



World Oil Supply Peaks Next Decade – New Transport Research Priorities

Brian Fleay

Associate, Institute of Science & Technology Policy, Murdoch University, Western Australia

Abstract

The world reduced dependence on Middle East oil after the 1970's oil crises by developing supplies in the North Sea, Alaska and Mexico, by substituting coal and natural gas and by pursuing energy efficiency. This strategy has run its course.

The world has been sufficiently explored for reliable estimates of ultimate recovery of conventional oil to be made. Discovery peaked in 1962 and is now one quarter of annual production. Conventional oil production outside the major Persian Gulf producers is expected to peak around 2000-1, followed by the world peak around 2010.

Australia's oil self-sufficiency will rapidly decline next decade with negligible local production from 2025. Natural gas is the main substitute fuel for transport and agriculture in the transition to an age "beyond petroleum".

Salinity issues and petroleum dependence means agriculture must get first call on remaining petroleum.

The rationale for these conclusions is summarised and some priorities for research and scenario development are outlined below.

- Transforming traffic forecasting methods with future fuel prospects as the central focus.
- Agriculture, mining and essential freight traffic has first call on remaining oil. Urban car travel must bear the brunt of oil's decline. What are the implications?
- Alternatives to petroleum fuels, their economic and transport prospects.
- The role and priority of natural gas as a transition transport fuel.
- The future for lubricating oil, bitumen and alternatives for road construction.
- Enhancing the role of walking and cycling in urban areas.
- The implications for both international and national trade and the global economy.
- The changed economics for road versus rail versus sea.
- The future of commercial aviation and tourism.
- The human, social and psychological dimensions of the greatest transformation our species has faced.
- The planning strategies needed and the role to be played by appropriate agencies.

Contact Author

Brian Fleay

59 View Street

North Perth WA 6006

Phone: +61 8 9328 7065

Fax: +61 8 9328 7065

e-mail: bfleay@inet.net.au

Introduction

Transport consumes over 60 per cent of the world's oil. The industry avoids discussion on the long term availability of petroleum products which power most transport. The industry assumes that petroleum products will continue to be available in increasing quantities. The electric power industry never makes this assumption for its fuels. Fuel availability for the life of a power plant is always a major issue.

One reason for this blindness is the wild claims made in the 1970's that oil was rapidly running out. By the mid-1980's these claims appeared to lack validity and to confirm economists views that shortages would cause prices to rise, new supply would be found and alternatives emerge. Only the bold and the rash warned of oil's imminent decline. There seemed to be vast unexplored territory and the world was awash with oil.

An added difficulty has been confusion and uncertainty on how much oil has been found and the rate of discovery. Oil occurs deep underground in irregular geological formations and it is difficult to judge how much extractable oil has been found. There are no rigorous standards for defining oil or assessing and reporting reserves. Secrecy and a lack of transparency prevails and independent, honest auditing is uncommon. Few have access to the data needed and most is confidential. Oil is power!

Therefore responsible people find it expedient to avoid asking these dangerous questions. Traditionally bearers of bad tidings have been put to the sword!

This situation has changed dramatically in the 1990's. The database is now adequate to answer these questions, the uncertainty is diminishing. The best informed parts of the petroleum industry have been galvanised into action, mostly by supporting retired petroleum geologists who have the freedom to speak unencumbered by corporate or government agency constraints. Major petroleum companies can no longer ignore the reality they face.

The cheap oil that powers our transport and agriculture systems will peak during the coming decade, oil the most economically effective of the fossil fuels, the one most suited to power transport.

Background

The discussion below draws extensively on Fleay (1999).

US oil production in the lower 48 states peaked in 1970 allowing the Middle East producers to use oil as a political weapon in the Israeli-Palestinian dispute. We had the 1970's oil crises. There was never an oil shortage and large discoveries in Alaska, the North Sea, Mexico and elsewhere were waiting in the sidelines. Cumulative consumption to 1973 was only 250 billion barrels, one eighth of the ultimate oil endowment. Ignorance was widespread on energy resources and the connections between energy and economics. The crises were about politics and power.

The industrialised countries reacted by minimising their use of Middle East oil, the world's cheapest. Expensive oil elsewhere was developed and gas and coal were substituted for many uses of oil. There were advances in energy efficiency and interest in renewable energy blossomed.

Economic growth slowed and consumption declined by 10 per cent between 1979 and 1986. A huge 35 per cent supply excess developed by 1984 and high oil prices collapsed in 1986. 1990's oil consumption has reached the highest levels ever despite its halving in the former Soviet Union.

The excess was nearly all back in production by the late 1990's and another 600 billion barrels has been consumed. We are about two years away from consuming half the world's endowment of cheap-to-produce conventional oil and from the peaking of non-Middle East production.

The Middle East has nearly 60 per cent of the world's remaining oil, but only produces 30 per cent. Only this region can expand production cheaply to offset declining oil fields elsewhere and cater for consumption growth, but only for another 8-10 years after which permanent decline of conventional oil should begin. By 2010 the Middle East will be producing 45-50 per cent of the world's oil.

There are no Alaskas or North Seas waiting in the sidelines.

