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Standing Committee on Industry and Resources
House of Representatives
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# Inquiry into the development of the non-fossil fuel energy industry in Australia: Case study into selected renewable energy sectors

**Submission by**

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## Executive Summary

Except perhaps for the introduction of nuclear power in the 1960's, the world's primary energy mix has not changed fundamentally in a century. Coal, oil & gas continue to do the heavy lifting, with hydroelectric power being the only renewable energy source making a substantial contribution.

It seems only natural that this should soon change as liability for greenhouse gas emissions is progressively factored in. Disturbingly however, renewables seem to be losing the race. New coal-fired power stations continue to be built around the world at an alarming rate, as existing plant lifecycles are extended from 30 to 50 to 80 years.

It is with a large degree of trepidation that I respectfully venture to suggest that there may be a dramatic way out of this predicament:

Liquid Air imported from Antarctica for $10-15 per tonne will permit the construction of super-efficient thermal power stations needing less than half their normal fuel. The resulting fuel surplus can then be cheaply redirected to other uses – including synthetic fuels manufacture and large scale capture of $CO_2$ directly from the atmosphere. Captured $CO_2$ streams can be piped for injection into local geosequestration sites as has been suggested, or back-loaded to Antarctica for permanent storage within the icesheet. Electricity prices might be affected by less than 2c per kWh.

At first sight this might seem to be a rather inappropriate and far-fetched idea, however the concept does appear to stand up to more detailed analysis, and it may also offer a key strategic advantage: If retro-fitting is easy then massive global greenhouse gas reductions might be possible very quickly.

An earlier vision of how a Liquid Air Economy might work was compiled in March 2007, and is included as Appendix A (3 pages). A subsequent detailed analysis and thermodynamic treatment is a work in progress, and is included as Appendix B (300 pages) with extracted charts included below in the body of this submission. The thermodynamic modeling accurately simulates commercial thermal power cycles. The earlier document needs to be revised in line with the subsequent work.

The availability of cheap liquid air impacts on a number of the renewable energy sectors that are listed for study under this inquiry – solar thermal, geothermal and hydrogen are all covered below.

## Our Three Big Energy Policy Challenges

**Energy Security**

- Primary energy demand projected to at least double by 2050
- $16 trillion earmarked globally to build 7,800 power-stations by then

**Peak Oil**

- Synthetic fuels (liquid fuels and hydrogen) produced from gasified coal and similar technologies
- Progressive reduction of carbon intensity for transport fuels

**Global Warming**

- GGE reduction target of at least 50-60% by 2050

## Existing energy infrastructure

Coal, oil & gas provide 85% of world primary energy, and they fuel an infrastructure that has taken a century to construct. Our global warming crisis has its roots in energy investment decisions that were made decades ago. Likewise the long-term fate of global warming depends upon the energy investment decisions that we make today. We will live with the consequences of those decisions for a long time.

We need to shop wisely. If we only have $1 to spend on infrastructure then we are compelled to spend it on the cheapest acceptable option. In the case of GHG abatement options, if our systems cost twice as much, then we can only afford to abate half as much GHG. The Stern Report points out that the world is already spending $250 billion on sub-optimal energy generation.

It is worth bearing in mind that fossil fuels are not the enemy per se – greenhouse gas emissions are. Our challenge is to effectively manage those. Renewables will need to compete on their own merit.

## The state of development and prospects for renewable energy

The "Techno-Economic Assessment of Power Generation Options for Australia" prepared last year by the CRC for Coal in Sustainable Development, says that various renewable energy technologies will likely become cost competitive with clean coal by around 2015.

Under such circumstances, I believe that we have a moral responsibility to make full use of these renewables wherever possible. This is strategically sound – it doesn't make sense to burn up finite coal reserves that will undoubtedly be needed by future generations for their carbon feedstock.

Renewable energy will surely have an important and increasing role, but we can also assume that the carbon constrained market will continue to spur innovation and competition across all sectors.

## Concentrating Solar Thermal

Constraints: remoteness to major markets, access to water, moderate thermal efficiency.

The CCSD report devoted an entire section to Concentrating Solar Thermal technologies, and said that large scale CST with thermal storage "is likely to be the most cost effective renewable technology" and the only one "that can make deep cuts in greenhouse gas emissions."

