

Victorian based Coal To Chemicals

economics and technology status

A brief prepared for BCIA

by Strategic Energy Consulting Pty Ltd and Gamma Energy Technology Pty Ltd



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Exec Summary

Victoria has substantial brown coal resources supported by significant infrastructure, from extraction to generation and distribution. It is currently used exclusively for power generation – however it is a suitable resource for other applications.

The production of chemicals or fuels from brown coal maybe carried out directly or indirectly. Figure 1 shows both a gasification and dissolution / liquefaction route along with the typical/ major products available from each process route.

Highlights from this briefing study have shown that:

- All the coal to chemical technologies covered in this report are both mature and technically feasible.
- The economic feasibility of a coal to chemical facility is very dependant on the product produced.
 - The levelised cost of Hydrogen production is within upper bound of current market prices, however it has an associated carbon dioxide risk.
 - Capital subsidies are not likely to be a useful incentive for Hydrogen production.
 - Urea may also be feasible, however the levelised cost of urea mid-point is above current market prices.
 - Capital subsidies or other financial instruments (e.g. loan guarantees) would both lower the levelised cost of product, reducing the risk and make the process more economic.
 - Urea production has a relatively low price on carbon dioxide emissions risk.
 - Synthetic petroleum products (from a Fischer – Tropsch facility) are not likely to be feasible unless the crude oil price is over \$130 bbl for the life of the facility.
 - Both methanol and ammonia require significant subsidies or assistance to become competitive with current market prices for those products.
- The local and regional impact of a large coal to chemicals facility would be substantial during both the construction and operation stages. Peak construction labour would be approximately 6000 jobs – with long-term operational roles approximately 400 – 500.

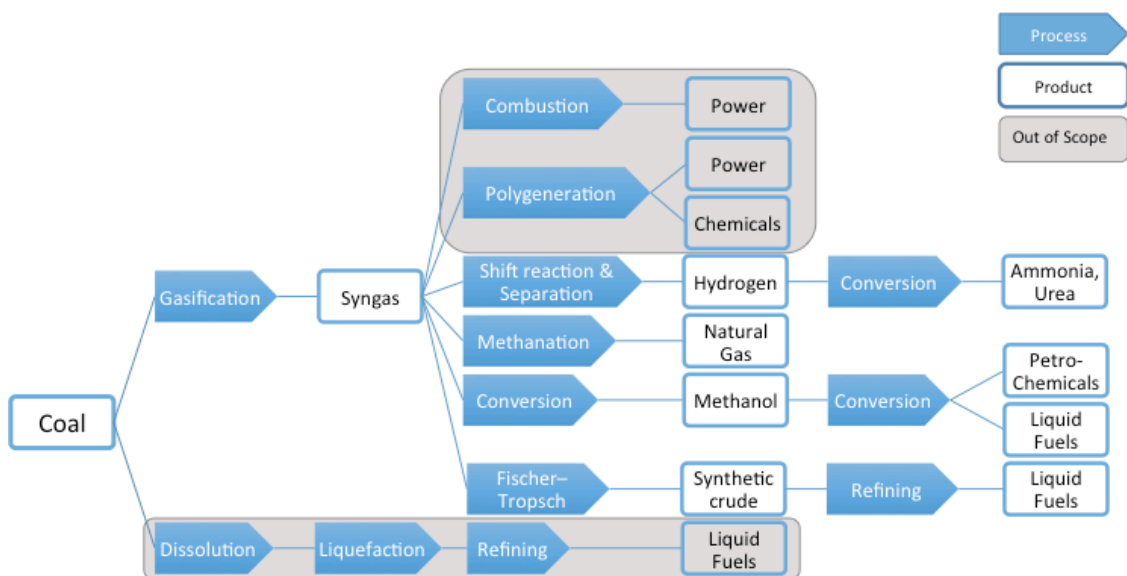


Figure 1 Coal to chemicals family tree

Table Of Contents

Exec Summary	2
Table Of Contents	3
Introduction.....	4
Potential Business Case.....	5
Technology & Capital Investment.....	5
Levelised Cost of Product and Competitiveness.....	6
Workforce and Regional Impacts.....	6
Why do CTX in Victoria.....	7
Economics.....	8
Levelised Cost Of Production	8
<i>Calculation Methodology.....</i>	<i>8</i>
<i>Levelised Costs Of Various CTX Products.....</i>	<i>9</i>
Construction Workforce.....	12
<i>Construction Execution Strategies</i>	<i>12</i>
<i>Coal To Chemicals Plant Schedule and Construction Workforce.....</i>	<i>13</i>
<i>Additional Regional Impacts.....</i>	<i>14</i>
Operational Workforce	14
Technology Review	16
Primary Conversion Technologies.....	16
<i>Gasification (indirect conversion)</i>	<i>16</i>
<i>Direct Coal Liquefaction (direct conversion).....</i>	<i>19</i>
Secondary Conversion.....	19
<i>Syngas Conditioning</i>	<i>19</i>
<i>Water-Gas Shift Reaction</i>	<i>20</i>
<i>Hydrogen production</i>	<i>20</i>
<i>Hydrogen Conversion</i>	<i>21</i>
<i>Methanol Synthesis.....</i>	<i>21</i>
<i>Fischer Tropsch synthesis.....</i>	<i>22</i>
Trends and Status	23
China	23
Appendix 1 – LCOP Calculation.....	25



Introduction

Victoria has substantial brown coal resources supported by significant infrastructure, from extraction to generation and distribution. The Latrobe Valley has one of the world's largest deposits of brown coal – 33 billion tonnes of potential economic resource, 13 billion of which is unallocated.¹

The Latrobe Valley in particular hosts a workforce that has significant specialised skills and knowledge in the energy sector and a traditional experience in heavy industry and large scale industrial projects which would be required for new developments. It is likely that these resources will play an important role in the region's future prosperity, particularly the ongoing conventional and alternative uses of the region's brown coal resource.

Brown coal will continue to provide the core of Victoria's base load electricity generation for the foreseeable future and is also a potential source of value-added products such as gas, diesel, fertilizer or other chemicals.

An understanding of the cost of potential coal to chemical (CTX) technologies will play an important role in determining the future opportunities for Victorian brown coal. Understanding production costs for the wide range of technologies studied will assist in determining the extent technologies will be competitive with existing suppliers.

The focus of this work was to present:

- A succinct description of various CTX options;
- A brief description of global trends of CTX;
- High level estimates of CTX options in Victoria;
- Capital cost of the plant (first of a kind);
- Levelised cost of product (LCOP); and
- High level estimates of the regional economic impact of a CTX project
- Options that may be required to make a CTX project feasible.

¹ https://www.rdv.vic.gov.au/_data/assets/pdf_file/0008/1153997/Latrobe-Valley-industry-and-employment-roadmap-WEB_v2.pdf (accessed Jan 2016)



Potential Business Case

One of the key objectives of this project was to examine the potential business case of establishing CTX plant in Victoria.

The key aspects of a CTX business case include:

- Technical feasibility of building CTX plant;
- Level of capital investment required for such a plant;
- Expected cost of product and its competitiveness; and
- Workforce and regional impacts of the project.

Technology & Capital Investment

Several product options have been considered for establishing CTX facilities in Victoria:

- Raw syngas
as an energy source, alternative to natural gas supply
- Hydrogen
for transportation and chemical industry
- Fischer-Tropsch (FT)
products as transportation fuel
- Methanol
as a chemical feedstock
- Ammonia
as a chemical feedstock
- Urea
as a locally manufactured fertiliser

Several other options, such as dimethyl ether (DME) or substitute natural gas (SNG) were excluded from the study. DME has a very limited (niche) market in Australia, and SNG is known to be economically viable for the countries that are importing natural gas.

80,000 bbl per day FT plant was chosen as a base case, being of similar scale to a small petroleum refinery (Table 1). Facilities for other products has been chosen based on the same Victorian brown coal input (60,000 tonnes per day), as the base case FT plant. As the base case plant has a multi-train design, decrease of production capacity will result in almost proportional decrease of required capital.

Table 1 Plant capacity and required capital investments

Product	Plant Capacity	Total Capital Required \$ Bn
Syngas	49,000 GJ/hour	12.00
Hydrogen	320,000 kg/hour	12.00
FT products	80,0000 bbl/day	14.20
Methanol	500 Tonnes/hour	13.10
Ammonia	470 Tonnes/hour	13.10
Urea	830 Tonnes/hour	13.65



Levelised Cost of Product and Competitiveness

Levelised cost of products (LCOP) has been estimated, as described in the relevant chapter. The comparison of LCOP with the current medium term market price of the products is provided in Table 2.