Interpreting the data base

The world is now sufficiently explored for reliable estimates of ultimate recovery of conventional oil to be made and the timing of the production peak estimated. Three retired petroleum geologists, Colin Campbell and Jean Laherrere from Europe and L.F. Ivanhoe from the US, are leading the debate on this issue in oil industry circles. Campbell and Laherrere are backed by Petroconsultants, leading Geneva-based petroleum industry consultants, who possess the only comprehensive data base on the performance history of the world's significant oil fields. No other analysts have ever had this luxury available to them.

Hydrocarbons range from natural gas, through light and heavy liquids to solid tars and bitumens. However, the light free-flowing oils comprise over 95 per cent of production, about 60 per cent comes from a few giant sized oil fields mostly at very low cost. This is known as *conventional oil* and includes increased yields obtained by water flooding and gas pressurisation to force out more of the oil-in-place.

This oil powers our contemporary transport, agriculture and industrial systems.

By contrast, *non-conventional oil* is derived mainly from tars, bitumens, heavy oils and shales and is expensive to produce. Tars, bitumen and shales are mined, then heated and processed with chemicals to produce an oil which requires further refining to produce the equivalent of crude oil. Heavy oils require fluidising in situ by steam or chemicals to permit extraction in the normal way.

The massive scale of these operations, their high energy consumption and environmental problems work against significant cost reduction. The energy consumed in production is high, the net energy yield is very low whereas that from most giant oil fields in their prime years is very high. Fleay (1999) discusses the constraints to producing oil from tar sands and shale oil; net energy yield and the connections between energy, ecology and economics. He introduces the concept of energy profit ratio (EPR), a measure of the economic quality of a fuel from an energy perspective. EPR is the ratio of the

energy content of a fuel divided by the direct and indirect energy consumed in producing it, the higher the ratio the more economically useful is the fuel

Oil is hidden in geological formations and only statistical estimates of oil-in-place and of the percentage that can be economically extracted can be made. There are no enforceable international standards on definitions, assessment and reporting of reserves. Reporters can choose criteria to suit their convenience. The art of good marketing is never to tell a lie, but never tell all the truth. Hence reported reserves data must be regarded first of all as political statements and interpreted with care.

A feature of Campbell and Laherrere's work is their rigorous attention to the correct use of statistics and their critique of the failings of others, backed up by access to Petroconsultants database. Consequently the authors of earlier estimates of oil reserves are being forced to revise them downwards. A consensus is converging on the 1800 to 2100 billion barrels range for ultimate production. These and other issues are well covered in Campbell and Laherrere (1995), Campbell (1997) and Fleay (1999). See also Campbell and Laherrere (1998).

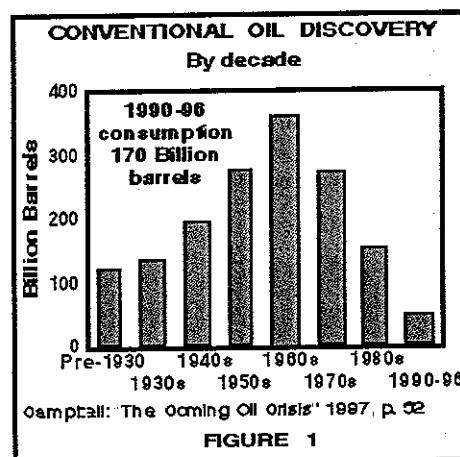
Discovery

Figure 1 shows conventional oil discovery to 1996 by decade. Discovery peaked in the early 1960's, has been below annual production since 1980 and is now less than one quarter of annual production. Only a limited amount is left to find and confident estimates of ultimate discovery can now be made.

Campbell and Laherrere (1995) p 1 say over 60 per cent of conventional oil has been found in 360 giant oil fields, less than one per cent of all fields. Giant fields held more than 500 million barrels on discovery and sophisticated techniques are not needed to discover them. They are usually found first because they are large, produce the cheapest oil and have a long life. About 2-400 billion barrels remains to be found

The wave of exploration after the 1970's oil crises did not find any new major petroleum provinces, despite exploration reaching new heights of technical sophistication and efficiency. Giant discovery peaked in the early 1960's and has slumped since 1980, Figure 2. Few giants are left to discover (Campbell 1997, p 28).

Most conventional oil has been and will continue to come from giant oil fields. Fields found more than 20 years ago produce 90 per cent of today's oil and 70 per cent comes from fields over 30 years old (Campbell and Laherrere 1995, p. 13). Most are ageing and many are in decline. The biggest and least depleted of the giants are in the Middle East



In these presentations revisions of reserve estimates in fields discovered years ago are backdated to the year of discovery. Most published data for annual changes in reserves include both revisions of reserves in previously discovered fields as well as new

discoveries. Revisions account for three quarters of additions to reserves since 1980, giving a misleading picture on the quantity of new oil actually being discovered. See Figure 3 in Fleay (1999) p 10. Backdating focuses on current discovery rates.

Enhanced recovery

Most oil fields yield about 35 per cent of the oil-in-place and the best achieve 60 per cent while in the more free-flowing natural gas fields yield is up to 80%. Some say that enhanced recovery techniques can increase oil yields. These techniques include steam flooding, injection of miscible fluids and fracturing the formation, i.e. changing the physical properties of the oil and of the formation, all inherently expensive and energy intensive operations. However, lower yields are mostly from fields with heavy viscous oils and/or tight formations while high yields occur where the oil is light and free flowing, or the formation porous, the main reasons for variations in yield.

