**1,285**
Road crash involvement costs	450	N/A	450
Environmental costs	282	157	439
Hidden subsidies	**2,017**	**207**	**2,224**

9.4 Perth: Network City Plan 2004

The *Network City: community planning strategy for Perth and Peel (2004)* attempts to address these problems of dysfunctional car-based urban development, and does so aware of the need to adapt to the era of declining petroleum fuels for transport[10] **(WAPC 2004)**. *An innovative democratic approach to developing such urban plans was used. See Section 1 for further detail*. Network City focuses on developing several urban centres and sub-centres as commercial and employment nodes and to maximise population growth by 'infill' in existing

[10] The focus on oil vulnerablity in Network City originated with the Minster for Planning and Infrastructure, Alannah MacTiernan. She publicly acknowledges that the future of oil supply is at the centre of her ministerial strategy and that she was inspired by my book *The Decline of the Age of Oil.*

urban areas, preferably around transit stations. Over time employment can be localised and car use and long-distance commuting reduced and strong local communities can emerge.

At this stage 'peak oil' has a low public profile in Network City. But the groundwork has been laid for people to mobilise and create a far reaching and rapid transformation of their lives to cope with the new energy environment. Democratic participation processes along the lines outlined in Section 1 will be necessary to achieve these tasks.

10. CHINA AND INDIA

China and India, but particularly China, are experiencing rapid economic and urban growth. Their population of 2.4 billion is double that of the developed industrial world with its high per capita resource consumption. *It is inconceivable that their resource consumption can grow to even half the levels of the developed world*. The most rapid rural-to-urban migration in history is occurring, partly as a consequence of the use of expensive nitrogen fertilisers in India that have undermined the viability of traditional agriculture. In China there is pollution on a massive scale and growing unrest as the wealth gap grows between the rural and urban population. 30 per cent of China's cropland is suffering from acidification from acid rain due to air pollution, and the impact of nitrogen fertilisers. China consumes 1.5 billion tonnes of coal a year and most of it is sulphurous.

There has been an eight-fold increase in China's automobile production since 1995 to 2.6 million in 2005. *China is the main driver of world consumption growth of oil and is now the second largest consumer after the USA*. If China and India were to reach Japan's level of oil consumption per capita (60 per cent of US) they would be consuming 100 million barrels of oil per day, and the world twice as much (**Wordwatch Institute 2006).**

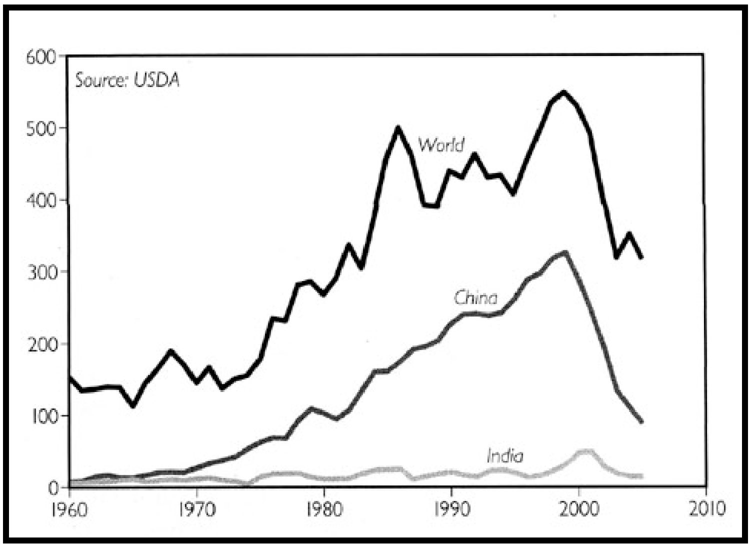
China is reputed to be aiming at 200 million vehicles. The USA has 214 million vehicles that use 160,000 km^2 of land for roads and parking—equals the area planted to wheat. At the Japanese level of road and parking provision (one-third the US rate per vehicle) 200 million vehicles in China would require 50,000 km^2 of land, *plus* the land consumed by urban sprawl.

World grain production was flat from 1996 to 2003, but increased by 9.5 per cent in 2004 due to favourable weather and higher grain prices, but still below consumption. Grain stocks have fallen since 1998 **(Flavin & Gardner 2006)**. *See Figure 8.* Grain consumption in China has outpaced production since 2000 where industrial and urban development is encroaching on cropland. Since 1979 China has lost an average of 5,000 km^2/year to urban development that now amounts to over seven per cent of the country's agricultural area—130,000 km^2, and most of this since 2000. The rate of loss would be even higher now as urban development is accelerating. *Additional agricultural land is being lost to infrastructure provision and industrial parks.*

Water shortages are also adversely impacting on grain production. Groundwater is pumped to irrigate wheat in northern China at rates exceeding recharge of aquifers from rainfall. As aquifers fail wheat production falls, compounded by the competition between cities and farmers for this water. This has been an important factor in China's grain production decline since 1998. In the 1990s in India 21 million tube wells were drilled and farmers pump out 200 km^3 of water each year at rates well in excess of recharge. One quarter of farms are irrigated with this water **(Brown 2004)**. India is facing grain supply and rural water crises of major proportions.

Do water shortages and urban/industrial development in China and India mean that their economic development is unsustainable because it compromises grain production? The world cannot meet the shortfall. The physiological limits of plants for further increases in grain yield per hectare are being reached. There is a limit to the proportion of the products of photosynthesis that can be diverted to grain at the expense of roots, stalks and leaves.

Figure 8
Grain Stocks
World, China & India 1960-2004
Million tons



China's escalating consumption of minerals is driving Australia's economic growth—iron ore, coking coal, nickel, alumina and copper. Our economic future is becoming integrated with that of China's, and to a lesser extent India, as they expand manufacturing, urban and service provision.

The Western industrial model is not an option for China or India. This reality will probably surface in the near future when a bad season leads to low grain production.

11. GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

11.1 Asia Pacific Partnership on Clean Development and Climate

Debate has grown since the 1980s over climate change due to carbon dioxide emissions from the burning of fossil fuels and other factors. The deliberations of the Intergovernmental Panel on Climate Change (IPCC) led to the draft Kyoto Treaty in 1999, formally endorsed in 2005. Australia and the USA are among a few nations that have not signed on to Kyoto. Recent weather patterns have led to growing acceptance of the reality of anthropomorphic climate change. That led to the inaugural meeting of the Asia Pacific Partnership on Clean Development and Climate (APPCDC) in Sydney in January 2006—Australia, China, India, Japan, South Korea and the USA. Only Japan has joined the Kyoto Treaty.

The Australian Bureau of Agriculture and Resource Economics (ABARE) produced a background report for the APPCDC meeting, *Technological Development and Economic Growth; Research Report 06.1* **(ABARE 2006).** The reference year is 2001 with projections to 2050 for population, economic growth, fuel consumption and greenhouse gas emissions. It examined three scenarios related to greenhouse gas emission reduction from fossil fuel use, (1) business-as-usual, (2) energy efficiency and fuel options, and (3) the latter plus greenhouse gas sequestration. **The report did not discuss the peak oil debate or its implications AT ALL, nor did it question any resource constraints to economic development that might**

exist, as have been raised in this submission. *Table 18* show the report's projections for oil consumption for the reference year and 2050 projections for scenario 3[11].

The ABARE projection for APPCDC oil consumption continuously increases to 2050 and is double the ASPO estimate for 2050 and approaches world consumption in 2005. APPCDC projected consumption of *all energy* in 2050 is more than world consumption in 2001 at 9,200 million barrels of oil equivalent (BP 2005). The ABARE projection implies cumulative world oil production by 2050 of around 3,000 Gb, which further implies a world ultimate of at least 6,000 Gb, 2.5 times the ASPO estimate. ASPO estimates world oil production in 2050 will be 35 million million barrels per day and will have virtually ceased in the US-48, Europe and Russia, *Figure 2. The US could not afford to import oil at more than double its current rate in 2050—and all its natural gas as well.*

Table 18

ABARE Oil Consumption Projections 2050

ASIA PACIFIC PARTNERSHIP ON CLEAN DEVLEOPMENT AND CLIMATE

Country	2001		2050			
	Oil—actual		All energy	Oil		
	M.toe[12]	M.bls/day	M.toe	Per cent	M.toe	M.bls/d
Australia	38	0.75	230	34	78	1.6
China	232	5.0	3,750	26	975	19.6
India	107	2.3	1,550	37	575	11.5
Japan	507	5.4	450	48	215	4.3
S. Korea	103	2.2	350	50	175	3.5
USA	896	19.6	3,300	42	1,385	28
Total	**1,614**	**35.3**	**9,650**		**3,400**	**68.5**
World	**3,552**	**76.3**	**Implied world oil consumption**			**~140**
ASPO						**~ 35**

ABARE projects a proportionate decline in coal use in all six countries by 2050, and in aggregate a corresponding slight increase for oil and gas and a strong increase for nuclear power. Nevertheless, consumption of ALL the energy sources considered increases from 2001 levels. There is not much doubt that resource depletion for petroleum resources will shape future energy regimes. *Neither coal nor nuclear have the qualities needed to substitute for petroleum in transport and agriculture as we use them today.*

The approaching decline of oil and gas production will be the main driver reducing greenhouse gas emissions arising from fossil fuel consumption. It is unrealistic to expect coal-based fuels to replace oil and gas in their transport roles. Policies to curtail fossil fuel consumption to reduce greenhouse gas emissions MUST be integrated with those for managing the decline of oil and gas production.

Government agencies like ABARE MUST start seriously addressing the peak oil issue and factoring it in to all their reports and recommendations.

11.2 Intergovernmental Panel on Climate Change

Since 1992 the Intergovernmental Panel on Climate Change (IPCC) has published reports on climate change arising from greenhouse gas emissions based on fossil fuel combustion scenarios and other factors ***(IPCC 2000).*** These scenarios are not reported in the media nor does IPCC make assessments of their likely occurrence. Environmentalists and others accept

[11] The data for 2050 in Table 13 was scaled off charts and should only be regarded as approximations. Actual oil data for 2001 is from BP (2005)

[12] M.toe equals million tonnes oil equivalent.

these emission projections without questioning their validity. **Few people are aware that the IPCC does not attach probabilities to them.**

The 40 IPCC scenarios for coal, oil and natural gas consumption are grouped into four major scenarios, each with variations within common themes. The storylines are based on economic and population growth patterns, environmental, greenhouse and land-use factors, technology innovations and polices together with different biases in fossil fuel consumption. *These lead to per capita fossil fuel consumption scenarios to 2100.*

The essence of the scenarios are described and critiqued below based on a study at Upsalla University in Sweden *(Sivertson 2002).* My aim is to raise sufficient questions needing answers to stimulate others to take the issues up in greater detail. The IPCC has begun revising its year 2000 scenarios, to be completed by late 2007.

IPCC developed a set of four scenario families incorporating the 40 scenarios. Each is described by a storyline ***(IPCC 2000a)*****.** Six teams developed long-range economic, technological and environmental models to generate quantifications of the storylines for different scenarios. The modeling teams are shown in *Table 19.* All scenarios from the same storyline constitute the scenario family. ***Marker scenarios*** were chosen as the most illustrative of a particular storyline but are neither more nor less likely than any other scenario.

There were no business-as-usual or disaster scenarios, nor surprise ones such as large-scale environmental or economic collapses. The scenarios were not intended to predict future energy prices, nor factors such as taxation levels.

Table 19
IPCC Scenario Teams

Acronym	Model name	Origin
AIM	Asian Pacific Integrated Model	National Institute of Environmental Studies in Japan
ASF	Atmospheric Stabilization Framework Model	ICF Consulting in the USA
IMAGE	Integrated Model to Assess the Greenhouse Effect	National Institute of Public Health and Hygiene in the Netherlands
MARIA	Multiregional Approach for Resource and Industry Allocation	Science University of Tokyo in Japan
MESSAGE	Model of Energy Supply Strategy Alternatives and their General Environmental Impact	International Institute of Applied Systems Analysis in Austria
MiniCAM	The Mini Climate Assessment Model	Pacific Northwest National Laboratory in the USA

The four main storylines are named A1, A2, B1 and B2. A1 has three sub-scenarios and several groups of scenarios, including ones that explore alternative fossil fuel-intensive developments, technology and economic growth differences. The four storylines describe future world's that are generally wealthier compared to the current situation. These are described below and shown in *Table 20,* with population projections for the *marker* scenarios.

- **The A1 storyline and scenario family** describes a world of low population growth and rapid economic and technology growth with convergence among regions dominated by American and European entrepreneurial and market perspectives, with high consumption.

    There are three sub-groups, as follows;

    AIC: clean-coal and environmentally friendly technologies, except for GHG emissions.

***AIG**: an oil and gas rich future with a rapid transition from *conventional* hydrocarbon resources to rich *unconventional* resources, including *methane hydrates*[13].*
***AIT**: a non-fossil fuel future with rapid development of solar and nuclear technologies, with mini-turbines and fuel cells used in energy end-use applications.*

- **The A2 storyline and scenario family** describes a world with self-reliance, lower trade and slow capital stock turnover, fewer social and cultural interactions and local identities maintained. High population growth. Regional economic development with slower economic growth and development of technology, is more fragmented and slower than in other storylines. Regions with energy and mineral resources become resource-intensive economies. Regions poor in resources minimise import dependence through technological innovation and use of alternative imports. Agricultural productivity has a high focus.
- **The B1 storyline and scenario family** describes a convergent world with the same low population growth as A1, but with rapid changes to a service and information economy with reduced material intensity and clean resource-efficient technologies. There is a global approach with high environmental and social consciousness and attention to equity, social institutions and environmental protection, income redistribution and high taxation levels. A transition to alternative energy systems. Cities are compact and designed for public transport. Low-impact agriculture and large wilderness areas. Low GHG emissions.
- **The B2 storyline and scenario family** emphasis is on local solutions to economic, social and environmental sustainability with high levels of education and welfare, moderate population growth, intermediate levels of economic development on local and regional levels with environmental protection and social equity. Urban development reduces car dependence and growth with an emphasis on food self-reliance. Reduced hydrocarbon-based energy systems.

The features belonging to the same family were ***harmonised*** in 26 scenarios to have common assumptions about global population and gross domestic product. The scenarios share some features but differ in others. The remaining 14 scenarios explain alternatives to the harmonised scenarios, e.g. in economic growth and population projections.

