COAL: LIQUID FUELS

Key Messages

Coal: Liquid Fuels is the latest in a series of reports by the World Coal Institute. It develops the position set out in Coal: Secure Energy on the role of coal in addressing today’s energy security concerns, through the key messages:

» Oil provides 35% of global energy consumption and more oil is used today than at any other time. Demand for oil will continue to grow, primarily due to rapid growth in vehicle ownership.

» Energy security concerns in the oil sector are increasing due to resource availability, supply security, political instability and infrastructure difficulties.

» Oil prices have risen dramatically and are expected to remain high.

» Liquid fuels from coal provide a viable alternative to conventional oil products.

» Coal is affordable and widely available.

» Coal reserves are vast and will be available for the foreseeable future without raising geopolitical concerns.

» Liquid fuels from coal provide ultra-clean transport fuels for use in the existing vehicle fleet, delivered through existing supply infrastructure; providing local and regional air quality benefits.

» Liquid fuels from coal provide ultra-clean cooking fuels, alleviating health risks from indoor air pollution.

» Carbon dioxide (CO₂) capture and storage offers the potential for major reductions in CO₂ emissions from coal.

This report calls for policy support to:

» reduce investment uncertainty

» implement carbon capture and storage

» encourage research, development and demonstration

» facilitate technology transfer

» address environmental concerns.

Copies of all WCI publications and further information on the coal industry are available on our website: www.worldcoal.org
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INTRODUCTION

COAL: LIQUID FUELS

There is no doubt that global energy demand is rising, driven by population growth and economic development. We are using around double the amount of primary energy we were 20 years ago, and are facing a doubling again over the next 20 years. >>

The Thirst for Oil

Oil provides 35% of our current total energy consumption, and more oil is used today than at any other time. Daily oil consumption in 2005 stood at over 84 million barrels per day (bbl/d) – an increase of 20% over 1995 levels [EIA 2006]. This rapid growth is forecast to continue, with consumption predicted to reach 90 million bbl/d by 2010 and over 120 million bbl/d by 2030 [IEA 2004].

Vehicle ownership worldwide has increased from around 200 million in 1970 to over 700 million today [TRL 2006]. Estimates suggest this will double worldwide by 2030 to around 1.5 billion; in the developing world vehicle ownership is expected to triple [IEA 2006].

96% of all energy used in transport comes from petroleum [WBCSD 2001], and transport represents the largest factor in world oil demand growth in the developed and developing world alike.

There is no doubt that oil is a finite resource and one that is not equitably distributed around the globe. Energy security is at the top of the international agenda, with physical oil availability concerns exacerbated by supply issues brought on by ongoing political instability in some regions and infrastructure difficulties in others. Economic development in populous nations such as China and India is resulting in significant growth in energy demand, leading to an even greater tightening of supply.
As a result, oil prices have risen dramatically over recent years, reaching almost $80 per barrel in July 2006. Oil futures prices are even higher, showing little sign of returning to the $20 per barrel of the 1990s – resulting in an upsurge of interest in alternative fuels.

Alternative liquid fuels can be made from solid (e.g. coal or biomass) or gaseous (e.g. natural gas) feedstocks, and can be used in existing vehicle fleets with no, or little, modification. Coal will have a significant role to play in the provision of these alternative fuels – it is the most affordable of the fossil fuels and is widely distributed around the world. Coal benefits from a well-established global market, with a large number of suppliers. The production of liquid fuels from coal will not require vast land resources or cause competition with food production.

The development of a coal to liquids (CTL) industry can serve to hedge against oil-related energy security risks. Using domestic coal reserves, or accessing the relatively stable international coal market, can allow countries to minimise their exposure to oil price volatility while providing the liquid fuels needed for economic growth. CTL fuels are ultra clean to use and the use of carbon capture and storage can minimise emissions from the manufacturing process.

This report, Coal: Liquid Fuels, considers the current status of the technology, costs, benefits and impacts, and provides a number of case studies to illustrate the market potential for this alternative, and valuable, use of coal.
COAL TO LIQUIDS: THE TIME IS RIGHT

>> Converting coal into a liquid fuel (coal liquefaction) is a tangible solution to the pressures felt by countries dependent on oil imports and adversely affected by high oil prices. >>

Liquid fuels from coal can be delivered from an existing pump at a filling station via existing distribution infrastructure and used, without modification, in the current vehicle fleet. Coal, including waste or low-quality coal, can be readily converted into a variety of fuels, with a number of key advantages:

>> Coal-derived fuels are ultra-clean: sulphur-free, low in particulates, with low levels of oxides of nitrogen.

>> Carbon dioxide emissions, over the full fuel cycle, can be reduced by as much as 20%, compared to conventional oil products, through the use of carbon capture and storage [Williams & Larson 2003].

>> Coal is mined in over 50 countries worldwide, and present in over 70 – infrastructure systems exist for utilising this resource to provide liquid fuels.

>> Ultra-clean coal-derived fuels can be used for transport, cooking and stationary power generation, and as a feedstock for the chemicals industry.

Direct coal liquefaction converts coal to a liquid by dissolving coal in a solvent at high temperature and pressure. This process is highly efficient, but the liquid products require further refining ('hydrocracking' or adding hydrogen over a catalyst) to achieve high grade fuel characteristics.