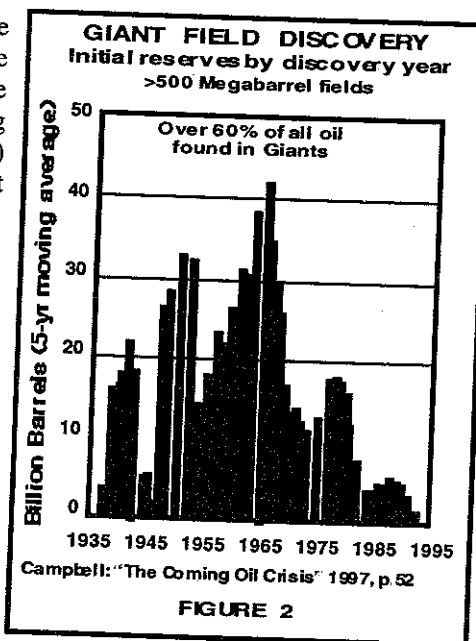
Campbell (1997, pp. 69-75) says many yield increases attributed to enhanced recovery are statistical artefacts. The increase is partly due to a change in reporting of reserves from say low 90 per cent probability estimates to ones closer to the median which statistically is close to the most likely figure.

Enhanced recovery is mostly in the non-conventional class based on cost and low net energy yields.

World production profiles

US petroleum geologist, MK Hubbert, pioneered the use of the logistic equation to describe discovery and production profiles in major petroleum provinces. In 1956 he successfully predicted the time and magnitude of the 1970 peak of US oil production in the lower 48 States.

Production and discovery profiles are normally bell-shaped for oil provinces and the peaks normally occur near the mid-point of ultimate production or discovery. Laherrere has extended the use of the logistic equation to those situations which have multiple peaks of discovery and production. He breaks the multi-peaked curve into the sum of several bell-shaped Hubbert curves each reflecting different phases of discovery and development.



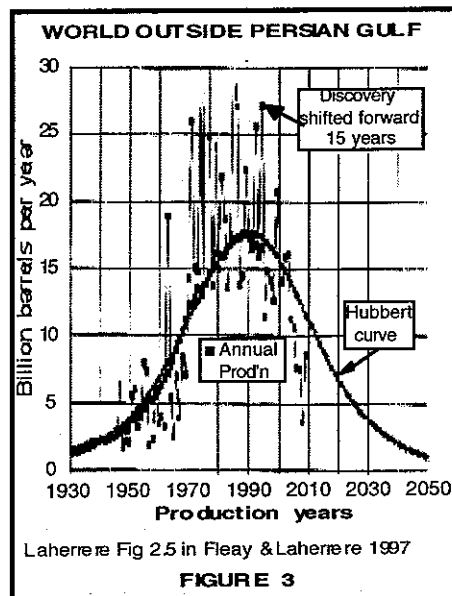


FIGURE 3

the mid-point of production to about 2006-7. Political and economic events will have a major influence on the pattern of Middle East oil development. Predictions would be hazardous.

The International Energy Agency (IEA) has adopted Campbell and Laherrere's views that physical constraints ultimately limit the amount of oil that can be produced (Campbell 1998). A report to the G8 Energy Ministers' March 1998 Summit accepted evidence on physical oil field performance that conventional oil production outside the Middle East would peak about year 2000 with a world peak about 2013, based on US Geological Survey estimates of ultimate extraction of 2300 billion barrels (IEA 1998). Campbell (1998) says the US Geological Survey is revising this estimate down to 2078 billion barrels, equivalent to a mid-point of about 2006-7.

However, the IEA's report claims without supporting evidence that non-conventional oil can replace declining conventional oil.

The next decade should see the transition through the peak of world oil production. According to Campbell and Laherrere (1995) decline thereafter will be exponential with supply halving about every 25 years, based on oil field performance data in Petroconsultants database.

Natural gas

Campbell, Perrodon and Laherrere (1996) estimated that ultimate production of the world's conventional natural gas would be 265 terra cubic metres with about one quarter produced by 1995. They say earlier estimates range from about 285 to 345 terra cubic metres. Discovery and assessment of natural gas has yet to reach the mature stage of oil. The former USSR had 38 per cent of the world's original natural gas endowment, mostly in the Russian Federation and 28 per cent is in the Middle East.

Figure 3 illustrates these points for conventional oil outside the Persian Gulf. The discovery plot has been shifted forward 15 years to illustrate how the production profile to 1995 mimics the discovery profile with a 15 year time lag. A Hubbert curve from 1930 to 2050 is also plotted for an ultimate production of 986 billion barrels, consistent with Campbell & Laherrere's 1800 billion barrels ultimate world production estimate.

Figure 4 shows actual production to date and future estimates by Campbell and Laherrere (1998) for the world and some major producing regions. The curves for the world and the Middle East region are double peaked reflecting the impact of the 1970's oil crises. Increasing the world ultimate to 2100 billion barrels only shifts

Peak production, the mid-point, is likely between 2025 and 2035. The IEA (1998a) estimates that production in North America, Europe and the Asian regions will peak between 2010-20. See Fleay (1999) for further comment and the relationships with population and feeding the world.