Table 20

Features of the IPCC Scenarios

Family	**A1**				**A2**	**B1**	**B2**
Scenario	**A1C**	**A1G**	**A1**	**A1T**			
Population growth	Low	Low	Low	Low	High	Low	Medium
Billions 2050	**9**				**11**	**9**	**9.5**
2100	**7**				**15**	**7**	**10**
GDP growth	Very high	Very high	Very high	Very high	Medium	High	Medium
Energy use	Very high	Very high	Very high	High	High	Low	Medium
Land-use changes	Low-med.	Low-med.	Low	Low	Medium-high	High	Medium
Resources available	High	High	Med.	Med.	Low	Low	Medium
Technical development	Rapid	Rapid	Rapid	Rapid	Slow	Medium	Medium
Change favouring	Coal	O&G	Even	Non-fossil	Regional	Efficiency and dematerialisation	Dynamics as usual

13 Methane hydrates are formed in cool deep ocean water (~ $0^{o}C$ and > 500 to 800m. depth) and comprise methane entrapped in a solid water molecular structure. About $900m^3$ of methane becomes trapped into a $1m^3$ solid. Unconventional gas includes methane hydrates and gas from coal beds.

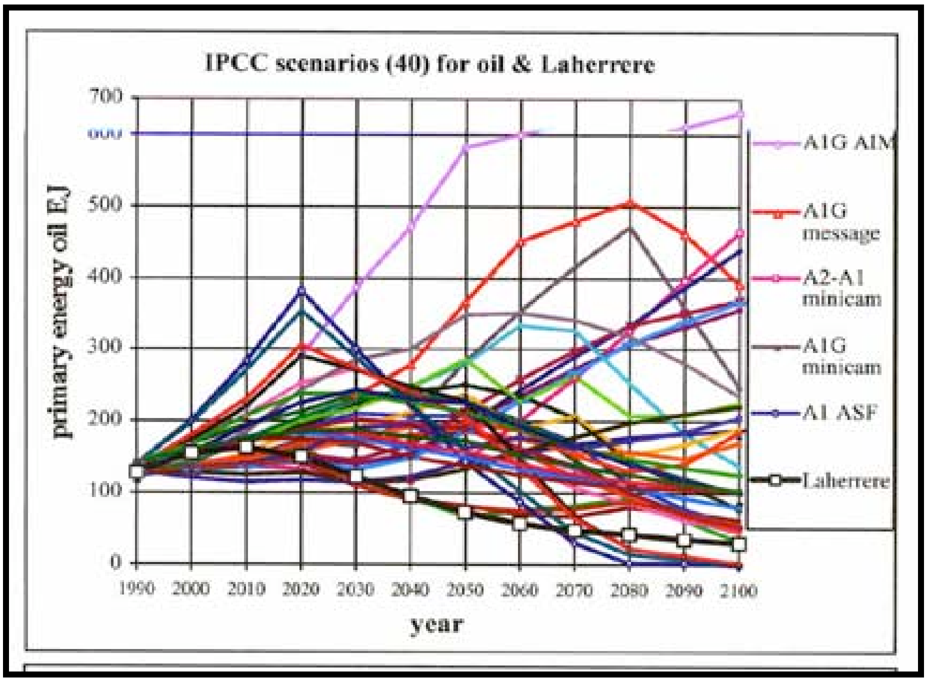
Figures 9 and 10 **plot the oil and gas production scenarios to 2100 for the 40 scenarios (Laherrére 2001). At the bottom in black are the ASPO projections for oil and gas for comparison.**

11.3 IPCC discussion

World population peaks at nine to fifteen billion people in some IPCC scenarios and some reach a peak before 2100 followed by population declines, *Table 20*. The discussion above on *agriculture, China and India* strongly suggest that the limits to world grain production are being reached, consumption growth has started to outstrip grain production growth, a key indicator of food sufficiency. World grain stocks per person halved between 1998 and 2003 *Figure 8.*

These facts suggest that world population will reach a peak of less than 8 billion people in the near future, followed by decline, limited by grain supply as the key element in food supply. Population levels of 9, 10 and 15 billion are quite unrealistic. IPCC fuel consumption projections are derived on a per capita basis. The A2 and B2 scenarios can be dismissed on these grounds alone.

Figure 9
IPCC 40 Oil Scenarios & Laherrére
1990-2100

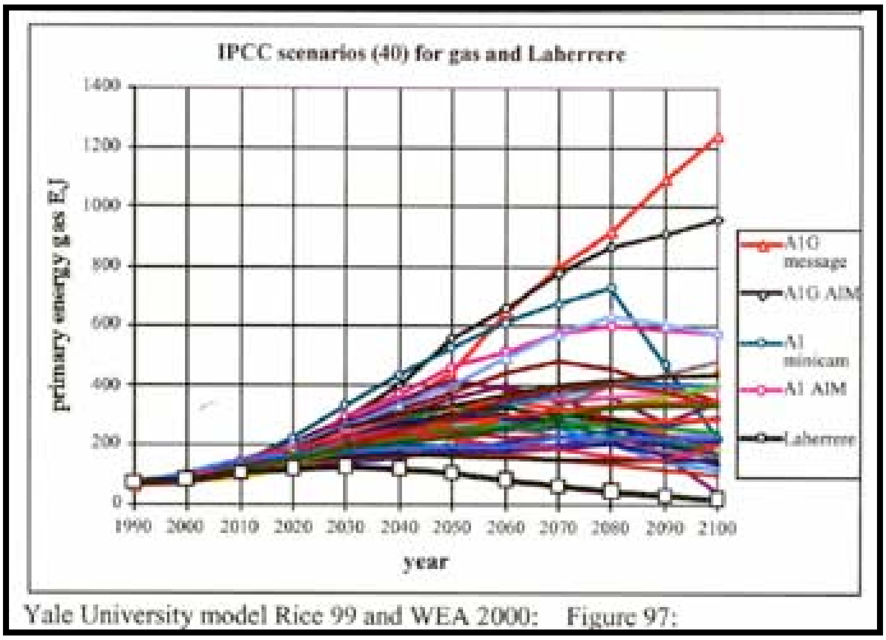


Economic growth is projected to continue to 2100 in all scenarios, up to twenty times recent levels for some. In the A1 scenarios all regions converge to the consumption levels of developed European nations. China and India aspire to the lifestyles of developed nations. As described above good agricultural land in China is being consumed at a rapid rate to this end and China is about to become a major grain importer on a scale that the world cannot meet. *China's present economic path is not sustainable in the short term.*

The Western Economic Model will not work for China or India or any other densely populated developing country (Brown 2005). But many IPCC scenarios are based on this model.

The unconventional oil and gas scenarios are derived from the IPCC population and economic growth models. Most A1, A2, B1 and some B2 scenarios assume large increases in *unconventional* oil production to 2100 that are unrealistic, as discussed above for tar sands and shale oil.

Figure 10
IPCC 40 Gas Scenarios & Laherrére
1990-2100



Methane hydrates occur extensively at shallow depths on the ocean floor where the temperature is close to 0^oC and the depths below 800m. The hydrate disintegrates at higher temperatures and lower pressures, releasing methane gas. Large-scale mining operations would be needed with *massive* environmental consequences *on the ocean floor* and where the methane is extracted and compressed for piping onshore. *The cost would be enormous and the risks very high.* The location and scale of such ocean floor projects would be beyond the scope of technology advances to make viable, the energy cost would be very high.

The high IPCC scenarios for unconventional oil and natural gas assume large-scale affordable production of oil and natural gas following major technology advances. The probability of this happening is virtually zero.

11.4 Conclusions

The IPCC scenarios to 2100 for population, economic growth, unconventional oil and gas are seriously deficient. There are other deficiencies as well that are not described, but the ones above are sufficient to make my point.

The decline of oil, followed by natural gas, will set the agenda for reduced greenhouse gas emissions from the burning of fossil fuels. Where coal might fit into this likely supply scenario is not yet clear and assessments are urgently needed. Using carbon trading to reduce greenhouse gas emissions is now an obsolete concept—it implies greenhouse is the sole determinant of energy policy. Oil has been made from coal in Germany (World War II) and in South Africa (apartheid years) but at high cost and low EPR, and considerable pollution. Coal is most unlikely to replace oil for transport. There are many other factors than greenhouse gas emissions involved in the future use of fossil fuels.

An integrated approach is needed that draws together population growth, food supply and transport dependence issues with controlling greenhouse gas emissions and responding to declining oil and gas supply.

However, global warming arising from anthropocentric greenhouse gas emissions is still a serious issue, but it is not the only one. For example, polar warming due to anthropocentric greenhouse gas emissions is melting permafrost in arctic regions with the potential to release massive quantities of trapped methane to the atmosphere, a potent greenhouse gas.

Why did the IPCC choose such outlandish scenarios for population, economic growth and production of petroleum-based fuels? *I offer this explanation.* IPCC began drafting its scenarios 15 years ago and faced the problem of persuading the member nations to agree to them. The IPCC based these high oil and gas scenarios on the assumption that technologies could emerge for their economic extraction from the resource bases that existed. But **IPCC did not attach probabilities to their technology projections[14]. T**he first priority of IPCC was to commence assessments of the climate consequences. No governments would have taken kindly to assessments projecting an end to economic growth, for example. *Instead IPCC adopted a wide range of options to accommodate all viewpoints on exploitation of the hydrocarbon resource base. Avoiding debate on these contentious issues allowed serious international investigation to begin into the consequences of anthropocentric greenhouse gas emissions.*

But 'peak oil' is now firmly on the world agenda in ways that did not exist 15 years ago. It is now possible to define probabilities on the 40 IPCC scenarios for oil and gas production.

Fifteen years of solid research into the influence of greenhouse gas emissions and other factors on climate change have followed. There is a growing acceptance of the reality of anthropocentric induced climate change and the need to respond to it. The southwest of Western Australia is already experiencing severe water shortages from the impact of sudden climate change to drier autumns and winters since the mid 1970s. The Water Corporation is investing some $1.2 billion in new water sources from 1998 to 2008 to meet the supply shortfall, along with demand management initiatives to curb water consumption.

The time has now arrived to abandon these obsolete IPCC scenarios and to replace them with more realistic ones that attach probabilities to the oil and gas projections to 2100. Strategies that respond to anthropocentric greenhouse gas emissions need integrating with those responding to the decline of oil and gas production.

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[14] "Personal communication from Dr. Barrie Pittock, a Lead Author of the IPCC Third Assessment Report, and former Leader of the CSIRO Climate Impacts Group. He and others have advocated estimating probabilities for emission scenarios and global warming trajectories, but this is still being worked on. The next IPCC assessment, due out in 2007, will discuss probabilistic assessments, which are needed for risk management."

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SENATE RURAL AND REGIONAL AFFAIRS
AND TRANSPORT COMMITTEE

INQUIRY INTO AUSTRALIA'S FUTURE OIL SUPPLY AND ALTERNATIVE TRANSPORT FUELS

*** APPENDICES ***

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APPENDIX 1

ENERGY QUALITY
and
ECONOMIC EFFECTIVENESS

By Brian J Fleay

January 2006

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

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. Some 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[1].*

Economic activity is driven by expenditure of energy, whether it is by human energy as labour, or by that labour amplified using external energy sources, such as fossil fuels, wind, waterpower and their derivatives. Human economic activity is embedded as a sub-system in the global environmental system upon which it is dependent for environmental support services and the receiving of wastes. The ultimate sources of energy are solar and heat from the interior of the earth. Energy is unique as it 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 that 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 extract primary energy from natural sources and to transform these into more convenient forms. One energy form cannot be transformed into another without irreversibly dissipating some of the energy used as waste heat. How much energy is needed to transform primary energy into useful energy is a critical economic issue. The net energy output matters—the difference between gross energy output from a source and the energy spent extracting and converting it into useable forms where. The higher the net energy output the more economically effective is the energy source. *The energy cost of obtaining useful energy is the second important economic aspect of energy quality.*

The different physical characteristics of fuels affect their usefulness and quality. For example, we will never see coal powered aeroplanes. However, we do have ones fuelled by petroleum products. Electricity is the most versatile, useful and economically effective form of energy. That is why we burn coal in power stations to generate electricity, even though half the energy is dissipated as hot gases into the environment. *This is the third important aspect of energy quality, the differing physical forms of energy that affect their usefulness, even when they may have the same net energy yield.*

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[1] The first law of thermodynamics says energy can neither be created nor destroyed but may be transformed from one state to another. The second law says: without compensating change elsewhere, heat can only flow from a hotter body to a colder body, introducing the concept of irreversible processes.

Human use of fossil fuels—the concentrated solar energy from millions of years ago—has significantly amplified human capacity to transform 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 increased per capita 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 lower grades are mined requiring more energy per tonne of product, unless technology counters the trend. But eventually the sheer volume mined overwhelms technology. And 100 per cent recycling is not possible—transport and processing are energy intensive processes as well. The volume of wastes overwhelms the capacity of biological and environmental systems to adapt to the impact. The use of energy to produce high quality goods and services for humans *necessarily* degrades and disorders the environment. *This is the fourth important aspect of energy; its use to meet human needs necessarily disorders the environment.*

These concepts hold an important place in the rapidly growing field of Ecological Economics.

Topics discussed

This paper discusses the causal relationships between energy consumption and gross domestic product (GDP), the effects of historical changes in fuel type and different uses of energy on these relationships, the net energy yield of fuels and the factors influencing this. The interdependence between energy quality, labour, technology and capital is discussed. The serious deficiencies of neo classical economics on these issues are discussed.

Most of this paper is based on work done in the USA, 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. Issues of energy quality are central to evaluation of alternative transport fuels and economic performance generally, and as an aid in assessing how to respond to this historic event.

ECONOMIC APPROACHES TO ENERGY QUALITY

Energy quality

Aggregating the vast number 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 thermal equivalents of different fuel types, e.g. as joules, or joules per unit volume or mass. This approach underlines most methods of aggregation in economics, and ecology. Examples are the gross domestic product/energy relation (GDP/E) and most net energy analyses. However, aggregating energy in this way ignores qualitative differences among energy vectors and end uses over time.

Energy quality here refers to the relative economic usefulness of different fuels and electricity per joule. The shift to higher quality fuels such as electricity and oil over time affects how much energy is required to produce a given GDP output.

The concept of energy quality needs to be distinguished from that of resource quality. Petroleum and coal resources may be identified as high quality because they provide a very high surplus energy relative to the energy used to extract the fuel. On the other hand, some forms of solar electricity may be identified as low quality sources 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 economic energy aggregation requires more advanced forms of aggregation.

