ASPECTS OF TECHNOLOGY ASSESSMENT IN A DEVELOPING PETROLEUM TRANSITION ERA

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Australia is faced with the need to augment and replace rapidly depleting indigenous petroleum. Because there are many possible solutions and wide ranging impacts associated with this problem, the use of an evaluative technology assessment framework is proposed. The purpose is to provide a means whereby likely technical, socio-economic, legal and regulatory requirements, and consequences of policy options can be canvassed and appraised. Factors influencing the credibility, usefulness and efficacy of such technology assessments are examined, and methodologies appropriate to one application, viz petroleum substitution, are explored. The energy sector is used primarily here, therefore, to exemplify the value of the technology assessment approach to policy making. A systems simulation and optimal resources allocation mode is used to illustrate planning procedures and to highlight such matters as innovation needs, resource requirements and societal changes.

Keywords: technology assessment, petroleum transition, energy policy, systems modelling, technological substitution

TECHNOLOGY ASSESSMENT: A BRIEF PREVIEW AND CRITIQUE

There is virtually nothing in our daily lives that has not been touched or transformed by scientific and technological development during the past few decades. The possibilities are immense for further developments leading to new capabilities and increased material benefits, as well as associated potential impacts and disbenefits.

To assuage these and other justified concerns, technology assessment (TA) has emerged, evolving from a rudimentary cost-benefit calculus to a more sophisticated form of policy analysis. The function and purpose of TA is to reduce the level of ignorance about the costs and benefits of technological change; that is, not necessarily to provide clear unequivocal answers, but to generate better questions and to expose the consequences of alternative policies. Hence, TA has been defined as the "systematic study of the effects on society that may occur when a technology is introduced, extended or modified, with emphasis on the impacts that are unintended, indirect and delayed."[1]

The role of technology assessment is two-pronged. It interacts dynamically with policy (government or corporate) and the aspirations and needs of society. At the socio-economic level it can help us to understand better the changes taking place as a consequence of technological development. For the corporation it helps, additionally, to identify impacts of social change on the company. The latter effect is important in our industrialised market economy since it enables the company to anticipate future regulatory restraints and to perceive evolving societal needs and demands.

Thus TA can be used as a policy tool. It is meant not only to describe the technologies but to assess policy alternatives and implementation strategies, and to identify resulting consequences. In essence, it can quantify alternative strategies and can provide a conceptual framework for development. However, because we are concerned with future impacts of present day decisions and policies, assessment scenarios will be full of assumptions and uncertainties. T.S. Eliot's comment is apt, "all knowledge brings us closer to our ignorance".

Some specific consequences of successful TA may be readily identified. It may:

- modify the project or technology to maximise benefits and to minimise costs, disbenefits and risks;
- define a monitoring programme as the technology becomes operational;
- stimulate R & D to achieve effective technological innovation and substitution, identify alternative routes for goal achievement, define risks more reliably, forestall negative effects;
- delay or prevent a project or technology from developing;
- indicate legal and regulatory requirements;
- focus socio-political issues.

Extra insight for the issue at hand should emerge from the assessment since the study goes beyond 'good or bad' and 'do and don't' advice.

In the OECD countries, TA is currently concerned with manufacturing industry, transportation systems, power networks and weaponry. However, citizen environmental and consumer groups may perhaps be forgiven for harbouring cynicism towards certain earlier rudimentary assessments. For example, on dams and nuclear power in America, "most benefit/cost studies don't tell us who gets the benefits and who gets the costs".[2] And "technologies are usually assessed by the same agencies that promote them", "what cannot be counted simply doesn't count",[3] and "results have been costly always, painful oftimes and ludicrous sometimes".[4] Thus many technology assessments have been circumscribed too closely by the problem, by the promoter or initiator, and by the budget.

The difficulties facing a TA have been illustrated by White who examined some European medieval technology developments.[5] The introduction of the spinning wheel into Europe during the thirteenth century was a classic example assessed by White. The spinning wheel increased yarn and textile production, and presumably linen prices fell and consumption increased. A contemporary observer could have surmised about the consequences and benefits of this development upon human welfare, especially in a cold and comfortless medieval Europe. But would a technology assessment on the spinning wheel at that time have identified a burgeoning book business based on the rag trade? Cheap waste linen cloth in place of expensive vellum parchment brought incentives to substitute expensive and laborious scribes. The advent of the printing press by Guttenberg catalysed a communications boom. 'Culture shock' was underway. It is doubtful that a technology assessment of the spinning wheel could have foretold that.