Australian oil and gas

The Australian Geological Survey Organisation's (AGSO) estimates of crude oil and condensate production to 2010 (AGSO 1998) are compared to forecast consumption in Figure 5. Condensate is liquid stripped from natural gas. Production is expected to peak in 1999 and decline rapidly thereafter. At April 1999 oil prices and exchange rates net oil imports in 1999 are likely to be 40 million barrels costing \$1000 million and 200 million barrels in 2010 for \$5000 million. Oil prices are likely to be higher in 2010 and who knows what the exchange rate might be. The Bureau of Resource Sciences (1996) p 75 says about half of Australia's ultimate oil production has been produced.

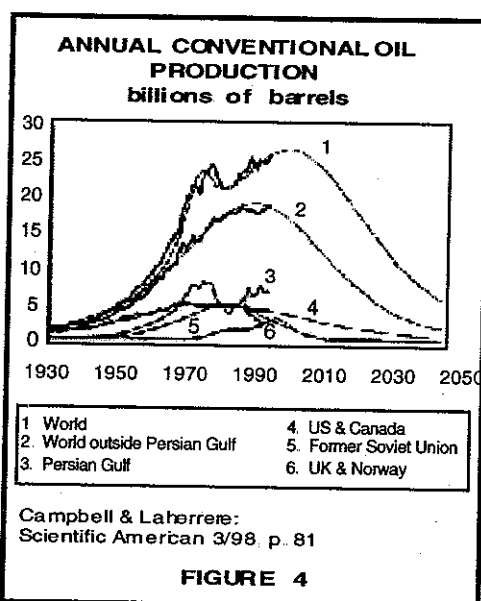
Australia's oil production will be negligible by 2030 and confined to some condensate at a time when world production is likely to be 60 per cent of present levels. The Timor Sea province is the least explored and operations are expensive due to ocean depths and distance offshore. Discoveries must be shared with Indonesia and the political situation there is inhibiting investment.

Only giant sized oil field discoveries can change this perspective. Australia's only two giants were discovered in the 1970's in Bass Strait.

Australia's crude oils are light and have a low yield of bitumen and lubricating oil. Some oil is exported and heavier Middle East crudes imported, partly for commercial reasons and partly to improve refinery yields of these products. Supply problems for bitumen and lubricating oil could arise after 2010.

The Bureau of Resource Sciences (1996) p 75 estimated that Australia's ultimate endowment of conventional gas was four times greater than for oil on an energy equivalent basis. So far nine per cent of this gas has been produced and nearly 80 per cent is off the north west coast of WA. However, 12 per cent is well off shore in deep water and will be expensive to develop.

Our natural gas endowment is smaller than people think and it is the only fuel we have to operate our present transport and agricultural systems from 2010. It must not be squandered.

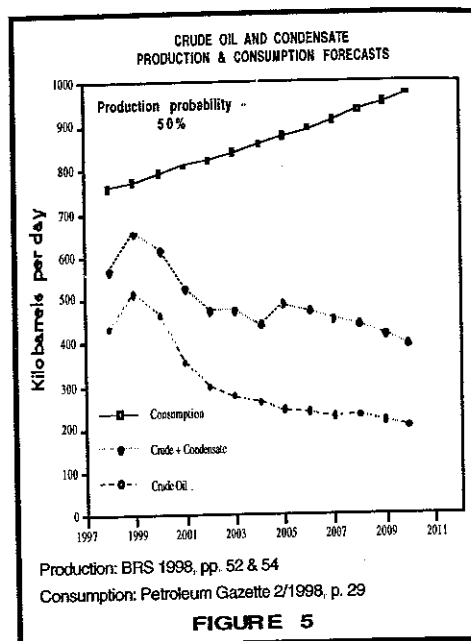


Conversion of diesel powered equipment to natural gas should commence immediately.

The transition begins

Oil prices collapsed in 1986 putting oil companies through the financial ringer. Cost cutting and downsizing in exploration and oil field development became the order of the day. Furthermore, this activity has been confined to the marginal high cost world outside the Middle East. Organisation of Petroleum Exporting Countries (OPEC) finances have likewise been savaged, the Arab billions have shrunk dramatically.

From 1986 over 60 per cent of consumption growth and production replacement in declining fields came from wells shut down in the 1980's when supply exceeded demand. This surplus was nearly all back in production by 1996 and the industry now does not have the physical and financial resources to develop sufficient new capacity in the high cost world outside the Middle East.



Warm northern winters and Asia's economic meltdown in 1997 reduced consumption growth leading to record low oil prices in 1998, compounding these problems and stretching the budgets of OPEC countries. Exploration and development budgets were slashed forcing companies to merge, eg BP-AMOCO-ARCO and Exxon-Mobil (Petroleum Review 1999). Saudi Arabia borrowed US\$5 billion to balance its budget.

Oil buyers only look at the supply - demand balance 12 months ahead. Developing new supply takes 5-7 years work and demand expectations to 2005 and beyond are uncertain. The present supply surplus is not large.

Saudi Arabia has two million barrels per day excess capacity and OPEC seven. Saudi's Sheik Yamani in an address to the Institute of Petroleum in London last year said that Middle East producers, by keeping prices down, could shift production, exploration and new development to the low cost Middle East and inhibit energy conservation programs in the rest of the world (Petroleum Review 1999a). Production and development costs in most of the Middle East are one-third to one-fifth of those in the rest of the world.

Such a development would be at the expense of the multi-national oil companies. The West Australian (1999) reported that these countries were negotiating with selected companies to develop new production and refurbish existing oil wells, but on their terms.