Figure A1-1 shows the changing composition of primary energy use in the USA since 1800 (Cleveland et al. 2000). Electricity includes only the primary commercial sources of hydropower, nuclear, geothermal, and solar. Similar patterns would apply to Australia, minus nuclear and geothermal.

Figure A1-1
US Primary Energy Use 1800-2000

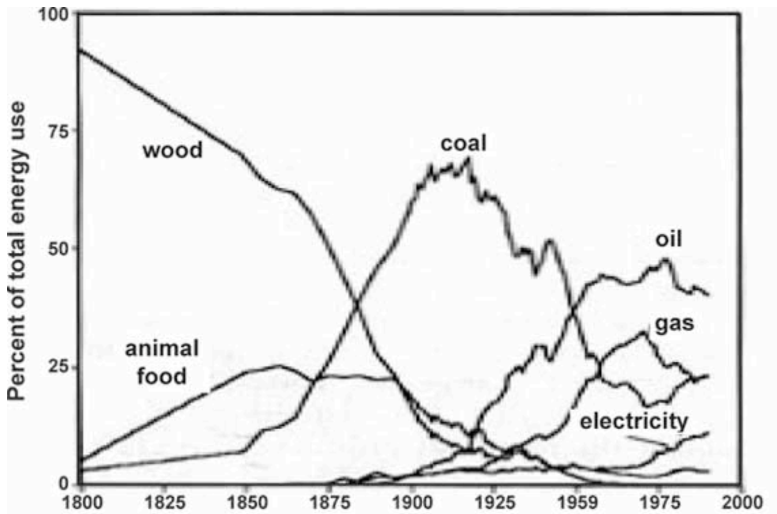


Fig 1 Composition of primary energy use in the US. Electricity includes only primary sources (hydropower, nuclear, geothermal and solar).

Economic approaches to energy quality

From a neo-classical economic perspective, the *value* of the heat equivalent of a fuel (e.g. joules per unit volume or mass) is determined by its *price*. Theory says price-taking consumers and producers set their marginal utilities and products of the different energy vectors equal to their market prices. These prices and their marginal productivities and utilities are set *simultaneously* in general equilibrium for an efficient market outcome[2]. The *value* marginal product of a fuel in production processes is the marginal increase in the 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 et al. (2000) say cartels and speculation as well as government policies and regulations also explain some of the price differentials between fuels, but not the substantial range that exists. The marginal product is determined *in part* by a complex set of attributes unique to each fuel such as physical scarcity, capacity to do useful work, energy density, cleanliness, ease of storage, safety, flexibility of use, cost of conversion, and so on.

[2] _ 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, whereas 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.*

But the marginal product is not *uniquely* fixed by these attributes. The energy vector's marginal product also 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 energy used in each application. When capital stocks have to be adjusted these responses may lead 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. Thus the price per heat joule varies substantially among fuel types and their end-uses—up to tenfold. *The various fuels and electricity are less than perfectly substitutable among energy uses.*

Cleveland et al. (2000) summarise attempts by others to quantify some of these relationships in US energy markets concerning *quality differences between energy types* and energy prices. They ask 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 for energy sources, and that several years of adjustment are needed to bring this relation into equilibrium—s*ee also footnote 1*. This suggests that *over time* prices do reflect the marginal product when differences in energy quality and end-uses are taken in to account—and hence also the economic usefulness of fuels.

Cleveland et al. (2000) say other analysts using models of industrial output as a function of fuel use have calculated the average economic 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 fuels are more effective in some uses than in others. Corresponding US energy quality factors relative to coal are 1.9 for petroleum and up to 18.3 for electricity.

Price-based aggregation

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 approach 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.

Cleveland et al. (2000) say 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.* Wastes are 'externalities' 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. It 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.

NET ENERGY OUTPUT 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. Georgescu-Roegen (1971) also contributed to the subject. 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, as discussed above. *In most net energy analyses, inputs and outputs of different types of energy are aggregated by their thermal equivalents*. Cleveland (2000) summarises his 1992 study that shows the limitations of this approach for US petroleum extraction from 1954 to 1992 (Cleveland 1992). His assumptions and conclusions are given below.

He obtained an index for net energy called energy return on investment (EROI) by dividing the thermal energy output of a fuel by the aggregated direct and indirect thermal 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 a quality correction factor for energy for both the numerator and denominator, with the latter result called the Divisia EPR. Key points in the calculations were:

- Only direct and indirect inputs of industrial energy were used - fossil fuels and electricity;
- energy inputs only included those used to locate and extract oil and natural gas and to prepare them for shipment from the wellhead;
- transport and refining costs were excluded;
- energy output was the sum of the marketed production of crude oil, natural gas, and natural gas liquids;
- *only the direct energy input of petroleum and electricity consumed was included*;
- indirect costs of energy included the energy used to produce material inputs and to produce and maintain the capital assets used to extract petroleum; and
- the energy intensity of capital and materials input was measured by the 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 after 1954, *Figure A1-2.* The quality corrected Divisia EPR declined 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. Electricity's share of total energy use rose from 2 per cent to 12 per cent over the period and its cost share from 20 per cent to 30 per cent. Thus, the two highest quality fuels, electricity and refined oil products, comprised a large and growing fraction of the denominator for the Divisia EPR compared to the heat equivalent EPR, causing EPR to decline faster in the former case**.**

When comparing EPR's for fuels *over time* changes in energy quality should be accounted for.

Figure A1-2
USA Thermal & Divisia EPR's

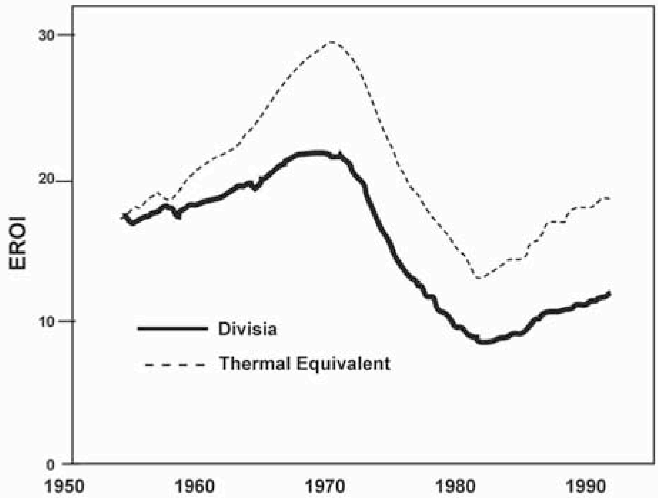


Fig 2 Energy return on investment (EROI) for petroleum extraction in the US, with energy inputs and outputs measured in heat equivalents and a Divisia index.

GROSS DOMESTIC PRODUCT and ENERGY RELATIONSHIPS

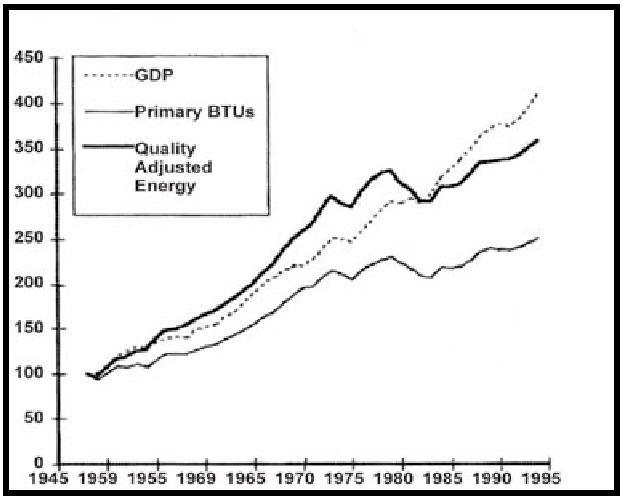
Gross domestic product (GDP) during a given period is the total monetary value of all the goods and services produced in a nation without deductions for depreciation or other business expenses, minus the net payments on foreign investments. It is regarded as a general measure of welfare. However, its 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, or lead to environmental degradation. For example, the dollar costs of fighting, cleaning up and restoration after 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 et al. (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. Some economists claim 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 and end-use over time.

Cleveland et al. (2000) quote one study by Stern (1993) for the US from 1947 to 1990 that did account for differences in energy quality. 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. He used Grainger causality tests on whether one variable in a relation can be meaningfully described as a dependent variable and the other variable an independent variable, and whether the relation is bi-directional or no meaningful relation exists at all. 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. There is less decoupling between GDP and energy use when the aggregate measure for energy accounts for qualitative differences, as shown in *Figure A1-3*. This correlation alone does not prove causality.

Stern's testing for the causal relationship between growth and energy use showed there is *a statistically significant relation* between energy use and GDP and that the direction of causality runs from the level of energy use to economic activity. **Adjusting for energy quality is as important as considering the context within which energy use is occurring. The implications for the importance of energy in the economy are quite significant.**

Figure A1-3
US GDP/Energy Relationships



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 than direct use of coal, but this advantage nearly disappears if petroleum is used as a source of heat. From the perspective of economics, *the law of diminishing returns* implies that the uses of high quality energies are first directed at tasks able to make the best use of the physical, technical, and economic aspects of an energy type. See the fourth paragraph on page 4. 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 sources increase the real GDP/E ratio faster than the later uses.*

Cleveland et al. (2000) report 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 show that changes in the energy mix can account for most of the downward trend in this ratio, *Figure A1-4*. Note that the plots are for the E/GDP ratio, not the GDP/E. One is the inverse of the other. For the USA, changes in the fuel mix from 1929 to 1972 explain 72 per cent 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. 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 ratios are associated with shifts in the types of energy 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. **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.**

The current high economic growth rate in China, as measured by GDP, may be partly due to this early phase of high economic returns from the initial uses of electricity. Charles Wolf (2004) from the Rand Corporation reports that China's GDP grew at 9 per cent per annum from 1998 to 2003 and labour productivity by 7 per cent, capping annual new jobs growth to 1-2 per cent or 10 million. The unemployed population is much greater when poverty stricken rural areas are included. Labour productivity in the USA grew by 3.5 per cent in the same period. If US GDP grew by 4 per cent then job growth could not exceed 1 per cent or 1.4 million people, 0.5 million less than the increase in the labour market. China would also have a much lower direct consumption of energy per capita by labour than in the USA. This would also tend to enhance GDP growth in China—see the discussion below. Do these differences in GDP growth reflect *in part* the later stages of productivity gains from use of electric power in the USA compared to China, and the higher direct consumption of energy/capita by labour in the USA?

TECHNOLOGY, LABOUR, ENERGY QUALITY AND GDP ECONOMIC POLICY

Technology

The energy surplus delivered by petroleum extraction in the USA is smaller than indicated by the unadjusted EPR's, *Figure 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 et al. (2000) say 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 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 changes to the kinds of fuel used in the economy and their division between households and intermediate sectors.
- Assumptions 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 *interdependence.*
- *Deindustrialisation:* 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 (fuel type) and energy efficiency.* The well-known Amory Lovins makes these mistakes.

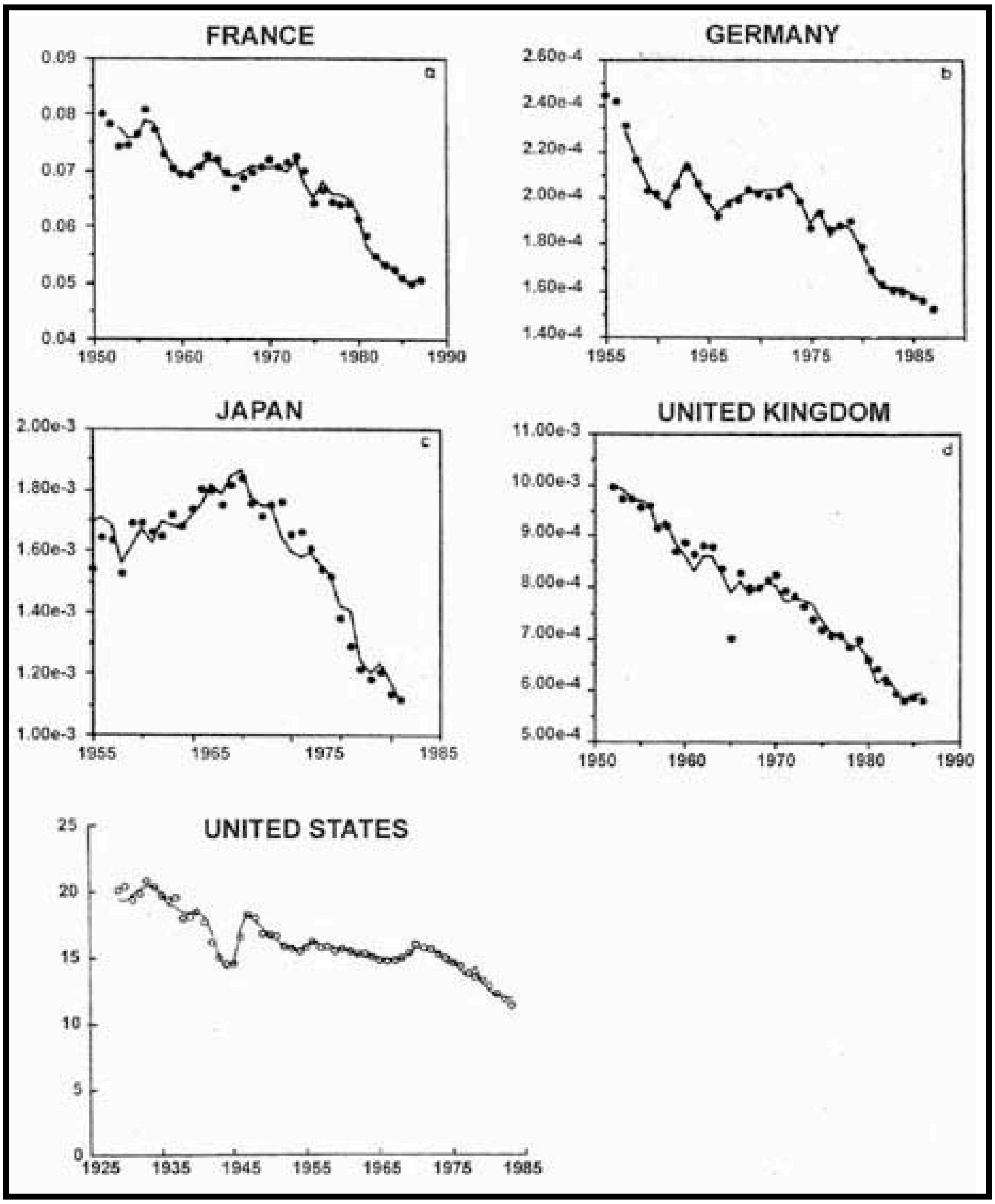
If decoupling is largely illusory, any rise in the cost of producing high quality energy vectors could have important economic impacts. Such an impact might occur if use of low cost coal to generate electricity is restricted on environmental grounds, in particular for climate change reasons. Four factors 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; and
- The decline of petroleum supplies in the near future—petroleum is of higher quality than coal.