How then, can TA help us to comprehend technological developments and future outcomes? The situation appears bleak and yet Australian society increasingly and rightly demands to have more meaningful information about, for instance, genetic manipulation, resource and industrial development, land use management, creeping 'big brotherism' of electronic data processing, and national defence and security.

TA is not a discipline, nor is it a branch of any other discipline. The question of applicable techniques and methodologies is a somewhat vexed one and is still subject to much debate. So far, assessments have drawn heavily from systems analysis, operations research, and science and engineering with scant regard for societal and cultural impacts. For the most part costs have been underestimated, opportunity costs ignored and externalities overlooked.

To counteract these and other criticisms, assessments are now characterised by an increasing comprehensiveness.[6] These reflect a pragmatic 'contingency approach' that, in addition to the technological factors, gives due attention to societal effects and adumbrates the decision making processes. Clearly, technology assessments need to be credible and useful and should be formulated such that the relevance and efficacy of alternative assessment constructs can be tested and appraised.

On procedure, Mayo typifies general sentiments stating that "although no particular assessment methodology can be uniformly applied with optimum results, a basic procedural pattern for organising an assessment effort can be very useful".[7] A strategy for a TA is presented (as summarised in Table 1) and is illustrated here, tentatively and indicatively, for the run-out of Australia's indigenous petroleum supplies and the alternative ways in which this problem may be approached. The major objective here is to use the energy sector to exemplify aspects, and the value, of the TA approach to policy making. Although only touched on lightly, clearly the TA could also provide insights on specific energy options. An essential feature, however, of this or any other technology assessment framework is that there must be a continued and critical questioning of the theories, methodologies, assumptions and implications used in the assessment.

TABLE 1

Technology Assessment Strategy

Components	Requirements
1. Problem definition	Define the assessment task
2. Technology description and forecast	Define and analyse past, present and likely future technologies
3. Social description and forecast	Describe present condition and identify societal values
4. Impact analyis	Describe probable impacts, evaluate and compare
5. Policy analysis	Identify decision options and actions, and all interested parties
6. Communication of results	Conclusion and recommendations

TECHNOLOGY ASSESSMENT: STRATEGIES, POLICIES AND CHALLENGES

Problem Definition

The TA needs clear statements that identify the problems, and that define the alternative systems to be examined. Usually, more than one project option needs assessing. Thus the possible systems alternatives may need dividing into subsets to facilitate subsequent modelling and impact analysis. The purposes of the TA may be exploratory, or avenues for achieving specified goals may be sought. All will have implications for funding, timing, actions and the decision process, for new technologies and alternative configurations, and for social, legal and jurisdictional requirements.

In Australia, petroleum replacement attracts much attention essentially because of dwindling indigenous supplies and concern for meeting future transportation fuels and chemicals needs.[8] Our current petroleum import bill is about $3,200 million. Since petroleum prices are expected to rise from a current $US26 to $US28 per barrel to about $US50 per barrel within ten years, at current projections and prices the petroleum import bill could rise to a collosal $US9,000 million (at constant 1985 $US). This spectre poses a real problem and some significant challenges for Australia.

Ideally, an overall macrosystem TA needs to be carried out such that the requirements, impacts and outcomes of all petroleum replacement and extension possibilities can be portrayed and analysed. The more important possibilities include increased exploration, conservation, stockpiling, substitution, and changes in utilisation and functions technology. The ramifications of one of the inter-related macrosystem alternatives are examined briefly here, namely petroleum substitution. Australia has huge coal, oil shale, and uranium resources and modest quantities of natural gas and LPG. Furthermore, the nation is well endowed with agricultural land and is blessed with abundant sunshine. At present, as primary energy sources, both coal and natural gas are perceived to play an increasingly important role.[9] The available alternatives appear, fortunately but bewilderingly, to be many and varied ranging from hard through soft technology options (see Figure 1).