The major oil companies face contraction. Suddenly upstream petroleum investments outside the Middle East have a significantly higher risk.

The industrialised world's 20 year strategy to minimise dependence on Middle East oil has run its course. Only this region can provide additional new supply and then only until around 2010 when world conventional oil production is also expected to decline.

Duncan (1999) assessed world per capita energy production from 1850 to 1995 (coal, oil, natural gas, hydro and nuclear electricity). He found production grew by 2.12 per cent from 1850 to 1940 when coal was the main fuel, 3.54 per cent from 1945 to 1973 when oil displaced coal, natural gas production began and most hydro electricity development occurred. However, since 1973 a plateau has been reached, there has been no increase in per capita energy production. Will the next decade see decline begin?

This time, unlike in the 1970's, the world has to face the consequences of oil depletion. By 2050 the Golden Age of Oil will be over.

Alternative fuels for transport

Present petroleum products are unique because of their high power-weight ratio, the fine control possible (eg diesel injectors) and their ease of storage and transport. That is why these fuels power over 90 per cent of all transport. Furthermore, the net energy yield of oil from giant fields in their prime is extremely high compared to any alternative fuel. The net energy yield from oil will decrease post-peak as oil fields age (Fleay 1999, pp. 32-37).

Natural gas is the best substitute for transport followed by electricity which has inferior storage and transport characteristics but is superior in converting energy into motion. Electricity's net energy yield is lower than for most petroleum products. Coal is an inferior transport fuel to all the others.

Hence there are no equivalent transport fuels to replace petroleum products, either in quantity or economic quality. It follows that the real cost of transport is going to increase early next century. A decline in the scale and scope of transport is inevitable (Fleay 1999 pp. 45-46).

We are at the climax of the fossil fuel age. Natural gas is the critical transition fuel to see Australian transport and agriculture through to an era "beyond petroleum".

Consequences of declining oil

Most mining and excavation operations are diesel powered, involve transport and often use hydrocarbon fuels for processing ores. The economics of these activities will be adversely affected by the decline of petroleum fuels.

About half the world's population is now fed from enhanced crop yields obtained by using hybrid grain varieties to replace traditional seeds, the Green Revolution. But only by use of nitrogen fertilisers manufactured from natural gas. There has been a nine fold increase in the use of synthetic nitrogen fertilisers since 1960, mostly in Asia.

The world's population must halve before the end of next century while reserving enough natural gas and oil for fertiliser manufacture, distribution and use over that period. In addition a sustained international effort to combat the severe degradation of the world's agricultural land is required.

Industrial agriculture in Australia has been described as a way of converting petroleum into food. Fertilisers, mechanised cropping, herbicides, food processing and transport networks all require petroleum inputs. Severe degradation of our nutrient deficient soils is occurring, including massive dry land salinisation in Southern Australia due to clearing of the land.

Western Australian experience demonstrates that halting of salinisation requires radical changes to agricultural practices that mimic the water using characteristics of the original vegetation on a catchment wide scale. These need tailoring to suit the sub surface geological conditions, site specific multiple solutions are required. The draft WA Salinity Action Plan is built around these concepts (SSC 1998).

A problem of similar dimensions is emerging in the Murray-Darling Basin posing a potential threat to South Australia's irrigated agriculture and public water supply.

160,000 sq km of land will become saline under present unsustainable farming practices. Saline ground waters are damaging buildings, roads and other infrastructure. The annual cost for roads is \$9 million in NSW. In WA 230 km of roads are affected, likely to double in 10-20 years and cost \$50-100 million over that period (PMSE&IC 1999, p. 6).

But farmers must also embrace the transition to an agriculture "beyond Petroleum". A radical transformation is inevitable and a contraction of cereal cropping is likely. Present European style broad acre farming practices are not sustainable in most of Australia.

The combined impact of declining oil and salinisation will have a major impact on the transport needs of rural Australia. The future is not clear.

This transformation will take decades and must have first priority for our remaining petroleum fuels which are vital to the development of the new agriculture. Hybrid petrol-electric vehicles and similar technologies will stretch out petroleum fuels, but no more than that.

Cars are the most expensive, inefficient and energy consuming transport mode for urban passenger travel. In addition there is noise, air pollution, congestion, a profligate consumption of land and a high human and property cost in accidents. The public is now mounting strong challenges to such car dependency in favour of public transport.

Add the argument of oil depletion and the reasons for change are compelling. Given the problems our agriculture faces it is unquestionable that urban car travel must bear the brunt of declining oil supply, a decline that begins in Australia this year.