Gever et al. (1991, p. 103-5) 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 in the inputs the *indirect energy costs of capital, labour, and government services* as well 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, must 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, e.g. nitrogen fertilisers made from natural gas in grain production.*

Figure A1-4
Energy/GDP Ratios - Five Countries



Labour

Gever et al. (1991, Ch. 3) report that 72 per cent 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 per cent 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 in paid 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 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 rider 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* gains more 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 does not account for variations in income within the population.*

In the USA variation in fuel prices accounted for less than one per cent of the variation in real GDP/E 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, pp, 91-92). The same applies to entire nations. Internationally, *differing* patterns of household energy consumption explains 57 per cent of the variation in real GDP/E ratios among nations (Gever et al 1991, p. 90). There was a sharp rise in the ratio in the USA during World War II due to gasoline rationing and voluntary cutbacks for the war effort, *Figure 4*. 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.

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 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, now limits to high quality energy supply are high on agendas everywhere.

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 or direct use by households 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) comments on US inflation adjusted wartime spending as a percentage of GDP for World War II (1939-44), the Korean War (7/1950-3/1957), the Vietnam War (7/1965-3/1967) and the Gulf War 1990-91 (8/1990-3/1991)—See Table 1.

Table 1

	World War II	Korean war	Vietnam	Gulf War 90/91
GDP increase – per cent	69.1	10.5	9.7	-1.3
Military spend per cent 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 and manned space journeys, 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.*

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 is 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 using heating or cooling devices. Another way is designing urban areas to minimise powered transport use and excessive use of energy in the food supply chain. 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 (DP&I 2005). It aims to convince Perth residents on a personal basis of the advantages of walking, cycling and public transport as alternatives to using cars for short journeys. The Network City Plan for Perth has similar objectives (WAPC 2004).

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 discussed above. 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.

CONCLUSIONS

Once the different qualities of fuels and their end-uses are taken into account there is a strong correlation between economic output, as measured by GDP, and energy use. Neo classical economic theory is seriously deficient in the way it incorporates energy and the physics of energy into its framework. As a consequence these economists are unable to fully appreciate the consequences of the impending decline of high quality oil supply and the environmental consequences of ever-expanding economic growth in a finite world.

Australia

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

- Firstly. Australia is 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 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 and is the driest continent while 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.

Australia can use natural gas as a transport fuel for freight and public transport, but only to buy time to sustain the long transition to more sustainable life styles not dependent on these fuels.

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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APPENDIX 2

CANADIAN TAR SANDS
& SHALE OIL
2 January 2006

These notes summarise features of these resources and the scale of operations required to extract and deliver liquid hydrocarbons to markets. The principal tar sand resources are in Canada and Venezuela and both countries have similar heavy viscous hydrocarbons. The economics are discussed with reference to the energy inputs required.

Tar sands

Four deposits at Athabasca in Alberta, Canada cover 120,000 sq. km and have about 1.7 trillion barrels of bitumen in place[3]. Possibly 300 billion barrels are recoverable, according to the National Energy Board of Canada, with four billion barrels being economic under 1997 conditions. Unlike conventional crude oil expensive exploration is not required. It is a black viscous tar-like material that is upgraded after extraction mainly by adding naptha and condensate from local natural gas to yield a synthetic crude oil that can be pumped (see below). Oil refineries require special process facilities to produce refined products. Some 90 per cent is too deeply buried for surface mining.

Two extraction methods are used with variations. One is a massive mining operation, after removing overburden, followed by processing of the tar sands to extract the equivalent of a heavy crude oil. Two tonnes of tar sand have to be mined to extract one barrel of heavy oil. *To produce four million barrels of oil a day requires mining and processing 3,000 million tonnes of tar sands a year*. The other in-situ method uses two horizontal wells with the injection of steam into one and the extraction of melted product from the other. The direct and indirect energy input required for both these methods is very high and equivalent to two barrels of oil for every three barrels produced[4].

In the mining method the excavated tar sand is crushed, mixed with hot water and steam for extraction of the heavy oil that floats to the top. Gypsum is added to the wastewater stream to facilitate the settling of fine tailings *in vast settling ponds over 10-20 years*. The gypsum is a by-product of the sulphur that is removed from the oil. Most of the water is recycled. The sheer scale of the industry has a profound environmental impact and the residual water from the ponds is discharged to the Mackenzie River that flows into the Arctic Ocean. Hydrocarbon vapours are condensed into naptha, kerosene and gas oil. Residual coke is stockpiled, sold, or used to provide process power and heat[5]. Greenhouse gas emissions are very high compared to conventional oil.

The region has 47 mining and in-situ extraction initiatives worth C$90 billion completed, under construction or scheduled to begin in the next two years. Capacity was 1.2 mn b/d at the end of 2004 and could rise to over 3 mn b/d by 2015. But there are many problems.

Labour and infrastructure limits and the scale of the projects are constraining growth and leading to substantial cost overruns. The Northern Alberta Institute of Technology trade college plans to train 160,000 skilled workers over the next decade. Getting equipment to the remote region poses its own logistics nightmare—there is only one 400 km two-lane highway from Edmonton. Water is becoming a limitation—the quantity used equals the oil output. Alberta's condensate production from natural gas, the main thinner used to dilute the heavy oil product, has been flat at around 160,000 b/d for several years, and is beginning to decline[6].

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3 One barrel equals 160 litres.
4 Youngquist, Walter 1997, *Geodestinies,* National Book Company, Portland Oregon, p. 215.
5 George, R, 1998, *Mining for Oil,* Scientific American, March p. 84.
6 Cope, Gordon 2005, *A sticky dilemma,* Petroleum Review, December, p. 36.

Cheap locally produced natural gas is the main fuel. Cope says it requires 750 million cubic feet of gas to produce one million barrels of oil a day in the mining cycle and 1,500 million cubic feet of gas by the in-situ steam extraction method for a current total of about 1.1 mn b/d of oil. The region now uses 220 billion c.ft of gas a year, some 3.3 per cent of Canadian production. However, North American natural gas production has begun terminal decline—see *Appendix 3*. Wholesale gas prices in the USA would currently be up to five times its cost of production at Athabasca and half Canada's production is exported to the USA[7]

Cope says strenuous efforts are being made to become more energy and water efficient. But there are limits due to the sheer scale of operations required. Alternative energy source to natural gas are being explored using some of the tar sand product.

Despite the optimism of the companies for the future, these problems will persist and grow. To produce even modest quantities of oil will require operations on a vast energy-intensive scale, unlike anything ever undertaken hitherto. The environmental problems will likewise grow.

Shale oil

"Shale oil" is a misnomer, it is really an organic marlstone. There is no oil incorporated in the shale, the name has a promotional motive. It contains a diverse range of organic matter with the generic name of kerogen, and is a *precursor* to oil that has not been subjected to the pressure and temperature regimes over geological time that are needed to transform it into crude oil. The largest resources are in the USA (upper Colorado River basin), also in Brazil, Scotland, China, Estonia and Australia[8]. Many attempts have been made to produce economically viable oil from shale since the 1920s, but so far all have failed—the latest at Gladstone in Queensland.

The fresh oils derived from the shale are usually very unstable and can have a high mineral content. They have an irrepressible tendency to form sediments and gummy materials and their physical and chemical characteristics and compositions deteriorate within hours. They must be upgraded to stable synthetic oils (e.g. by hydrogenation) before transport, used as a refinery feedstock or marketed as fuel products[9]. There may be some scope as feedstock for petrochemicals.

The most recent attempt to trial commercially viable oil-from-shale was by Southern Pacific Petroleum and Central Pacific Minerals (SPP & CPM) from the Stuart deposits near Gladstone in Queensland. This used a new process developed by Suncor, a company active in tar sands development in Alberta Canada, and is probably an advance on anything tried before. A Stage 1 pilot plant began construction in 1998 designed to produce 4,500 barrels/day from 6,000 tonnes of shale (1.33 tonnes per barrel).

The shale was mined, crushed and fed into a four stage process incorporating rotary kilns similar to those used to manufacture cement;

- a flash dryer operating at 150°C to reduce the moisture content to 8-10 per cent; then
- heating to 250°C in a rotary kiln; then
- heating to 500°C in another furnace to crack the kerogen to yield hydrocarbons as gases that are then distilled into products as in a normal refinery; and
- the remaining carbonised rock is ignited *with oxygen* to 750°C in another furnace that provides the heat for the preceding processes.

The volume of overburden removed to access the shale is comparable to the volume of shale mined and the waste shale from the furnaces expands by about 10%—the mine site is not big enough to receive the spent shale and returned overburden[10]. A massive and costly problem if the

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7 BP June 2005, *BP Statistical Review of World Energy.*
8 Youngquist, Walter 1997, *Geodestinies,* National Book Company, Portland, Oregon, p. 220.
9 Fathoni,A. and Batts, B. 1992, *Shale oil Instability: A Literature Review,* Chemical Engineering in Australia, March, p.13.
10 Cook, A., Hutton, A. & Kanisler, A. 1980, *Oil Shales,* Scientific Australian, April p. 6.

project is operated on a large scale. Significant greenhouse gas emissions are involved compared to conventional oil production.

All processes at Gladstone worked except the flash dryer—some of the fines were ignited and emitted an appalling stench (mostly sulphuretted hydrogen) that raised complaints in Gladstone 10 km away. The environmental protection agency shut the plant for more than a year. Operating the flash dryer at a lower temperature solved the problem, but that reduced the throughput and the plant ran at a loss[11]. The solution proposed was to introduce Stage 2 at 15,000 barrels/day using 25,000 tonnes/day of shale (1.67 tonnes per barrel) at a cost of $600 million. But SPP could not raise the funds and went into receivership.

The shale oil resources and reserves published in an addendum to CPM's 1997 Annual Report were estimated at 28.6 billion barrels of oil from 68.2 billion tonnes of shale (2.4 tonnes per barrel). All the problems described above and their associated costs and environmental impacts would grow with the much larger plants needed to produce say 400,000 barrels a day, about 50 per cent of Australia's current oil consumption. It would require mining and processing about 360 million tonnes of shale a year and handling a comparable quantity of overburden. The potential odour and air pollution problems would be immense.

Oil from shale is never likely to be a commercial proposition, despite what many of its advocates say. *It has been said the "oil from shale is the fuel of the future, and always will be.*

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APPENDIX 3

NORTH AMERICAN
NATURAL GAS and ELECTRIC POWER
A DOUBLE WHAMMY!!

By Brian J Fleay

January 2006

BACKGROUND

The US produces 8.5 per cent of world oil, consumes 25 per cent and imports 65 per cent of this at about US$750 million per day. US oil production peaked in 1971 and is now two-thirds of the peak rate. The US consumes 24 per cent of world gas and North America 27 per cent. Gas imports from Canada have increased fourfold since 1985 and provides 15 per cent of US consumption. Yet these countries only have four per cent of the world's gas reserves (BP 2005).

The US pioneered the consumption of oil and natural gas, so we should not be surprised if it leads the world in their depletion. This paper gives a summary of US and Canadian natural gas supply and demand, and the implications. A production decline has begun forcing simultaneous declines in natural gas and electric power consumption. The US must now reduce consumption of both, as well as oil. An historical turning point has been reached.

THE EXISTING US NATURAL GAS SYSTEM

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11 Sykes, Trevor 2003, *The day the shale oil dream died,* Australian Financial Review, 3 December p. 52.

The US had 360,000 producing gas wells in 2000 with 74,000 drilled since 1994 (Udall 2001). In 2005 North America had 1,870 rigs (two-thirds of the world total) that drilled over 20,000 new wells, yet both oil and gas production have slowly declined (Rach 2005). New wells were mostly being drilled between the old ones—running fast to stand still. Most new gas wells rise quickly to a peak and rapidly decline—up to 60 per cent over two years (Simmons 2002). About 80 per cent of discovered natural gas in the US has been consumed. The principal gas fields are in Texas, Louisiana, the Mid-West, offshore in the Gulf of Mexico and in the Rocky Mountain states.

There is a nation wide network of gas pipelines. Mexican natural gas is minor and production almost matches consumption. The US consumed 645 billion cubic metres (Bcm) of gas in 2004, and imported 96 Bcm from Canada at a cost of US$20 billion. An additional 25 Bcm was imported as LNG (BP 2005).

In 2000 residences consumed 22 per cent, commercial 13 per cent, industries 37 per cent, electric power 25 per cent and pipelines 3 per cent. Energy intensive industries consume 80 per cent of industrial demand (Simmons & Co International 2005). Electric power includes 'in-house' industrial generation as well as utilities. Peak gas consumption is in winter for domestic and commercial heating when gas consumption in cold weather exceeds production by up to 25 per cent. Surplus production in the warm months is stored in depleted oil and gas fields for extraction in the winter.

Electricity consumption has been growing at 2-3 per cent per year (BP 2001). 52 per cent of generation capacity in 2000 was obtained from ageing coal-fired plant, 20 per cent from ageing nuclear power stations, seven per cent from hydroelectric, and gas turbines 16 per cent. Installation of gas turbines has surged due to population and per capita consumption increases, and to replace ageing power plants. By 2005 about 200,000 MW of new gas-fired power plants had been commissioned since 2000. A one per cent increase in coal fired and nuclear power generation decreases gas consumption by 10 bcm per year (Simmons & Co International 2005). Australia's installed generation capacity is some 42,000 MW.

