



**COOPERATIVE RESEARCH CENTRE FOR COAL IN SUSTAINABLE
DEVELOPMENT**

Established and supported under the Australian Government's Cooperative Research Centres Program

**A FRAMEWORK FOR ENERGY POLICY SCENARIO
CONSTRUCTION**

RESEARCH REPORT 79

Authors:

**Thomas S Brinsmead
Cliff Hooker**

The University of Newcastle

December 2007



QCAT Technology Transfer Centre, Technology Court
Pullenvale Qld 4069 AUSTRALIA
Telephone (07) 3871 4400 Facsimile (07) 3871 4444
Email: Administration@ccsd.biz

This page is intentionally left blank

DISTRIBUTION LIST

CCSD

Chairman; Chief Executive Officer; Manager TT&C; Files

Industry Participants

Australian Coal Research Limited	Mr Mark Bennetts
BHP Billiton Mitsubishi Alliance	Mr Ross Willims
.....	Mr Ben Klaassen
.....	Dr Andre Urfer
CNA Resources.....	Mr Ashley Conroy
CS Energy	Dr Chris Spero
Delta Electricity	Mr Greg Everett
Queensland Department of Mines & Energy.....	Mr Bob Potter
Rio Tinto (TRPL).....	Dr Geoff Bongers
Stanwell Corporation	Mr Howard Morrison
Tarong Energy	Mr Dave Evans
The Griffin Coal Mining Co Pty Ltd	Mr Charles Martelli
Verve Energy	Mr Ken Tushingam
Wesfarmers Premier Coal Ltd	Mr Patrick Warrant
Xstrata Coal Pty Ltd.....	Mr Colin Whyte
.....	Mr Barry Isherwood

Research Participants

CSIRO	Dr David Brockway
Curtin University of Technology	Prof Linda Kristjanson
Macquarie University	Prof Jim Piper
The University of Newcastle	Prof Barney Glover
The University of New South Wales	Prof David Young
The University of Queensland	Prof Don McKee

This page is intentionally left blank

Disclaimer

Use of the information contained in this report is at the user's risk. While every effort has been made to ensure the accuracy of that information, neither Australian Black Coal Utilisation Research Limited (ABCUR) nor the participants in the CRC for Coal in Sustainable Development make any warranty, express or implied, regarding it. Neither ABCUR nor the participants are liable for any direct or indirect damages, losses, costs or expenses resulting from any use or misuse of that information.

Copyright

© Australian Black Coal Utilisation Research Limited 2007

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, whether electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of Australian Black Coal Utilisation Research Limited.

Table of Content

	Executive Summary	1
I	Constructing simple and combined scenarios	2
II	Internal scenario structure and adaptive policy	3
III	Selection of Characterising Parameters for Scenario Space	4
IV	Conclusion	12

This page is intentionally left blank

EXECUTIVE SUMMARY

An energy scenario is a coherent narrative of the successive states of an energy system from the present to some future end-state configuration.

There are two significant first order parameters characterising an energy technology configuration : i) which energy medium and tertiary technology serves transport demands, and ii) which resource, primary technology and energy medium serves stationary demands. These yield a key second order parameter value: iii) the place on the integration continuum formed by these two media. Integration refers to the physical interrelations between the technologies for these two media, at generation, delivery and waste removal, with extremes of identity and independence. Desirable configurations are located midway on this continuum, where adaptive interconnections peak.

To form a structured range of energy scenarios that span the available options while sustaining adaptive capacity, it is necessary to articulate the integration structure. To do this form a two-dimensional array of fuel/technology alternatives for transport and stationary demand, using one dimension for each. This yields 6(stationary) x 4(transport) = 24 combined alternatives, each with its own level of integration. Then from those that lie off but near the diagonal, = the midway integration configurations, choose a suite that between them occupy all rows and columns. (This suite may not be unique but, with scenario mixes allowed, any version suffices.) Take the fuel/technology arrangements of these to form the long-term end-states of each of a corresponding suite of energy scenarios. For these scenarios, the aim is to understand the key adaptive options within-, and among-, scenarios so as to locate the key decisions points at which shifts in commitment should be considered and/or can easily occur.

Introduction. This report provides a structured range of future energy scenario end-states that span the available technological options, permitting the construction of scenarios designed to sustain adaptive capacity.

The Research Report Physical Constraints and Options in Energy Policy laid out the basic physical structure of energy systems, providing both the physical options/contingencies to be considered and the physical constraints on pragmatically feasible choices for designing an energy system. To summarise, overall energy flow in a societal energy system has three stages: primary source to secondary fuel media to tertiary services production. The fuel media: electrical, chemical, mechanical and thermal, have a systematic inter-conversion structure with conversion efficiency ratios associated with each connecting pathway. Each energy technology is located at one of these stages and corresponds to a pathway down into or out of, and/or around, the conversion diamond, characterised by its combined inefficiencies and consequent waste streams. This overall framework provides the physical constraints on choices for designing an adequate system. The *Basic Energy Problem* [BEP] is to align the 3 stages so that services demand is effectively (in time, by location, and by fuel type) met by available energy resources.