FIGURE 1

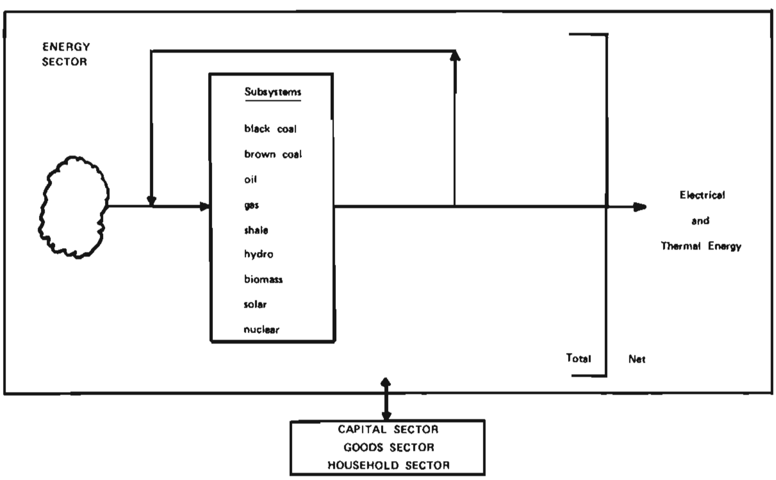


FIGURE 1 Overall Energy System 'Australia'.

Petroleum substitution, particularly in the transportation sector, has become synonomous with synthetic oils (the so-called synfuels), LPG and methanol since a straight liquid for liquid stubstitution is envisaged, and also since this is how the traditional large oil and mining companies appear to see the development of Australia's huge coal and oil shale resources. A number of feasibility studies have been produced worldwide and additionally, of course, there is experience from Sasol's $7 billion coalplex investment in South Africa. Resource developers, however, are increasingly being faced with the inescapable economic facts of diminishing marginal utility, and increasing marginal cost and disbenefit cost of fossil fuel usage. These cannot be ignored and sooner or later are bound to lead to a reduction in demand and to the development of alternatives.

It is conceivable that bio-energy could be introduced in the short term and that there could be a massive commercial hydrogen business by the turn of the century.[10] Likely markets for hydrogen in Australia can be guessed at (see Table 2) but perception of needs are fuzzy and unquantifiable at present and consequently beyond corporate planning interests.

TABLE 2

Markets for Hydrogen in Australia

Non Fuel
Ammonia
Upgrade of carbon oxides (into methanol, ethylene, urea, protein and other chemicals)
Hydrotreating and hydrocracking (of heavy oils, tar sands, shale oil and coal into fuels and chemicals)
Metalliferous (e.g. iron ore into iron)
Fuel and Energy Vector
Natural gas, gasoline, diesel substitute (e.g. in town and industrial gases; in air, land and sea transportation)
Energy storage and transmission (as a complement to electricity)

Appropriate modelling and technical analysis can provide insight into innovation needs and developments required to meet specified goals and future given circumstances. As is emphasised here, the assessment also needs to examine the impacts of such technological developments in a physical and social context. In this way the technical, resource, and social requirements for effective deployment of candidate technologies can be better understand.

Forecasts

Forecasting, especially technological forecasting with the emphasis on science and technology, has become a particular favourite activity in recent times.[11] Other less quantifiable aspects, such as the human, social and political impacts and limits to growth, have been relatively neglected.[12] By contrast, "economic forecasting", according to James Henry, "is one of the hottest fields in the US economy. . .".[13]

In a technological era, difficulties with TA 'forecasts' arise when the dominant paradigm becomes technically orientated at the expense of societal factors and, therefore, becomes dependent upon data of questionable veracity and accuracy. Because of this orientation, there is a real danger that the TA will be systematised with a consequent focus on the modelling methodologies rather than on the original problem. Furthermore, a reliable data base is the *sine qua non* of any worthwhile assessment, but this can prove a somewhat elusive will-o'-the-wisp. For instance, there are disparate ways of gathering and ordering facts and figures with attendant opportunities for inaccuracies, omissions and obfuscations that can all result in over-simplifications and distortions. Even data derived through econometric and input-output modelling, and economic indicators such as elasticities, may contain compounded epistemological errors since economic theory itself, with its roots in equilibrating and reversible processes, appears flawed.[14] Further, the apparently non-quantifiable data, which may be crucial, may not be accounted for at all, and core assumptions underlying the forecast may be faulty.