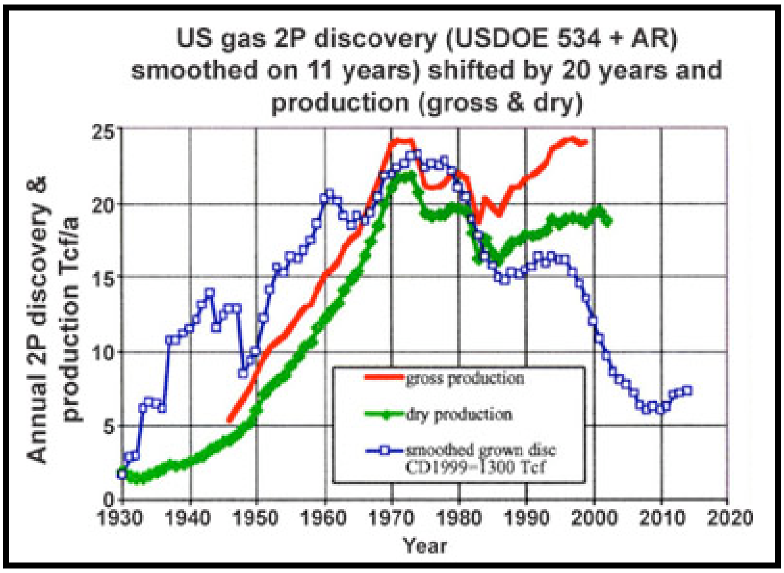
This surge was driven by the 1990s information technology boom and in response to rapid growth in residential air conditioning plants for summer cooling. Gas consumption by gas turbines was expected to double by 2010, increasing total consumption from 640 Bcm in 2001 to 750 Bcm. Government agencies and industry analysts in 2000 saw no major problems in expanding gas production at modest cost—up to US$3/M.Btu (Simmons 2000). During the 1990s Henry Hub gas prices ranged from US$1.5 to US$2.50/M.Btu's. However, by the end of 2000 gas prices reached $9/M.Btu as a hot summer boosted power demand (BP 2001). Gas prices spiked at US$15/M.Btu in late 2005 and have been mostly just over US$10/M.Btu's.

Bottlenecks in the US electric transmission and gas pipeline networks are arising from this growth and the changed patterns of supply and consumption. The Californian energy crisis in 2000 began a response that has reduced gas consumption and increased gas well drilling rates. High prices have trimmed gas consumption by use of alternative fuels, minimum use of gas turbines, conservation and reduced industrial use. Mild weather in winter and summer has also helped. Energy efficiency has received a higher profile.

Figure A3-1 shows the plot of North American natural gas discovery shifted forward by 20 years compared to the plots of raw and dry gas production (Laherrére 2003). The dry gas profile is what is left after subtracting from the raw gas the methane obtained from coal beds and liquids extracted from wet natural gas (eg ethane, butane and propane). The difference between gross and dry production is about equally divided between coal seam gas and these liquids. The production profile is broadly mimicking the discovery profile with a lag of 20 years.

The upturn in gas discovery since 1990 is in deep water fields offshore in the Gulf of Mexico (>300 m. depth). Some are due to come on line by 2007 with no significant ones scheduled beyond then. The production downturn in 2002 foreshadows the decline about to commence.

Figure A3-1
NORTH AMERICAN NATURAL GAS



Jean Laherrére Petrotech 2003 New Delhi

Natural gas flows more freely in geological formations than oil under equivalent circumstances. Consequently more of the gas-in-place can usually be extracted from gas fields than from equivalent oil fields—as much as 80 percent compared to 25-45 per cent. There is less scope for enhanced production initiatives for gas as decline sets in. Also the higher development costs for gas infrastructure, especially for transport, ensures that maximum production profiles tend to be extended plateaus rather than the more sharply defined peaks common for oil. Decline therefore begins at a later stage of field depletion. Both factors mean the production declines for natural gas are often steeper than for oil, and commence when about 70-80 per cent of the extractable gas has been produced. North American gas production has reached this stage.

To compound these problems with gas coal is now being imported to the US Appalachian region with an increase to 30 million tonnes in 2006 and 60 million tonnes in 2007, 75 per cent from Colombia. Production is declining as the high-yielding thick horizontal seams have been mined out. Limited rail capacity is preventing transport of coal from mines in Montana in the west. The US mined 1.01 billion tonnes of coal in 2004 (Australian Financial Review 2005).

NEW NATURAL GAS OPTIONS

North American options need to be considered in the global context for natural gas. *Table 1* shows world gas reserves, production and consumption for 2004 by region (BP 2005). The reliability of the reserve figures is not good, especially for the former Soviet Union and the Middle East.

The main US options are deep gas below the existing fields in Texas and adjacent states, gas from the Arctic coast off Alaska and from the Mackenzie River Delta in NW Canada, tight gas in the Rocky Mountain states, methane extracted from coal beds and imports of LNG. There is some scope for more gas discoveries in deep water in the Gulf of Mexico.

Since the mid-1980s the number of skilled drillers, petroleum geologists and geophysicists in the US petroleum industry have declined as exploration and development activity fell away in the low oil price regime and with declining opportunities for exploration—US oil production peaked in 1971. Key technical personnel are mostly over 50 years old and heading for retirement. Few students are training in these specialist fields at universities. This personnel shortage is a major constraint to the potential gas developments discussed below—also for oil development as well (Simmons 2000). A similar situation exists in most countries.

TABLE 1
WORLD GAS RESERVES, PRODUCTION & CONSUMPTION 2004
Billion cubic metres

	Reserves	Production	Consumption
North America	7,300	763	784
Central & South America	7,100	129	118
Former Soviet Union	58,700	733	625
Europe	5,400	318	483
Middle East	72,800	280	242
Africa	14,100	145	69
Asia Pacific	14,200	323	368
World Total	**179,500**	**2,692**	**2,689**

Texas Deep Gas

This is deep gas in formations below existing fields. It involves drilling to a depth of 5 km, requires a new generation of heavy-duty rigs and is very expensive. Rig manufacturers do not have the capacity to build the rigs needed, even if contractors would buy them in advance of drilling contracts (Simmons 2000). It is not proven that large quantities are available and the risks are higher. A large effort and a decade or more is needed to prove viability and ramp up production.

Arctic Coast Gas

The most viable project (US$7.8 billion for pipelines alone) proposes a 1400 km first stage pipeline from the Mackenzie River Delta (US$2.6 billion) linking to Alberta pipelines, a similar second stage pipeline from the Alaskan North Slope linked to the Mackenzie system, then twin pipelines from Alberta to Chicago as a third stage. Planning is under way but with no commitment to proceed. To be viable the Alaska project needs sustained gas prices above US$3.5/M.Btu. The first two stages would take at least five years to build and the whole project could eventually deliver close to 56 Bcm per year (Lask 2003). Production from existing sources could decline by this quantity in that time frame. Decisions to proceed are not likely in the short term.

Rocky Mountains

There is existing production but 40 per cent of potential fields are under public lands, mostly as conservation reserves where drilling is prohibited. Most is in fields where the gas is tightly held and where extraction is very difficult. There are conflicting claims on how much oil and gas might be extracted in these regions, and on how difficult and expensive its development might be.

Coal bed methane

There is substantial methane in shallow coal beds in the Rocky Mountain States. Production is expanding in the wake of rising gas prices. Dewatering of gas bearing formations is often required leading to environmental conflicts and with landowners on disruption to ground water and its consequent pollution. Many shallow wells relatively close together are needed.

LNG

The capacity of existing US receiving terminals is 28 Bcm/year. In 2004 the US imported 20 Bcm (10 per cent of world LNG), principally from the Carribean and Algeria (BP 2005). These terminals are being expanded to come on-line from 2005, with the position unclear after 2008.

The US Energy Information Agency forecasts that US gas consumption will grow to 870 Bcm in 2025 from 625 Bcm in 2003, led by the electric power industry. LNG imports are forecast to grow from 18 Bcm in 2004 to over 180 Bcm in 2025 (Qinlan 2005). This business-as-usual growth forecast must be suspect. Imports would compensate for declining North American production.

UK gas production has commenced a steep decline and Europe (Netherlands and Norway) will soon follow as the North Sea gas fields approach extraction of 80 per cent of the gas-in-place. The UK is rapidly expanding LNG import capacity. Europe consumes 17 per cent of world gas.

Potential US, Chinese and European LNG imports is stimulating the development of new LNG plants and tanker construction around the world. 180 Bcm of LNG was traded in 2004, principally to Japan, South Korea and Spain. Projects under construction and in advanced planning could double LNG production capacity by 2010 (Qinlan 2005). See *Table 2.*

Some projects may not be completed, but others could replace them. Qatar has imposed a moratorium on further LNG development to 2012 until it has digested its current program and assessed the performance of its North Field (Gavin 2005).

TABLE 2
LNG CAPACITY 2005-2010
Billion cubic metres per year

Country	2005	2010
Algeria	35	40
Indonesia	46	67
Nigeria	18	63
Malaysia	38	47
Qatar	35	95
Australia	22	38
Six others	-	9
Total	**194**	**359**

The number of LNG tankers increased from 154 to 175 during 2005 and those on order rose from 56 to 107 at a cost of US$200 million each. Costs are rising due to the stretched capacity of shipyards, which are also faced building oil tankers to replace an ageing fleet (Qinlan 2005). Major investment is required in new LNG terminals. There is fierce opposition to new terminals in the USA on environmental and safety grounds. LNG infrastructure is expensive. Natural gas imports will aggravate the US trade deficit. *These scenarios will tend to raise natural gas prices worldwide.*

US Gas Scenario to 2010

Simmons & Co International (2005), a financial services company servicing the oil and gas industry in Houston Texas, considered these interacting supply and demand factors in a February 2005 report, *Outlook for Natural Gas Supply: 2005 and Beyond.* The data is shown in *Table 3.*

TABLE 3
OUTLOOK FOR US NATURAL GAS SUPPLY & DEMAND
Billion cubic feet per day

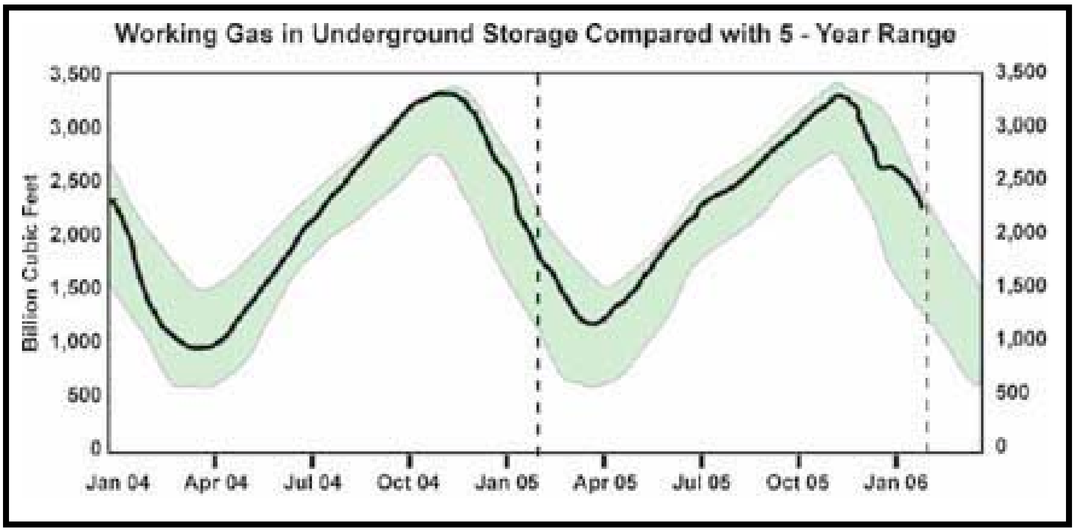
	2004	2005	2006	2007	2008	2009	2010
Dry Gas production	51.2	50.7	49.9	49.2	48.4	47.5	46.5
Canadian imports	9.4	9.3	9.2	9.1	9.0	8.9	8.8
LNG imports	1.8	2.4	3.3	3.9	5.5	6.0	7.0
Total supply	**62.4**	**62.4**	**62.4**	**62.2**	**63.0**	**62.4**	**62.4**
Exports	1.9	2.0	2.0	2.1	2.1	2.2	2.2
Consumption	**60.8**	**60.8**	**60.8**	**60.8**	**61.3**	**61.8**	**62.4**
Residential	13.4	13.2	13.0	12.8	12.8	12.8	12,8
Commercial	8.2	8.1	8.1	8.0	8.0	8.0	8.0
Industrial	19.5	19.7	19.9	20.1	20.4	20.7	21.0
Electric Power	14.1	14.1	14.2	14.3	14.5	14.7	14.9
Gas Pipeline	1.8	1.8	1,8	1,8	1.8	1,8	1.8
Other	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Total Demand	**62.7**	**62.8**	**62.8**	**62.9**	**63.4**	**64.0**	**64.6**

GAS STORAGE FOR WINTER DEMAND

Natural gas is the principal fuel used to keep people warm in winter. Consumption can exceed production by as much as 25 per cent during cold spells. Surplus capacity in the warmer months is used to recharge salt domes and depleted oil and gas fields for extraction in winter. Heating oil is used as well. The winter drawdown on these storage ranges from 1,400-2,200 Bill.c.ft depending on the winter's severity. The rapid growth in gas turbines to meet summer electric power peaks is eroding the capacity to recharge these storages. The worst combination is a hot summer followed by a cold winter. Now declining gas production is amplifying the shortfall.

Figure A3-2 shows the working gas in storage from September 2003 to 2005 (EIA 2005). The shaded band represents the range of storage levels over the five years before 2003. The 2003 winter was cold and storage declined from a record 3,100 billion cubic feet (88 Bcm) in November 2002 to 660 bill.c.ft (19 Bcm) in March. Any further storage decline and the extraction rate would have fallen rapidly. The 2003 summer was mild as were both seasons in 2004, and the 2005 winter. Acute gas supply crises did not arise in these years.

Figure A3-2
North American Gas Storage
Billion cubic feet



However, the 2005 summer was hot and by December gas storage fell from 270 bill.c.ft (8 Bcm) above the 2004 level in April to 195 bill.c.ft (5.5 Bcm) below it, mainly due to greater use of gas turbines by electric power utilities and the damaging impacts of hurricanes Katrina and Rita in autumn (EIA 2005). Henry Hub gas prices in late September spiked at US$14/1000 c.ft, *seven* times the price in the late 1990s. Natural gas production and the capacity for refineries to build heating oil stocks for the coming winter were adversely affected. A cold November followed by the warmest January in 43 years led to record storage levels by February 2006 with gas prices falling below US$10/1000 c.ft. The supply/demand balance in the US is strongly influenced by the weather.

WHAT OF THE FUTURE?

Soon the USA may not have enough North American gas to meet winter heating demand AND to run gas turbines for peak summer electric power demand for air conditioning, especially in seasons of extreme temperatures. Restricting summer power demand would stress electric power systems and compromise reserve generating capacity and increase the risk of cascading power system failures as happened in the eastern USA and Canada in August 2003.