Indirect coal liquefaction first gasifies the coal with steam to form a ‘syngas’ (a mixture of hydrogen and carbon monoxide). The sulphur is removed from this gas and the mixture adjusted according to the desired product. The syngas is then condensed over a catalyst – the ‘Fischer-Tropsch’ process – to produce high quality, ultra-clean products.

An array of products can be made via these processes – ultra-clean petroleum and diesel, synthetic waxes, lubricants, and chemical feedstocks. A similar process, using different catalysts, will produce alternative liquid fuels such as methanol and dimethyl ether (DME).

Efficiency and productivity can be improved by co-producing liquid fuels, electricity and chemical feedstocks (known as polygeneration). Carbon dioxide emissions from the production process can be significantly reduced through carbon capture and storage – and costs may be offset as a result of changes in sulphur management (see Section 5).
Coal to Liquids: South Africa

South Africa has been producing coal-derived fuels since 1955 and today around 30% of the country’s gasoline and diesel needs are produced from indigenous coal. The former state-owned company Sasol expanded its coal to liquids capacity in the late 1970’s with the construction of the Sasol II and III facilities, now known as the Sasol Secunda Complex. While significant floor price protection was offered initially, little protection remains today.

The total capacity of the South African coal to liquids operations now stands in excess of 160,000bbl/d of product. Sasol has produced over 1.5 billion barrels of synthetic fuel and chemical products since it commenced its coal to liquids operation, and its products are currently sold in over 90 countries around the world. Sasol is now working on Project Turbo which will enable the production of unleaded fuels. These fuels will add to over 200 fuels and chemical products that the company already manufactures. The Sasol operation, as well as providing a secure and reliable supply of oil to the domestic market, also makes a significant contribution to the South African economy. Sasol directly contributes R21 billion ($3 billion) or 2% to national gross domestic product (GDP). Sasol saves the country more than R29 billion ($4 billion) a year in foreign exchange and contributes more than R6 billion ($1 billion) annually to the Government in taxes and levies.
ENERGY SECURITY

The use of coal – affordable, abundant and available – can help address energy security concerns.

In *Coal: Secure Energy* the World Coal Institute looks at coal’s role in a balanced energy mix – particularly regarding security of supply in power generation – and how the use of clean coal technologies and carbon capture and storage can allow those security benefits to be realised while alleviating environmental impacts [WCI 2005].

Energy security considerations are potentially even more important in the transport sector. Oil products provide 96% of the energy used in transport – a far cry from the ‘balanced energy mix’ being sought as a sensible paradigm for stable economic development. As oil prices have risen dramatically over recent years, the possibility of hedging risks through the use of alternative fuels – Coal to Liquids (CTL); Gas to Liquids (GTL); and Biomass to Liquids (BTL) – is being seriously considered.

Energy security, of course, is not limited to concerns around high oil prices. It is a complex mix of issues around resource access, security and availability of supply infrastructure, rapidly changing patterns of production and consumption, unusual and adverse weather events and geopolitical tensions.

**Resource Availability**

The most fundamental concern about oil supply is the physical quantity of remaining reserves. The world’s total proven conventional oil
Coal: Liquid Fuels

Reserves currently stand in the region of 1.2 trillion barrels, or about 40 years of supply at today’s production levels [BP 2006]. While unconventional resources (oil shales, tar sands etc.) are being developed, demand is also forecast to rise at an average rate of 1.6% per annum between now and 2030 [IEA 2004].

Gas to Liquids (GTL) plants are currently operating in Malaysia and Qatar, and several others are planned. However, gas reserves are forecast to last only another 65 years. Gas prices are comparatively high and, as markets expand and interconnect, greater competition for resources may be expected, particularly with regard to liquefied natural gas (LNG) for power generation. GTL is effectively limited to stranded natural gas fields – i.e. those that are either too remote from a market, making construction of pipelines prohibitively expensive; or those where the market is saturated and export costs are too great.

In contrast, coal reserves are forecast to last well into the future – on a global average for a further 155 years, but in some countries domestic reserves may last much longer [BP 2006]. There are vast reserves in the USA, Russia, China, India and Australia, and many other countries have reserves more than adequate for over 100 years of use at current rates.

Coal is the world’s fastest growing energy source and is set to continue on this path [BP 2006]. New resources are being identified in, amongst others, Mongolia, Nigeria and Botswana, and production is increasing rapidly in Venezuela and Colombia.

Biofuels are also a growing market. Brazil has led the world with its biofuels programme (ethanol from sugarcane), and the US now uses 20% of its corn for ethanol production – supported by tax credits and its value as a replacement of the fuel additive MTBE. Global ethanol production provides around 0.4% of world oil consumption, and further rapid growth is expected.

However, growing biomass for fuels requires large land resources, and may in some parts of the world have to compete with food production or indeed with biomass for commercial electricity production – especially where subsidies or incentives have already been put in place. Biomass production for fuels on this scale can also have a significant impact on biodiversity. BTL plants are the most costly of the alternative fuel production systems to build, and feedstock costs are variable.