1. Constructing simple and combined scenarios

An energy scenario (trajectory) is the time sequence of states of an energy system from the current state to some future end-state, charting the development of its energy technologies, media, services and wastes. Adequate scenarios satisfy the policy constraints at each time period, hence each of their states is a solution of the Basic Energy Problem [BEP] of supplying energy services demanded with available energy resources for that time.

In order to develop an energy policy strategy, it is helpful to identify the full range of possible technological scenarios that will satisfy the BEP. To reduce the complexity of this analysis, especially for the intermediate periods between the current state and some future end-state, we initially consider only structurally simpler long term end-states where only a few mature technologies exploiting abundant resources can compete for dominance. Other end-states can be constructed as mixes of these. Maturity means that implementation problems are overcome, technological learning accomplished, diverse applications developed and economies of scale exploited. Because large uncertainties prevent the prediction of which single particular energy system structure would be the most desirable in the long term (and even which will actually be feasible), several of the simplest BEP-satisfying scenarios (e.g. solar thermal electricity supplying both stationary and transport demands) are constructed, each utilising one of a select set of technologies (those that both have access to abundant resources and are likely to be mature by 2050), so that more complex combined scenarios can be formed out of them. Provided all the valuable technological alternatives are covered by the initial selection and the individual scenarios don't form new emergent possibilities when combined (so long as combinations remain simple proportional mixes), this technique is a valid approximation and greatly reduces analytic complexity. We will then call the single-technology scenarios, *basic* scenarios. The main purpose of this report is to identify the complete range of basic scenario end-states. An adaptive strategy will then keep as broad a range of combined scenario end-states open to realisation for as long as possible until uncertainties about their relative feasibility and desirability are resolved as much as possible (as traded-off against the options benefit-cost of doing so).

There is a clear first-order, operational reason for including combined scenarios: their performance may be better than any single-technology scenario. While many combinations are too technically unlikely, too inefficient or too trivially different to be worth including, the primary concern in the shorter term ought to be to not exclude in advance any combination that may later prove genuinely useful. This leads to a clear 2nd-order, strategic reason for including combined scenarios: the functionally redundant pathways they create (say, producing hydrogen from photolysis, biomass and electrolysis) present potentially valuable adaptive options.

While combined scenarios are thus valuable, in practice scenarios do have synergistic and exclusionary interrelations, e.g. (synergy) solar thermal inputs to steam pre-heating and carbon dioxide separation from exhaust gases can complement coal or gas fired power generation with carbon capture, while (exclusion) the use of fossil fuels for transport will effectively exclude their use for electricity generation due to constraints on greenhouse emissions and (in the case of natural gas) possibly on resource availability. So the assumption of simple mixes holds only approximately and we shall have to correct the analyses where appropriate to allow for departures from it.

II. Internal scenario structure and adaptive policy

Basic scenarios will often need to be internally complex to satisfy the BEP, e.g. agricultural biofuel production would strain to satisfy transport demand, let alone stationary demand as well. There are two significant first order parameters characterising a scenario end-state: i) which energy medium and tertiary technology serves transport demands, and ii) which resource, primary technology and energy medium serves stationary demands. Because transport services place particularly onerous demands on the properties of transport fuel, the choice of dominant transport technology is a particularly significant parameter for structuring the energy system. The dominant energy resources and media for serving the remaining stationary demands characterise the remaining dominant energy transformation pathways and the overall performance (efficiency, adaptability, ecological impact, etc.) of the remaining sector within the energy system.

However, from the point of view of acquiring adaptive options, how the technologies and energy media of i) and ii), that is, of the transport and stationary energy infrastructures, relate to one another is a further particularly important consideration. If, e.g., liquid hydrocarbons were used to supply both transport and stationary demand from the same primary production technology through the same delivery and waste retrieval systems, etc., then there would be the closest possible relationship (namely identity) between them. But while this may promote efficiency from economies of scale, it could not promote competitive efficiency among technologies and it could not provide any but internal hydro-carbon technological options since there is only one kind of energy medium involved. The same would apply to an all-electricity system. On the other hand, if transport used liquid hydrocarbons and stationary demand was met from photovoltaic electricity that would represent the most distant relationship (independence) between transport and stationary energy infrastructure since at no point do these media technologies physically relate to one another through less than two media conversions. This would decrease economies of scale and do little to promote competitive efficiency among technologies and while there are two kinds of technologies available, the range of options is reduced because of the lack of interrelationships between them.

These considerations lead to recognition of a key second order parameter: iii) the place on the integration spectrum formed by these two media. Integration refers to the physical interrelations between the technologies for these two media, at generation, delivery and waste removal. As has been illustrated, the integration parameter value range is from identity to independence. Call this the integration spectrum.

Adaptive policy interest lies in technological interrelations that create alternative possibilities for overall energy provision (and other spinoffs – eg network management technology - if possible). Considerations of the kind provided above suggest that the number of these interrelations peaks around midway between identity and independence on the integration spectrum. As one moves from identity toward independence the number of functional interconnections first grows, then declines. Energy uncertainties are expected to remain significant for at least several decades, so it is sensible to aim to keep the energy system within the highly adaptive midway region of the spectrum during this time, through the judicious development of combinations of technologies. In consequence, the focus is on mid-spectrum policies, the aim being to understand the key adaptive options within-, and among-,

scenarios, so as to locate the key decisions points at which shifts in commitment should be considered and/or can easily occur. This identifies when, and how, to shift commitment among components as learning proceeds and the uncertainty profile shifts.