Andrew Liveris, CEO of Dow Chemical, *"insists that Americans are facing the worst energy crisis in their history, they just don't know it yet"* (Australian Financial Review 2005a). *"They should worry that there may not be enough natural gas to heat and cool their homes"*, he said. Three years ago Dow's annual bill for energy and hydrocarbon raw materials was $US8 billion. Today that number approaches US$22 billion. American companies are moving their operations overseas to take advantage of lower energy prices.

The days of cheap gas are over for the USA and the economic burden of oil and natural gas imports are escalating. An increasing investment in these energy sources is emerging relative to the benefit obtained that has worldwide impacts and will push up gas prices everywhere.

What are the uncertainties in this emerging scenario in the USA? Some are listed below:

- Accuracy and timeliness of the key performance information—this is critically important when supply and demand are so finely balanced.
- How frequent will extreme winter and summer seasons be?
- How vulnerable is petroleum infrastructure in the Gulf of Mexico to extreme hurricane damage?
- Will production decline more steeply as the impact of infill wells in existing fields decreases?
- Will the drilling boom be sustained and how effective will it be?
- What is the scope for increased gas supply from coal bed methane and from fields in deep water offshore?
- Can the USA afford the increasing cost of imports of oil and natural gas?
- What will be the additional economic impact of restoration work arising from hurricanes Katrina and Rita on the gas and oil supply agenda?
- What will be the future of industrial consumption of gas and the survival of these gas dependent industries as their international competitiveness is eroded?
- How effective will fuel substitution be in reducing gas consumption—other electricity sources and oil products replacing gas? Are the easy gains from substitutions already achieved?
- How effective will energy conservation and efficiency initiatives be? Some are easy to apply, such as the resetting of thermostats, while others take time to implement.
- New gas turbines are more energy efficient than older installations—more kilowatt-hours per cubic metre of gas. How much older less efficient plant will be shut down?
- Finally, as the gas supply shortfall becomes visible, what will be the political and cultural response to the prospect of people freezing in winter?

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APPENDIX 4

TRANSPORT FUELS AND ENERGY QUALITY

B.J.Fleay
January 2005

BACKGROUND

Petroleum products dominate transport fuels with a minor role for electric rail traffic. Commercial shipping, and especially aviation, is almost exclusively petroleum powered. 60 per cent of the world's oil fuels transport. Land transport uses 65 per cent of Australian petroleum product consumption and nine per cent is used for aviation. The following qualities have led to the domination of petroleum products as transport fuels.

- They are available at convenient locations.
- They have high energy profit ratios, especially for oil from giant oil fields (see the discussion below).
- They have compact and cheap fuel storage characteristics—high power-weight and power-volume ratios;
- They have good storage and portability characteristics;
- Fine control is possible in compact engines;
- The environmental impact from production to end-use is low compared to coal.
- Flexible responses to vehicle motion are possible.

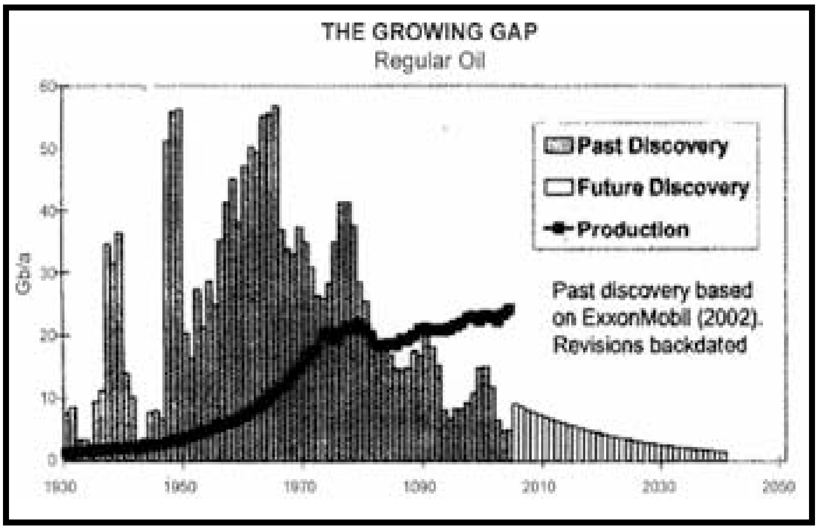
It is unlikely that any alternative transport fuels will be able to fully match all these favourable characteristics. This paper discusses criteria for comparing the quality and effectiveness of transport fuels.

World oil discovery and production

We face around 2010 the beginning of the decline of world oil production as the best and biggest oil fields reach their prime (ASPO 2005). Laherrére (2003) also gives a comprehensive overview. Discovery peaked over 40 years ago has been declining ever since, and is now only one quarter of world oil production. Consumption has exceeded discovery since 1980, *Figure A4-1.* 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. But nearly half the oil comes from just 116 giant fields, 14 of these produce 20 per cent and four fields produce 11 per cent (Simmons 2002). Giant fields are usually easy to find, are therefore found first, and produce the cheapest oil for a long time. Discovery of giants has almost ceased, existing ones ageing and many are decline.

Figure A4-1
ASPO Oil Discovery/Production
Gigabarrels/year



Net energy and energy profit ratio

Net energy analysis is one way of evaluating the productivity of energy systems. Some of the commercial energy obtained from nature must be used to extract and convert it into useful forms. A crucial economic issue is what proportion should be so used. Net energy 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. It can be measured by *energy profit ratio (EPR),* sometimes called *energy return on investment*.

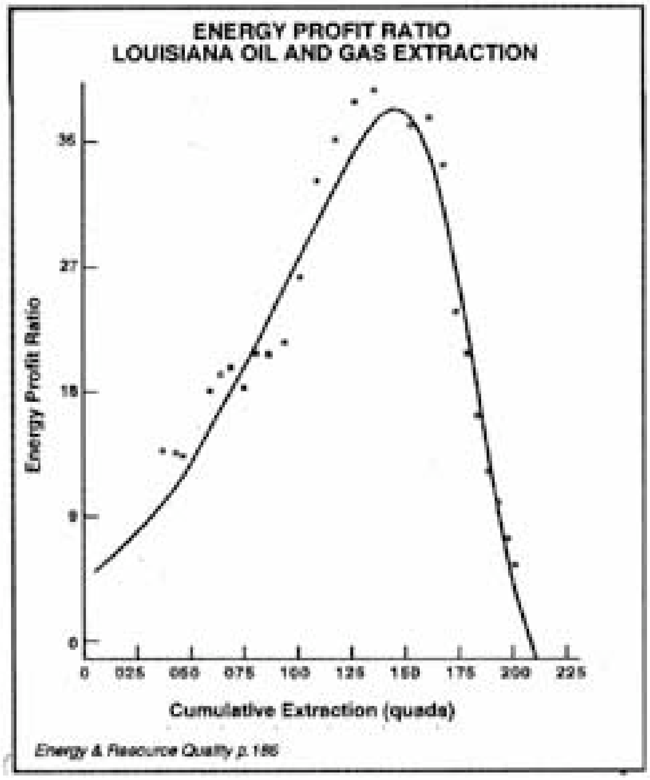
$$EPR = \frac{\text{energy output}}{\text{energy input}}$$

There has been a long debate about the relative strengths and weaknesses of net energy analysis. Not all energy sources with same net energy yield have equivalent performance in specific end uses, eg as transport fuels. Other qualities impact on their usefulness and the economic merit of fuels, such as those listed above for transport. In most net energy analyses, inputs and outputs of different types of energy are aggregated by their thermal equivalents and disregard other aspects of energy quality. This subject is discussed in more depth in Appendix 3.

To paraphrase George Orwell from his famous book, *Animal Farm,* ‘all fuels are equal but some are more equal than others’.

Figure A4-2 shows the EPR profile for Louisiana USA oil and gas production plotted against cumulative production (Hall et al. 1986, p.186). Small and large field performance is aggregated for both oil and natural gas. The Louisiana *giant oil fields* would have had higher EPR’s than shown. There has been no correction of energy inputs for energy quality over time, as discussed above. Note that the highest EPR’s were in the middle range of the production cycle and began decline after two-thirds of the petroleum had been extracted. *On the downside of production net energy yield declines faster than gross output, the reverse of the upside.* The net energy yield counts, the energy used for useful things. Not all oil-producing regions have such simple EPR profile.

Figure A4-2
Louisiana USA Oil & Gas EPR



ALTERNATIVE TRANSPORT FUELS COMPARED

Figure A4-3 compares quality characteristics of transport fuels. Their EPR's are listed on the vertical axis and they are *ranked* from on the horizontal axis according to improving quality characteristics. The EPR data is mostly for the USA from Cleveland et al (1984), also in Gever et al (1991, p.70) and Hall et al (1986, p.48). *Figure A4-3* shows EPR's, at wellheads, refineries and power plants. Marketing and distributing petroleum products would use additional energy.

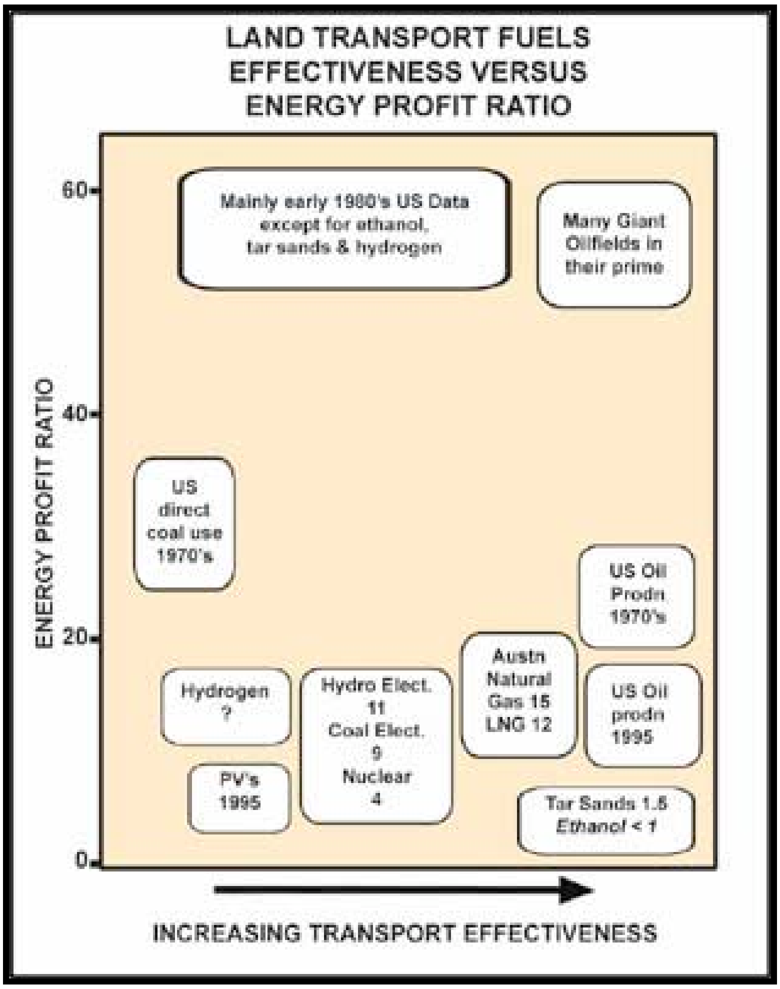
What *Figure A4-3* shows is the unique role that oil from giant oil fields have played, ranked well above all alternatives. But their best years are now mainly in the past.

***Liquid fuels** are listed on the right* because they are the most convenient and adaptable transport fuels and the technology and distribution systems for their use are well developed. *Natural gas is to the left* 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 often exist. Natural gas is the only fuel immediately able to substitute for petroleum products in land and sea transport on any scale. LNG may be the best way to use natural gas for heavy vehicles such as trucks. Oil from Canadian tar sands has an EPR of 1.5—see Appendix 1, (Youngquist 1999). *In 1998 Australian oil production had an EPR of 12 and refined products (petrol and diesel) 9.5 at the refinery. Natural gas production had an EPR of 15 and LNG 12 at Burrup in the Pilbara (Lenzen 2001).*

Large-scale biofuel production (such as anhydrous ethanol and biodiesel), according to studies by Giampietro, Uligiati and Pimentel (1997) embracing several countries, *"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 energy inputs, they found that the fossil fuel 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. *If all of Australia's annual wheat* *harvest were converted to anhydrous ethanol its energy content would only equal 12 per cent of the equivalent energy content of our annual oil consumption. The equivalent figure for Australian sugar is 7 per cent.*

Figure A4-3
Transport fuel effectiveness



***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 have the same energy content as a one tonne lead acid battery, the reason why battery operated cars have never gained a large market—and never will (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 disadvantage of only generating electricity while the sun is shining. The EPR expectations for thin film silicon technology have yet 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 would be at the expense of existing uses.

The EPR shown 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 long-term decommissioning of nuclear plants and the disposal of nuclear wastes—unknown costs much of which will occur AFTER the plants are decommissioned. There is a substantial fossil fuel input in the mining and processing of uranium ores that produces hazardous wastes. As the high-grade uranium ores are mined out lower grades will be needed with mounting energy inputs and waste disposal problems. 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.

Direct use of coal *as a fuel for transport* (e.g. coal fired locomotives) has the disadvantage of being a solid and dirty fuel with low energy efficiency.

Hydrogen *is being promoted as a transport fuel* using fuel cells to generate electricity. But hydrogen has to be manufactured using other 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. When compressed, its energy per unit volume is low compared to all liquid and gaseous alternatives (petrol, diesel and compressed natural gas) so that its storage and transport costs are high by comparison. A high proportion of the energy content of the hydrogen is needed to compress it. The proportion of its energy content needed for all these tasks is very high.

One option is to manufacture methanol from natural gas or biomass that can be used directly in some fuel cells to generate electricity. It does not have the transport and storage problems of hydrogen. 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 to the left of electric power on *Figure A4-3* and have a low EPR.

Given these problems and the steps needed to manufacture hydrogen, then to generate electricity in a fuel-cell, it is unlikely that it will have the performance of historical petroleum products for transport (Wald 2004). A net energy approach 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—one component can be critical. Platinum is less plentiful than gold and the only operating mines are in southern Africa centred on Zimbabwe and in Russia. The platinum could be 40 per cent of the cost of fuel cells (Ashley 2005).

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 5A-3. 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 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 5A-3* is crucial. At a minimum taking account of differing energy qualities in ways discussed in this paper is 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.

Australia

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

- Firstly, Australia is 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 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 and is the driest continent while 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. 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.

Australia can use natural gas as a transport fuel, especially for freight and public transport, but only to buy time for the long-term transition to more sustainable life styles not dependent on these fuels.