Using coal and biomass together to produce liquid fuels can offer some valuable benefits. Biomass can be used in the less costly coal to liquids plants thereby reducing capital outlay. Reducing the amount of biomass used will put less pressure on land use and biodiversity, and reduce competition with food crops. Co-processing of coal and biomass, in conjunction with carbon capture and storage, provides an opportunity to produce liquid fuels with near-zero net greenhouse gas emissions [Williams et al 2006].

Security of Supply
Geopolitical issues dominate oil and gas security of supply discussions. The location of the world’s oil and gas resources and their availability to consumers is a major concern, and import dependency is a considerable part of this. Countries and governments may feel an elevated level of risk if over-dependent on one particular fuel source or on imports from one particular region – particularly if the region is...

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1 Methyl tert-butyl ether is a fuel additive to increase the octane rating of gasoline, thus improving combustion efficiency and reducing sulphur emissions. It was originally used to replace lead, but health and water contamination concerns have led to its withdrawal in some places.
an unstable one where risks may change frequently. While greater freedom of trade, connectivity of markets and interdependence of fuels should go a long way to alleviate potential difficulties, these are not fully in place.

Coal offers a number of security of supply benefits. Coal has a particularly broad geographic resource distribution – it is present in more than 70 countries worldwide and currently mined in 50 of those [WEC 2004]. Coal users can benefit from utilising their own indigenous resources, or by accessing affordable coal in a well-established market from a wide variety of countries and suppliers. Even taking into account the costs of transformation, coal-derived fuels can provide a hedge against the volatility of oil prices and facilitate greater economic independence through the stabilisation of demands on foreign currency reserves.

In the oil sector, production is still dominated by the Organization of Petroleum Exporting Countries (OPEC)2, which has accounted for almost half of the growth in world oil production since 1995 and its production is at its highest level ever. OPEC accounts for more than 40% of total world production, covers almost 80% of global proven reserves, and its exports provide over 50% of the world’s internationally traded oil.

Net oil imports in the OECD3 rose to 59% in 2005 – the highest share since 1979. Chinese oil consumption has more than doubled since 1995, and the majority of this is imported. In the USA, domestic production reached its peak in 1971 and has been declining steadily since. The USA now tops the oil import charts, buying in some 13 million bbl/d – almost three times the amount of the next largest importer, Japan.

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2 The Organization of Petroleum Exporting Countries (OPEC) consists of 11 of the world’s largest oil producing nations: Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela.

3 The Organisation of Economic Co-operation and Development (OECD) consists of 30 member countries sharing a commitment to democratic government and market economy. It is widely considered to be representative of “developed” industrial market economies.
Many of the OPEC countries have a history of political instability, and most are concentrated in the currently unstable Middle East. Attacks on energy infrastructure in OPEC nations due to ongoing conflicts are a cause for increasing concern, most recently in Iraq and Nigeria. Distribution infrastructure and oil supply routes are also potentially at risk – chokepoints are particular worries, where congestion may slow supplies, or which may be at risk as conflict targets. Pipelines, refineries and other energy infrastructure have all recently been the focus of conflict-driven attacks.

Security of supply is not merely the physical security of infrastructure. For example, political concerns in Venezuela resulting from the re-nationalisation of the oil industry have led to investor withdrawal.Industrial issues may also affect supplies – as during winter 2006 when Gazprom, the Russian gas monopoly, turned off its supplies to Ukraine. While the circumstances surrounding this act – non-payment and disagreement over prices – may have justified the action in the views of the supplier, their readiness to do so caused worry to many other customers. If the dispute had lengthened, technical issues around gas delivery would have created supply problems to a much larger area.

The broad distribution of coal resources and the variety of supply routes ensure that such difficulties are extremely unlikely where countries are involved in the international market. If one supply route were to be cut off for any reason, a host of other suppliers and import facilities can be utilised.

The availability of oil refining capacity to meet the need for modern fuels is a further concern in ensuring a constant supply of oil products. The scale of necessary investment – some $500 billion is needed by 2030 – is challenging for all, but particularly for developing countries, and especially in light of dwindling resources.

Aging refineries need to be upgraded or replaced to meet changing needs as product specifications change. The demand for low or ultra-low sulphur fuels is putting further strain on current processes due to shortages of the hydrogen necessary for their production.
The uncertainty about availability and security of oil and gas supplies has led many governments to consider their positions and exposure to oil-related risks. Investors are carefully assessing their options and looking at alternative fuels and processes.

Rising Fuel Prices

Oil and gas prices are increasing both in absolute terms and in volatility, largely as a result of the constraints and concerns discussed in this paper. Coal prices have been historically lower and more stable than both oil and gas on an equivalent energy basis, and despite the growth of index and derivative based sales in recent years, this is likely to remain the case.

By July 2006, oil prices had reached highs of $78 per barrel (NYMEX) as a result of ongoing supply issues and exacerbated by further conflict in the Middle East. The role of OPEC is a complicating factor – the Organisation may be considered a single supplier, significantly reducing the amount of competition in the sector and thus reducing the overall ability of the market to correct prices.

Average monthly US natural gas prices during 2005 reached $8.79/million BTU, peaking at over $15/million BTU in December 2005 (Henry Hub). European prices showed similar volatility. The average European natural gas price was $6.28/million BTU – compared to an annual average price during the 1990’s of $2.50.