The definitive work on this subject is by Newman and Kenworthy (1999), *Sustainability and Cities: Overcoming Automobile Dependence*. Their book takes account of oil depletion as described in this paper. They concluded that reducing car dependence in favour of electric transit and changed land use patterns was the key strategy for cities to become more sustainable. Their principal conclusions from a comprehensive study of 46 cities around the world were:

- Private transport energy use per capita is inversely proportional to population density by a factor of up to six to one.
- High urban density and the priority of transit over roads and car orientation were strongly correlated.
- More persons walked or rode bicycles to work in cities with high urban density.
- High mobility is not necessarily related to city wealth. Data suggests that cities with high wealth are associated with lower mobility (ie transit rather than car orientated). There is a need to distinguish between mobility and access.
- Car orientated cities spent a higher proportion of their wealth on journeys to work.
- Car orientated cities spent a higher proportion of their wealth on passenger transportation. The range was under 5 per cent for wealthy Asian cities to 8 per cent in European cities and 12-13 per cent for car based US and Australian cities. Perth was the highest at 17 per cent, the classic case of urban sprawl.
- Low density cities spent more of their wealth on passenger transportation than high density cities.
- Greenhouse gas emissions and other air pollutants per capita are higher in car orientated cities.
- Kilometres travelled per capita and travel time in car oriented cities is high and increasing, offsetting gains in higher speeds, fuel efficiency and lower exhaust emissions from freeway travel.
- Fare box return covers a higher proportion of transit costs in transit orientated cities than in car based ones.
- Transport energy consumption in transit orientated cities (electricity) is about half that in car orientated cities (petrol).

Sustained Federal and State leadership is required to manage urban restructuring over the long term with an agenda to match the expected decline of oil. The social, equity and human dimension of intense and sustained change need addressing. A caring and cooperative approach that facilitates the restructuring of work and businesses associated with the car economy is needed to maintain social cohesion and strengthen community spirit.

Contraction of the global economy will begin early next century as transport becomes more expensive. Only a remnant will remain by the middle of the century. A global economy requires cheap transport.

The main focus of economic activity will shift to reducing total resource and energy consumption by first pursuing resource and energy use efficiency at the local level. Concurrently the economy and communities will have to be restructured to thrive on local resources as far as possible, to build systems that need less consumption and recycle resources efficiently, to live better lives by consuming less. The latter systems approach must be the main response.

Work will become more labour intensive. Increasing labour productivity by applying energy to labour will diminish. Labour is not scarce. It is high quality resources and energy that are scarce.

Declining oil, strategic assessments and research priorities

We face the greatest transformation of human affairs since the steam age began in the late 18th century. Indeed a transformation as great as occurred with the beginning of agriculture 5000 years ago. These previous episodes ushered in an expansion of human population and an increase in resource consumption. However, this third transformation involves a reduction in population and resource consumption compressed into a much shorter time frame. Our human capacity to adjust in a fair and compassionate way with minimum damage to the planet's other life forms and support systems will be taxed to the limit.

The situation we face is unique in another way. Oil and natural gas are central to our industrial culture. Because these occur in geological formations we know how much will be available for the next 50 years, in the absence of extreme political and economic upsets. The physical characteristics of oil fields will control production. There is a timetable, an agenda that we have to work to.

We need to assess the boundary conditions and options open to us. Some issues with a transport focus are outlined below. The list contains many contradictions and incompatibilities. However, its purpose is to stimulate action. The inconsistencies will be resolved by action.

In the discussion below the short term means the next 10 years, medium term 10 to 25 years ahead and long term is beyond 2025.

An independent broadly based Commonwealth planning agency is needed to develop programs for petroleum demand management and structural change to progressively end dependence on petroleum fuels, oil first and then natural gas. Social and economic adjustment issues are central to this task.

General issues of significance for transport

Economic quality of petroleum resources: Estimate the life cycle energy profit ratio (EPR) profiles for Australia's oil, gas and coal resources and the direction these are heading. We need a realistic picture of what useful economic work our remaining fossil fuels will be able to achieve, their net energy yield.

Relate petroleum royalties to EPR: Use EPR estimates of oil and gas development projects as the central criteria for royalty charges aimed at preventing the development of petroleum resources with unacceptably low net energy yield.

Develop EPR criteria for energy efficiency projects: The energy saved by energy efficiency and conservation measures must be greater than the energy consumed in implementing these measures. Fuel types are also important.

Oil import prospects: Make high, medium and low estimates of the prospects for oil imports in the short and medium term in an environment of declining world production. The prospects for stable imports in the long term are negligible.

Transport implications of major restructuring of agriculture: Develop several short, medium and long term scenarios with rural communities and the community generally.

on the transport implications of combating salinity and shifting agriculture away from dependence on petroleum.

Petroleum priority for agriculture: It is essential that agriculture's transformation succeeds and it will take time and experimentation. Petroleum fuels are indispensable to this transformation. Research is needed into the meaning of this priority and the implications across a wide range of economic, social, pricing and other criteria.

Trade and the global economy: Scenarios on the contraction of the global economy and the consequences for trade are needed.

Population and agriculture: Australian agriculture feeds a population of 60-80 million people. This is certainly going to reduce, but by how much? Flannery (1994) says Australia can only support 12 million people in the long term. There are major transport implications. A range of population scenarios is required.

Balance of Payments: Increasing oil imports will adversely impact on our balance of payments. The farmers response to the salinity problem could reduce grain exports, impacting on the balance of payments.

There is 25 per cent excess capacity in world car manufacturing and the biggest manufacturers have initiated the most significant technological shift in the industry's history, viz. petrol-electric hybrid cars then possibly fuel cell powered vehicles. The number of manufacturers is likely to fall from 17 to under 10 by 2005 (Economist 1997 & 1999). What are the consequences for Australia's car manufacturing industry? If it contracts vehicle imports could increase substantially. Scenarios exploring the impact on the balance of payments are needed.

Alternative transport fuels, bitumen and lubricating oil

Natural Gas: Develop an action plan to shift road land transport from oil based fuels to natural gas by 2015. Appropriate supporting legislation, tax and fuel excise changes may be needed.