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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APPENDIX 5

AUSTRALIAN LIQUID BIOFUELS
NATIONAL PRODUCTION BOUNDARIES
Brian Fleay
February 2006

This paper compares the energy content of ethanol derived from Australia's annual production of sugar and wheat, less the domestic consumption of wheat, with the energy content of annual consumption of auto gasoline, auto diesel and primary oil. It demonstrates the energy content of anhydrous ethanol from sugar and wheat would be a small fraction of the energy content of annual consumption of petroleum-based fuels, especially in drought years. While anhydrous ethanol from biomass is technically viable as a transport fuel it cannot be produced on a scale that replaces current petroleum products. Similar limits would apply to biodiesel. It is not remotely possible to divert much of these agricultural products to fuel production at the expense of food supply.

Sugar

Annual production of sweeteners (sugar and honey) is notionally 5 million tonnes with variations according to seasons and markets. Honey is a negligible component (ABARE 2005). One tonne of sugar yields 0.385 tonnes of anhydrous ethanol that has a high heating value (HHV) of 29.65 GJ/tonne (Patzek & Pimentel 2005). Thus potential annual anhydrous ethanol production from sugar is 1.925 million tonnes with an HHV of $57x10^6$ GJ.

Wheat

From 1991/92 to 2004/05 average annual wheat production was 18.6 million tonnes with a range from 8.97 million tonnes (1994/95) to 26.13 million tonnes (2003/04). Average production from 1999/01 to 2004/05 was 21.3 million tonnes (ABARE 2005). We will use a figure of 22 million tonnes. Domestic consumption of wheat is just over 5 million tonnes per year, leaving 17 million tonnes that could be converted to ethanol.

Proposals for production of anhydrous ethanol from wheat quote a yield of 0.4 litres per kilogram of wheat (Grant et al. 2005). Ethanol has a density of 0.787 kg/litre that translates this yield to 0.315kg ethanol/kg of wheat. This figure is consistent with the ethanol yield from corn in the US (Patzek 2005). Thus there is a potential annual production of 5.4 million tonnes of ethanol from wheat. At an HHV of 29.65 GJ/tonne this is 161 million GJ per year (Patzek 2005).

In the drought year of 2002/03 Australian wheat production was only 10.1 million tonnes, leaving 5 million tonnes for ethanol production that could yield 1.6 million tonnes of ethanol, or 47 GJ.

Petroleum fuels

The HHV of gasoline is 46.7 GJ/tonne and its density ranges from 720 to 800 tonne/klitre – we will use a figure of 740 kg/klitre. The HHV therefore is 34.6 GJ/klitre (Patzek 2005). Annual consumption is 19,876 ML (14,708,600 tonnes) equivalent to 688 million GJ (ABARE 2005).

The HHV of diesel is 45.9 GJ/tonne and its density is 0.84 kg/litre. The HHV therefore is 38.6 GJ/litre (Patzek 2005). Annual consumption is 15,185 ML (12,755,000 tonnes) equal to 586 million GJ (ABARE 2005).

The HHV of crude oil is 42 GJ/tonne and its annual consumption is 38.8 million tonnes, or equivalent to 1,630 million GJ (BP 2005).

The Table below summarises the position. Depending on ethanol from grain must take into account domestic grain consumption for food and seed. There would be major supply crises in drought years.

Potential Annual Ethanol Energy Output
Compared to Annual Petroleum Products

Annual Petroleum Products GJ x$10^{6/}$/yr		Wheat $161x10^6$GJ/yr	Wheat $47x10^6$GJ	Sugar $57x10^6$ GJ/yr
		Per cent petroleum product		
		Good year	Drought	Good year
Gasoline	688	23%	7%	8%
Diesel	586	27%	8%	10%
Gasoline+diesel	1,274	12.5%	3.5%	4.5%
Crude oil	1,630	10%	3%	3.5%

REFERENCES

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BP 2005, *BP Statistical Review of World Energy,* June 2005.

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ADDENDUM

UNITED STATES FOSSIL FUELS AND BIOMASS ENERGY

The United States is the most energy intensive consumer in the world. The data below compares the energy consumed from fossil fuels with the potential biomass energy arising from photosynthesis.

The annual fossil fuel consumption in the United States of America, if all burnt, would yield 20×10^{15} kcalories of energy. The energy content of the annual net addition to all biomass from photosynthesis is 13.5×10^{15} kcals (Pimentel & Pimentel 1996). The fossil energy potential is 40 per cent greater than that for all biomass. About 70 per cent of biomass energy is fixed on agricultural land. Oil comprises 40 per cent of US fossil fuel consumption, most of it as transport fuels.

REFERENCE

Pimentel, David & Pimentel, Marcia 1996, *Food, Energy, and Society,* University Press of Colorado, p. 20.

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APPENDIX 6

POPULATION GROWTH, NITROGEN FERTILISERS AND TRANSPORT

B.J. Fleay February 2006

INTRODUCTION

Human population quadrupled during the 20th century. Many factors fostered this expansion, but the synthesis of ammonia from nitrogen and hydrogen was the main one[12]. Nitrogen fertilisers derived from ammonia made possible the dramatic increases in crop production necessary to feed this population growth. Nitrogen is only a minor constituent of living matter compared with carbon, hydrogen and oxygen, but it has a vital role to play in DNA and protein. The other three elements can move readily from their huge natural reservoirs whereas nitrogen remains largely locked in the atmosphere and can only be converted with difficulty and high-energy inputs into forms that plants can use. Nitrogen is therefore commonly the limiting nutrient to plant growth, hence of food supplies. Historically, nitrogen as a nutrient has come primarily from leguminous plants and animal manures on the farm, with a small component of nitrogen oxides from the atmosphere created during lightning strikes.

This understanding of the role of nitrogen in food production emerged in the late 19th century. It inspired the Germans Haber and Bosch to develop a commercial process for synthesis of ammonia from atmospheric nitrogen and hydrogen, which they achieved in 1913 using a process fuelled by coal. However, the initial ammonia production was used to manufacture explosives—without which World War I would not have been possible. Until 1913 guano imported

[12] This summary is based primarily on information from Vaclav Smil's excellent book *Enriching the Earth,* The MIT Press Cambridge Massachusetts, 2001.

[12] Only short stalks could support the heavy grain load.

from islands offshore from Peru had been the principal feedstock for the manufacture of both nitrogen fertilisers and explosive compounds for munitions[13].

During the 20th century the Haber-Bosch synthesis helped sever the traditional tight link between cropping and animal husbandry that had kept populations close to rural food sources. Increasing amounts of fixed nitrogen now travel, not only within individual countries, but also among nations and continents. Individual farms and agricultural regions, have ceased to be functional units within which the bulk of crop nutrients were kept cycling in traditional farming over centuries. Specialised cropping has emerged separated from specialised and concentrated animal production, with further specialisation in food processing, packaging and distribution to households.

Cheap transport fuelled by petroleum products has also made this transition possible. Food is now often transported more than 2,000 km to reach the dining room table. Both factors based on fossil fuels have made possible the quadrupling of world population over the last century and their migration to cities. Many adverse environmental consequences have followed.

Nitrogen fertilisers since 1950

The use of nitrogen fertilisers did not 'take-off' until after World War II, when significant process efficiency improvements and cost reductions were achieved in the USA, including switching to natural gas as the primary fuel. This coincided with the development of hybrid corn and grain varieties dependent on nitrogen fertilisers for high yields. The price of ammonia in 2000 at constant dollars was one-third of the 1950 price.

World consumption of nitrogen fertilisers increased from 4.8 M. tonnes N in 1950 to 11.3 Mt N in 1960, then to 31.6 Mt N in 1970, 60.6 Mt N in 1980 and 85.7 Mt N in 2000. High yielding short-stalked cultivars of corn, wheat and rice were introduced in Asia and elsewhere (the so-called 'Green' Revolution). Crop yields per hectare more than doubled, more than matching world population increase. Ammonia production increased from 4 Mt in 1950 to 129 Mt in 1998—but not all for fertilisers.

The energy input for ammonia production declined from 85 GJ/t of NH_3 in 1950 (coal route) to 26 GJ/t in 2000 from the best natural gas plants (average, 46 GJ/t.). Only 10 per cent is now produced from coal-fired plants, mostly small ones in India, Pakistan, China and South Africa. About 80 per cent of ammonia production uses natural gas as a fuel with steam reforming of the gas to produce hydrogen. This step has the biggest energy input. If all nitrogen fertilisers were manufactured via a natural gas route it would consume five per cent of world production.

Additional indirect and direct energy inputs are required for transport, storage and application of the fertilisers on farms. It requires nine times as much energy per tonne to produce nitrogen fertilisers as does the production of phosphorus and potassium fertilisers.

Nearly half of the nitrogen inputs to farming now come from nitrogen fertilisers, over 75 per cent with the most intensive farming practices. The rest is from natural sources. Direct application of ammonia to soils is used in the USA. However, urea (45 per cent N) is the world's leading N fertiliser and requires 35 per cent more energy per tonne N than does ammonia. North America, China, Indonesia, India and Pakistan are the world's largest producers of urea. Nitrogen fertilisers are now about 45 per cent of the world nitrogen cycling and represent a major transformation of the natural global nitrogen cycle.

Use of nitrogen fertilisers stagnated in the early 1990s due to decline in the former Soviet Union following the collapse of the Soviet Union and the curbing of over-use in Europe arising from farm subsidies. Low-income countries use of nitrogen fertilisers increased from seven percent of the world total in 1950 to 70 percent in 2000—a 180-fold increase in absolute terms. There is a wide variation within and between countries, with African countries using the least.

Global crop production would be halved without nitrogen fertilisers, but assessing the issue is complex. In 1996 low-income countries consumed 64 per cent of nitrogen fertilisers that provided half the nitrogen diet input for 2.2 billion people—but still with malnutrition problems. There is a wide variation within this group. Nitrogen fertiliser based food exports from affluent countries feed another 200 million people—bringing the total to 2.3 billion in poor countries. Their population has increased by about seven per cent since 1996.

However, the affluent countries have a higher than needed protein intake with a high proportion from grain-fed animal products (i.e. from feedlots). They could have an adequate diet with substantially reduced protein and meat consumption (obesity is a problem) freeing up significant grain to feed a hungry world. Average per capita food consumption in 1995 at 1900 crop productivity could only feed 2.4 billion people.

U.S. agriculture derives about 45 per cent of its total nitrogen supply from ammonia synthesis, but a large proportion of this goes to support food and feed exports and a high provision of animal foods. The U.S. is the largest exporter of agricultural products in history. During the 1990s 20-25 per cent of the corn harvest, one-third of soybeans, 40-50 per cent of wheat and rice production, and 10 per cent of meat production was exported. These exports contained one-third of the 10-11 Mt/year of nitrogen in the crop harvest.

About 70 per cent of the United States cereal and legume harvest is fed to animals to make available almost 75g of animal protein a day per capita. Meat protein is inherently more costly to produce than fat, with broiler chickens three times more efficient than cattle for converting grain nitrogen into meat protein. Pigs are in between while aquaculture (herbivorous fish) is the most efficient. Reducing per capita consumption of animal foods by one-third could cut U.S. nitrogen applications for domestically consumed food by about one quarter to 5.3-5.6 Mt N, cutting recent nitrogen applications in half. Even then average annual meat consumption would be high. Lowering the excessive waste of food would reduce this input even further, and adopting healthy traditional Mediterranean diets could reduce the dependence on N fertilisers even further. U.S. agriculture in the 1990s could have supplied a healthy diet to 250 million people without using any synthetic nitrogen compounds, but would cease to export food. The U.S. reliance on nitrogen fertilisers is not a matter of dire necessity.

China

By contrast China has an absolute dependence on nitrogen fertilisers. Its population has doubled to 1.3 billion since 1961. In the early 1970s China purchased 13 of the world's largest ammonia-urea complexes, and more followed. By 1990 China was the world's largest producer and consumer of these compounds. Now about 75 per cent of all nitrogen reaching Chinese farmland comes from nitrogen fertilisers with 90 per cent of its protein supply coming from domestically grown crops. Two-thirds of all nitrogen in China's food originates in the Haber-Bosch synthesis of ammonia. Plant foods are the main food source but consumption of animal products per capita has tripled since the early 1980s.

China is likely to add a further 300 million people by the mid-21st century and they will expect further improvements in their diet—more meat protein. Consumption of animal products from feedlots is growing rapidly as is aquaculture based on imports of soybeans from Brazil. But food imports cannot play a major role. Further intensification of cropping will be necessary, which is unthinkable without further substantial increases of average nitrogen applications.

These 300 million people will have to live somewhere and will occupy land that can only further reduce the available cropland. In addition the rapidly expanding urban population and car use will occupy more cropland for roads, parking and urban sprawl. If China reached Japan's car ownership rate of one car for very two people it would require paving of 130,000 km^2 of land for roads and parking (0.02 ha per vehicle). This is over half the land area devoted to rice cultivation, the principle food staple with production of 135 million tons per year[14]. Already the loss of agricultural land and water for irrigation is eroding China's capacity to grow grain, especially wheat. Smil's estimates probably under-estimate the crop yield intensification needed in China. *Soon China may be forced to import grain on a scale the world cannot provide.*

Other populated low-income, land-scarce countries absolute dependence on synthetic nitrogen fertilisers is also increasing rapidly. A large ammonia plant is under construction at Burrup Peninsula in Western Australia to service India's nitrogen fertilizer needs. Food distribution inequalities mean that protein malnutrition is widespread in these countries, especially in Africa.

Virtually the whole world population increase by 2050 is expected to occur in low-income land-scarce countries—up to three billion people. However, crop yields are showing a declining response to increased nutrient applications. These countries would have to use at least 85 per cent more nitrogen fertiliser than they do today—with a further increase to eliminate malnutrition. The Haber-Bosch process could be supplying 60 per cent of the nitrogen reaching world croplands, and its products would be indispensable for ensuring basic nutrition for some 60 per cent of the world's people.

While there is uncertainty and wide variations, about half of all nitrogen applied in inorganic fertilisers does not end up in crop tissues. Most of the losses are due to soil erosion, through denitrification leading to emissions of oxides of nitrogen (greenhouse gases), as well as leaching of nitrates to ground water and rivers. There are eutrophication consequences and disruption to ecosystems not accustomed to high nitrogen inputs. These intense cultivation practices also lead to depletion of soil organic matter and deterioration of soil structure, increasing the risk of soil erosion. In some poorly buffered soils high nitrogen inputs lead to acidification and mobilisation of heavy metals, with acid waters leaching into rivers and crop yields declining. Applications of lime are needed to counter the acidity, both from soils inherently acid prone and from nitrogen fertiliser application and legumes. This is now the case in many parts of Western Australia's wheatbelt with its nutrient deficient soils.