III. Selection of Characterising Parameters for Scenario Space

One scenario taxonomy takes the choices of technology for meeting tertiary demands as the defining characteristic. Of dominant concern will be meeting fuel demand for transport and for stationary demand: heating/ cooling, chemical processing, essential electrical, and mechanical demands. Transport needs can only be met by fuels for a) gas expansion engines [GE] or b) electromotive engines [EM], and there are three candidate fuels for each technology, a dedicated fuel (hydrocarbons for GE, electricity for EM) and two fuels, hydrogen and compressed air, that can be used with either engine type: directly in GE engines or converted on-board to electricity for EM engines.

Alternatively, characterising scenarios by primary energy conversion technology (= by resource exploited and energy media supplied) is appropriate for analysing the constraints due to resource supply limitations, yielding a scenario taxonomy focused on the six primary energy resource/media combinations:

- 1) fossil fuel resources: coal, backed by gas and oil,
- 2) biomass (natural, agricultural and industrial) for thermal combustion or biofuels
- 3) hydrogen from solar photolysis,
- 4) electricity from solar photovoltaics,
- 5) mechanical (mostly indirect solar): tidal, wind, wave, hydro-electric, and
- 6) thermal (geothermal including ground sourced and water sourced heat pumps; nuclear including breeder, thorium, fusion; and solar thermal).

Among them these include four abundant primary energy resources: geothermal, nuclear, solar radiant, and coal. Of (1) only coal is long-term abundant and in a carbon constrained world fossil use is destined to become increasingly restricted. To each of these primary resources can be added another, equivalent resource, also largely transitory, especially to capture intermediate possibilities: energy transformation efficiency improvements plus conservation-motivated re-shaping of tertiary demand. This “resource” is substantial but also destined to decline because it primarily exploits the once-only historical improvement potential left from our profligate past practices, together with once-only efficiency gains from process re-design as knowledge progresses.¹

The primary resources/ media have been organised so that chemical energy media are clustered together, and electromechanical media are clustered together – with these two particular clusters, intra-cluster conversion is more technically convenient than inter-cluster conversion. The above ordering also has the fortunate property that adjacent media happen to have transportability, storability, and waste properties that are relatively similar compared to non-adjacent media. In fact, this almost results in a well-ordered suite of energy media, with media higher on the list tending to be more versatile – that is, able to provide for most of the services that can be met by media further down on the list, but not vice versa.

¹ It is useful to consider (6) as a primary resource, not only because it reduces demand on other primary resources, but because it draws attention to the fact that this option also involves investment in technology infrastructure and should compete with standard supply options on risks, costs and adaptiveness - where it is often the better alternative - rather than the tendency to treat it as inherently different and less attractive, and so in practice often ignore it.

For example – the transportability and storability of fossil fuels makes them more suitable to serving (existing) transport technologies than the other media, yet they can also deliver chemical energy, alternatively provide any services that could be provided by electricity, as well as motion (mechanical energy) through the internal combustion engine or thermal energy via bare combustion. Electricity can provide motion or heat quite efficiently, but is a less efficient source when energy in chemical form is desired. Mechanical energy is higher quality than thermal energy, and so on. Note that the hierarchy is not strict – chemical energy can be less transportable than electricity, and it is not the case that conversions towards the top of the list are consistently less efficient than those in the other direction.

Following the method of Section II above, we effectively combine these two characterisations by considering the interaction of primary resources with final media demand for transport. These characterisations then each form one dimension of a two-dimensional combined analysis of options, given in Table 1 below. Each dimension is listed in the order presented above, the six primary conversion technologies re-arranged by fuel medium initially produced so as to correlate this with the final fuel demand type for transport. To gain a feeling for the capacity to acquire adaptability, each transport medium and associated technology is qualitatively evaluated for its closeness to the existing situation, as well as its internal (within transport sector) adaptability. Each stationary medium and associated technology is similarly qualitatively evaluated for its closeness to the existing situation and its adaptability, as well as the extent to which it supports large scale centralised activity. Each cell of the resulting matrix represents the outcome of combining a transport technology with a stationary medium and associated technology. It can be thought of as a 2050 end-state, one possible infrastructural design for satisfying the BEP. Each cell is qualitatively evaluated for the extent to which the stationary and transport technologies are based on similar principles requiring similar skill sets to manage, support inter-substitution of media, and compete for similar energy resources, all of which together characterise the degree of integration the scenario manifests. The degree of integration reflects the number of transform interrelationships providing access from one dimension to the other, stationary to transport supply and vice versa, and has been qualitatively estimated on the basis of technology and media interrelationships.

For example, photovoltaic/ mechanical technologies, e.g., produce electricity directly and are thus highly integrated with battery electric transport technology; electricity becomes the near-universal medium (End-states 11a,b). However the high demand for electricity leads to competition for the corresponding restricted primary supply resources. And while electricity and electrical generation technologies each have their own inherent adaptabilities, their dominance results in the energy system being highly efficient, but with very limited system adaptability when faced with the development of other energy technologies. Conversely, where the two media and technologies are quite separate (End-states 3a,b and 4 and 13a,b and 14), there are few technological interrelations, limited substitutability of transport and stationary energy media, and limited competition for resources.²

² Recall that independence does not mean no interrelationships, but that those available all require two or more transforms. Thus, e.g., it is possible to transform chemical energy into compressed air or electricity by first converting the chemical energy into heat through combustion and then using the heat to drive a compressor or turbine, but this is a 2-transform pathway. There is however no equivalent way to transform compressed air or electricity into chemical energy. So the disconnect is substantial.