I believe that if solar thermal technologies do offer a better solution to our greenhouse gas abatement problems, then that would be preferable to importing liquid air from Antarctica. There are some serious economic obstacles to overcome before such an achievement is possible however.

That is, if we don't retro-fit our main thermal power stations with liquid air turbines, then we will continue to waste fuel (thereby further increasing our emissions liability) and miss out on the potential windfall of surplus coal that might otherwise be used for accelerated global-scale extraction of $CO_2$ direct from the atmosphere.

It might be preferable however, to use CST (topped up by natural gas) to provide heat for DAC absorbent recycling and thus provide 100% direct use of the solar heat resource. The economics are unlikely to compete with a liquid air economy overall, but it would be hugely satisfying if they did.

Conversely, if used in conjunction with liquid air cycles, CST electricity generation would benefit from increased thermal efficiency and aerial intensity, and by eliminated the need for cooling water.

## Geothermal

Constraints: remoteness to markets, access to water, low thermal efficiency

Although classified as a renewable energy source, geothermal heat sources are certainly not renewable – at least not on any meaningful human time-scale. Over time the temperature of the rocks decreases until after 30-50 years the ground is effectively cold and a new location must be found and new boreholes drilled.

High class geothermal sites are a prize asset that might benefit substantially if used in conjunction with liquid air cycles. Water availability issues would disappear, but a hybrid solar or gas system would be needed to deliver the hot temperatures necessary for economic liquid air use. The vastly improved thermal efficiency suggests very favorable economics.

## Hydrogen & Liquid Fuels

Constraints: primary energy source, carbon feedstocks, development of hydrogen market

The need to preserve our coal resource is balanced by the need to maintain return-on-investment for our existing mine infrastructure. In the presence of a coal surplus due to the liquid air economy, we would need to find alternate markets for all our projected coal production. In the medium term this might mean accelerating the use of coal in recycling hydroxide absorbents to extract atmospheric $CO_2$, and progressively in the longer term as a syngas feedstock for synthetic fuel production (hydrogen and liquid fuels). Both are worthy uses of our precious coal resource.

## Coal-Fired Power

Coal power stations consume large amounts of fuel and water, and generate substantial emissions. A number of technological options are being developed for clean coal, however, no clear winners have emerged in the race, and investment decisions are potentially being delayed as we wait for hydrogen and liquid fuels manufacturing pathways to become clear.

Integrated Gasification Combined Cycle (IGCC) power stations only make economic sense if we factor in the benefits of synthetic fuel production, but until the market for syn-fuels develops (15-20 years) their expense cannot be justified. Pulverised fuel plants are cheaper for now but will lock us into an undesirable long term emissions liability.

There are proven prospects for incremental efficiency improvements with high temperature and pressure Advanced Super-Critical designs, but the potential for future increase eventually hits a wall. Figure 1 shows that incremental improvements are small, and cycle efficiencies inherent in IGCC don't translate to better fuel efficiency due to losses in the gasification process.

Retro-fitting with liquid air cycles holds far greater promise for radical improvements (doubling of fuel efficiency) and I believe research should be pursued accordingly.

## Geo-Sequestration

Clearly the coal, oil & gas industries are under immense pressure to adapt to life in a carbon-constrained energy market. Australian industry has responded with world-class innovations. Research into geosequestration by the Australian Petroleum CRC, GEODISC, the CO2-CRC and others has defined emission hubs and $CO_2$ injection sites around Australia.

Unfortunately most emission hubs don't have a suitable injection site within reach. For these sites an alternative storage location or method is needed. Unlimited permanent storage in Antarctica might become affordable if a liquid air facility were to be built and excess $CO_2$ could be back-loaded to Antarctica.

## The Liquid Air Economy – An Historic Opportunity

Refer to Appendix A

Liquid air technology extends the life, productivity and value of all our thermal energy resources, and there are many chemical and physical processes that benefit from the availability of cheap cryogenic heat sinks.

No doubt if liquid air became widely available at $10-15 per tonne it would spark some kind of revolution across many diverse industries. Potential new applications for liquid air would likely proliferate.

Economic activity would be spurred also by the availability of surplus fuel and abundant electrical generation capacity. The liquid air economy represents an historic opportunity for industry, and will significantly alter the way we view all our energy markets.

Refer to figure 2 for an estimate of the potential fuel surpluses that are possible.