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[14] Brown, Lester R. 2004, *Outgrowing the Earth,* W.W. Norton & Company, New York. See also short items on www.earth-policy.org

Haber-Bosch synthesis of ammonia has made it possible to sever the traditionally tight link between cropping and animal husbandry, and to transport increasing quantities of fixed nitrogen not only within individual countries but also between nations and continents. This has given rise to dysfunctional nitrogen cycling. Individual farms, even whole agricultural regions, have ceased to be functional units within which the bulk of crop nutrients were kept cycling during centuries and millenia of traditional farming. Specialised cropping has emerged separated from equally specialised and concentrated animal production, with further separate specialisation in food processing and final distribution to households.

Long distance transport of fixed nitrogen fuelled by petroleum products has replaced this traditional pattern through imports of fertilisers, by export of food and concentrated feed crops for animal husbandry, and the export of meat, dairy and aquaculture products. These movements are significant on both national and international scales, as well as on the farm. About 30 per cent of the world's nitrogen fertiliser production is exported, plus about 15 per cent of all staple crops as well as 10 per cent of all meat. In addition there are significant internal movements within countries. These developments have made possible the migration of people to cities—soon half the world's population will live in cities dependent on significant transport components for their food supply from fertiliser factories to farms, on farms, from farms to food processors, then to retail centres and homes.

These transformations of food production and transport have impressive economies of scale, but they create significant environmental problems at both ends. Synthetic fertilisers can provide specialised mono-croping, but the reduced or completely absent recycling of organic wastes gradually lowers the concentration of the soil's organic matter and with it the rich population of microorganisms. There are undesirable consequences for soil quality, above all greater soil compaction resulting in worsened tilth, easier erodibility, lowered water-holding capacity, with weakened ability to support diverse soil biota and to buffer acid deposition. At the other end, it is increasingly difficult to dispose of nitrogen accumulation arising from concentrated meat production at feedlots that now contain thousands of animals. More efficient use of fertilisers and more rational diets with stabilised populations can reduce nitrogen applications and lower the burden on the biosphere.

The decline of North American indigenous oil and gas reserves has reached a stage when a far-reaching transformation may be imminent in the USA towards reduced nitrogen fertiliser consumption and less meat oriented diets, especially if it is to remain a major exporter of food[15]

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[15] Gever, John, Kaufmann, Robert, Skole, David, Vorosmarty, 1991. *Beyond Oil: the Threat to Food and Fuel in the Coming Decades,* University Press of Colorado. www.oilanalytics.org.

APPENDIX 7

FERTILISER AND AGRICULTURE IN AUSTRALIA ENERGY AND TRANSPORT IMPLICATIONS

BJ Fleay February 2006

BACKGROUND

Australia has the most nutrient deficient soils in the world, especially in the southwest corner of Western Australia. Present crop production only succeeds through extensive use of fertilisers. Grain cropping and dairy farming in Western Australia only became viable with the application of superphosphate. This was also dependent on mechanised crop production and on the construction of railways to transport the fertilisers to farms and the products to markets and ports for export. The role that trace nutrients play in plant nutrition was discovered in Western Australia in the 1930s (e.g. copper and zinc). These trace elements were added to superphosphate after World War II and made farming possible on the sandy soils from Geraldton to Esperance.

The introduction of legumes such as subterranean clover and lupins in the *higher rainfall zones* in the 1940s significantly improved crop yields and the protein content of cereals. Stock carrying capacity on pastures was trebled. This required applying superphosphate every year.

Use of nitrogen fertilisers began in Australia from 1960 and rose steadily to around 450,000 tonnes in 1990[16], then steeply to over 1.5 million tonnes in 2002[17]. Much of the growth in the 1990s was used to increase grain yields and protein content. There is growing concern on the adverse impacts of soil acidification arising from the use of nitrogen fertilisers and legumes. Crop yields decline significantly, ground water is acidified and metals are mobilised and then discharged into streams. In Western Australia lime and dolomite use has grown rapidly since the late 1980s to counter soil acidification. Nearly 900,000 tonnes was applied in 2002, and 200,000 tonnes per year of gypsum as a soil conditioner. The manufacture of nitrogen fertilisers is very energy intensive.

There is a significant transport component in delivering these fertilisers to farms and in applying them on farms, as well as in delivering farm products to local and world markets. The bulk of these inputs are delivered to farms by diesel fuelled road transport, whereas most of the grains are transported to local markets and ports by rail.

Australia currently produces about 30 million tonnes of wheat in an average season and exports around 75 per cent. About 40 per cent is grown in Western Australia. Australia produces enough food to feed up to 80 million people.

Such agriculture practices in Australia are more dependent on fertilisers than perhaps anywhere else in the world.

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[16] Grains Council of Australia 1995, *Milling Wheat Project; Inventing the Future*, prepared by Booz Allen & Hamilton (Australia) Ltd, p. 26.

[17] Australian Bureau of Statistics 2001-02, *Agricultural Commodities 7121.0*, *17*, p.29.

Fertiliser use and Australian agriculture

The table below shows the tonnes of mainly nitrogenous, phosphatic, potassium-based, compound and blended fertilisers used in Australia and W.A. for the years ended 30 June 2001 and 2002. **Lime, dolomite and gypsum usage** is shown as well[18]. The Australian Bureau of Statistics does not distinguish between the different types of nitrogen fertilisers, which contain variable proportions of active nitrogen. Nor does the ABS distinguish the components in compound and blended fertilisers. These may include phosphate fertilisers enriched with trace elements as well as nitrogen-phosphorus blends, among others. Most of the superphosphate is used to fertilise pastures. In Western Australia by far the major quantity of fertilisers are used for grain production and pastures in the wheatbelt. Further increases are possible, especially for lime, if farmers adopt Dept. of Agriculture recommendations.

Fertiliser used in Australia
thousand tonnes

Fertiliser	Australia		W. Australia 2002
	2001	2002	
Nitrogenous	1,289	1,560	399
Phosphate	1,450	1,782	428
Potassium	165	345	110
Compound & blended	2,146	1,782	495
Sub-total	**5.049**	**5.470**	**1,432**
Lime—acidity control	1,745	2.353	785
Dolomite	155	197	78
Gypsum—soil cond.	1.376	1,715	228
Sub-total	**3,277**	**4,266**	**1,091**
Grand Total	**8,326**	**9,736**	**2,523**

The use of nitrogen fertilisers in grain production has increased significantly since the early 1990s driven by concerns about the declining protein content of wheat and the desire to increase yields per hectare. The turning point was the Grain Council of Australia's 1995 report, *The Milling Wheat Project*, a response to fiercely competitive markets, declining production due to droughts, the low wheat yields per hectare and the long-term decline in protein content. In Western Australia there has been a rapid increase in the use of lime and dolomite to counter the adverse impact of soil acidification arising from use of legumes and nitrogen fertilisers, as well as in other acid-prone soils. The limestone is quarried at about 30 coastal sites between Geraldton and Esperance

Vaclav Smil says the average energy input for ammonia production in 2000 was 55 GJ/tonne as N with an additional 35 per cent for its conversion to urea (74 GJ/tonne as N). Urea contains 45 per cent nitrogen that translates into 33 GJ/tonne of embodied energy in urea. He says the typical energy cost of phosphorus in superphosphate (14 per cent P) is 30 GJ/tonne, or 4.5 GJ per tonne of superphosphate[19]. On this basis the energy input for the production of the nitrogen fertiliser used in W.A. in 2002 was 13.5 PJ and the corresponding figure for superphosphate was 2.1 PJ. If compound fertilisers, were primarily superphosphate there would be an additional 2.5 PJ, rising to 6.8 PJ extra if 30 per cent of the combined fertiliser was urea.

If the 2.5 million tonnes of fertiliser and lime is transported to farms by articulated trucks, say with an average haul of 165km, and a return trip equivalent to 75km for a fully laden truck, then the transport task amounts to 600 million tonne-km. Australian articulated trucks consume 1.2 MJ of

[18] Australian Bureau of Statistics 2001-02, *Agricultural Commodities 7121.0*, *17*, p.29.
[19] Smil, Vaclav, 2001, *Enriching the Earth; Fritz Haber, Carl Bosch, and the Transformation of World Food Production,* pp. 130-137, The MIT Press Cambridge, Massechusetts, London, England

fuel per tonne-km[20]. Thus this road transport task within Western Australia required 0.7 PJ (19.5 ML) of diesel fuel.

The total energy input for *production* of all the fertilisers used in W.A. in 2002, excluding lime quarrying, was possibly in the range of 18 to 23 PJ, depending on the composition of combined fertilisers. The energy content of the fuel needed for fertiliser transport within W.A. would be an additional 3-4 per cent. These fertiliser production and transport energy costs are equivalent to 500-640 ML of diesel.

There would be additional direct energy use in lime quarrying operations and in applying the fertilisers to the land on farms, mostly as diesel. Additional fossil fuel energy used in W.A. agriculture would be embodied in the provision of vehicles, machinery, road infrastructure, the provision of diesel fuel, herbicides, labour and other services.

The total energy inputs embodied in the fertilisers must now be one of the largest components of fossil fuel energy going into farm production in W.A.

Food system embodied energy

Muriel Watt made a comprehensive study of the fossil energy input into the Australian food system for 1974-75[21]. She studied energy inputs from farms to dining room tables, including for transport of food to coastal ports for export. Total energy inputs were 567 PJ of which 40 per cent was indirect energy embodied in inputs (58 per cent of this was on farms) and 60 per cent was primary energy. 31 per cent of energy was consumed on farms, 23 per cent in food processing, 9 per cent in retailing and 37 per cent in households. Based on Watt's study transport in 1974-75 consumed 88 PJ or 15 per cent of primary energy use in the food system[22].

There has been a fifteen-fold increase (1.4 million tonnes) in the use of nitrogen fertilisers in Australia since 1975, equivalent to an additional 54 PJ of energy input to the 1974-75 food system from the manufacture of nitrogen fertilisers alone, or about 10 per cent. On farms this comprises a 50 per cent increase in the energy embodied in inputs to agriculture since 1975.

There is a need for contemporary energy input-output studies of the Australian food system along the lines of that by Muriel Watt. Such studies should include the embodied energy components in transport infrastructure, vehicle provision and servicing, financial and government services.

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APPENDIX 8

HOW MUCH TRANSPORT TO GET CEREAL TO THE BREAKFAST TABLE?

Brian Fleay April 2005

Breakfast cereal was once manufactured in North Fremantle using West Australian grain. Now it comes from factories in Sydney and Melbourne with a long transport chain from farms to cereal factory and from the factory to supermarkets. Buyers travel between their homes and supermarkets to shop. Which are the most transport intensive segments in this supply chain?

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[20] Laird, P., Newman, P., Bachels, M. Kenworthy, J. 2001, *Back on Track; Rethinking Transport Policy in Australia and New Zealand,* University of New South Wales Press. Derived from Tables A8 and A10, p.182. 1ML of diesel = 0.036PJ.

[21] Watt, Muriel 1982, *An Energy Analysis of the Australian Food System,* Thesis, Murdoch University, Western Australia.

[22] Fleay, Brian J. 1995, *Decline of the Age of Oil,* Pluto Press, Sydney, p. 119 & 121.

For simplicity we will assume grain is transported from farms in NSW to a cereal factory in Sydney, then transport of the cereal from Sydney to supermarkets in Perth via a warehouse with buyers traveling by car between homes and supermarkets in Perth. We will estimate the distance traveled per tonne of grain and fuel used per tonne for each transport segment. The details for each transport segment are described in the Table below. The estimates are based on a similar study by the World Business Council, *Mobility 2001 at the end of the twentieth century and its sustainability,* p.6-18 www.wbcsdmobility.org. The table below summarises the outcome:

Transport segments

TRIPS	Distance km	Load tonnes	Litres fuel	Km per tonne	Litre per tonne
Farm to railway yard by truck	30	10	10	3	1
Rail to Sydney terminal, 90t hopper car	200	90	90	2.2	1
Sydney, by road to and from factory	20	20	8	1	0.4
Rail, Sydney to Perth, Kewdale yard	3,500	30	800	115	27
Road, Kewdale yard to Supermart	35	15	12	2.3	0.8
Sub-total	-	-	-	***123***	***30***
Cars, Home-Supermarket-Home	***400***	***1***	***33***	***400***	***33***
TOTAL	**-**	**-**	**-**	**523**	**63**

Trip Descriptions

- Movement of grain in 10 tonne truckloads from NSW farms 30 km to a rural rail terminal (3 km/tonne @ 3.4 km/litre, or 10 litres of fuel for the trip, or 1 litre/tonne).
- Rail transport in 90 tonne wagons 200 km to a Sydney rail grain terminal (2.2 km/tonne @ 5 litres of fuel per 1,000 tonne-km—90 litres, or 1/litre/tonne for the trip).
- Road transport within Sydney for grain from the rail terminal to a cereal factory and return to rail terminal with packaged cereal—20 tonne loads and 20 km for the return trip (1 km/tonne @ 2.5 km/litre—8 litres of fuel, or 0.4 litres/tonne).
- Rail transport of the 1 kg cereal packages in seatainers 3,500 km from Sydney to Perth terminal at Kewdale (30 tonnes cereal net per rail wagon, 115 km/tonne @ 8 litres of fuel per 1,000 tonne-km—800 litres, or 27 litres/tonne).
- Road transport from Kewdale to supermarkets via a warehouse (two trips)—15 tonne loads net for 35 km (2.3 km/tonne—12 litres of fuel, or 0.8 litres/tonne)
- Buyers 8 km return car trip between home and supermarket to buy one 1 kg packet of cereal (1,000 trips for 1 tonne—8,000 km/tonne @12 km/litre = 670 litres of fuel. **Allocate 5% of each trip to the cereal purchase = 400 km/tonne using 33 litres of fuel).**

Comment

These estimates should be taken as indicative only as they are dependent on important generalisations and assumptions made. Varying some of the parameters would give an indication of the range of values. Nevertheless they do suggest that car trips by customers to supermarkets dominate the transport task in getting foodstuffs from farms to households, even when the product is transported from one side of the continent to the other. There is additional transport on farms and upstream of farms to deliver goods and services to farms.

It reinforces the urgent need for transport/energy assessments of the entire food supply chain from farm inputs to the kitchen table. Transport chains are becoming exceptionally long and energy intensive (petroleum based fuels) and vulnerable to disruption with dire consequences.