The comparative price of coal is significantly lower. The overall trend in coal prices over 2005 was a downward one, in stark contrast to oil and gas. Its overall affordability and availability have contributed to coal remaining the fastest growing fuel in the world [BP 2006].
Recent financial forecasts have suggested future average coal prices of $45 per tonne — roughly $70 per tonne of oil equivalent\(^4\), or under $10 per barrel of oil equivalent. Oil prices, governing the price of conventional liquid fuels, are likely to remain high — the US Government predicts a range to over $90 per barrel for the period to 2030.

The constraints of resource availability, supply security, refinery capacity and changes in product demand, are unlikely to ease. The result is investment in alternative supplies: additional capacity from conventional oil fields previously too expensive to exploit; unconventional oil, such as oil sands from Canada and Venezuela; or alternative processes — CTL, BTL or GTL.

The use of wheat for ethanol production (biofuels) however, may lead to competition between food and oil markets. 2006 has seen wheat prices rise to a 10 year high due to a combination of very dry weather conditions and the expected growth in biofuel production. Global wheat production is expected to fall short of demand this year, the fifth of the past six years where demand has exceeded supply. The global wheat stocks-to-use ratio in 2007 is likely to be the lowest in three decades [UNFAO 2006].

\(^4\)‘Tonnes of oil equivalent’ is the unit used to provide a common measure of different energy sources.

1 tonne of oil equivalent = 10^7 kcal, or the average net heat content of one tonne of crude oil.
The low price of coal compared to the high price of other fuel sources, whether oil (currently trading at $600 per tonne), ‘unconventional’ oil, or gas, provides a degree of longer term investment certainty that has generated a significant amount of interest in CTL fuels worldwide.

The conversion of any feedstock to provide an alternative fuel requires sizeable upfront investment and all alternatives are more costly to build than a conventional oil refinery. The cost of building a conversion facility varies according to location, but recent work suggests that CTL plants are one of the most cost-effective of the alternative fuels, particularly when overall operating costs and the low cost of coal are considered. CTL capital investment costs range around $50,000-$70,000 per barrel of daily capacity, compared to $100,000-$145,000 per barrel of daily capacity for biomass to liquids plants [US DOE 2005].

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Liquid fuel from coal is not a new idea, but its development has been constrained by low oil prices — typically oil prices need to be of the order of $35 per barrel or higher for coal to liquids to be economically attractive. In the USA, studies suggest certain liquid fuels can be produced in conjunction with electricity production at a ‘break even crude oil price’ of between $27 and $45 per barrel, including the costs of carbon capture and storage [Williams & Larson 2003].

SECTION THREE
COAL TO LIQUIDS: INVESTMENT

The growth in demand for liquid fuels, together with the dramatic increase in oil price and energy security concerns, is creating a unique situation for the potential rapid development of coal to liquids industries around the world.

Unconventional Petroleum Liquids Capital Cost Investment (thousand $ per daily barrel of capacity*)

Source: Energy Information Administration
* 2004 Dollars
The capital cost of CTL plants is also expected to decrease through the ongoing development of the technology. Although CTL has been operating for many years in South Africa, a broadening and growth of the market will drive both existing providers and new entrants to develop more efficient and cost-effective processes to gain market advantage.

New developments notwithstanding, CTL currently provides one of the most affordable alternatives to conventional petroleum production.

**Gas to Coal – USA**

Natural gas prices are also a driving force behind CTL projects – rising prices in the USA are leading to the conversion of a gas-based ammonia fertiliser production plant in Illinois to run on local coal. Rentech Energy’s new polygeneration plant will also produce ultra-clean diesel and electricity. The CO2 produced will be used for enhanced oil recovery, and ultimately stored permanently in depleted oil reservoirs.
World Coal Institute

In China, private car ownership has increased dramatically over recent years. Ownership is expected to reach around 250 million by 2025 – equivalent to 150 cars per thousand people [China Daily 2004]. In 2004 this figure was just 10 cars per thousand people. In North America current ownership is at 770 cars per thousand people [IEA 2004]. The pressure to provide infrastructure and fuels is immense – and coal-derived fuels can play a significant role.

Fuels produced from coal also have potential outside the transportation sector. In many developing countries, health impacts and local air quality concerns have driven calls for the use of clean cooking fuels. Replacing traditional biomass or solid fuels with liquefied petroleum gas (LPG) has been the focus of international aid programmes. LPG, however, is an oil derivative and is thus affected by the expense and price volatility of crude oil. At current oil prices the affordability of LPG is questionable, potentially causing consumers to return to the use of traditional biomass resources – wood or dung – with resulting health impacts.

Coal-derived dimethyl ether (DME) is one of a suite of fuels that can be produced in the CTL process and is receiving particular attention.
today. It is a product that holds out great promise as a domestic fuel. DME is non-carcinogenic and non-toxic to handle and generates less carbon monoxide and hydrocarbon air pollution than LPG. DME can also be used as an alternative to diesel for transport, as well as for on and off-grid power applications. The use of DME in combined cycles is a proven technology, and emissions are as low as from natural gas. Where DME replaces domestic coal use, CO₂ emissions may be up to 40% lower.

China in particular has taken up DME production – financing from the World Bank Group has been secured for a 400,000 t/year plant in Inner Mongolia to provide fuel for household cooking and heating, transportation and power generation. A further project in Ningxia Province has benefited from US Trade Department assistance and will provide power, chemical feedstock and liquid fuels.