## Power-station Cooling Water is Eliminated

A substantial benefit of liquid air cycle technology that bears repeating in its own right, is that liquid air power cycles do not require any cooling water. This has huge implications for local water supplies and for the siting of power-stations in areas of physical water shortage.

## The Value of Direct Air Capture (DAC)

A real fly in the ointment when seeking to identify an ultimate greenhouse strategy lies in the mathematical formulation of the emissions problem itself:

Put simply, our dilemma in tackling greenhouse gas emissions on a global scale is much like the problem faced by goldfish in an increasingly dirty bowl - the waste has nowhere else to go and can only keep building up. No amount of emissions reduction can make the water clean again.

The best bet for our hapless goldfish is to have someone change the water. But for us, the proposition of making 4 billion $km^3$ of dirty air simply go away is quite absurd. Might it be possible though, to install some kind of atmospheric filter to scrub excess global emissions over time?

Hydroxide absorbent systems (as outlined by Klaus Lackner and others) require vast energy inputs and have been dismissed as impractical by the energy industry to date. But with the prospect of a substantial fuel surplus from our existing infrastructure that obstacle might be entirely overcome.

It would be immensely satisfying if large scale direct air capture were to become available at $15-30 per tonne $CO_2$ as described by such authors. Cooling towers made redundant by liquid air turbine cycles might be used instead for direct air capture.

## Liquid Air Manufacture in Antarctica

Annual surface temperatures on the East Antarctic plateau average around –60°C. This intensely cold ambient temperature offers huge advantage in the manufacture of liquid air by either hot or cold compression methods. Refer to figures 3a & 3b for a comparison of compression work and fuel requirements of compression plant operating in Australia vs Antarctica. These figures assume dry air operation.

Industrial production of liquid air by the Claude liquefaction process requires that chemical absorbents be used to remove water and carbon dioxide that would otherwise condense and foul the equipment. Liquid air produced by such means typically costs $100-200 per tonne. In Antarctica the air is so cold that there is essential zero water vapor, and carbon dioxide removal is simplified as well.

Thus if a liquid air manufacturing complex were to be constructed on a suitably large scale on the Antarctic plateau, it is quite reasonable to project manufacturing costs of $10 per tonne or less.

High thermal efficiency combined-cycle plants that can fully utilize recuperated compression heat to drastically reduce fuel consumption might prove especially effective – particularly if ultra-efficient turbines and compressors are developed. Cold compression requires less overall compression effort, but the plant complexity and added fuel demand might make it a less desirable option.

Power-stations and liquefaction equipment can operate throughout the year to optimise plant utilisation, whilst various maintenance and system optimisation tasks would occur during summer. Substantial hydro-electric power can be generated from the liquid air as it is flows through tunnels from the plateau at 3,000m elevation to ports along the coast.

To give some idea of the volumes involved, a 2000 MW power station such as Loy Yang A in Victoria would require about 1 tonne of liquid air per second – about 30 million tonnes per year. On a global scale that equates to 30-40 $km^3$ of liquid air to be shipped (allowing for some evaporative losses). This compares with about 4-5 $km^3$ of oil that is shipped globally each year. Certainly an unprecedented volume, but not out of the realms of commercial possibility given that bulk shipping is typically a very small cost relative to most enterprises.

## Carbon Dioxide Sequestration in Antarctica

Imported $CO_2$ can be pumped to permanent storage locations within and under the icesheet. The whole process is very clean and the environmental footprint is surprisingly small.

A year's worth of global $CO_2$ emissions is enough to form a liquid $CO_2$ lake 25 $km^3$ in volume beneath the ice. Compare this to the 30 *million* $km^3$ total volume of the Antarctic icesheet. Imagine a stack of copy paper 60 reams tall - a single folded sheet of blue copy paper placed underneath this stack would represent 40 years worth of global emissions (60 reams = 30,000 sheets, and 1 sheet = 1,000 $km^3$).

## What will it cost?

An early best estimate is for liquid air at $10-15 per tonne. Thus:

An extra 1-2c / kWh for electricity seems reasonable;

Or an extra 5-10c / litre for transport fuels.

This is equivalent to about $30 / $tCO_2$ avoided for black coal, or $20 / $tCO_2$ avoided for lignite.

In simple terms, liquid air combined cycles will double the efficiency of thermal plants, and thus halve fuel and boiler related costs. Further savings are possible due to more efficient air separation (for oxy-fuel units) and coal gasification processes. Nor are cooling towers required for the liquid air cycles.