Table 2 LCOP and market price of the products

Product	Midpoint LCOP	Market price	Units
Syngas	10.7	8	\$/GJ
Hydrogen	4.7	5	\$/kg
FT products	124	90	\$/bbl
Methanol	673	430	\$/tonne
Ammonia	674	580	\$/tonne
Urea	363	360	\$/tonne

As shown in Table 2 without government financial support only hydrogen and potentially urea are price competitive with the imported products. Limited government investments (in the order of 25% of capital requirements) moves urea production fully into the cost-competitive region.

While hydrogen may be cost-competitive without government subsidies, it has two significant risks:

- The LCOP is very close to the top range of market pricing, making hydrogen on the edge of price competitiveness; and even a limited drop in the market price for hydrogen represents a major commercial risk.

The high ratio of O&M component in LCOP for hydrogen makes government investments in the establishing production facilities not very efficient, and requires rather constant subsidies.

- LCOP of hydrogen is very sensitive to carbon price. The base case was considered with no carbon price associated with the product. However, carbon price of \$20 per tonne of CO_{2-e} almost doubles hydrogen LCOP.

Urea, with the limited government support, probably in the form of loan guarantees or capital grants, may be a very cost-competitive industry in Victoria.

Workforce and Regional Impacts

A large construction workforce would be required to construct a coal to chemicals facility, which would peak at some 6,000 roles ranging from labourer through to skilled craftsmen and supervisors over an 8-year construction period. In addition, significant long-term operational roles will be created. Table 3 shows the approximate operational role impact in terms of jobs created.²

² Typically, a 2.5 to 3.5 local jobs creation multiplier is applied to operational roles – including those supplying goods and services. In addition to the jobs created, more than 300 locals business are likely to be actively engaged with the facility. For example - <http://bellbayaluminium.com.au/client-assets/documents/Health%20Safety%20and%20Environment/2014%20Bell%20Bay%20Aluminium%20SD%20Report.pdf> (accessed Jan 2016)



Table 3 Operational Jobs Created and Regional Impacts

Product	Operation Jobs Created		Additional Regional Jobs	
	Initial Levels	After 5 years	Initial Levels	After 5 years
Syngas	450	300	1,350	900
Hydrogen	500	400	1,500	1,200
Fischer-Tropsch products	600	450	1,800	1,350
Methanol	500	450	1,500	1,350
Ammonia	500	400	1,500	1,200
Urea	550	450	1,650	1,350

With such a significant increase in local employment, regional impacts will be locality and region specific. For example, it is likely additional school and other service capacity may need to be increased depending on existing infrastructure and resources. Additional housing demand (short and long term) may also be required, that will be generated with all the subsequent positive economic benefits of development and redevelopment in housing sector.

Although difficult to quantify without a specific project and location, regional impacts will also include:

- Increased local council revenue from rates and other services;
- Improvements to local infrastructure and the subsequent flow on; and
- An increase in the overall skill base and experience of the local workforce – which is likely to attract additional industry participants to the region.

Why do CTX in Victoria

Victoria, and the Latrobe Valley, in particular, is an ideal site for a coal to chemicals facility.

Victoria offers investors the opportunity to develop projects using one of the world's largest, high-quality coal resources, located close to potential geological carbon storage sites. With an abundance of brown coal occurring in thick seams close to the earth's surface, Victoria is home to one of the largest and lowest cost energy sources in the world³.

Victoria is potentially very well suited to carbon storage, as the Latrobe Valley is near some of the world's best potential storage sites in Bass Strait. However, these storage opportunities are still under review.³

A recent regional cost factor study, which was incorporated into the Australian power Generation Technology report⁴ showed that there was no regional disadvantage for construction projects for Victoria.

The Latrobe Valley's traditional strengths in heavy industry associated with the power generation sector provide the region with considerable opportunities to develop a coal to chemicals industry. These opportunities rest not only in the linkages between these industries and the resource-based sectors, but also in their potential to grow and diversify the economic base of the region through the production of specialised and differentiated products, adoption of new technologies and innovative processes, export market development and in developing supply chains across the economy⁵.

³ <http://www.energyandresources.vic.gov.au> (accessed Jan 2016)

⁴ Australian Power Generation Technology Report, 2015. <http://www.co2crc.com.au> (access Jan 2016)

⁵ https://www.rdv.vic.gov.au/_data/assets/pdf_file/0008/1153997/Latrobe-Valley-industry-and-employment-roadmap-WEB_v2.pdf (accessed Jan 2016)



Economics

Levelised Cost Of Production

Calculation Methodology

The Levelised Cost of a Product (LCOP) seeks to account for all physical assets and resources required to deliver one unit of the product. LCOP could be defined (similar to LCOE⁶) as the constant dollar product price that would be required over the life of the plant to cover all operating expenses, payment of debt and accrued interest on initial project expenses, and the payment of an acceptable return to investors. Per unit of output, the LCOP aggregates a share of the initial capacity investment with periodic fixed and variable operating costs.

Aspects to consider when interpreting the levelised cost of production in this study include:

- The costs are presented as First Of A Kind (FOAK) costs in Victoria, Australia.
 - Many coal to chemical facilities already exist in other regions, and many aspects of each of the technologies covered are fully mature, though not all currently incorporated into a coal to chemicals facility.
- The capital costs, production capacities for various products and O&M expenses are based on data from a number of public and non-public domain studies, which have been adjusted to appropriate plant designs and escalated to the Australian productivity factors as required.⁷
- No mine development costs are included in these capital costs – if coal cannot be sourced from an existing mine a new development would be required.
- The coal characteristics are summarised in Table 4.
- No carbon price was considered for base case.

Table 4 Victorian Brown Coal Characteristics

Coal Composition	Brown Coal % as received
Moisture	61.50
Carbon	26.31
Hydrogen	1.85
Nitrogen	0.23
Sulphur	0.15
Oxygen	9.16
Ash	0.80
Heating Value (MJ/kg)	
Higher heating value	9.92
Lower heating value	8.06

A detailed description of the calculation is given in Appendix 1 – LCOP Calculation.

⁶ LCOE – Levelised Cost of Electricity

⁷ including: Australian Power Generation Technology Report, 2015 <http://www.co2crc.com.au> (access Jan 2016)



Levelised Costs Of Various CTX Products

The levelised costs of various products (as well as the project assumptions) are presented in Table 5.

The LCOP data has been normalised to the current medium term prices for selected products as shown in Figure 2. The products with LCOP below 100% of the market price (such as hydrogen) are potentially commercially viable even without subsidies/investments from the government. Ammonia and Urea could be commercially feasible, depending on the particular plant design. Methanol, Fischer-Tropsch products and raw syngas without significant financial assistance from the government are unlikely to be commercially feasible.

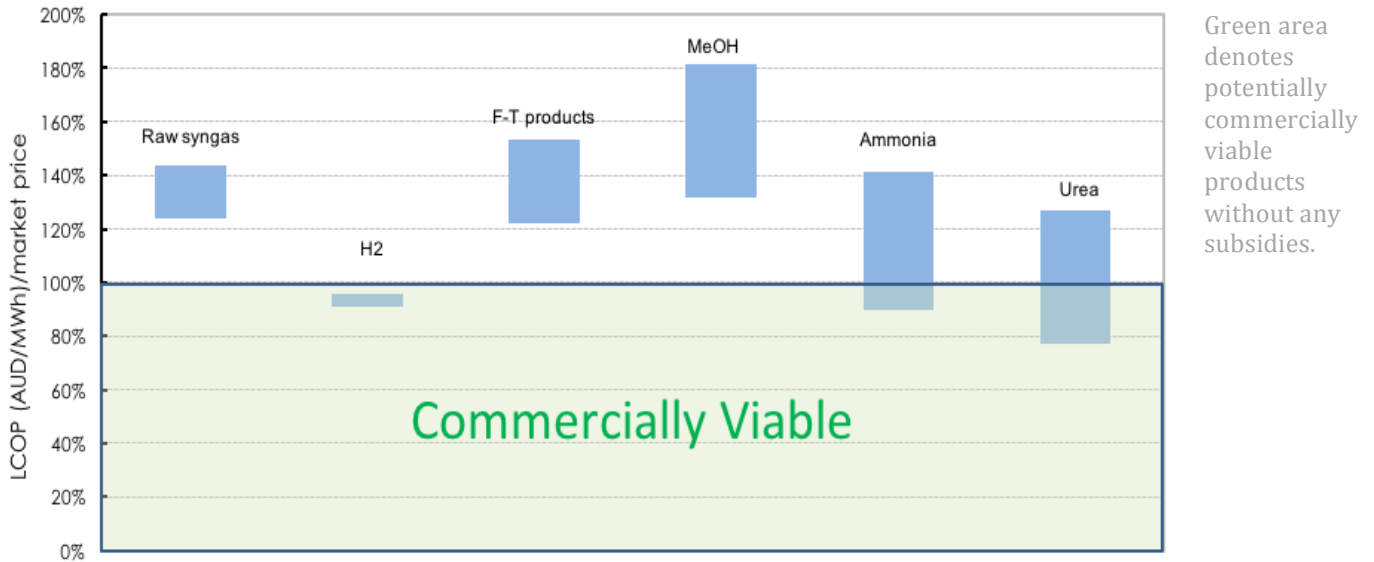


Figure 2 LCOP normalised to the product market price

The structure that makes up the LCOP costs is shown in Figure 3. For raw syngas and hydrogen, the O&M expenses represent the critical component of the LCOP costs. For other products, financial charges (construction cost of the plant) is the largest portion of LCOP.