This lack of specificity is problematical, particularly for the socio-political forecasting aspects. Suggested approaches to increase the meaningfulness and appraisability of forecasts, include the use of social indicators (such as degree of alienation, wealth distribution and consumption patterns) with probabilities attached to them, and a prose description of future events and likely socio-political conditions.[15] The dilemma arises, of course, between an apparent eclectic process of data selection and the almost mutually exclusive characteristics of large data containing systems attempting to model real and complex situations. Yet forecasting is, and must be, an integral part of technology assessment. Methodologies are needed for the generation and canvassing of policy options, despite the fact that all will have inherent limitations and that their efficacy will diminish the longer the time horizon being envisaged. There is no dearth of modelling candidates, however, from intuitive, extrapolative through simulative. Virtually any discipline technique and method appears applicable to TA (see Table 3).[16]

TABLE 3

Some Modelling Methodologies

		Comment
1.	Delphi	estimates and evaluations by 'experts'
2.	Time series analysis and projection	Short term (yearly) cycle forecasts
3.	'Naive' techniques e.g. $\hat{Y}t+1 = Yt$ $\Delta\hat{Y}t+1 = K\Delta Yt$	Short term forecasts
4.	Growth or logistics curves	Measures technological maturity and substitution
5.	Causal methods e.g. multiple regression, econometrics $\hat{Y} = f(X_1\ X_2\ X_3 \ldots X_n)$	Medium term forecast e.g. demand for important substances depends upon — price — the alternative technologies — GDP, others
6.	Systems analysis e.g. optimisation simulation (e.g. system dynamics)	 Optimal allocation of resources 'Scenario' portrayal (e.g. see Fig.2)

Planning models tend to be segregated and simple, being aimed, essentially, at making projections about individual energy forms. Thus important information and insights about price movements and elasticities, supply and demand patterns for coal, oil, electricity and so forth are actively sought by governments, electricity authorities and by industry.[17] In Australia the more complex modelling approaches are concerned with developing, and linking, input-output and supply optimisation models.[18]

The energy transition system, however, is seen to be multi-faceted, complex, dynamic, non linear and not readily amenable to analytical treatment. Because of the complexities and uncertainties, a systems analysis approach, incorporating a number of modelling techniques, is favoured for technology assessments. This is in preference to an approach based solely on the more restrictive 'surprise free' extrapolative forecasting methods (as typified by methods 2 through 5 in Table 3).

Hybrid models, including PIES, BESOM, and ETA-MACRO, have all been developed in the pursuit of energy independence in the US. The Project Independence Evaluation System (PIES) consists of an econometric demand model, a special purpose supply model, and an interlinking linear programming model.[19] PIES has been used to evaluate the impact of decontrol of domestic oil and gas prices on the oil import requirements for the US during the 1980s.

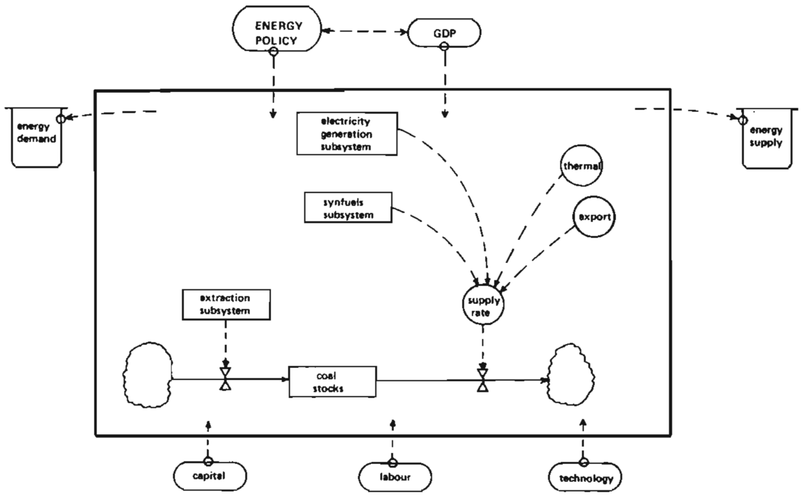
BESOM and ETA-MACRO are longer term energy models. The Brookhaven Energy System Optimisation Model (BESOM), minimises the total cost of satisfying a given set of energy demands, resource constraints, and conservation efficiencies, all on an annual basis.[20] BESOM has been used to study interfuel substitution between electric and non-electric forms in the US energy system. MARKAL, a related system to BESOM, has been used to examine Australia's energy needs and to explore possibilities for Australian oil conservation.[21] Criticisms are that: BESOM is biased towards high technology and capital intensive projects; the demand for energy forms is assumed; price-demand relationships are indeterminate; and determination of technological substitution is ambiguous.