Rigorous costings for liquid air manufacture in Antarctica aren't possible at this stage, however reasonable assumptions can be made that suggest that components mass-produced here and delivered with fully scaled logistical support will be affordable. All Antarctic expenses would be reflected in the price of the liquid air delivered to power stations here.

Detailed analysis and trials would determine which hot or cold compression method is the most affordable. Refer to figure 4.

## Emissions Trading

The success of such a venture depends upon the existence of a suitable emissions trading mechanism. A system of liquid air manufacture in Antarctica offers some unique opportunities for co-operative efforts between a multitude of countries and organizations, and might well serve as a catalyst for productive emissions trading negotiations. It is much a pity that more work was not available in time to make a credible submission for the Prime Minister's Taskforce on Emissions Trading earlier in the year.

An Antarctic project will help to fulfill many of the aims of The Asia-Pacific Partnership on Clean Development and Climate (AP6). Australia and our partnership countries China, India, Japan, Republic of Korea and the United States would all be very well placed to leverage the substantial economic benefits that will accrue from the strategic development of the energy services sector to incorporate liquid air technologies.

## Concluding Remarks

This is a very dry subject – thank you for reading this far. I hope that I have found the right words, and that my conservationist friends will forgive me for suggesting such an adventure in Antarctica. I am not saying that we definitely must do this thing. I sincerely hope that other energy alternatives (such as solar thermal) do prove to be superior, and that we can avoid the need to consider such a plan.

Independent analysis will soon show whether this proposal holds up to scrutiny or not. At the moment though, and very unfortunately, I don't think that the world has the luxury to rule out any options until something is ultimately ruled in.

If it does happen that there is public support, and a liquid air facility is developed in Antarctica, then we might well be comforted by the knowledge that this is a very friendly thing to do for the planet as a whole, and kind to the wildlife and heritage values of the white continent itself.

We've learned much over recent decades about how to respect and care for our environment and to do things well – cleanly and safely. We must trust ourselves to thoughtfully plan and carry out whatever global warming solutions we ultimately decide to commit to.

## Acknowledgements

I very much wish to thank my wife Leanne, and our children for their good-humored support and encouragement over an extended period – and especially for helping with all the printing and running back and forth in recent times.

I am most grateful to the committee for the opportunity to tender this submission, and am very willing to attend any follow-up hearings should the committee so require.