Hybrid cars and fuel cells: Hybrid petrol-electric vehicles will soon be on the market (eg Toyota's Prius) and possibly fuel cells next decade. Potential fuels are hydrogen, methanol, natural gas and petrol, each with different net energy yields. However, significant improvements in km per litre appear to be possible, but the purchase price of vehicles may be higher.

Research is needed into the likely rate these vehicles will be introduced, their affordability and the consequent impact on fuel consumption and oil imports.

Bitumen and lubricating oil. Both are residuals obtained from heavy crude oil fractions in refineries. Australian crudes are light and have insufficient heavy fractions to produce enough bitumen and lubricating oil. About one-third of local crude is exported and replaced by heavier Middle East crudes for this and other commercial reasons - light crudes command a premium price. In the medium term the prospects for crude oil imports will deteriorate. Research is needed to confirm there is a problem, identify its magnitude and timing and to consider options.

Australian oil refineries: There are nine refineries owned by four companies with output close to Australian consumption and operating at low profit levels in competition with imports. Crude oil supply will decline from the medium term and it is debatable what refineries will remain in 2025.

Scenarios need evaluating for the orderly decline of the industry in ways that are not disruptive to transport, leaving the country stranded.

Petroleum product wholesale and retail trades: These trades are in constant conflict with the refiners and major oil companies. Rationalisation of the number of service stations is occurring. From the medium term further contraction will occur due to declining petrol and diesel availability, but there may be a role for natural gas distribution. Vehicle servicing is also associated with service stations.

Scenarios need developing to propose strategies for the industry's decline.

Urban transport

The future of cities: Develop scenarios in which city populations may either continue to grow, stabilise or contract

Integration of land use and transport planning: Present road traffic forecasting methods aggregate trips at the local level thereby ignoring the important role of walking and cycling. Research new planning methods that concentrate on local walking and cycling with larger system networks as the residual, making future fuel supply a central issue.

Electric rail transport: Develop strategies to use this mode as the prime transport initiative to change land use to higher density away from petroleum powered vehicles, integrating with cycling to expand the catchment area. The latter is an important short term strategy to rapidly increase transit patronage at low cost.

Electric bicycles: Battery operated bicycles are the most efficient way to use battery driven vehicles as there is not a heavy vehicle plus battery to move (Kilsby 1999). Electric bicycles are already used extensively in Japan and can play a major role in small cities and towns. Research all aspects to promote and eliminate barriers to their use, including integration with transit to expand the passenger capture area of stations.

Shopping Centres: Only allow new shopping and commercial centres at appropriate transit stations.

Integrate commercial and residential development: Reform land use zonings that separate residential from commercial and industrial to allow appropriate commercial and industrial activities mixed with residential so that most trips to work can be on foot or by bicycle.

Parking and vehicle plus salary packages: Reform tax and other legislation that encourages excessive provision of parking and car commuting, such as car plus salary packages and free parking.

BOOI motorways: Develop strategies for managing the financial difficulties that BOOI motorways in Sydney and Melbourne will soon face.

Transport financing: Reform the present capital financing methods for urban roads from fuel excise and other charges and electric rail transit mainly from loans which favours roads and disadvantages transit. Treat transit as an investment in the city rather than one in a transit enterprise. Research new funding options and the consequences for declining revenue from petroleum taxes.

Freight transport

Relative economics of sea, rail and road: The relative economics of these three modes will change as oil's decline takes grip and its real cost rises. For moderate to long distances (eg Melbourne-Perth) road freight consumes four to five times more energy than rail (Mason 1997). Water borne freight energy use was about equal to rail in the 1970's (Hall, Cleveland & Kaufmann 1986). However, sea freight does not need capital intensive track infrastructure whose real cost will rise and which suggests that sea freight may gain an advantage over rail and road. Ships only need ports most of which already exist. This is important as most Australian's live close to the coast. Embodied energy studies are needed to verify this judgement in conjunction with studies to estimate the real increase in the cost of transport generally.

Global economy contracts: This paper poses the contraction of the global economy as an outcome of oil's decline based on the expectation that real transport costs will increase. Research is warranted to explore this proposition and the implications for Australia.

Agriculture and freight: The response of farmers to salinity and reduced dependence on oil are going to radically alter rural transport needs in ways difficult to foresee. Scenarios to cover a range of plausible outcomes is needed with regular reviews.

Trucks and road damage: A fully laden truck causes 7-9,000 times greater damage to a road than does a car. Acrimonious debate occurs between the trucking industry and road authorities on fees and charges to cover this cost. The real cost of repairing and reconstructing roads will increase next century and it may even be difficult to maintain the roads we have under any circumstances. This suggests reducing axle loads and a shift to rail.

Present research into this issue needs to consider the very serious consequences arising from the decline of oil.

Would the \$3 billion Pacific Highway upgrade from Newcastle to Brisbane be better spent upgrading, double tracking and electrifying the railway instead? There would then be electric rail from Rockhampton to Wollongong and Lithgow in close proximity to seven million people.

Aviation

Aviation is the transport mode most vulnerable to oil's decline. The only alternative fuels appear to be natural gas and hydrogen, with hydrogen probably the superior choice on weight grounds, see Fleay (1999, p. 37). The change-over will be a very high risk multi-billion dollar exercise that will take years of research and development.