Where the stationary resource and transport demand technologies are partially overlapping (for example fossil or biomass resources combined with hydrogen based transport, end-states 5a,b) there are many pathways interconnecting the two dimensions. Liquid fuels can supply transport fuel directly if GE transport technology is used and fuel cells if EM transport technology is used, and can also be gasified to produce hydrogen directly. Conversely, hydrogen can serve some stationary demand directly, and can be converted to all other forms in the same number of transforms as can liquid fuels. These interrelations can be exploited to provide system adaptiveness to a range of technological developments, in addition to the adaptiveness provided by simply replacing one medium by the other. E.g. were photolysis technology to become a competitive alternative, its hydrogen output could complement fossil fuels in transport as well as stationary uses, while were EM powertrains to become competitive, then the hydrogen could be coupled with fuel cell technology to provide system access to that technology. Conversely, these same pathways create potential synergies between the two dimensions, a related adaptability capacity of the system, e.g. where transport demand for hydrogen from de-carbonised fossil resources permits photolysis technology to start up and mature along its technology learning curve, or where improvements in hydrocarbon technology offers similar improvements in hydrogen technology. The substitutability of media also results in a similar adaptability of primary resources suitable to meeting demand.

		Fossil	Biomass	SolarH	PV	Mech	Thermal
		IOP: VH, RA: H C: H	IOP: M, RA: H C: L-M	IOP: L, RA: M C: L-H	IOP: H, RA: H C: L-H	IOP: VH, RA: L C: L-MH	IOP: H, RA: M C: H,(M-H)
Liquids	TOP: VH, TA: MH	1a. TI: VH, MS: H, RC: MH	1b. TI: H MS: H, RC: H (L abund),	2. TI: M, MS: M, RC: M (abund)	3a. TI: L, MS: VL, RC: L	3b. TI: L, MS: VL, RC: L	4. TI: L, MS: L, RC: L
Hydrogen	TOP: M, TA: H	5a. TI: H, MS: M, RC: MH	5b. TI: M, MS: M, RC: M (L: abund)	6. TI: VH, MS: VH, RC: H (H abund)	7a. TI: LM, MS: MH, RC: L	7b. TI: LM, MS: MH, RC: L	8. TI: LM, MS: M, RC: ML
Electricity	TOP: M, TA: M	9a. TI: VH, MS: MH, RC: ML	9b. TI: H, MS: M, RC: M (L: abund)	14. TI: M, MS: M, RC: ML	11a. TI: VH, MS: VH, RC: H (M abund)	11b. TI: VH, MS: VH, RC: H (M abund)	12. TI: VH, MS: VH, RC: H (H abund)
Compressed Air	TOP: M, TA: L	13a. TI: L, MS: ML, RC: M	13b. TI: L, MS: L, RC: L	14. TI: L, MS: L, RC: L	15a. TI: M, MS: M, RC: MH	15b. TI: VH, MS: M, RC: H	16. TI: H, MS: M, RC: H

Vertical axis: transport fuel medium; evaluated aspects

TOP – Transport Organisation Proximity: closeness to the current system
TA – Transport Technology Adaptability: within sector adaptability

Horizontal axis: stationary fuel medium; evaluated aspects

IOP – Industrial Organisation Proximity: closeness to the current system
RA – Resource Adaptability: within sector adaptability
C – Centralisation potential: capacity for centralised (large scale) economic organisation

Matrix locations: scenario end-states; evaluated aspects

TI – Technology interrelatedness: similarity of stationary and transport energy technologies
MS – Media Substitutability: conversion of media between stationary and transport applications
RC – resource competition: energy supply competition between stationary and transport sectors.

Evaluation scale: VH – very high, H – high, M – medium, L – low.

End-state integration spectrum location:

Identity, Highly Interrelated, Moderately Interrelated, Somewhat Interrelated, Independent

Table 1: Scenario Integration Space

Table 1 then allows alternative scenario possibilities to be compared, including the capacity of each possibility to use one of its two media to back up the other, a useful indicator of its adaptability. Backup media for a specified possibility can also be selected on efficiency and adaptability grounds as appropriate. The integration results are as anticipated in Section III. Those media combinations showing extreme to very high integration also show high competition for the same resource and lower adaptability, and fall on or near the diagonal because of media ordering, those showing minimal or no integration or resource competition predominantly occupy the far off-diagonal positions and those showing more highly adaptable, intermediate degrees of integration occupy the intermediate positions, off but near the diagonal.³

In order to completely cover the full range of options for transport and stationary energy transformation technologies, there remains to select a set of basic scenarios that span the salient possibilities in Table 1. In principle any subset of end-states from these 24 possibilities that between them cover each major resource/technology combination suffices to form the end-states of a suitable set of basic scenarios, since combinations of them are then capable of capturing all of the possibilities. However, it is sensible to choose a subset that focuses on the 16 highly aligned or partially overlapping end-states, since these represent the two chief competing system features, respectively the most efficient and most adaptable energy system configurations. For instance, the following 7 end-states form an attractive basis for development:

- S1. (highly aligned) biomass with biofuel transport technologies (end-state 1b, with 1a, 2, 5a,b and 6 nearby);
- S2. (partially overlapping) solar hydrogen, with advanced biofuels for transport (end-state 2, with 1b, 5b and 6 nearby);
- S3. (partially overlapping) fossil fuels (with carbon sequestration) and maximum demand management, combined with fuel cell transport technology (end-state 5a, with 1a,b, 5b nearby);
- S4. (partially overlapping) solar thermal with hydrogen based transport (end-state 8, with 3b, 4 and 7b nearby);
- S5 (highly aligned) photovoltaic and mechanical with battery electric transport (end-states 11a,b, with 12, 15a,b and 16 nearby);
- S6. (highly aligned) large scale thermal (nuclear or geothermal) with battery electric transport (end-state 12, with 11b, 15b and 16 nearby);
- S7. (partially overlapping) thermal (nuclear, geo- or solar) and compressed air (end-state 16, with 11b, 12 and 15b nearby).

Each of these end-states can be developed into a fully fledged scenario by equipping them with a description of a trajectory over time from the present to that end-state. These are constructed retrospectively, considering the policy periods in reverse order so as not to exclude any adaptive possibilities, in accordance with the backcasting method to be used (see Discussion Paper #8, available at www.ccsd.biz). This then completes the basic scenario

³ We observe that had we compressed the representation by reducing media on both dimensions to just chemical and electro-mechanical, the extremes would exactly appear as the diagonal and off-diagonal elements respectively but all the intermediate integration information would have been obscured. Even separating electrical and mechanical media obscures all but one intermediate position. This encourages us to think that the present representation is the simplest useful one.

selection and construction task and opens the way to their adaptive analysis (see Discussion Paper #9, available at www.ccsd.biz).

To illustrate the construction, there follows in Figure 2 one possible end-state flow diagram, a variant of S4 with some additional influence of S5 above. For comparison, we first show in Figure 1 the equivalent diagram for our existing energy flow organisation, simplified by omitting electrified rail transport and a variety of smaller stationary flows, such as local photovoltaic augmenting wind electrical generation.

Figure 2 shows a system configuration where electricity generation is provided predominantly by a combination of solar thermal and natural gas plant and individually limited resources: wind, hydro, with some photovoltaic, wave and tidal resources. Transport is highly energy efficient and provided predominantly by electric rail and hydrogen fuel cell vehicles, which are supplied by the gasification of coal and biomass, and by biofuels produced by emerging industrial photosynthetic processes. Thermal energy by-product from gasification technology is exploited for direct industrial use or electricity cogeneration. Some vehicles also run on natural gas refined from coal seam methane. Areas suited to forestry cultivation but not harvesting, including land regeneration, are exploited as carbon sequestration sinks. Energy storage is provided by pumped hydro-electric, compressed air and electrolysis hydrogen. The electricity grid is decentralised. Due to the relative scarcity and high cost of energy, it is to be expected that both passive local source supply and service demand management measures are also strongly implemented.

These diagrams focus on qualitative energy media flows, with some comparative flows sizes indicated by flow line thicknesses. Not explicitly included is information about (i) specific primary source and tertiary demand types, for example ground thermal and roof-top flat-plate solar thermal are both included under the 'local thermal' source, while heating/cooling, electrical lighting and so on are all included under 'stationary services', (ii) specific energy generation and transmission technologies and any transformations among media that occur internally to them (for instance within a coal-fired steam turbine electricity generator), (iii) associated material flows, for example of water, (iv) spatial locations of resources, technologies and transmissions, (v) energy waste streams and any co-generation activities using those streams, (vi) environmental impacts and (vii) wider economic impacts (for example on the kinds and levels of skills demanded). Some of this excluded information is implicit in these diagrams, deducible using general information about societal energy provision. All of it would be relevant to a thorough evaluation and assessment of energy options. However, it is better suppressed at this point in order to focus on potential physical options in the organisation of energy provision.

Note the richer mixes of energy technologies and energy flow interconnections provided in Figure 2 compared to those of Figure 1, an example of an unintegrated organisation, interconnections that would also be much greater than those that corresponding highly integrated scenario end-state could deliver.