Mr Zane Smith

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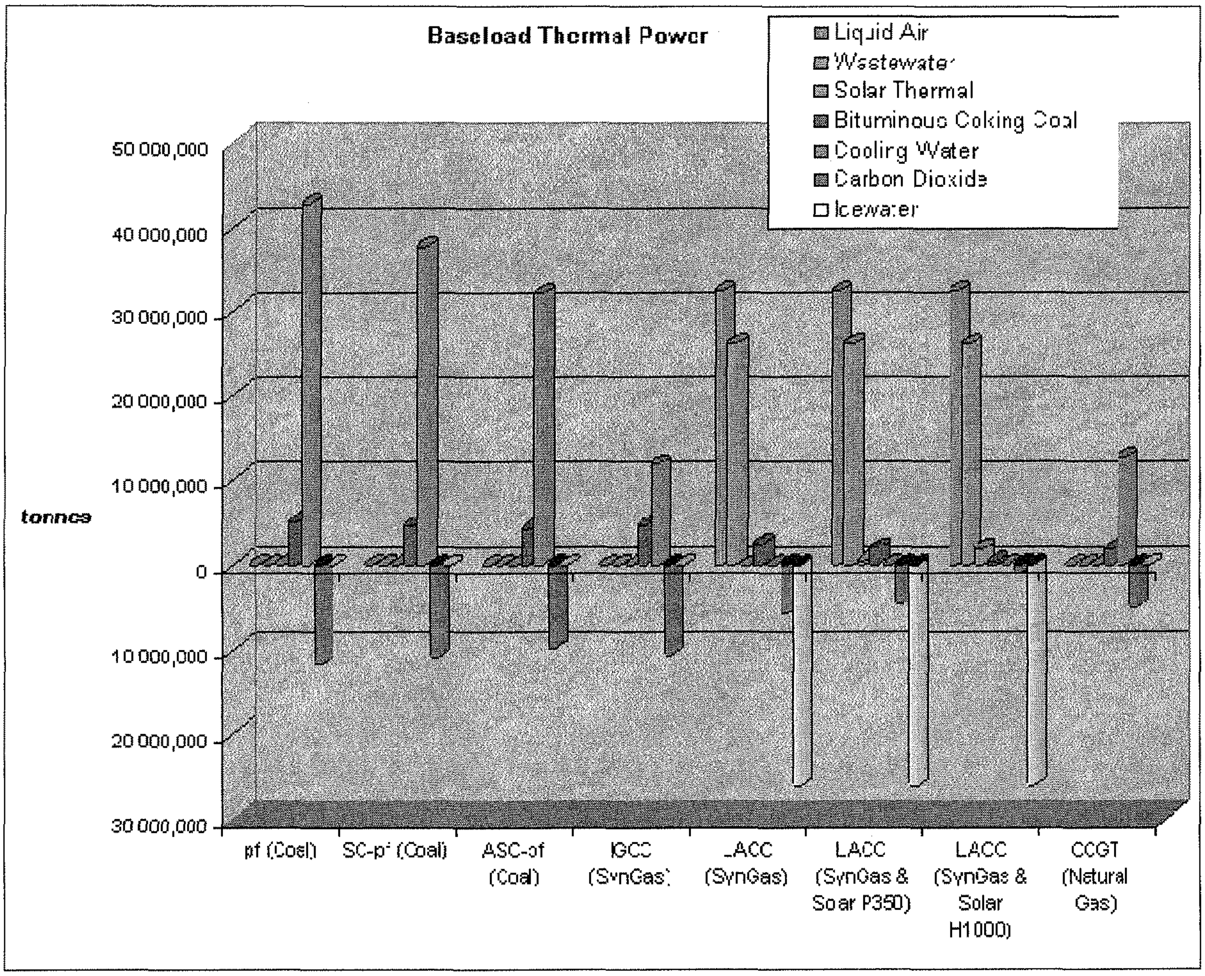