Certain of these criticisms led to development of the Energy Technology Assessment — Macroeconomy (ETA-MACRO) model. ETA-MACRO is a general equilibrium model that covers the US energy sector.[22] The demand side consists of a hybrid econometric and engineering process analysis model, whilst the supply side uses a conventional linear programming model. A macroeconomic growth model, that provides for a substitution between capital, labour and energy inputs, is then coupled with the ETA demand and supply sides. ETA-MACRO brings the energy sector directly into the macroeconomic production function. For example, the model shows that limitation policies on nuclear energy induce conservation, which in time increases costs and reduces GDP.

These models are sophisticated and valuable, and, perhaps, may have applications in the Australian context. However, such models treat energy like any other common economic commodity and, typically, do not go beyond the black box of inputs (feedstocks) and outputs (fuels). In other words, the techniques are concerned essentially with economic efficiencies and do not look explicitly at the technical factors influencing technological substitution and change. With this as an objective in mind, an alternative approach is examined.

Illustratively, the energy system 'Australia' (consistent with the TA framework and the Problem Definition) is categorised into more manageable sub-systems (see Figures 1 and 2). Here, the overall systems model framework consists of a system dynamics simulation.[23] This is coupled to a linear programming-based resources allocation mode and a macroeconomy interactor. The overall model thus provides a general disequilibrium representation for linkages between the economy and the energy sector and, furthermore, the model has a built-in optimal resource allocation capability. Additionally, although not developed here, a number of quantitative intuitive societal forecasting techniques (such as the cross-impacts between trends analysis)[24] can also be incorporated into the simulation, thereby providing further information about the effects of energy transition programmes on social development. Such an overall model clearly concentrates on what is quantifiable, namely the resource needs (the economic factor inputs), outputs and certain disbenefits and outcomes.

FIGURE 2



(Solid lines are material flows, dotted lines are information flows)

FIGURE 2. Black Coal Subsystem.

The model endogenously generates major energy aggregates and additionally, is suited particularly to assessing technological substitution and change. Linkages generate macroeconomic dynamics (specifically changes to GDP, consumption and investment), although the model is based explicitly on economic decision making at the microeconomic level. In this way, and by incorporating other indicators (for instance, societal and pollution indicators), the technological, environmental and socio-economic requirements and outcomes can be determined, evaluated and appraised for specified policy options and circumstances.[25]

Specifically, each subsystem (e.g., black coal in Figure 2) is driven by a particular policy or planning objective. It is then possible to simulate energy flows from source (whether coal in ground, hydro, solar, or whatever) to the consumer sector.[26] It may be appreciated that the primary energy needed, both to provide an amount of useful energy to the consumer sector, and the energy sequestered in that provision, is a function of a number of factors. These include: demand, rate of growth (or decline) of the system, changes in transformation and extractive technology, quality of resources and of energy forms, distances from transformation system and the market, and other factors.

An optimal decision making mode may be coupled, as appropriate and necessary, at the resource extraction, electricity generation, and synfuels and chemicals process stages (as indicated in Figure 2). The main purpose of this is not only to assist with optimal development and operating strategies, but additionally, and importantly in some instances, to provide extra insight into the pressure points for further technological innovation and substitution. This aspect of the model has been used successfully to examine technological substitution in the Australian chemicals and fuels industry.[27] Evaluations were made under widely differing circumstances including: changing feedstock prices; *laissez-faire* versus self-sufficiency policies; varying transportation fuel options; and possibilities for solar-hydrogen systems. Such an allocation mode, using a monetary and/or energy analysis basis, provides a tactical and strategic planning framework. (Tactical, because through changing the circumstances one can model rates of process substitution. Strategic, because it is possible to determine how corporate and government policy options can be met.)

Once the technological basis and likely direction of technological change (based upon technical and economic criteria) are better understood through an allocation model of this type, the results and data can be incorporated into the simulation model. In this way the consequential dynamic relationships between allocation strategies and the economy for given energy or resources policies can be explored.

The overall systems model amounts to a 'what-if' scenario portrayal, albeit in skeleton form — a considered and considerable aid to structured thought. As predictive tools, however, a 'fleshing-out' with prose descriptions and social indicators is necessary so that the socio-political and legal issues can be highlighted and appraised. Clearly, there may be limitations to this approach, but it does provide insights into the factors influencing technological substitution and hence is a necessary component for the TA.