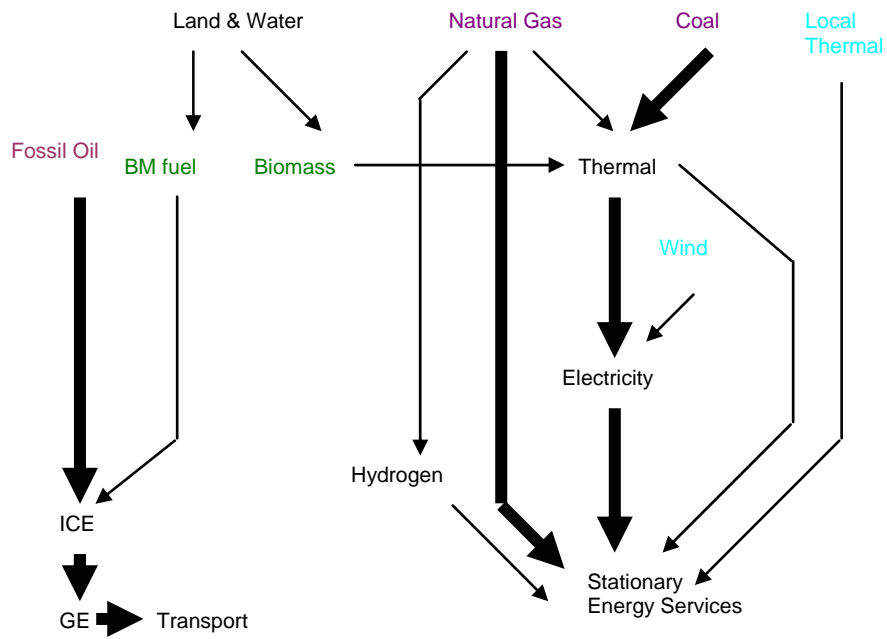


Figure 1: Current Energy Pathway Structure

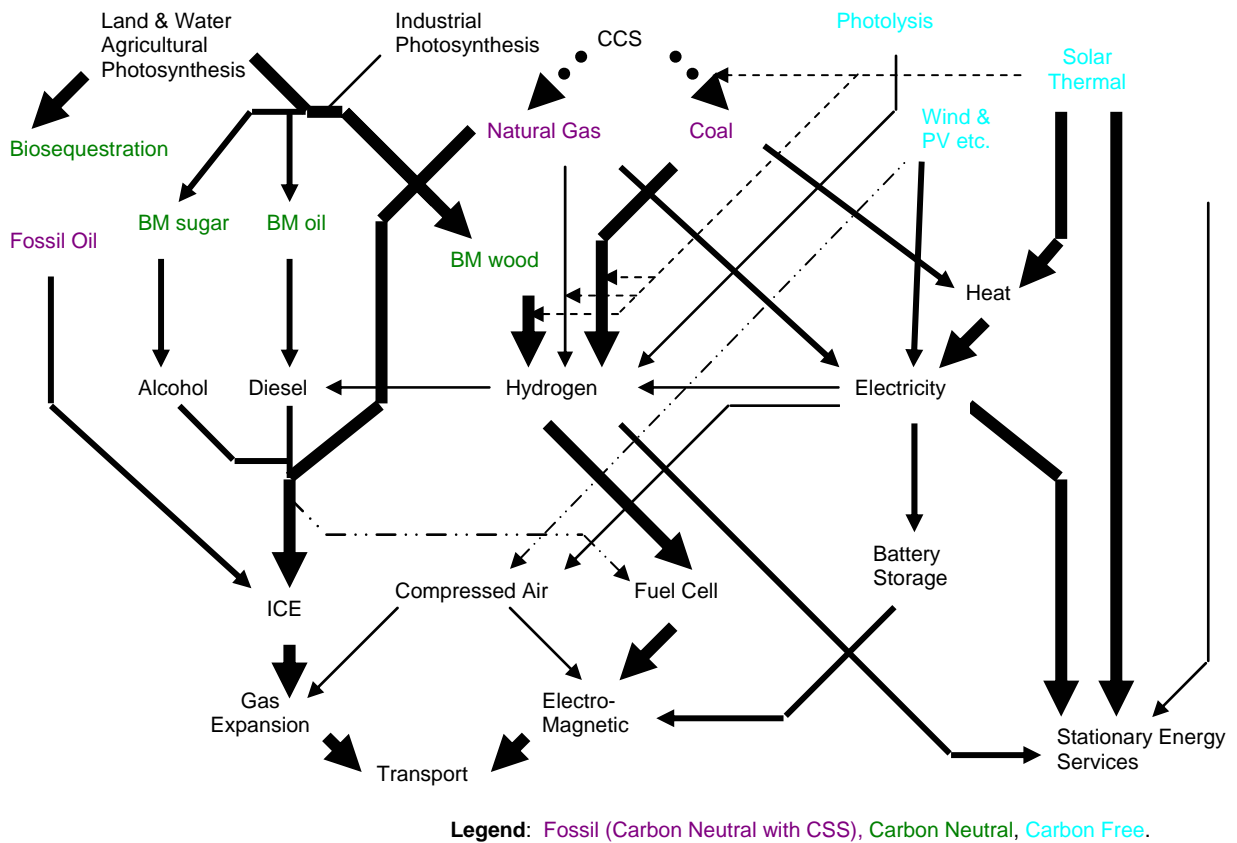


Figure 2: Decentralised Renewables and Hydrogen Scenario

Figure 3 provides a simplified representation of the main alternative pathways for providing transport and stationary energy services. The more leftward elements represent the more demanding service technologies and applications, and the resources and media with the greater range of applicability. It is also the case that media conversions from left to right are typically first-law efficient (though resulting in a quality downgrade) and media conversions from right to left tend to be energetically costly. This justifies conceiving of these energy resources, media and services as being a (partially) ordered set, forming a “quality hierarchy”.⁴