Figure 1. Baseload Thermal Power

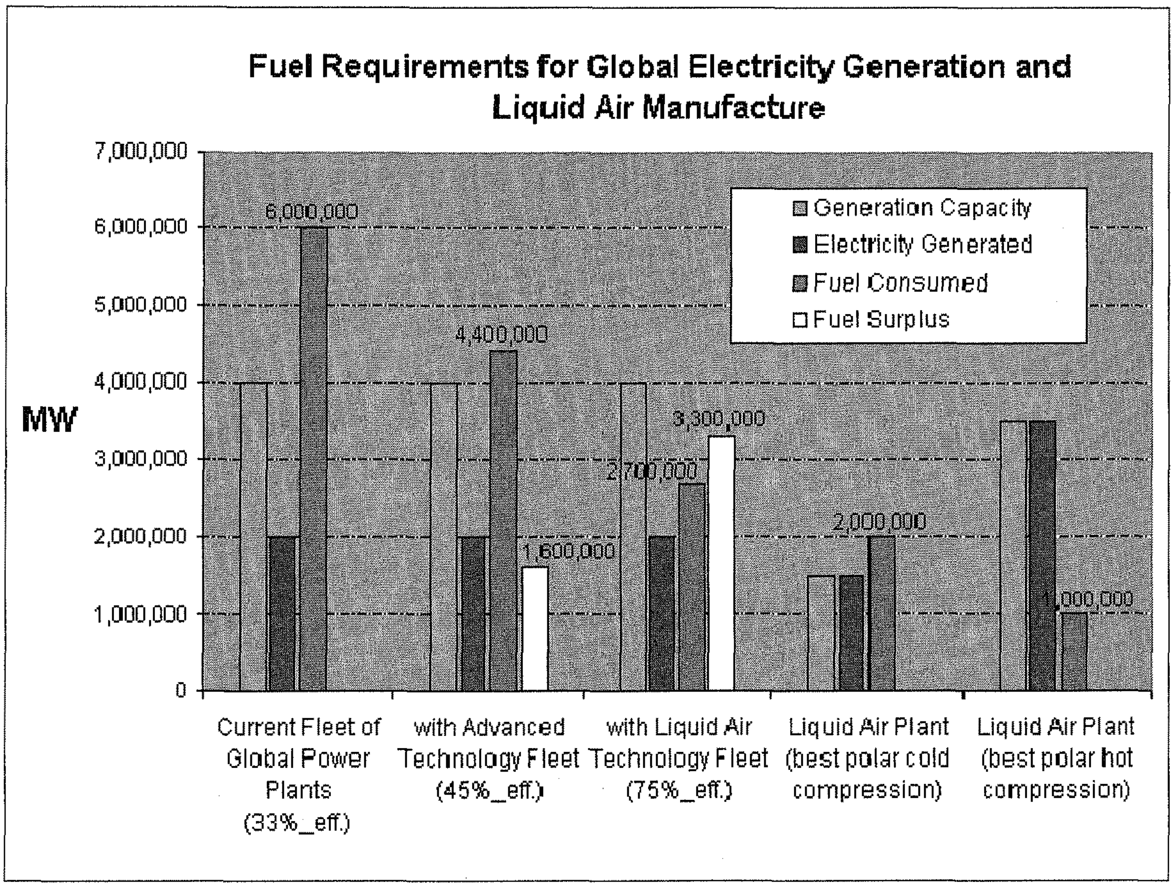


Figure 2. Fuel Requirements for Global Electricity Generation and Liquid Air Manufacture