Impacts

In Australia, the energy sector comprises a relatively small, but essential part of the economy (about 5 to 6 per cent of GDP). However, it is still sizeable in absolute terms, and it could grow and alter considerably. The energy alternatives situation is complex, there being many available options. The transition to, and solutions for, a post petroleum economy will be tempered by local conditions, and national carrying capacity and capabilities. Final selection of the alternatives will be influenced by political expediency, the need to avoid economic hardship and environmental catastrophe, and be hedged by the realities of sunk investments, industrial transition rates and the will to meet new challenges.

To aid the decision-maker, technology assessments will need to provide a menu of alternatives, together with an analysis of their consequences. The identification and evaluation of the impacts of technological change require considerable skill and imagination, since there are no complete models, paradigms, or algorithms which can comprehensively identify all consequences. Indeed, in some instances, the technology may become all pervasive and yet so diffuse that the impacts may not be readily identified.

There are many formal qualitative and quantitative evaluation methods that may be applied, including economic analysis, social surveys and other analyses, resource, technical and 'net energy' analyses, and environmental impact analysis. Technology assessors can thereby account for the investment, material resources, labour, social, training and logistics and other requirements for full deployment of the technology.

Indicatively, in the developing transition to a post petroleum era, some specific concerns for the economy, social equity, national security and the environment are reflected in the following:

- the continuing fluctuations in price and availability of petroleum and consequent influence on the timing of substitution processes;
- lead times necessary for commercialisation of new technologies;
- the timing of substitute fuels such that they will be available in the quantities and forms most appropriate to needs;
- the availability and cost of capital (and other resources such as trained manpower) to enable energy resources development;
- the politico-economic implications (Australia, being a marginal petroleum producer,[28] faces fears of price sabotage by OPEC, with consequent effects on exploration, conservation and substitution programmes);
- government actions (fiscal and monetary policies and energy policies);
- the societal impacts (the quality and extent of employment, and process and product safety and utility) in a supposed post industrial era, and environmental impacts.

Thus the ramifications appear limitless and the impacts correspondingly extensive and substantial. Some of these are selected and developed here, and although seemingly biased and simplistic, serve to illustrate further the questioning form of the TA.

Should there be relatively rapid run-out of indigenous oil supplies, Australia could utilise its natural gas and LPG resources. Justifications for developing indigenous natural gas, as opposed to, say, synfuels, include the following:

- it is a least capital cost intensive option;
- it would utilise existing infrastructure;
- it is a premium fuel having the highest energy efficiency (for production, reticulation and utilisation);
- it could satisfy all transportation needs to the year 2010;
- it has well understood conversion technologies.

The case for natural gas upgrading may be oversimplified, however, and the impacts would need to be fully explored in the TA. Difficulties are recognised, and these would include:

- accuracy of the reservoir statistics;
- funding and operation of the gas extraction programme;
- establishment costs etc. for LPG terminals and storage facilities on the Eastern seaboard;
- where to locate liquid fuels synthesis plants;
- and, not least, the State interests in what they regard as their indigenous resources, and the position of existing contracts.

Despite all this, it is surprising that the natural gas to liquid fuels and LPG options have not attracted more immediate interest in Australia.

By comparison with petroleum and natural gas processing, coal liquefaction and oil from shale are more complex, more resource intensive (for land, labour, capital and technology), less energy efficient and more problematical from both societal and environmental viewpoints.

Without doubt, synfuels from coal or shale oil could supply all Australia's needs, and some could be exported as well. However, prodigious quantities of coal and/or shale would have to be upgraded. (For example, 85 million tonnes of coal would be needed for 850PJ gasoline per year for a self sufficiency policy. These are respectively about the quantity of coal mined and the quantity of gasoline consumed in Australia at present.)

Because of the high capital costs and associated risks, it is highly probable that government (i.e. the taxpayer) would be asked to provide significant economic incentive to stimulate investment in synfuels,[29] and in other alternatives such as hydrogen. These are likely to include:

- investment tax credit and accelerated depreciation;
- project completion guarantees;
- access to capital;
- guaranteed market prices.

Synfuels may be needed and may be produced with immense effort and cost, but they do represent a quagmire of uncertainty and risk (see Table 4 for some attributes of synfuels programmes). Despite their obvious candidature as petroleum substitutes, their consideration to the exclusion of all other alternatives could lead to missed opportunities and accusations of cognitive dissonance and myopia against Australian industry and government.