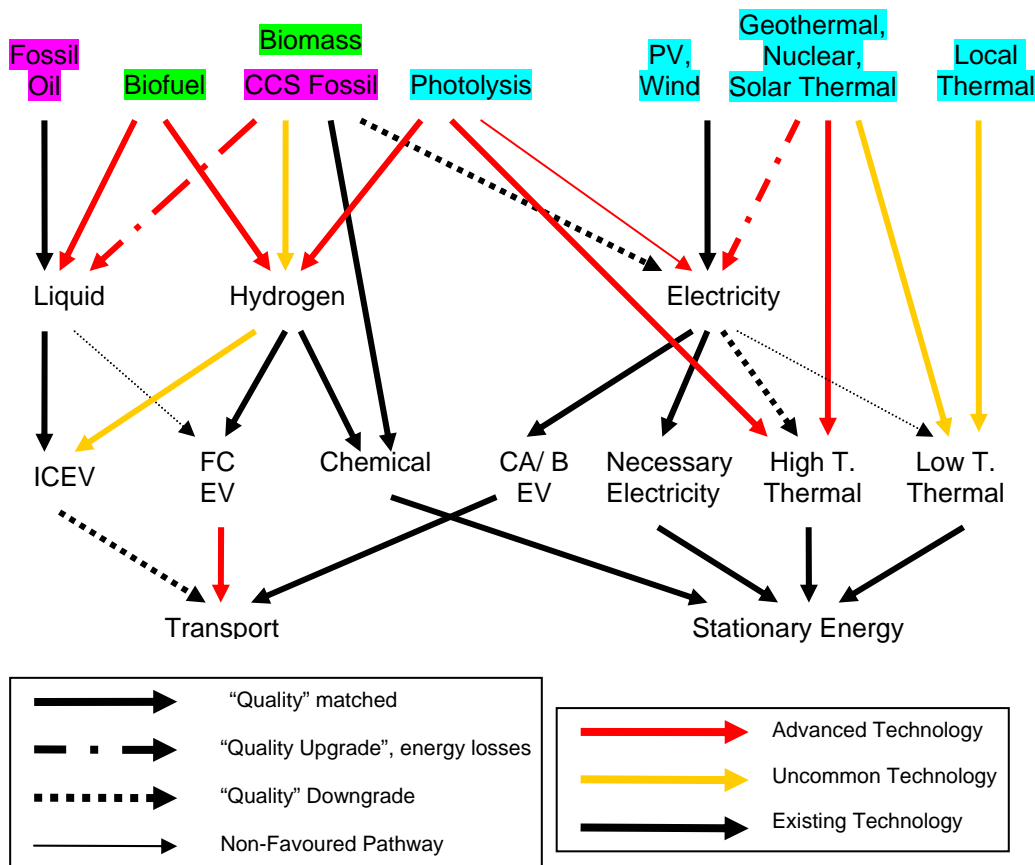


Figure 3: Energy Pathway options, stylised

The reasonableness of this ordering is a little more obvious if the intermediate energy media are not represented, as in Figure 4. We observe that resources are better matched (in general) to particular service applications, and that although some can be “upgraded” to supply more demanding applications, this is typically (energetically and economically) costly, and most resources can be exploited for more tolerant applications, although from an overall perspective this may be considered wasteful of a relatively high quality energy resource. The solid “quality matched” pathways in Figure 4 identify those alternative resource options for

⁴ There are some exceptions – the generation of electricity from chemical biomass or fossil sources represents an energy “quality” upgrade with corresponding first law inefficiency. However, electricity appears lower on the hierarchy in Figure 3 because it does not easily supply transport services. Liquid fuels, in contrast, can supply transport easily and also could serve most stationary applications, though this would be (economically) relatively wasteful.

meeting energy services that are, on efficiency grounds, the most reasonable (assuming that the overall transformation pathway is not via a quality mismatched energy medium, such as solar thermal-electricity-low temperature cooling, fossil-electricity-battery transport, or coal-methanol-fuel cell-transport). Resource options on either side of the most reasonable are increasingly unsuitable, respectively, inconveniently converted and more prudently applied to more demanding applications.