The benefits of CTL can be realised particularly in countries that rely heavily on oil imports and that have large domestic reserves of coal. There are a number of CTL projects around the world at various stages of development, the most advanced being in China, the USA and Australia. There is also strong interest from other countries including Indonesia, Germany and India. Like South Africa, all of these countries have large domestic reserves of coal and much smaller reserves of oil.

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal Production (million tonnes of oil equivalent)</th>
<th>Ranking as a Coal Producer</th>
<th>Ranking as an Oil Importer</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1107</td>
<td>1</td>
<td>3</td>
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<tr>
<td>USA</td>
<td>576</td>
<td>2</td>
<td>1</td>
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<tr>
<td>Australia</td>
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<tr>
<td>India</td>
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<td>South Africa</td>
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<td>Russian Federation</td>
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<td>Indonesia</td>
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<td>Germany</td>
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<tr>
<td>Kazakhstan</td>
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</tbody>
</table>
China is the world’s second largest consumer of oil. Over 50% of its oil is now imported – a dramatic rise of almost 40% from 2004 – at over 3 million bbl/d. At this level, price rises are keenly felt – a $1 per barrel increase in the cost of oil results in a $1.2 billion additional burden to China’s foreign exchange reserve. In the first five months of 2006, crude oil imports cost China some $10 billion more than the same period in 2005 [Ministry of Commerce, 2006].

These circumstances have led China to develop domestic capacity in oil substitutes, thereby decreasing import expenditure while improving energy security and investing in domestic economic growth. In 2005, Shenhua – one of China’s largest energy companies – started construction of the largest CTL plant in China. This project will have an ultimate capacity of 50,000bbl/d and will be located in North China’s Inner Mongolia Autonomous Region. The first stage of this plant is expected to begin production in late 2007 with gasoline, jet fuel and diesel fuels being the primary products. Shenhua plans to build further CTL plants, worth in the region of $10bn, including a number in joint ventures with Sasol of South Africa and Shell. These plants will make the equivalent of 10 million tonnes of crude oil by 2010. Shenhua hopes to lift this production to 30 million tonnes by 2020, equal to about 16% of China’s present crude oil output of 180 million tonnes [China Daily 2006]. A number of other energy companies have embarked on a similar course.

These projects are also attracting international development financing. The International Finance Corporation (IFC, the

Underground Coal Gasification for Liquid Fuels

Linc Energy are currently investigating the potential for a CTL project in Queensland, Australia. Here the coal will be converted to syngas while ‘in-situ’ or underground by an established process. This method has the potential to reduce capital costs significantly, as the costly surface gasification step is removed. Underground Coal Gasification (UCG) has been taking place at the site since 1999 and is the largest UCG project outside the Former Soviet Union. In 2006 Linc Energy announced plans to expand the Chinchilla project to include the production of CTL fuels and electricity from the site. The production target of the CTL process from the Chinchilla site is 20,000 barrels of diesel fuel per day – approximately 10% of Australia’s needs.
private sector arm of the World Bank) is providing $50 million in equity and loans for China’s Xinao Group to support the conversion of coal to DME. A further $140 million in loans from commercial banks has been arranged by the IFC.

**Australia**

Australia has the fifth largest proven coal reserves in the world and is the largest coal exporter. However, it relies on imports to meet its oil needs and current market conditions have prompted interest in the development of a domestic CTL industry.

Monash Energy has established a project to produce 62,000 bbl/day of coal-derived diesel and other liquids, and aims to have a demonstration plant in place by 2010. The plant will also produce 220 MW of electricity to power the process and supply the national electricity grid.

The plant will be located in SE Australia and will use the local, low-grade brown coal. CO₂ emissions will be captured from the process and transported less than 200 km for geological storage in the oil and gas fields of the Bass Strait. The results of the pre-feasibility study indicate the project would have multiple benefits for the Australian economy. These include A$20 billion spent on local goods and services, a contribution of some A$15 billion to the national and state economy through payment of corporate income tax, and enabling some A$80 billion to be avoided in oil imports over 50 years [Monash Energy 2006].

The Monash project is being developed with the possibility of a future hydrogen economy in mind. As a hydrogen stream is produced during the CTL process, the project will be designed for easy modification to produce hydrogen rather than CTL fuels. Designing this flexibility will allow the plant to continue to operate and provide some certainty for investors.

Ample coal reserves and storage capacity in this region of Australia may prove attractive to further CTL developments.

**USA**

The USA consumes and imports more oil than any other country in the world, making it particularly vulnerable to supply disruption or price rises. It does, however, have 27% of the world’s proven coal reserves. Large scale application of CTL technology therefore has the potential to alleviate many of its energy security concerns.

There are currently a number of projects undergoing feasibility studies in the USA, including the Medicine Bow Project in Wyoming, the Waste Management and Processors Inc (WMPI) project in Pennsylvania and the Rentech project in Illinois. There are also projects proposed in Arizona, Montana, and North Dakota.