While carbon price has been not been considered for the base case, the relative sensitivity of LCOP to carbon price has been considered for most of the products Figure 4. Hydrogen is the most sensitive to CO₂ prices, while urea and Fischer-Tropsch are the least affected by carbon price.

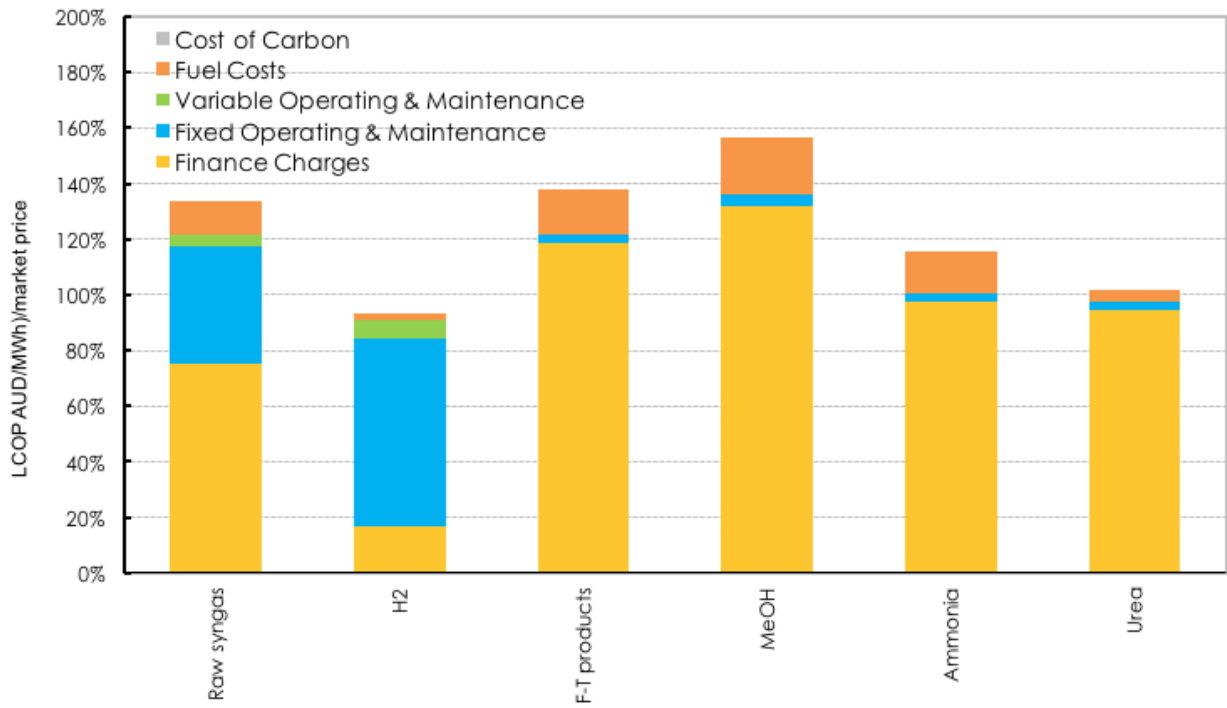


Figure 3 Structure of Normalised LCOP for various CTX products⁸

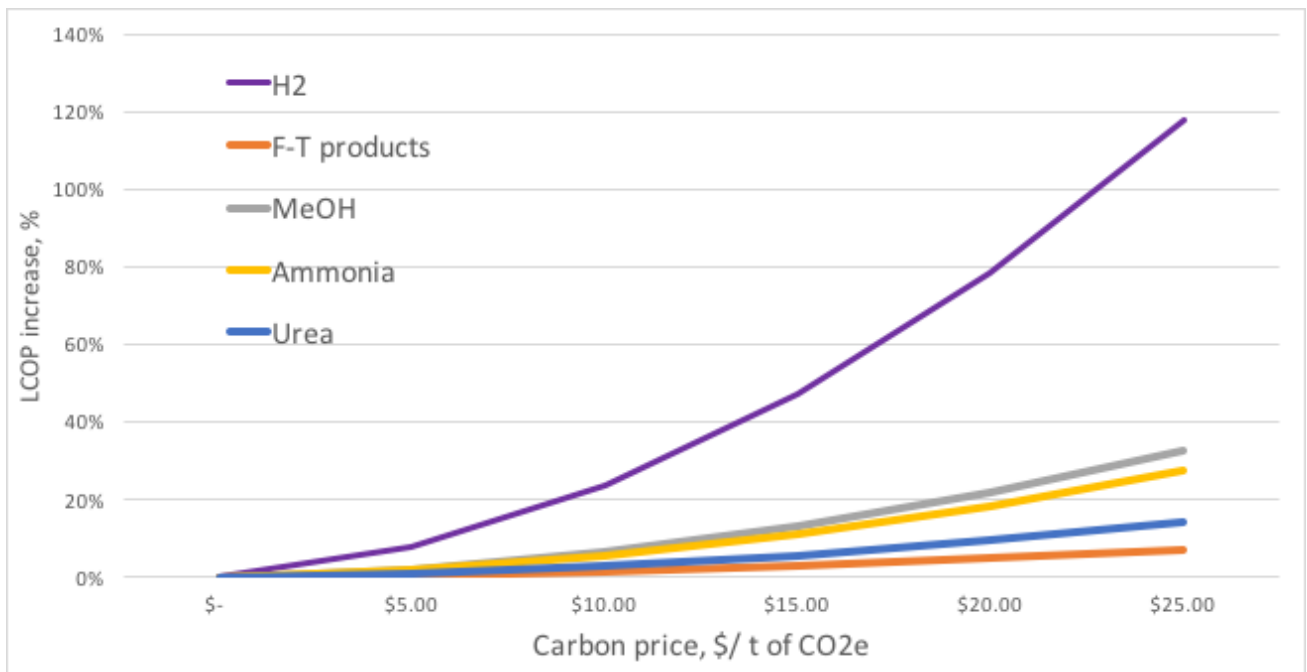


Figure 4 Relative sensitivity of LCOP to CO₂ prices

⁸ LCOPs and its components have been normalised to the market product price for each product.



Table 5 Levelised cost of product for various CTX opportunities

		Syngas	H ₂	F-T products	MeOH	NH ₃	Urea	
Project Assumptions		GJ	kg	bbl	tonne	tonne	tonne	
Project Contingency and owners costs	%	10	10	15	10	10	10	
Construction period	years	6	6	6	6	6	6	
Equipment capital costs								
Equipment capacity	Production units per hour	49,000	320,000	3,300	500	470	830	
Equipment capital cost (low)	\$/production per hour	290	40	4,700	34,000	36,000	21,500	
Equipment capital cost (high)	\$/production per hour	340	50	5,600	25,500	23,500	14,000	
Capacity and Performance								
Conversion efficiency	(tonne of Coal/production unit)	0.09	0.01	1.24	7.76	7.73	4.38	
Capacity factor	%	85	85	85	85	85	85	
Fuel prices (high)	AUD/GJ	0.75	0.75	0.75	0.75	0.75	0.75	
Fuel prices (low)	AUD/GJ	1.5	1.5	1.5	1.5	1.5	1.5	
CO ₂ emissions intensity	Kg CO _{2-e} /production unit	N/A	74	115	3,000	2,500	680	
Operating and maintenance								
Fixed O&M	AUD/production capacity	25	25	22	138	135	77	
Variable O&M	AUD/production unit	0.33	0.33	0.1	0.1	0.1	0.1	
LCOP								
LCOP high		11.5	4.8	134	781	825	451	
LCOP low		9.9	4.6	106	565	523	274	
LCOP Mid Point		10.7	4.7	124	673	674	363	
Capital cost		6.0	0.9	107	567	569	336	
Fixed O&M		3.4	3.4	2.96	18.5	18.2	10.3	
Variable O&M		0.3	0.3	0.00	0.1	0.1	0.1	
Feedstock price		1.0	0.1	13.94	87.3	87.0	16.4	
Carbon price		N/A	Carbon intensity (tCO _{2-e}) x carbon price (\$/tCO _{2-e})					
Current product market prices		AUD/production unit	8	5	90	430	580	360

Construction Workforce

Key factors influencing a project execution schedule are the availability of local and regional infrastructure, adequate construction labour availability, and available manufacturing capability and lead time requirements.