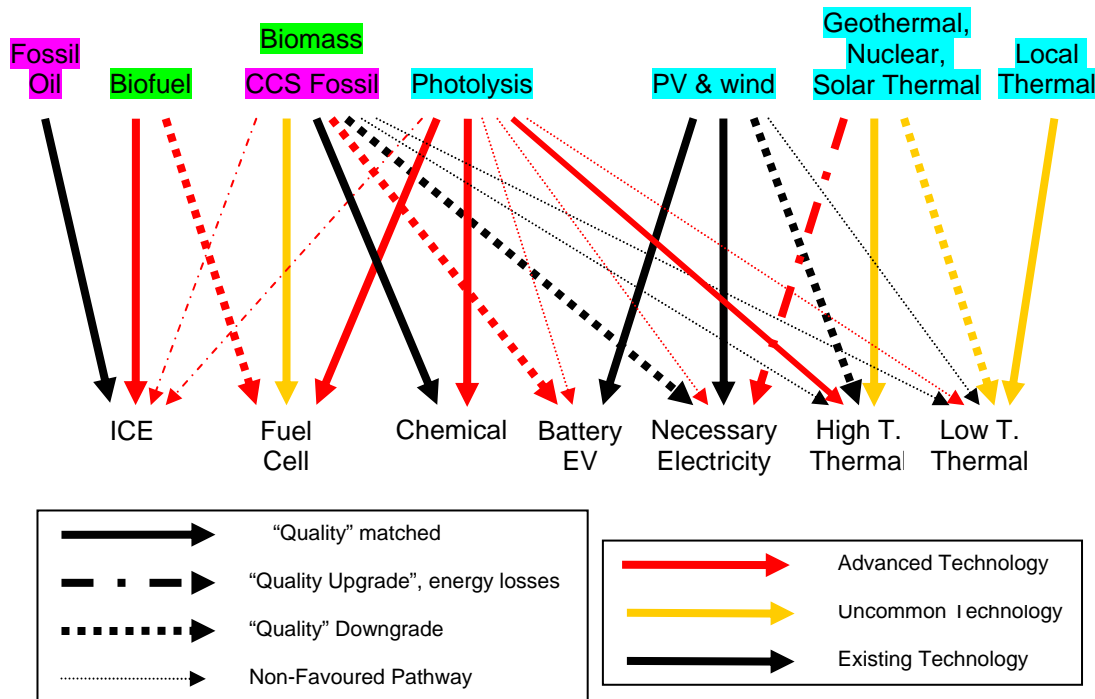


Figure 4: Quality Matching in Energy Systems

IV. Conclusion

This report has identified a broad range of technological pathways for the provision of energy services and used these to characterise an essentially complete set of alternative basic energy system configurations. Due to the special requirements of transport services for translocatable power delivery, a significant parameter characterising any given energy configuration is the nature of the energy pathway(s) for the delivery of transport services. The four major transport fuel media alternatives are chemical: a) liquids, b) hydrogen, and electromechanical: c) compressed air, d) battery-stored electricity. The nature of transport energy provision strongly influences the desirability of alternatives for the provision of the remainder of energy services – the stationary services including chemical energy, necessary electricity (communications and information processing, controllable motion, and nocturnal lighting); high temperature heating and low temperature heating and cooling. These constraints arise due to competition for resource or waste sink capacity and synergies due to technological similarity. The six main available primary energy resource alternatives are chemical: a) fossil, b) biomass – agricultural or industrial, c) direct solar hydrogen production; or electromechanical: d) direct solar electricity production, e) indirect solar climatic fluid motion and gravitational, or f) thermal – large scale centralised nuclear, direct solar thermal, geothermal – and small scale local solar thermal, solar illumination and ground source heat.

Four major transport technology alternatives and six major primary energy resource alternatives for stationary services together provide a cross-product of twenty-four major alternative basic energy system technological configurations. These twenty-four major alternatives span the range of all possible (and reasonably policy functional) configurations, any of which can be created as mixes of the basic configurations. Each of the twenty-four basic configurations, defined by transport fuel medium and technology, and stationary primary energy resource, is associated with yet another, higher order, descriptive parameter – the degree of technological integration between the transport and stationary technologies. This parameter describes how technologically similar are the energy pathways supplying transport and stationary services, and can vary from identical, through similar and interrelated, to independent. It is strongly correlated with the degree of competition between the two sectors for limited resources (eg natural gas, biomass, uranium) or waste sinks (global net carbon sequestration capacity, local air quality limits), the potential for synergies that arise from the combination of related technologies, the efficiencies that result from the similarity of skills and governance institutions required to manage the technologies, and the extent to which segments of each pathway can form a redundant alternative for those of the other – either via inter-convertible media (electricity and hydrogen) or dual application technology (fuel cells, electric motors, compressed air power systems). The most adaptably resilient basic configurations will tend to be those whose stationary and transport sectors are neither identical, nor independent (as they are currently, recall Figure 1), because these will tend to have the greatest number of qualitatively distinct interconnections between the two sectors.

Combinations of essentially technologically identical pathways are represented in the diagonal of the basic scenario configuration possibility matrix (Table 1), those slightly off-diagonal will have the richest interconnections, and those far off-diagonal will be more independent. This is due to the fact that the Table has been organised such that there is a correspondence between the transport and stationary media alternatives, and furthermore, the technologies with relatively similar properties (basic underlying physical principles, overall performance) appear in adjacent rows and columns. Thus, future development of a configuration towards that of a nearby cell in the Table is relatively easy.

Matching primary energy resource to final service reveals an almost well-ordering of high-versatility to low versatility primary resources, and demanding to tolerant applications, suggesting that each service has a range of corresponding well-matched primary resources, plus a small number of possible, but less efficiently suited, resources as alternative supply options.

Actual energy system configurations will be composed of mixes of these basic scenario configurations. (However the present situation in Australia, for example, is dominated by one of these, namely the independently organised thermal stationary/ liquid fuel transport state.) Scenario mixes can lead to technological mixes that are potentially even more richly interconnected. It is such richly interconnected technology mixes that are expected to lead, provided the individual component technologies are at a sufficient scale, to the greatest degree of industrial adaptive capacity – the flexibility to meet the needs of changing circumstances. It simultaneously leads to the greatest potential for the development of synergistic technological combinations, providing yet more flexibility. Developing richly

integrated technological configurations of this kind should be the aim of an adaptive backcasting scenario construction for an adaptive energy policy.