DKRW Energy’s CTL project in Medicine Bow, Wyoming is being designed to produce 11,000 bbl/d of various fuels – primarily diesel. D KRW Energy has long-term plans to further expand the capacity of the facility to produce as much as 40,000 bbl/d of fuels. The Medicine Bow project will also include the construction of an integrated gasification combined cycle (IGCC) unit to produce electricity on the site using the syngas and steam produced in the CTL process. During the first phase, an estimated 45 MW of power will be generated. The CO₂ produced from the CTL...
process will be captured and sold for enhanced oil recovery and storage in the region. The sulphur removed from the process will be sold into the agricultural market.

**Indonesia**

Indonesia has significant coal reserves and has been particularly focused on the export market in the past. Between 2003 and 2004 Indonesia’s coal production rose by 17.3%, faster than any other country [BP 2005]. Indonesia became a net importer of oil in 2004, and although still a member of OPEC its production continues to decline. As a result, coal production has been increasingly focused on the domestic market – for power generation and potentially for synthetic fuels.

In early 2006 Bumi, Indonesia’s largest private energy company, announced its plans to build an 80,000bbl/d CTL facility in South Sumatra.

**Germany**

Germany is the fourth largest oil importer in the world and the ninth largest coal producer. The indirect CTL ‘Fischer-Tropsch’ process was invented in Germany during the 1920s, and has now re-emerged as a technology of interest.

A pre-feasibility study is being undertaken for a 3000bbl/d facility at the Schwarze Pumpe industrial facility at Spreetal – the first phase of a larger 20,000bbl/d project. The Spreetal Project will also incorporate an expansion of the existing methanol production and power plant at the site, which currently use syngas derived from coal, waste oils, biomass and municipal wastes. The project is seeking financial support from the Saxony (Sachsen) State Government and is currently eligible for a €100 million ($128 million) grant.

**India**

India currently imports over 70% of its oil needs, yet has 92 billion tonnes of proven coal reserves. At current production and consumption rates, India has well over 200 years of coal available.

Although no CTL projects have been formally proposed to date, South Africa’s Sasol have had a number of discussions with both government and industry. The Government of India’s Investment Commission envisage investments of around $6 billion [Business Standard 2006], and a feasibility study has been ordered by the Minister of Coal. India’s high ash, low grade coals would be well-suited to conversion, and rapid development is to be expected.

**Market Incentives**

Although CTL can produce oil at prices competitive with conventional oil supply, some financial risks are present due to the upfront capital costs. While all new technologies entail risk, governments can take steps to share the risk and promote more rapid technological outcomes than the private sector and market alone. Coal to liquids, as with all alternative fuels, may require some initial incentives to enable its energy security benefits to be realised. In the USA, for example, the government is already providing incentives that relate to CTL development. The 2005 Energy Policy Act and Transportation Bill encourage the development of CTL by creating a new loan guarantee programme for innovative CTL technologies.
The US Clean Coal Power Initiative provides loan guarantees for companies wishing to develop clean coal-fired power generation. This can be applied to a polygeneration CTL and power plant, where emissions of CO\(_2\), NO\(_x\) and SO\(_x\) are lower per MW than a conventional coal-fired plant. The WMPI CTL project in Gilberton, Pennsylvania, due to commence construction in late 2006, has recently secured a $100-million federal loan guarantee under the US Clean Coal Power Initiative. The state of Pennsylvania is also looking to support the venture with tax credits and a purchase agreement for a proportion of the fuel produced at the facility. The project will produce 5000 bbl/d of diesel fuel and will utilise low grade waste coal from the Pennsylvania region.

The USA’s proposed Foreign Oil Displacement Act seeks to provide financial tax incentives for CTL projects. Specifically, the bill would provide a 28% Investment Tax Credit and exemption from the Fuels Excise Tax for CTL fuels, a benefit already seen in the biofuels (ethanol) industry.

The US military is also currently considering alternative fuels – and the high quality of coal-derived fuels could provide a suitable solution. A guaranteed price for the fuel from the US Government (via sales contracts with the military) would reduce the exposure of the US military to oil price fluctuations while encouraging further CTL developments.

In China, project developers Shenhua are seeking guarantees from the Chinese government to provide a floor price for the fuel they produce – the return on investment is thus ensured for the developer while the oil price risk is assumed by the government.

Governments can thus provide a number of market incentives:

- Public/private partnerships: where government and industry become partners in the project.
- Government loan guarantees: a guarantee could, for example, cover construction costs and is a commitment from the government to pay part or all of a loan’s principal and interest to the lender if the borrower defaults.
- Tax incentives: e.g. federal investment tax credits or fuel excise tax exemptions that lessen the tax burden on the company.
- Accelerated depreciation: a method of calculating the depreciation in value of the facility at a faster rate than would be done normally, thus lowering the value of the assets and decreasing tax.
- Providing a floor price for the fuels produced: i.e. an agreed minimum price that the government will pay for the product even if the market price falls below this level.
 SECTION FIVE

MEETING ENVIRONMENTAL CHALLENGES

Converting coal to liquid fuels provides ultra-clean, sulphur-free products, low in aromatic hydrocarbons (such as benzene), and offering significant reductions in vehicle emissions such as oxides of nitrogen, particulate matter, volatile organic compounds and carbon monoxide.

They are readily bio-degradable and non-toxic. Fuel consumption is lowered, reducing emissions of end-use carbon dioxide.