Due to the large scale of potential multi-train coal to chemicals plants, it is often advisable that they be constructed on a “time-phased” basis. A time phased approach is used to schedule construction to enable production after the first phase is completed. This is to generate cash flow while subsequent production units are completed in subsequent phases.

The requisite infrastructure, balance of plant, mine development and all other requirements will also be time-phased as necessary to support the facility while optimizing cash flow and return on investment. The size and extent of construction work force requirements would likely far exceed local and regional availability for most projects covered in this study.

For large and complex projects, it is likely that they would require construction staff from 300 to 5500 people spread over 6 years of the construction phase. Construction staffing would require careful planning and management for the lifetime of any project. Any project of such scale and complexity should utilise a mix of employment arrangements designed to accommodate the anticipated workforce mix.

A key element of a time-phased execution is the development and sustainability of an adequately trained construction work force. It would be critical to plan and sequence the work to coordinate an overlapping and smooth transition of the completion of each phase of work into commencing of the next phase of work. This execution philosophy will promote a safe and cost effective execution through the synergies of repetition of similar work activities and site personnel development and experience factors. In addition, continuity and sustaining of the construction workforce promotes the shortest reasonable schedule durations.

Smaller projects, from the construction point of view, would be similar to the first stage of a large production facility.

The coal mine that supplies coal to the chemical production facility also requires a staged ramp-up to the production levels required to support demand – however these are not considered in this study.

Construction Execution Strategies

For projects of this size, a construction execution strategy would be developed. Elements of such a strategy should promote a worldwide fabrication and procurement plan that saves cost, meets quality objectives and supports construction needs for timely equipment and material deliveries.

A key element of a time-phased execution plan is the development and sustainability of an adequately trained construction workforce. A project will need to plan and sequence the work to coordinate an overlapping and smooth transition of the completion of each phase of work into commencing of the next phase of work. This execution philosophy will promote a safe and cost effective execution through the synergies of repetition of similar work activities and site personnel development and experience factors. In addition, continuity and sustaining of the construction workforce promotes the shortest reasonable schedule durations.



A logistics study to understand the routes and mode of transportation for people and materials from potential worldwide sources of supply to Victoria would also need to be undertaken.

Coal To Chemicals Plant Schedule and Construction Workforce

Front End Engineering Design (FEED) is the first phase of work that is required once project approval has been secured. The FEED stage is generally not included in construction times – and is typically carried out by a large engineering firm in a large city.

Once a project is approved to proceed to detailed engineering, an Engineering Procurement and Construction (EPC) contract is awarded and the “construction phase” begins.

Construction will continue to work directly with the Home Office Engineering and Procurement Project Team. This will include the finalisation of detailed plans, procedures, processes etc. In addition, early site work and plans will be phased-in and implemented. Key facility infrastructure, temporary facility development, site preparation work, utility installation, construction housing camp, etc. will be set-up early during detailed engineering phase in preparation for subsequent heavy construction operations.

As engineering is completed and as available materials will support safe, effective and sustainable field operations, heavy construction of the new facilities will commence, in accordance with the detailed project plan and schedule.

A generic construction schedule in Figure 5 shows the various elements involved and the timelines for a large coal to chemicals facility (equivalent of a 70,000 – 90,000 BBL/day coal to liquids or a 2.5 to 2.7 million m³/hour H₂ production facility). A smaller project will obviously be completed within a shorter period of time.

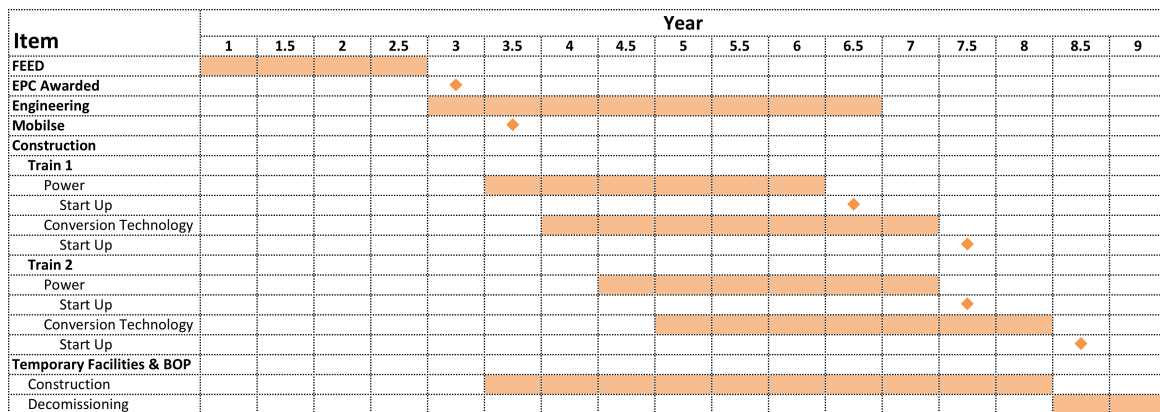


Figure 5 Construction schedule for a large generic coal to chemicals facility (time phased)

An estimate of the workforce from the project scheduled in Figure 5 is shown in Figure 6. The engineering / home office workforce is shown separately to the construction workforce. The peak work force is during the height of construction in both construction of Train 1 and Train 2. Significant engineering / home office support is required for the construction of both Train 1 and Train 2.



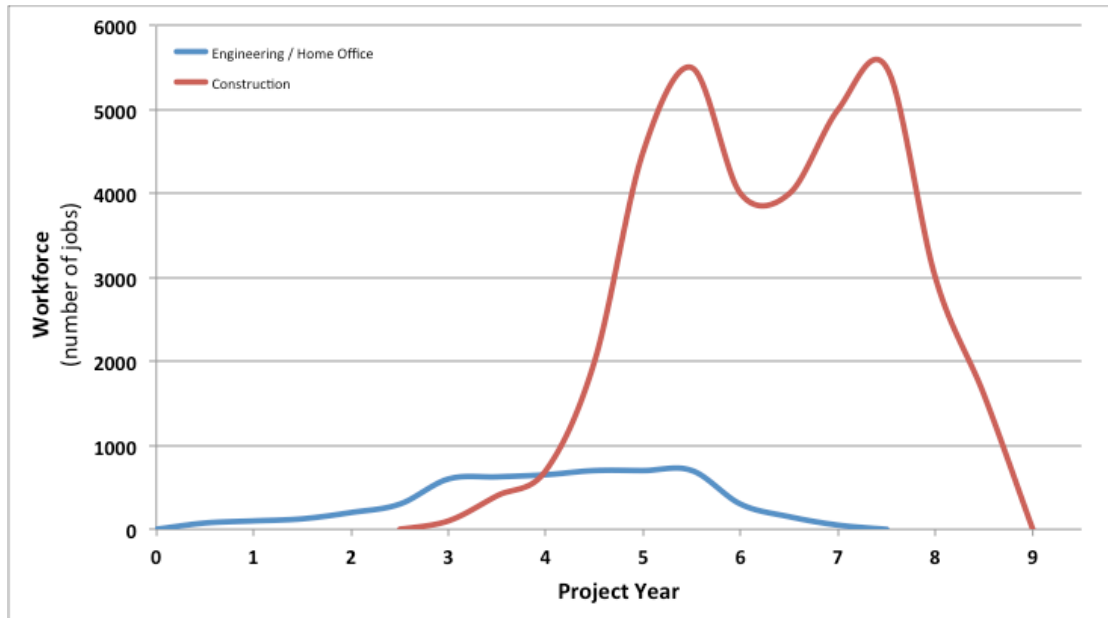


Figure 6 Engineering / home office and construction workforce (time phased)

Additional Regional Impacts

An Economic Impact Analysis (EIA) is used to estimate how spending associated with a particular project or industry flows through a regional economy. It may cover direct, indirect and induced effects of a new project. While every project is different in terms of the level of construction, imported versus local components and scale – generic factors may be applied.

Typically, a 2.5 to 3.5 local jobs creation multiplier is applied to operational roles – including those supplying goods and services. In addition to the jobs created, more than 300 local businesses are likely to be actively engaged with the facility.⁹

Operational Workforce

The operational workforce for a coal to chemicals facility is very heavily dependent on both the overall size and the product being manufactured. The initial operational staff, and subsequent staffing levels are 5 years of operation are given in Table 6. Most complex chemical plants begin operations with higher levels of staff to assist in early operations and reduce operational risks. Over time, staffing levels return to the long run expectations for such facilities.