TABLE 4

Synfuels Programme — Some Attributes

Positive
Liquid fuel independence
Utility from approximately 860 petajoules liquid fuels
Possible self sufficiency
Indigenous resource development
Technology is known
Investment multiplier effect
Employment multiplier effect
Negative
High opportunity cost (in diverting finances away from other needy areas such as welfare, education, other resource projects etc.)
Huge resource requirements
Capital resource requirements
Capital account energy release
Local and global environmental impact
Inflexible (probable 30 year) option
Synfuels will need substituting one day

In Australia there are favourable conditions for more extensive use of electricity and solar systems and for the development of hi-tech solar hydrogen and bio-energy technology systems. However, entry costs for soft energy pathways are considered to be prohibitively high at present. To be more accurate, the capital costs are much higher and although the operating costs (and hence the amortised cost into perpetuity) are much lower than for conventional systems, the long term benefits are conventionally discounted as being virtually valueless. Since such options could help to augment and substitute petroleum, they all need to be included and appraised comparatively in the TA. Clearly, however, the limitations and disparities for the various investment appraisal criteria (e.g. DCF techniques) need to be fully identified and assessed.

It is worthwhile here to examine briefly one possible macro technological alternative, namely, a massive solar hydrogen option. Hydrogen is a renewable resource; the feedstock (water) covers 71 per cent of the planet and it is universally available. Hydrogen is environmentally benign, producing water on combustion. It is a convenient and safe energy carrier. Hydrogen produced from coal is already cheaper than gasolines via petroleum[30] and *a fortiori* is cheaper than any envisaged synfuels process based on natural gas, coal or oil shale.

Although usually discounted at presented in Australia, hydrogen's time may in fact be closer than is normally acknowledged. The impetus for the emergence of hydrogen usage on a massive scale is perceived to arise mainly through:

- the spectre of decreasing availability and increasing price of petroleum;
- constraints imposed on coal mining because of environmental and occupational health policies;
- constraints imposed on nuclear power (due to problems of availability of fuel, the siting of plants, waste disposal and terrorism);
- concern for acid rain, carbon dioxide and waste heat 'greenhouse' effects and their real costs of containment;
- the insufficiency of bio-energy production;
- the need for a viable, durable, long term energy future.

Through cause and effects such as these, more nations are actively investigating hydrogen economy possibilities. Canada, for instance, currently spends about $6 million annually on research and development on hydrogen production, storage and utilisation and is contemplating increasing this to $1 billion over the next five years. A massive worldwide hydrogen technology export business worth $400 billion is envisaged, with hydrogen becoming the world's highest tonnage commodity by the turn of the century.[31] By comparison, the present interest shown by Australian industry and government in the hydrogen economy appears to be negligible. In Australia, we still believe in the precept of energy abundance — find it, mine it, and use it up or export it. Whilst it may be considered acceptable to maximise consumption for the present, this precept may well metamorphose soon into a law of energy scarcity with all its attendant implications for real costs, limitations and conservation.

In a developing petroleum transition era, clearly all alternatives and their impacts need to be examined closely. Fossil fuels certainly have an important role to play, but their net social benefit and utility in the economy and the environment needs to be compared with the net social benefits of such energy alternatives as hydrogen, solar, bio-energy and nuclear. Only then, with the best information available, should policy options be generated and actions taken.

Policies

Governments are now beginning to believe that security of energy supplies is a matter of national security. Certainly the development of indigenous sources of energy can insulate Australia against supply difficulties and price movements, but such benefits must be weighed against the costs.

Petroleum price rises, attendant scarcities, and increasing reliance upon foreign sources will mean a decline in real income for Australians and, directly or indirectly, will adversely affect our balance of payments. It would, therefore, seem imprudent for Australia to assume that petroleum can be imported and will always be available as required. The consequent direct costs of possible supply interruptions to the community would be too large: industrial and mining activity would be slowed if not halted, and unemployment would immediately increase. Arguably a rising import bill may not be a major factor in the overall balance of payments picture, particularly if substantial export earnings are realised from minerals, agricultural produce, and from coal, natural gas and uranium. This signifies that increasing output and productivity, or higher value manufacturing activity is needed just to maintain the economic *status quo*. Alternatively, and still with high cost, policies may be directed to mitigate vulnerability and to engender self-sufficiency. The benefits (such as fuel security, regional developments, employment and investment multiplier effects, and export earnings potential) and costs of this option need to be carefully assessed against the alternatives.

