COAL–TO–LIQUIDS
an alternative oil supply?

WORKSHOP REPORT

IEA Coal Industry Advisory Board workshop
IEA Headquarters in Paris, 2 November 2006

IEA – 9, rue de la Fédération – 75739 Paris Cedex 15
WORKSHOP PROGRAMME – Thursday, 2 November 2006

Opening Session
Mr Claude Mandil, Executive Director, International Energy Agency
Mr Preston Chiaro, Chief Executive – Energy, Rio Tinto & CIAB Chairman

SESSION 1: Experience with Coal-to-Liquids Technologies in South Africa and Japan
Chaired by Dr John Topper, Managing Director, IEA Clean Coal Centre

A Primer on the Technologies of Coal-to-Liquids
Mr Daniel C Cicero, Technology Manager – Hydrogen & Syngas, Office of Coal and Power R&D, US Department of Energy National Energy Technology Laboratory

Coal Liquefaction Development in NEDO
Dr Sadao Wasaka, Director General, Environment Technology Development Department, New Energy and Industrial Technology Development Organization, Japan

Commercial Experience in South Africa with Coal-to-Liquids and Coal-to-Chemicals
Mr André Steynberg, Technology Manager for Coal-to-Liquids Technologies, Sasol Technology (Pty) Ltd

Discussion

SESSION 2: Policy Drivers for CTL in the USA, Industry’s Response and the Environmental Implications
Chaired by Mr Steven F Leer, Chairman and Chief Executive Officer, Arch Coal Inc

Policy Implications for CTL in the USA
Dr Roger H Bezdek, President, Management Information Services Inc and lead consultant to Southern States Energy Board’s report The American Energy Security Study

CTL Projects – key issues and economics
Mr Robert C Kelly, Executive Officer, DKRW Energy LLC

Sequestration of CO₂ from CTL Processes
Mr I Merrick Kerr, Chief Financial Officer, Rentech Inc.

Discussion

SESSION 3: CTL Projects in China and the Developing World
Chaired by Mr Eric Ford, Chief Executive Officer, Anglo Coal Australia Pty Ltd

China’s Development Strategy for Coal-to-Liquids Industry
Dr ZHANG Yuzhuo, Chairman, China Shenhua Coal Liquefaction Corp & Vice President, Shenhua Group Corporation Limited

CTL Technology in China and Polygeneration Opportunities
Prof LI Zheng, Director, Tsinghua-BP Clean Energy Research and Education Centre, Tsinghua University

The Shell Perspective on Coal-to-Liquids
Mr Nicolás Ximénez Bruidegom, General Manager: Clean Coal Energy Europe, Shell Gas & Power International

Discussion

SESSION 4: Prospects for CTL in Europe, Australasia and Globally
Chaired by Dr Don Elder, Chief Executive Officer, Solid Energy New Zealand Ltd

Prospects for Coal-to-Liquids in Australasia
Mr Jeff Cochrane, Chief Executive Officer, Monash Energy

From Mine to Wheel – the role of lignite-to-liquids in tomorrow’s energy supply
Mr Matthias Hartung, Executive Vice President, RWE Power AG

The Context for Coal-to-Liquids – an oil industry view
Dr Atul Arya, Vice President – Group Strategy, BP plc

Discussion

SESSION 5: Coal Market and Policy Implications of a Growing CTL Demand
Chaired by Preston Chiaro, Chief Executive – Energy, Rio Tinto & CIAB Chairman

Panel discussion with:
Dr Victor K Der, Director – Office of Clean Energy Systems, US Department of Energy
Dr Roger H Bezdek, President, Management Information Services Inc.
Mr Jeff Cochrane, Chief Executive Officer, Monash Energy
Mr André Steynberg, Technology Manager for Coal-to-Liquids Technologies, Sasol Technology (Pty) Ltd
Dr ZHANG Yuzhuo, Chairman, China Shenhua Coal Liquefaction Corp & Vice President, Shenhua Group Corporation Limited
Mr Bill Senior, Senior Advisor – Technology, BP Alternative Energy

Panellists offered their own, short commentary in response to the key questions and issues emerging from the workshop. CIAB Members and other participants were then invited to join an open discussion, followed by concluding remarks from the Chair.
Background

Oil supply security and price concerns have led to a renewed interest in coal as an alternative feedstock for the production of transport fuels and chemicals. By using coal conversion technologies, such as coal-to-liquids (CTL), the world’s vast coal resources could become an important alternative to crude oil.

CTL describes both coal gasification, combined with Fischer-Tropsch (F-T) synthesis to produce liquid fuels, and the less developed, direct coal liquefaction technologies. Coal gasification is applied widely in the production of chemicals and fertilisers, notably in China where 8 000 coal gasifiers are operating. Fischer-Tropsch synthesis, first developed in Germany during the early decades of the 20th century, has been further developed and improved in South Africa by Sasol.

In the past, CTL has substituted for imported oil: during the 1930s and 1940s, when coal-rich Germany needed a secure source of transport fuels; and, since the 1950s in South Africa, where 40 million tonnes of coal per year are still converted into 160 000 barrels per day (b/d) of crude oil equivalent. Following the oil price shocks of the 1970s, significant coal liquefaction R&D was undertaken in the USA, Europe, Japan and Australia, although much of this development work was subsequently put on hold as oil prices stabilised from the mid-1980s and through the 1990s.