⁹ <http://bellbayaluminium.com.au/client-assets/documents/Health%20Safety%20and%20Environment/2014%20Bell%20Bay%20Aluminium%20SD%20Report.pdf> (accessed Jan 2016)



Table 6 Operational Staffing Levels¹⁰

Product	Approximate Staffing Levels	
	Initial Levels	After 5 years
Syngas	450	300
Hydrogen	500	400
Oil	600	450
Methanol	500	450
Ammonia	500	400
Urea	550	450

Typically, a 2.5 to 3.5 local jobs creation multiplier is applied to operational roles – including those supplying goods and services. In addition to the jobs created, more than 300 locals business are likely to be actively engaged with the facility.¹¹

¹⁰ Estimates of staffing levels are based on the Altona Energy project – Victoria, the ZeroGen project – QLD, Kemper County IGCC – USA, Pickanjinie project – Qld and other industry sources.

¹¹ <http://bellbayaluminium.com.au/client-assets/documents/Health%20Safety%20and%20Environment/2014%20Bell%20Bay%20Aluminium%20SD%20Report.pdf> (accessed Jan 2016)



Technology Review

The production of specific chemicals from coal is typically from proprietary systems or processes, using specialised process systems. Figure 7 shows both a gasification and dissolution / liquefaction routes along with the typical/ major products available from each process route.

Power production and dissolution / liquefaction are not within scope for this project. Polygeneration is also out of scope for this briefing – being both a power and chemical production opportunity. It is possible that project proponents would prefer a polygeneration scenario, which gives the project options to mitigate the risks of commodity price shocks.

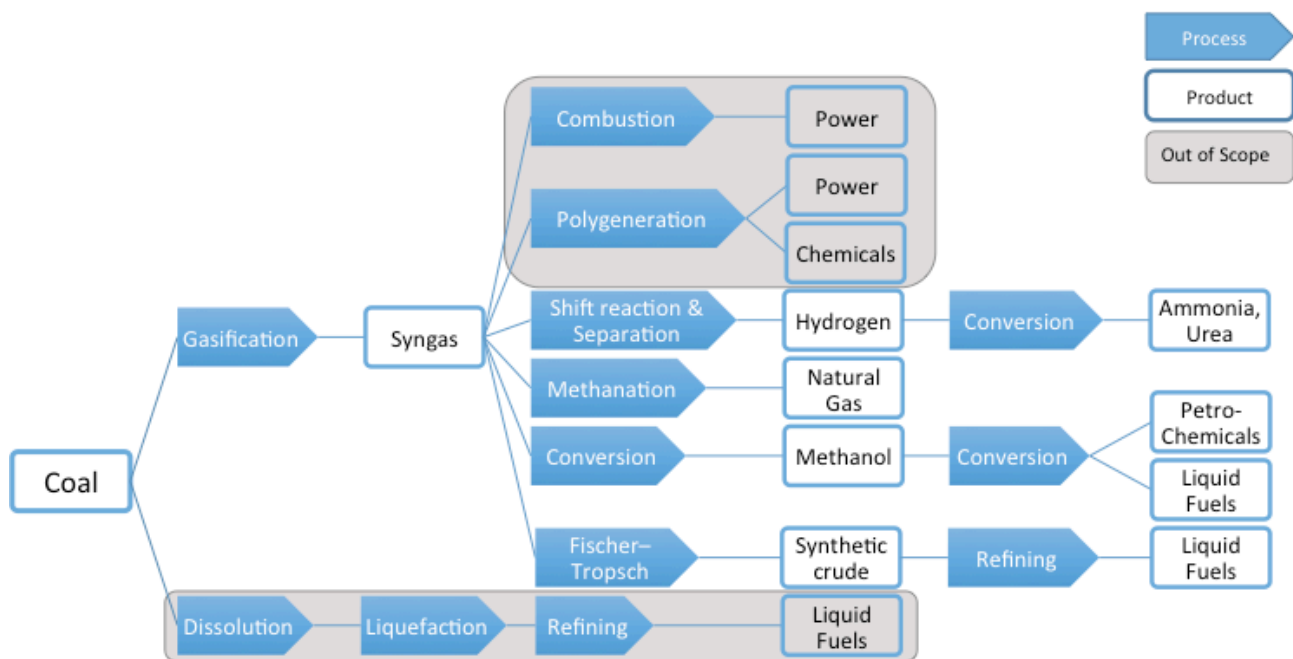


Figure 7 Coal to chemicals family tree

Primary Conversion Technologies

Gasification (indirect conversion)

Gasification is the thermal conversion of a carbonaceous feedstock to a synthesis gas (syngas) comprising mainly CO, H₂, H₂O, CO₂ and small quantities of CH₄. Additional components may be present as contaminants, typically compounds of sulphur, nitrogen and other elements depending on the feedstock and the feed gas. This process from a functional point of view is an equivalent of methane reforming, which is used as a first stage in conventional chemical industry based on natural gas feed.

Gasification, as the partial oxidation of coal, produces a syngas - a mixture of predominantly CO and H₂. The gasification process is quite complex and is accomplished through a series of physical transformations and chemical reactions within the gasifier. Coal undergoes several different reactions / processes including:

- **Pyrolysis:** This occurs as the coal is exposed to rising temperature.
- **Devolatilisation and breaking of the weaker chemical bonds** occurs, releasing volatile gases and forming char.
- **Combustion:** The volatile products and some of the char react with limited O₂ to form CO₂ and CO.
- **Gasification:** The remaining char reacts with CO₂ and steam to produce CO and H₂.
- **Water-gas-shift and methanation:** These are separate reversible gas phase reactions taking place simultaneously based on gasifier conditions. These are minor reactions which play a small role within in the gasifier.

Three major types of gasification – fixed bed (also known as moving bed), fluidised bed, and entrained flow. These processes are illustrated in Figure 8. Underground gasification is another class of gasification that uses the natural geology of the coal formation to contain the gasification reaction (this technology is not covered in this report, and under current environmental guidelines not likely to be used commercially in Australia in the near future).

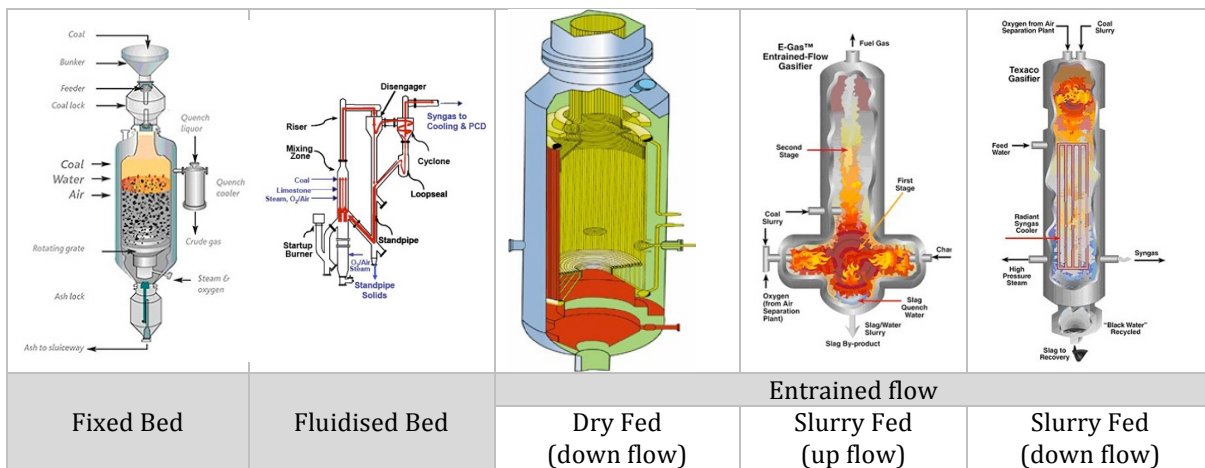


Figure 8 Gasification can be effectively carried out in a wide range of reactor categories¹²

Pressurised gasification is preferred for integrated gasification combined cycle (IGCC) and chemical applications to avoid large auxiliary power losses for compression of the syngas up to combustion turbine inlet pressure. Since synthesis reactions and economics are generally improved by higher pressure, pressurised gasification is typically favoured for the synthesis application. The general gasifier characteristics are described in Table 7.