Transport Emissions

Synthetic fuels from coal can be used directly in today’s vehicles, with no need for modification. Road trials of synthetic fuels in several European capitals and elsewhere demonstrate that significant local air quality improvements can be achieved through the reduction of these tailpipe emissions. Studies in the USA suggest particulate emissions can be up to 75% less than traditional diesel, and oxides of nitrogen can be reduced by up to 60%.

The optimisation of new engines for synthetic fuels can produce even greater reductions, particularly of nitrogen oxides. New engine design, such as direct injection, will offer greater efficiencies.

The introduction of synthetic fuels will also have an immediate positive impact on emissions across the entire existing vehicle fleet, as it can be used in vehicles and existing fuel supply infrastructure without the need for any modifications.

Process Emissions

The conversion of any feedstock to liquid fuels is an energy intensive one, and process emissions must be considered. While the coal to liquids process is more CO2 intensive than conventional oil refining, there are options for preventing or mitigating emissions. Due to the broad global distribution of coal reserves, emissions may also be avoided through shorter fuel transport distances.

For coal to liquids plants, carbon capture and storage (CCS) can be a low cost method of addressing CO2 concerns and may result in greenhouse gas emissions being some 20% lower over the full lifecycle than fuels derived from crude oil [Williams & Larson 2003]. Where co-processing of coal and biomass is undertaken, and combined with carbon capture and storage, greenhouse gas emissions over
the full fuel cycle may be as low as one-fifth of those from fuels provided by conventional oil [Williams et al 2006].

Carbon capture and storage involves the capture of CO₂ emissions from the source, followed by transportation to, and storage in, geological formations. CCS is particularly applicable to the CTL process as the CO₂ stream produced from CTL is at a very high concentration – very little of the costly CO₂ separation is required before transport and storage.

Once the CO₂ has been captured there are a number of storage options available. The CO₂ can be stored in deep saline aquifers or be used to assist in enhanced oil recovery and subsequent CO₂ storage. CO₂ can also be captured and sold to the food and beverages industry, displacing CO₂ currently sourced specifically for this purpose from naturally occurring CO₂ deposits. This also provides an extra source of revenue for the project.

CCS is already being used on a coal gasification plant at one of the largest and longest running CCS projects in the world in Weyburn, Canada. The Great Plains synfuels plant in Dakota, USA, produces natural gas and other chemicals through the gasification of low quality coal. 60% of the CO₂ generated from the gasification process is captured and transported via pipeline to the Weyburn oil field in Saskatchewan, Canada. At the Weyburn site, the CO₂ is used for enhanced oil recovery and stored geologically. Weyburn has been operating since 2000 with a total of 5Mt of CO₂ stored. In this case, the sale of the CO₂ is an extra revenue source for Dakota Gas while reducing greenhouse gas emissions.

**Cost Savings: Co-Capture and Co-Storage**

Further opportunities for large cost savings exist through an alternative approach to sulphur management. In a traditional plant, sulphur is removed from the syngas to prevent poisoning of the reaction catalyst. If this sulphur (in its gaseous form) is separated with the CO₂ and stored in the same geological formations, overall costs can be reduced still further by removing the need for a separate sulphur removal system. This in turn reduces the capital cost of the plant significantly, providing a low-cost sulphur/carbon management system that can be cost-effective even without a price on carbon.

Recent studies on IGCC power generation have shown that the CO₂ mitigation cost of such co-capture plants is at least four times lower than separate CO₂ and hydrogen sulphide (H₂S) capture plants [Ordorica-Garcia et al 2006].

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5 For further information about carbon capture and storage please refer to the WCI website www.worldcoal.org

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**SECTION FIVE END**
POLICY RECOMMENDATIONS

>> The use of coal-derived fuels can provide enormous energy security benefits, particularly in those countries with ample indigenous reserves of coal. >>

Other countries may take advantage of coal’s well-established world market to access affordable supplies for their power or liquid fuel needs.

However, the capital costs of synthetic fuel plants – whether coal, gas, or biomass – are significant. While coal is a competitive option, the availability of investment is a key issue – particularly in developing nations.

Coal-derived fuels are ultra-clean to use and have enormous benefits for local air quality, however, CO₂ emissions from the process remain a challenge. Incorporating carbon capture and storage must be an integral part of the design process – for enhanced oil recovery, for product to the food and beverage industry, and ultimately for geological storage.

To reap the energy security benefits of reduced dependence on oil some policy support will be needed.

>> Policy support to reduce investment uncertainty – a number of market-based incentives have been identified in this document, including tax incentives, floor price guarantees and government investment guarantees.

>> Policy support for carbon capture and storage – the Intergovernmental Panel on Climate Change has established that capacity is available for permanent storage of the world’s CO₂ emissions for hundreds of years. Policy support is needed to remove legal and regulatory barriers, to enhance international collaboration and to determine operational frameworks.

>> Policy support for research, development and demonstration (RD&D) – while CTL technologies are proven, and a large operational experience has been gained, further RD&D will improve efficiencies and reduce process impacts. Further RD&D into fuels and vehicles will optimise the benefits of using synthetic fuels.

>> Policy support for technology transfer – e.g. through bilateral and multilateral funds, through export credits and guarantees and through joint ventures.