Massive investment in fuelling systems will be required. It seems likely that commercial aviation will contract.

Scenarios for aviation fuel supply need developing as part of the Sydney Airport duplication saga.

Tourism

Contemporary tourism and the associated hospitality industry are highly dependent on abundant cheap transport. These are now major industries in Australia and are high earners of foreign exchange. Research is needed into the likely impact of declining oil on tourism.

Conclusions

The next decade will see a the transition to an era of permanent decline in the supply of cheap oil. There are no substitutes in sight to replace petroleum products to power transport, either in quantity or comparable economic performance. Therefore a real increase in the cost of transport will occur and a decline in the scale and scope of powered transport is inevitable with far reaching consequences. Every facet of our lives will undergo unending change.

Agriculture in Australia is particularly dependent on petroleum given our nutrient deficient soils and climate compounded by the massive salinity problems in southern Australia arising from clearing of the natural vegetation. The restructuring of agriculture to the extent this is possible must receive first priority for our remaining petroleum fuels. It follows that urban car travel must bear the brunt of the decline of oil.

The predictable rate of oil's decline sets the agenda. An appropriate Commonwealth agency is needed to guide the process of change. We cannot forecast how positively and creatively our communities will respond to the challenges, critical factors in outcomes.

Hard nose decisions will be required and there is not much room for error. But we must be caring for people and the environment in our approach. The more caring we are the more hard nosed the decisions can be, the easier and faster we can proceed down the paths of constructive change. If everybody pursues their own self-interest we can become locked in conflict, unable to adapt and will dissipate unproductively the scarce high quality petroleum fuels that are so essential to the transformation to a world "beyond oil".

REFERENCES

- Australian Geological Survey Organisation (1998) *Oil and Gas Resources of Australia 1998*. Australian Geological Survey Organisation Canberra.
- Bureau of Resource Sciences, BRS (1996) *Oil and Gas Resources of Australia 1995*, Bureau of Resource Sciences Canberra.
- Campbell, CJ and Laherrere, JH (1995) *The World's Oil Supply 1930-2050*, Petroconsultants SA, Geneva Vol. 1.
- Campbell, CJ (1997) *The Coming Oil Crisis* Multi-Science Publishing Coy, London and Petroconsultants SA, Geneva.
- Campbell, CJ (1998) Personal communication.
- Campbell, CJ and Laherrere, JH (1998) The End of Cheap Oil, *Scientific American* New York, March pp. 78-83.
- Campbell, CJ, Perrodon, A and Laherrere, JH (1996) *The World's Gas Potential* Petroconsultants SA, Geneva.
- Duncan, R (1999) World Energy Production: Kinds? Amount? Per Capita? Who? *Institute on Energy and Man*, Seattle.
- Economist 1997 *The Coming Car Crash: Global pile-up*, 10 May, p. 19, London.
- Economist 1999 *The Car Industry: Barbarians at Bavaria's Gate*, 13 February p 21, London.
- Flannery, Tim (1994) *The Future Eaters*, Reed Books Melbourne.
- Fleay, BJ (1999) Climaxing Oil: How Will Transport Adapt? Theme paper presented to the Chartered Institute of Transport in Australia's National Symposium, Beyond Oil: Transport and Fuels for the Future, Launceston Tasmania, 6-7 November 1998. Published with a post Symposium Postscript as Occasional Paper 1/99 by the Institute of Science and Technology Policy, Murdoch University Western Australia.
- Fleay, BJ and Laherrere, JH (1997) Submission to Dept. of Primary Industry and Energy's Green Paper on a Sustainable Energy Policy for Australia. Published by the Institute for Science and Technology Policy, Murdoch University WA as Occasional Paper 1/97.
- Hall, CAS, Cleveland, CJ & Kaufmann, R (1986) *Energy and Resource Quality, The Ecology of the Economic Process*, Wiley Interscience New York.
- IEA, International Energy Agency (1998) *World Energy Prospects to 2010*. <http://www.iea.org/g8/world/summary.htm>
- IEA, International Energy Agency (1998a) *Energy Investment*, paper presented to the G8 Energy Ministerial in Moscow, 1 April 1998.
- Kilsby, D (1998) *On a Tankful of Beans: Human Powered Transport* Paper to Chartered Institute of Transport National Symposium, November Launceston Tasmania.

Mason, Peter 1997 *Opportunities and Challenges for Increased Private Rail Operations*. Paper presented to the Chartered Institute of Transport and the Transport Panel of the Institution of Engineers Australia, Perth Western Australia 16 October 1997.

Petroleum Gazette (1998) *Australian Institute of Petroleum* (2), Melbourne

Petroleum Review (1999) *Low oil prices dictate industry restructuring*, January p. 34, London.

Petroleum Review (1999a) Sheikh Yamani quoted in *Oil yesterday, today and tomorrow*, January p. 18, London.

Prime Minister's Science, Engineering & Innovation Council (PMSE&IC) 1999 *Dryland Salinity and its Impact on Rural Industries and the Landscape*, Occasional Paper Number 1, Dept. of Industry, Science and Resources.

SSC, State Salinity Council 1998 *Salinity Action Plan: Draft Update 1998*, Government of Western Australia

West Australian (1999) *Gulf dictates terms for its oil*, p. 32 April 13.