A major role of Government is to manage uncertainty and risk in the attainment of the nation's social and economic goals. In a petroleum transition era this means providing a framework for encouraging alternative energy systems development, and for the equitable sharing of the burdens and benefits of technological change. Accordingly, evaluative criteria such as effectiveness, efficiency, equity, flexibility and implementability for assessing policy alternatives are essential.[32] For petroleum substitution policy issues it follows that policy formulators and decision makers will need answers to many questions, some of which are posed in Table 5.

TABLE 5
Policy Issues

	Criteria	Comment
1.	How may the policy objectives be achieved?	What is the size of the problem? Which processes, if any, will be commercialised; synfuels, LPG, hydrogen, bio-energy?
		Is this a short term or long term solution?
		Where is (are) the complex(es) to be situated?
		What are the exogenous factors and their effects?
2.	What are the costs, risks and benefits?	Who will put up the money and how?
		Will a 'gasoline' tax be needed to assist synfuels or hi-tech energy enterprises?
		What are the infrastructure needs?
		What are the environmental impacts?
		What are the macro-economic effects?
3.	What will be the distribution of costs, risks and benefits?	Who (or, what State) pays and benefits?
		What relationships are needed between government and the private sector?
4.	How flexible and adaptable are the options?	What is the situational relevance?
		What is the duration and reversibility of the option?
		Where do the responsibilities for decision making lie?
5.	What is the acceptability of the option?	How readily can the alternatives be applied?
		How much innovation, trained manpower and educational infrastructure generally is needed?
		What is the legal position?

Clearly public policy issues in a developing petroleum transition era go beyond the scientific and technological levels and the interplay of normal market forces. As Nehnevajsa and Menkes have stated, there is "a fundamental shift in our economic forces which has accompanied a recognition of changing economic realities".[33] From a pre-World War 2 'production of abundance' problem arose a 'management of abundance' problem with its concern for the equitable distribution of wealth. With current concern for non-replenishable resources, and the inherent limits on technology and capital to find alternatives, society may enter a new phase, the 'management of scarcities'.

CONCLUDING COMMENTS

A developing petroleum transition era may provide a regular Pandora's box for Australia, full of challenges, opportunities, bonanzas, dilemmas and conflicts. With the exception of petroleum, Australia has abundant and wide varieties of energy sources. In particular, there are significant deposits of other non-renewable fossil fuel and uranium energy resources. Perhaps because of this, and despite some concerns for the domestic transportation market and the balance of trade, there appears to be a general apathy towards the newer energy technology possibilities. The present day law of exploitation and maximum consumption is well suited to our *laissez-faire* economy. Such precepts, whilst arguably advantageous in today's market economy, are likely to prove highly inappropriate in a developing era of energy scarcity with all its attendant implications for real costs, limitations and conservation. In the extreme, energy scarcity and the consequent law of allocation point to, and appears essentially suited to, a managed energy economy.

The transition era may prove burdensome or it may contain tremendous wealth creation possibilities. The socio-political impacts of either fossil fuels and uranium expansion or curtailment schedules, for instance, would have far reaching consequences, as would indeed the development of hi-tech soft energy pathways (such as solar-hydrogen). TA can canvass, test and appraise the consequences, both intended and unintended, of energy policy options and thereby help to shape and sharpen policy formulations.

Using the systems approach, it is evident that a range of possibilities may be portrayed ranging from 'surprise-free' extrapolation and projection to 'surprise-full' politico-economic influences and technological breakthroughs. In an overall TA it is clearly necessary and desirable to incorporate socio-economic linkages and descriptions, both to engender appropriate harmony for science, technology, society and the environment, and to mitigate the limitations and caveats presently inherent in computer based quantifications.

This paper has attempted to touch on aspects of TA appropriate to the Australian energy scene. It is hoped that it will help to provoke further critical questioning and discussion on the assessment and management of technological developments in Australia.

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   > A technology assessment does not divine the future, but is ideally a tool for contingency planning, crisis avoidance, and policy option analysis. It develops alternative strategies that are internally consistent and subject to explicit constraints.
   >
   > Policy choices must often be based on compromise and decision makers are responsible for assuring that the compromises are equitable and that costs and benefits are fully allocated — both in terms of dollars and social costs and benefits. The anticipated information of an assessment should be therefore:
   >
   > 1. Identify technological developments
   > 2. Specifiy alternatives based on the distribution of a variety of costs and benefits among affected parties
   > 3. Present social choice and policy options compatible with a wide spectrum of future environments.

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