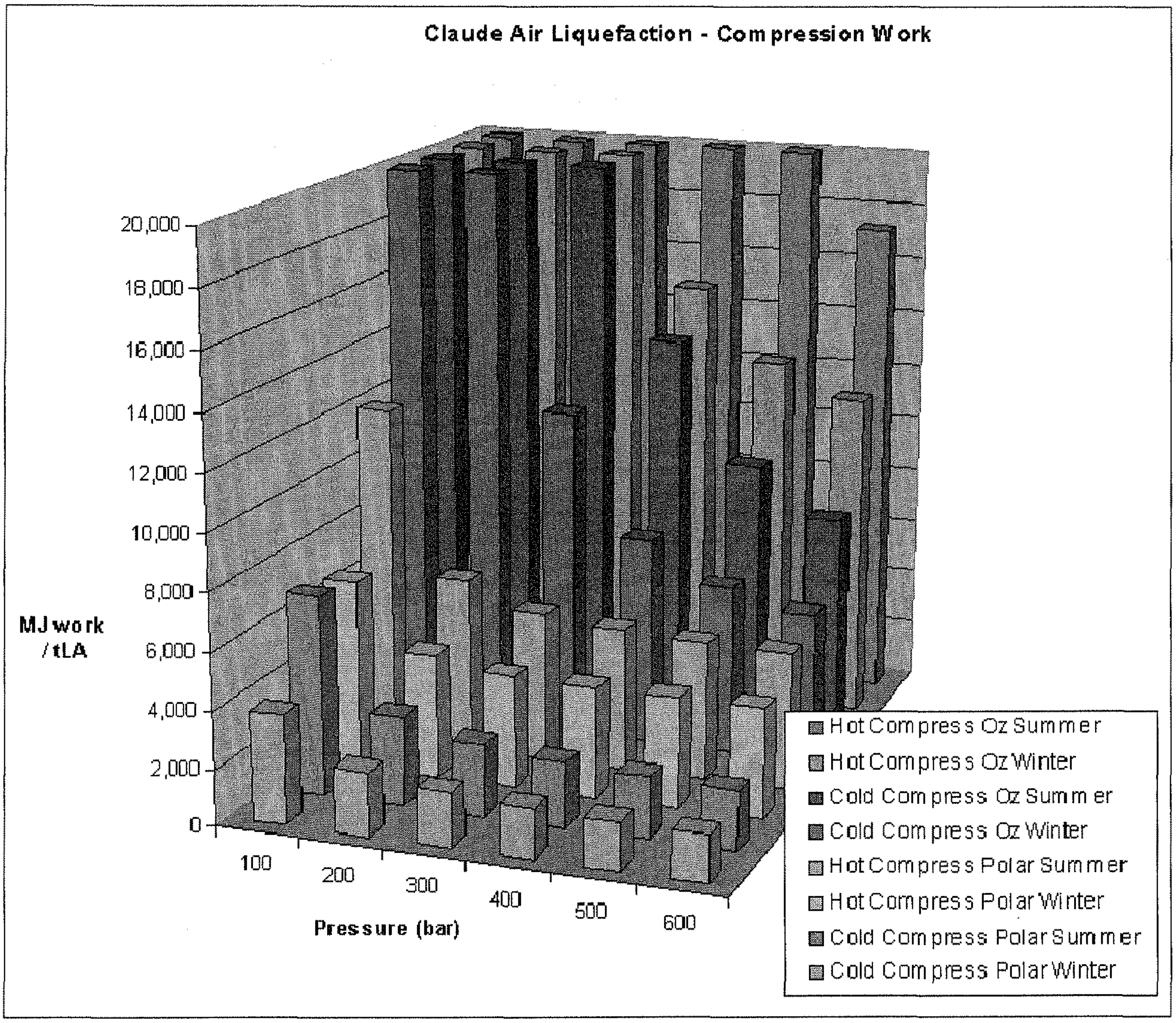


Figure 3a. Claude Air Liquefaction – Compression Work

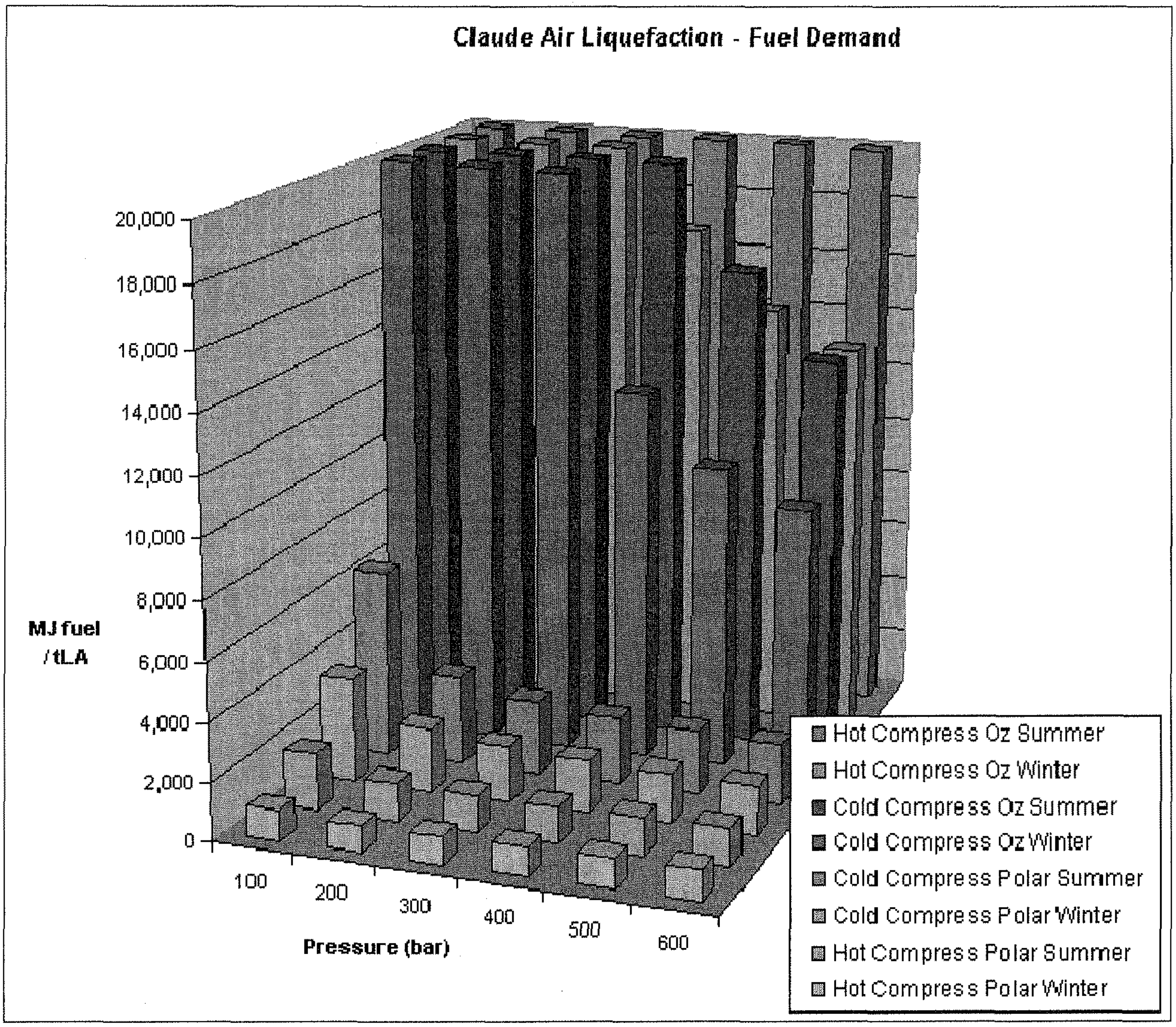


Figure 3b. Claude Air Liquefaction – Fuel Demand

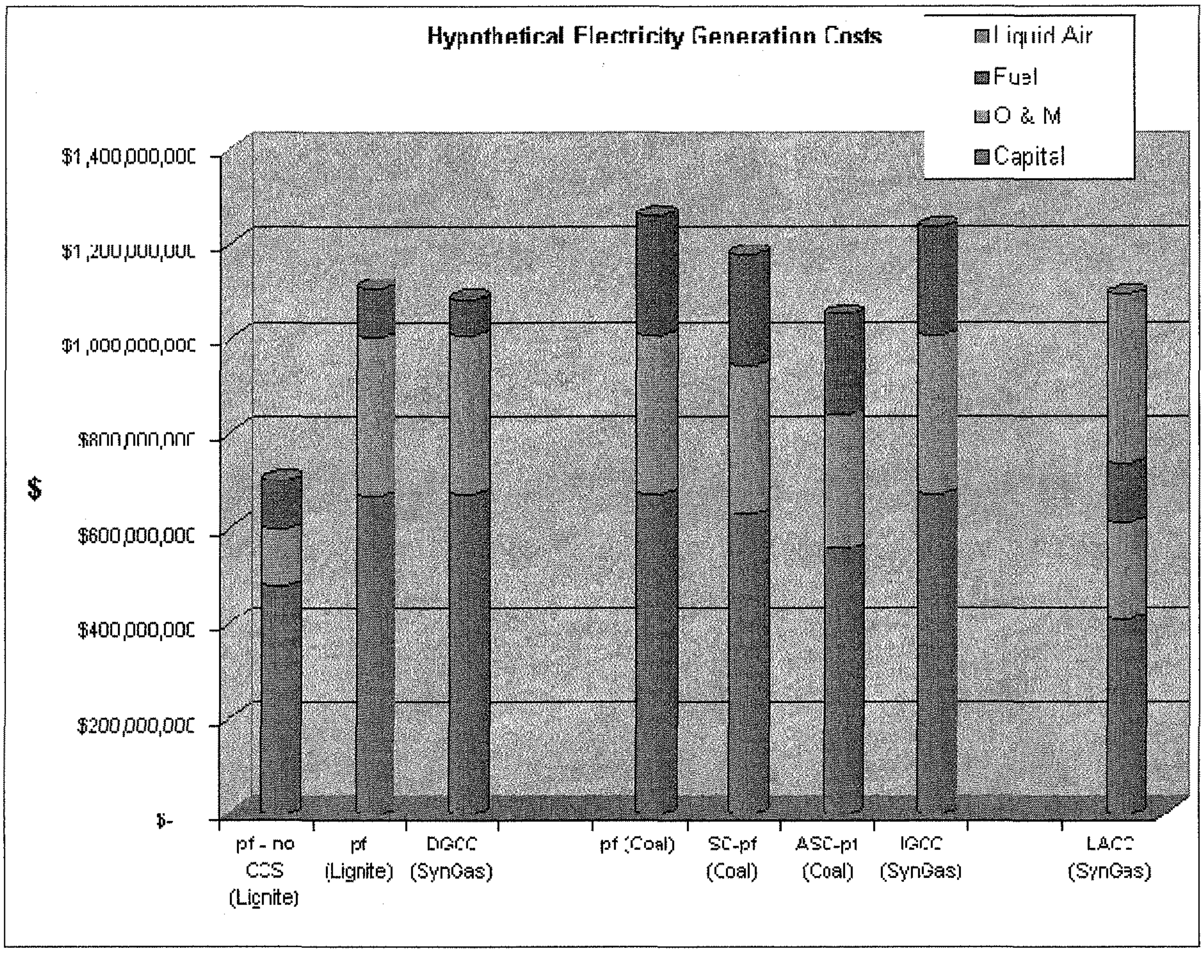


Figure 4. Hypothetical Electricity Generation Costs

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A complete list of reference sources has not been attempted at this time, however works by the following authors have been particularly useful:


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