¹² www.powerfactbook.com.au (accessed Jan 2016)



Table 7 General gasifier characteristics¹³

	Fixed Bed	Fluidised Bed	Entrained Flow	
	Dry Ash	Dry Ash	Dry Fed	Slurry Fed
			Preferred feedstock	lignite, reactive bituminous coals
Fuel size	6 - 50mm	<6mm	<0.5mm	
Ash limits	no limits	no limits	<25% preferred	
Ash handling	Slagging/non slagging	non slagging	slagging	
Exit gas temperature	400 - 650°C	900 - 1000 °C	>1250°C	
Key distinguishing characteristics	hydrocarbons liquids in raw gas	large char recycle	large amount of sensible heat energy in hot raw gas	
Key technical issues	finer and hydrocarbon liquids	carbon conversion and bed agglomeration	raw gas cooling and refractory life	

The Transport Integrated Gasification (TRIG) system was chosen for the design basis of gasification of brown coal. The TRIG system is an advanced pressurised circulating fluidised bed gasifier that operates at temperatures between 815°C and 1,065°C. The TRIG system is simple in design and has no internals, expansion joints, valves or other moving parts. Figure 9 shows a diagram of the TRIG system.

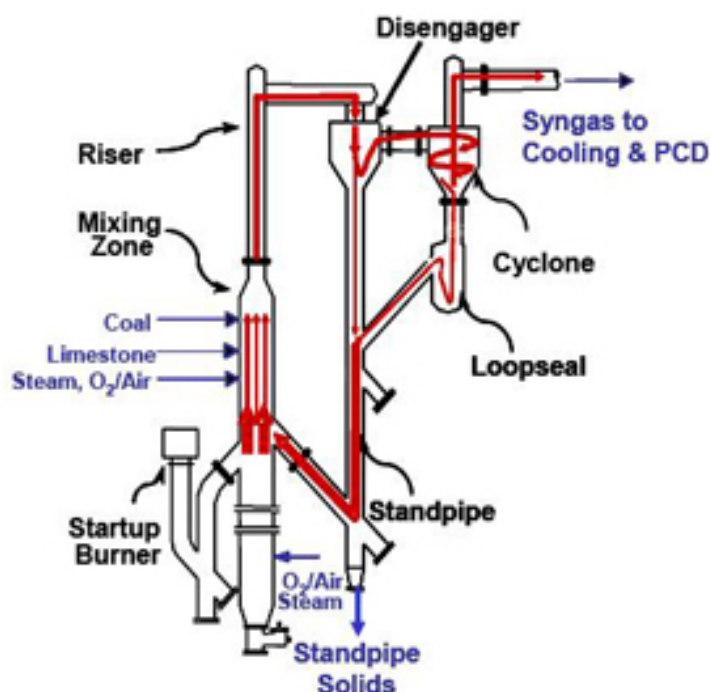


Figure 9 The TRIG system, an advanced pressurised circulating fluidised bed gasifier¹³

¹³ www.powerfactbook.com.au (accessed Jan 2016)

Direct Coal Liquefaction (direct conversion)

Direct Coal Liquefaction (DCL) is a dissolution process, which involves contacting coal directly with a catalyst at elevated temperatures and pressures with added H_2 , in the presence of a solvent to form a raw liquid product which is further refined into product liquid fuels. DCL is termed direct because the coal is transformed into liquid without first being gasified to form syngas.

While the DCL process is, in principle, the simpler and more efficient of the two processes. It does, however, require an external source of H_2 . The DCL process results in a relatively wide hydrocarbon product range consisting of a variety of molecular weights and forms, with aromatics dominating, hence substantial upgrading is required to produce transportation fuels.

Secondary Conversion

Secondary conversion processes take the coal-derived syngas and using various processing steps, produce the final product. This process is similar to natural gas reforming, refer to .

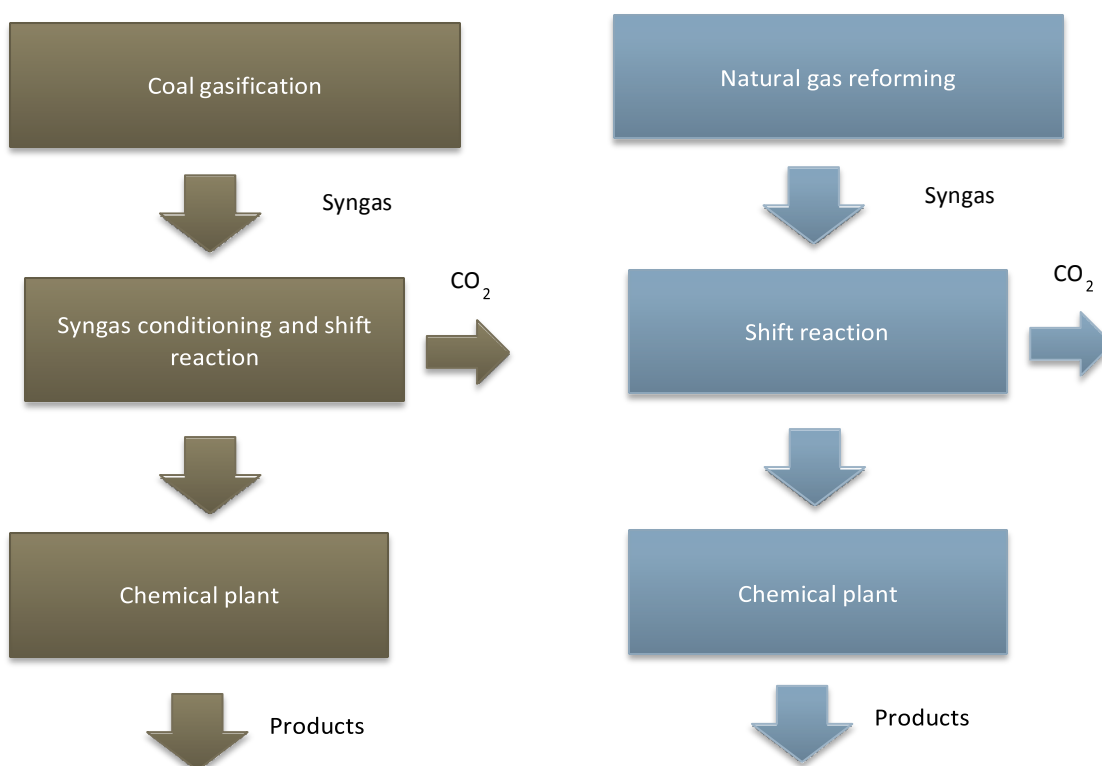


Figure 10 Schematic diagram of coal - and natural gas-derived syngas processing

Syngas Conditioning

Coal derived syngas needs to be processed to remove impurities and conditioned via the water gas shift reaction to achieve the desired H_2/CO stoichiometric ratio for further chemical synthesis.

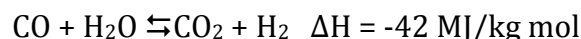
Various ratios required for different CTX products are presented in Table 8. Syngas from methane reforming does not require extensive processing, however still requires conditioning by shift reaction. After syngas conditioning, the gas mixture is the same for both the coal-derived syngas and syngas produced from methane reforming. For several applications, such as hydrogen production, syngas processing requires an acid gas removal step.

Table 8 H₂/CO ratios for various CTX products

Product	Required H ₂ /CO stoichiometric ratio
Fischer-Tropsch products	2.1:1
Methanol	2.05:1
Hydrogen	95:1
Methane	3:1

Water-Gas Shift Reaction

The water-gas shift reaction converts carbon monoxide in the syngas with steam to carbon dioxide and hydrogen:



The reaction typically takes place in a fixed bed over a catalyst in the range 230°C – 500°C. There are various types of catalyst available to promote the shift reaction. The two most likely alternatives are cobalt-molybdenum and iron oxide. There is extensive experience with both catalysts in the production of syngas for chemicals such as ammonia and methanol.

- Cobalt-Molybdenum, or sour gas shift catalyst.
This catalyst operates in the sulphide state and therefore must be used with at least a minimum amount of sulphur in the feed stream. The sour gas shift unit is therefore located upstream of the acid gas removal system. This catalyst also promotes the conversion of COS to H₂S as well as the hydrolysis of HCN to NH₃, CO₂ and H₂, so that its position in the gas processing scheme may be independent of COS and or HCN hydrolysis units. In many cases, exercising this option can eliminate the need for separate hydrolysis of COS and HCN. A further feature of this catalyst is its ability to retain arsenic, though at the cost of loss of activity.
- Iron oxide, or sweet shift catalyst, also known as high temperature shift catalyst.
This catalyst operates in the reduced oxide state as Fe₃O₄, and is typically promoted with other metal species; e.g., Cr and/or Cu. It is tolerant of a small degree of sulphur slip, but sulphur slip would in most cases leave with the CO₂ and could violate the CO₂ pipeline specification for H₂S. Consequently, the pipeline specification for H₂S may be more restrictive than the catalyst specification.