>> Policy support can address environmental concerns while recognising the energy security benefits. Clear, long-term environmental policies provide certainty for investors and operators alike.

The coal industry supports such initiatives, and is committed to working closely with governments and process operators to maximise the benefits that this valuable substitute for traditional liquid fuels can bring.
**ANNEX**

**THE COAL TO LIQUIDS PROCESS: TECHNOLOGY OPTIONS**

**Carbonisation & Pyrolysis**
High temperature carbonisation is the oldest process for producing liquids from coal. Coal is heated to around 950°C in a closed container – decomposition takes place, and the volatile matter is driven off. This is typical of the coke-making process, and the hydrocarbon liquid (coal tar) is predominantly a by-product.

The process produces very low yields and upgrading costs are relatively high – so the coal tar is not traditionally used in the transportation fuel sector. Coal tar is used worldwide for the manufacture of roofing, waterproofing, and insulating compounds and as raw materials for many dyes, drugs, and paints.

Mild pyrolysis is a lower temperature carbonisation, or decomposition, process. Coal is heated to between 450°C and 650°C, driving off volatile matter and forming other compounds through thermal decomposition.

Liquid yields are higher than for high-temperature carbonisation, but reach a maximum of 20%. The main product is a char. This process has been used to upgrade low-rank sub-bituminous coals in the USA – it increases calorific value and reduces sulphur content.

Rapid pyrolysis occurs by subjecting coal to contained temperatures of around 1200°C, but for only a few seconds. This process is aimed at producing chemical feedstocks rather than liquid fuels. Carbonisation and pyrolysis produce a small proportion of the total product as liquid fuels which still require further treatment. A demonstration plant was built in the USA (operational 1992 to 1997) for coal upgrading, but there is little scope for economically viable liquid fuels.

**Direct Liquefaction**
Hydrogen is added to the organic structure of coal, breaking it down to the point where distillable liquids are produced.

There are a number of different methods, but the basic process involves dissolving coal in a solvent at high temperature and pressure followed by the 'hydrocracking' (i.e. adding hydrogen over a catalyst).
Liquid yields can be in excess of 70% of the dry weight coal feed, with thermal efficiencies of around 60-70%. The liquids produced from direct liquefaction are of much higher quality than those from pyrolysis and can be used unblended in power generation or other stationary applications. However, further upgrading is required for use as a transport fuel. There are two main groups of direct liquefaction processes:

» Single-stage: provides the distilled liquids (distillates) through one primary reactor or reactor chain. Most of these have been superseded by two-stage processes to increase production of lighter oils.

» Two-stage: provides distillates through two reactors or reactor chains. The first reaction dissolves the coal either without a catalyst or with a low-activity disposable catalyst, producing heavy coal liquids. These are further treated in the second reactor, with hydrogen and a high-activity catalyst to produce additional distillate.
The two-stage processes have often derived from single-stage reactions – the Catalytic Two-Stage Liquefaction process was developed from the H-Coal single stage. This technology is the one chosen for Shenhua’s Inner Mongolia plant in China, as the proprietary HTI Direct Coal Liquefaction Technology. Pulverised coal is slurred in a recycled process solvent, then preheated, mixed with hydrogen and fed to the first reactor, which operates under typical conditions of 435-460°C and 170 bar. A second reactor completes the liquefaction, operating at higher temperatures. The reaction catalyst for both stages is a nano-scale, iron-based one, dispersed in the slurry.

**Indirect Liquefaction**

Indirect liquefaction involves the complete breakdown of the coal structure by gasification with steam. The composition of this synthesis gas, or ‘syngas’ is adjusted to give the required balance of hydrogen and carbon monoxide. Sulphur compounds are also removed at this stage to prevent poisoning of the reaction catalyst as well as to provide low-sulphur transport fuels.

The syngas is then reacted over a catalyst at relatively low pressure and temperature. Products vary according to the reaction conditions and catalyst. Methanol, for example, is produced using a copper catalyst (at 260-350°C and 50-70 bar). DME is produced by a partial hydration of methanol over further catalysts – for example, activated alumina and a fixed zeolite).

The only commercial-scale indirect coal liquefaction process currently in operation is at Sasol in South Africa.

The Sasol process is based on the Fischer-Tropsch (FT) liquefaction process. Sasol uses both the low-temperature FT process (fixed bed gasification, slurry-phase FT), and the high temperature (HTFT) process incorporating circulating fluidised bed gasification, and Sasol Advanced Synthol technology.

The HTFT process operates at 300-350°C and 20-30 bar, with an iron-based catalyst, and produces a lighter suite of products, including high-quality ultra-clean gasoline, petrochemicals and oxygenated chemicals.
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- Coal as a strategic resource, essential for a modern quality of life, a key contributor to sustainable development and an essential element in enhanced energy security.

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- Highlight the valuable role affordable and abundant coal resources play in a world ever more concerned with energy security.

- Improve understanding of the importance of coal as the single largest source of fuel for electricity generation, and its vital role in other industries – including steel production, cement manufacturing, chemicals and liquid fuels.

- Form strategic partnerships and alliances to coordinate actions and maximise resources to improve the perception of coal worldwide.

- Ensure decision-makers and opinion formers are fully informed of the contribution of coal to social and economic development.

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