Hydrogen production

Once syngas is conditioned – cleaned from critical impurities and went through the required shift reaction, hydrogen could be removed by a separation system for further use, while remaining highly concentrated CO₂ stream can be captured for subsequent use (e.g. fertiliser production, enhanced oil recovery etc.) or sequestration.

There are several separation systems that could be used to extract hydrogen from the syngas stream.

The most common ones are based on either pressure swing adsorption or liquid solvents. During pressure swing adsorption process, initially hydrogen is adsorbed under the high pressure from the syngas with the solid sorbents, followed by hydrogen release from the sorbent during the pressure drop stage.



The liquid solvents (methanol in Rectisol process, and Selexol in Selexol process) physically dissolve acid gas components (CO_2 , H_2S etc) from the syngas, leaving hydrogen enriched stream, that could easily be purified. The solvent is then regenerated by heat to release CO_2 for further use or sequestration.

Advanced hydrogen removal systems, based on the hydrogen selective membranes are still under development.

Hydrogen Conversion

The most common usage of hydrogen produced from coal is ammonia production, followed by manufacturing of fertilisers and/or explosives (**Figure 11**). Ammonia and urea synthesis are very mature technologies, although currently they are more often using natural gas as a source for syngas/hydrogen production.

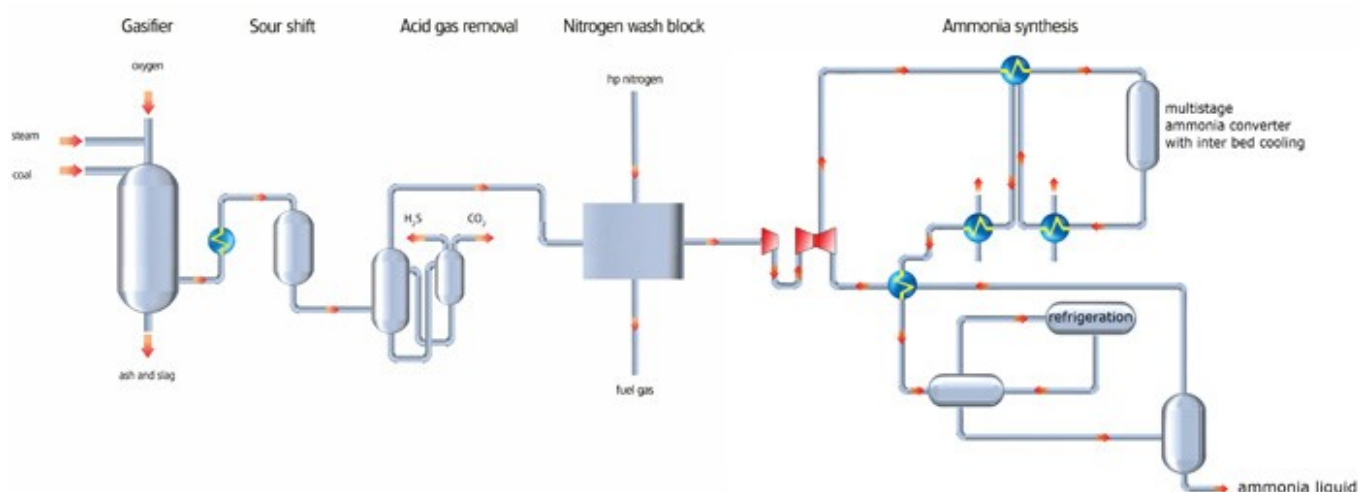


Figure 11 Schematic diagram of ammonia production from carbonaceous feedstock¹⁴

Methanol Synthesis

The coal to methanol production involves coal gasification as the first step (Figure 12). In all cases the gasification stage is carried out in exactly the same manner for methanol production as for ammonia production. The differences are in how the gas is processed. Gas derived from coal gasification contains too much carbon for methanol production. This excess carbon must be removed in the form of carbon dioxide. Methanol synthesis catalyst is even more sulphur sensitive than ammonia synthesis catalyst; consequently, all of the sulphur must be removed before the gas meets the methanol synthesis catalyst. Any purge from the methanol loop is normally used to assist in the superheating of the waste heat derived steam.

¹⁴ <http://www.jmcatalysts.cn/en/syngas-catalystproducts-ammonia-fromcoal.htm> (accessed Jan 2016)

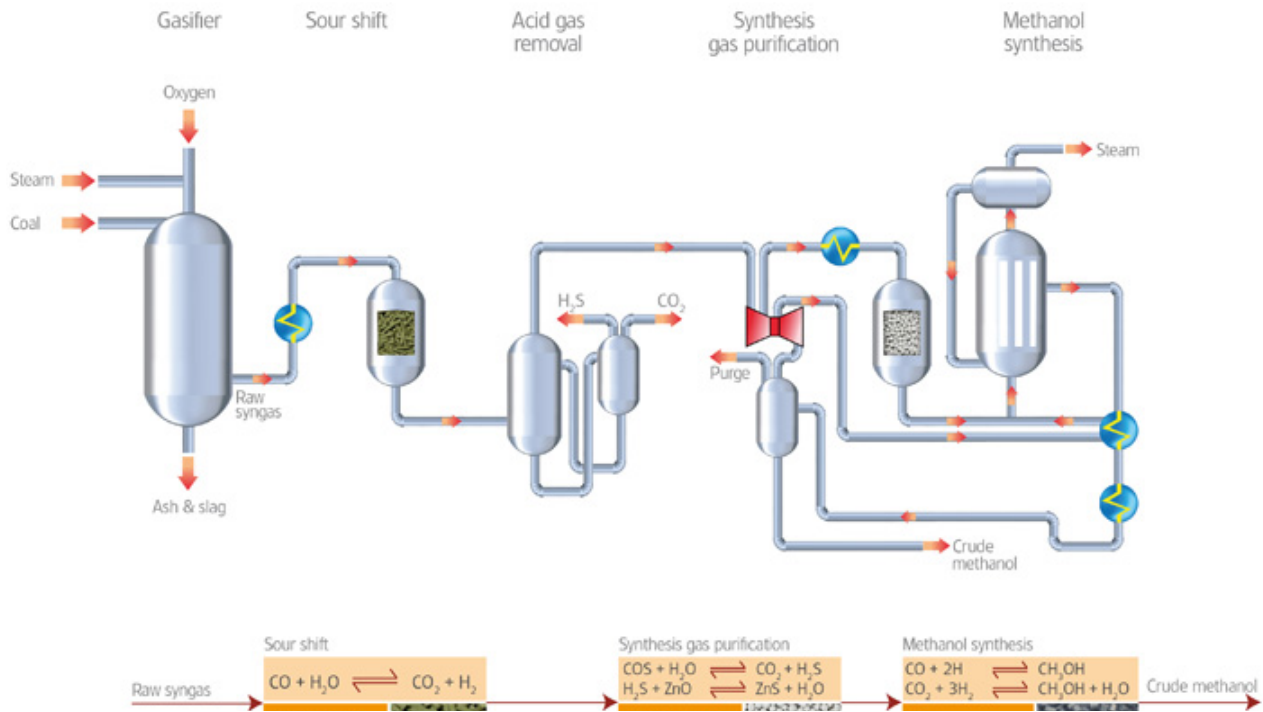
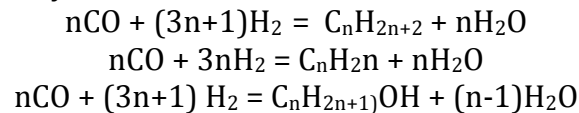


Figure 12 Schematic diagram of methanol production from coal¹⁵

Fischer Tropsch synthesis

Fischer Tropsch synthesis involves the synthesis of hydrocarbons and alcohols from syngas. The origins of Fischer Tropsch processing can be traced to 1902, when Sabatier reported that hydrocarbons could be formed by reacting carbon monoxide and hydrogen over nickel or cobalt catalysts. However, the basis of present day processes was developed in the 1930's. The reactions involved can form hydrocarbons or alcohols:



The basis of the reaction mechanism involves a step by step polymerization of C_1 units, in which the product distribution is a measure of the termination of the chain.

Fischer Tropsch technology can be used to convert syngas into hydrocarbons and alcohols. Syngas entering the reactor should have a $\text{H}_2:\text{CO}$ ratio of ~ 2.1 . A cobalt based catalyst is used most widely and high molecular weight waxes are produced. These may be easily hydrotreated to produce diesel. Iron based catalysts are also used and seem favourable for coal based syngas in that they are a little more forgiving on impurities and syngas ratios.

Current commercial operations operate at either high temperatures ($\sim 340^\circ\text{C}$), using an iron catalyst, to produce mainly olefins and gasoline together with alcohols aldehydes, carboxylic acids and aromatics. Pressure has little effect, but alkalization increases the production of higher molecular weight products.

Alternatively, commercial operations are carried out at about 230°C over iron or cobalt catalysts to produce mainly diesel and linear waxes. The $\text{H}_2:\text{CO}$ ratio is critical and CO favours higher molecular weight products at higher pressures. It must always be remembered that FTS produces a range of products, from methane up.

¹⁵ <http://www.jmcatalysts.cn/en/syngas-catalystproducts-methanol-coal.htm> (accessed Jan 2016)

Trends and Status

While coal-to-chemical plants are being considered globally, the major activities in this area is happening in China. Chia's activity in this sector is due to the combination of several factors: relatively low construction and labour costs; economy is oriented towards exporting manufactured products, rather than raw materials; limited access to the natural gas as a chemical feedstock; and large coal reserves.

China

There are 53 coal-based methanol production plants operating in China with a total production capacity of approximately 30 million tonnes of methanol per year. 13 large plants are to be built and commissioned by 2016, bringing overall methanol production capacity to more than 55 million tonnes per year. It should be noted that the sharp increase of coal to methanol production capacity occurred within last 5 years, with the threefold production increase since 2009.

There are currently 34 coal-based ammonia and fertiliser production plants operating in China with a total production capacity of more than 11 million tonnes of ammonia per year. Five more plants are to be built and commissioned by 2016, bringing overall ammonia production capacity to 13 million tonnes per year.

The ammonia production in China has a steady but relatively gentle increase over the last 8 years.

Refer to Figure 13 and Figure 14 for the number of methanol and ammonia plants and annual production.

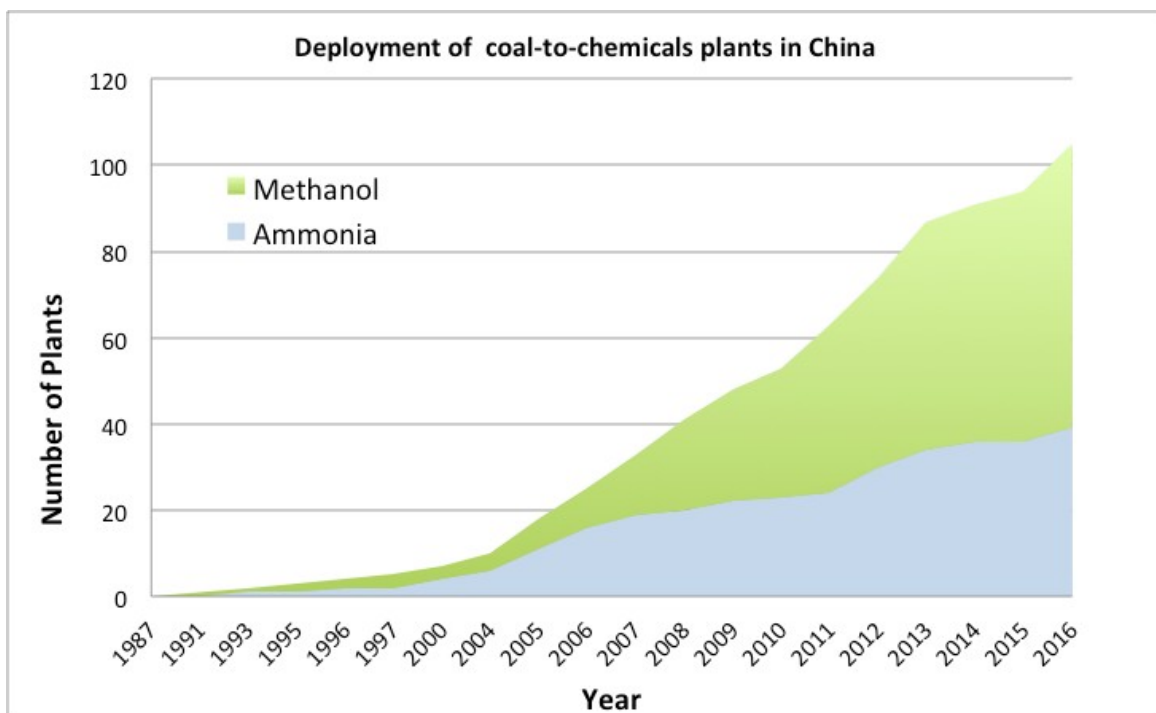


Figure 13 Annual growth of coal to chemicals plants in China



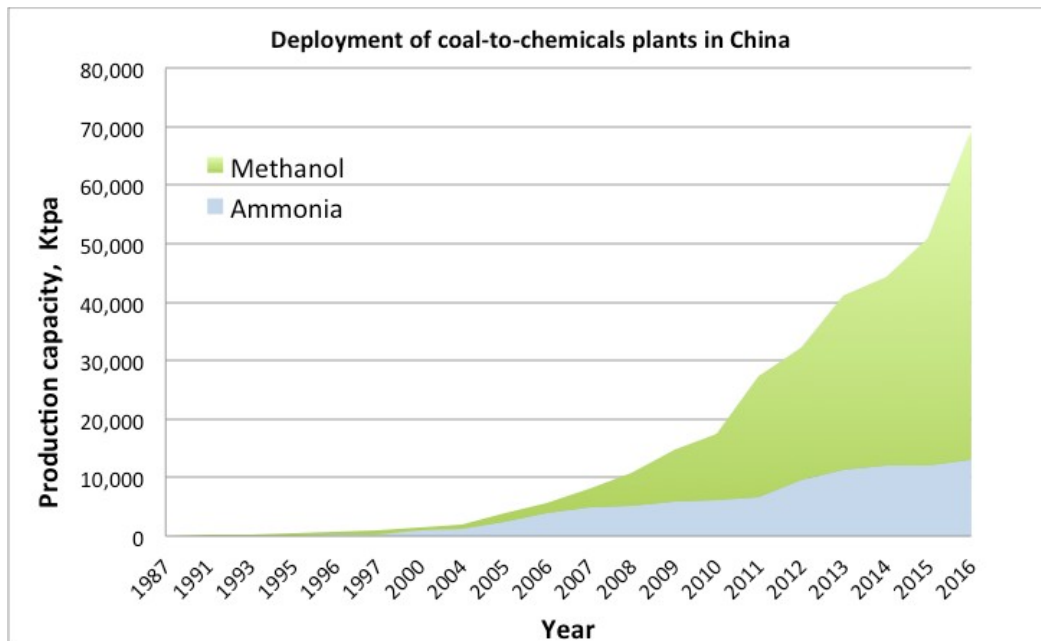


Figure 14 Annual growth of production of coal to chemicals plants in China

At present there are a limited number of FT plants operate in China with a total production capacity of under 10,000 bbl/day. Even if the planned increases in production capacity to 185,000 bbl/day by 2020 occur, this only offers modest levels of production compared to the current and projected level of imports of tens of millions bbl/day.

Therefore FT production is not likely to be a significant participant in Chinese (and global) energy portfolio; unless there will be a sharp and sustainable increase in oil prices and a step-change in FT technology costs.

Appendix 1 – LCOP Calculation

There are various ways to calculate LCOP, and in this study we have used the comprehensive formula taking into account financial assumptions (cost of capital, debt ratio, inflation rate, taxation life, and corporate/property taxes):

$$LCOP = \frac{\sum_{t=1}^n \frac{I_t \cdot T + M_t + V_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{P_t}{(1+r)^t}},$$

where:

- LCOP* is the levelised cost of product
- I_t is the investment expenditure in the year t
- M_t is the fixed O&M expenditure in the year t
- V_t is the variable O&M expenditure in the year t
- F_t is the feedstock (fuel) expenditure in the year t
- P_t is the product output in the year t
- T is the tax factor
- r is discount rate
- n is the life of the plant

The following financial assumptions have been used for LCOP estimates:

Asset book life	30 years	
Asset tax life	30 years	
Inflation Rate (CPI Escalation)	2.5%	
Corporate Tax Rate	30%	
Property Tax / Insurance	2%	
Debt Financing Percentage	70%	
	<i>nominal</i>	<i>real</i>
Cost of Equity	11.5%	8.78%
Cost of Debt	8.0%	5.37%
WACC before tax	10.53%	7.83%
WACC after tax	7.37%	4.75%

The capital cost of production capacities for various products, and O&M expenses are based on data from a number of public and non-public domain studies, which have been adjusted to appropriate plant designs and escalated to the Australian productivity factors as required.

The feedstock assumptions (carbon and moisture content, calorific value, low and high prices) used in the study are the same as for the Victorian brown coal based power generation cases used in Australian Power Generation Technology study.¹⁶

¹⁶ Australian Power Generation Technology Report, 2015 <http://www.co2crc.com.au> (access Jan 2016)