Today, with the return of high oil prices, China is constructing a 60 000 b/d CTL plant and, with plans for further projects, aims to produce one million barrels per day (mb/d) by 2020. In the USA, new incentives have been introduced for coal-based transport fuels and coal companies are now assessing the commercial viability of new projects as one component of a wider vision to make greater use of the country’s vast coal resource.

Technical Background

Coal may be used to produce liquid fuels suitable for transportation applications by the removal of carbon or addition of hydrogen, either directly or indirectly. The first approach is usually known as carbonisation or pyrolysis and has low yields; the second is called liquefaction. As the cost of converting coal into useful liquid fuels is higher than the cost of refining crude oil, it is the relatively low price of the raw coal feedstock that provides the main incentive to pursue the technology.

Direct liquefaction is potentially the most efficient route currently available, yielding in excess of 70% by weight of the dry, ash-free (daf) coal feed, under favourable conditions. Although many different direct processes exist, common features are the dissolution of a high proportion of the coal in a solvent at elevated temperature and pressure followed by catalysed hydrocracking of the dissolved coal with hydrogen gas. The overall energy efficiencies of the very best modern processes are generally in the range 60-70% and the technology has been demonstrated at large pilot plants. Although no commercial plants yet exist, Shenhua Group’s first CTL facility is under construction in China using direct liquefaction technology.

The less efficient, but commercially proven, indirect liquefaction process relies on the gasification of coal to produce synthesis gas (a mixture of carbon monoxide and hydrogen) which is then reacted over a catalyst at temperature and pressure to produce the desired liquid products. It is this indirect process, using well-established Fischer-Tropsch synthesis, that has been commercialised by Sasol in South Africa and will be used in several new projects proposed in China. For modern plant, overall energy efficiency is typically >40%.

Summary

This workshop, “Coal-to-Liquids – an alternative oil supply?”, was held in conjunction with the annual Plenary meeting of the IEA Coal Industry Advisory Board. Coal industry leaders from IEA member countries joined their counterparts from South Africa, China, Russia and Poland to debate developments in a field that has attracted renewed attention because of recent high oil prices and concerns over the security of energy supplies. Coal-to-liquids (CTL) has a long history in South Africa and Sasol now converts 40 million tonnes of raw coal per year to produce 160 000 barrels per day (b/d) of crude oil equivalent using the commercially-proven indirect liquefaction process. In the USA, companies are moving ahead with projects that seek to reduce the country’s dependence on imported oil, encouraged by a variety of Federal and state government incentives. However, it is in China where new projects are being developed in earnest, with a major construction project underway in Inner Mongolia. This plant, using newly-developed direct liquefaction technology and scheduled for commissioning in 2008, will produce one million tonnes of oil products each year (20 000 b/d) with a planned expansion to 100 000 b/d.

Dr ZHANG Yuzhuo, Chairman of China Shenhua Coal Liquefaction Corporation, explained that this project formed one component of a strategy that would limit oil imports to below 50% of China’s demand by 2020 when direct and indirect coal liquefaction plants are expected to meet 10-15% of the forecast 450 million tonnes (9 million b/d) annual oil demand. The global abundance of coal means that CTL could play an important future role, especially if greater experience leads to improved economics. However, as in other energy sectors, the scarcity of capital and skills was considered to be a major hurdle. NGOs, industrialists and policy advisors were all agreed that using coal as an alternative to oil for producing transport fuels will require carbon dioxide capture and storage (CCS), if significant increases in carbon dioxide (CO2) emissions are to be avoided.

In OECD countries, the need for CCS was taken as a given by project developers. In China, it is not a priority, but participants at the workshop heard a clear willingness to apply the technology if some way could be found to cover the economic cost. The CIAB will consider this challenge over the coming year within the broader context of how clean coal technologies can be more widely deployed.

Opening Session

Mr Claude MANDIL, Executive Director of the International Energy Agency, welcomed delegates from around the world. He saw CTL as an important topic, framing his comments in terms of the “3 E’s” of good energy policy: security of energy supply, economic development and environmental protection. In explaining why alternatives to oil were desirable for energy security reasons, he referred to President Bush’s 2006 State of the Union Address in which the President stated, “America is addicted to oil”. MANDIL agreed that the transport sector was too dependent upon oil, so the IEA needed to understand the potential for alternatives, including biofuels, coal-to-liquids, gas-to-liquids and biomass-to-liquids, not to replace oil, but as part of a diverse mix. However, he queried if CTL would be cost effective enough to contribute to economic growth; he looked forward to the workshop’s findings on this point and cautioned against government subsidies. MANDIL noted with concern that CTL may add to pollution and CO2 emissions, unless abatement measures were taken (e.g. CO2 capture and storage). With the coal industry enjoying stronger demand growth than previously expected, he briefly mentioned that World Energy Outlook 2006 would raise serious questions about the sustainability of this growth. To conclude, MANDIL said that bold steps were needed to achieve the “3 E’s”, because the world was not on a pathway to sustainable energy supplies.

Mr Preston CHIARO, Chief Executive – Energy at Rio Tinto and CIAB Chairman also welcomed delegates and oversaw the day’s proceedings.
Discussion Issues
Concerns over the cost and security of oil supplies may be driving the interest in CTL, but would a shift to coal bring new concerns over the security and price of coal supplies? CTL raises many other issues, not least its potentially high CO₂ intensity and process water demand. With CO₂ capture and storage (CCS) at the coal liquefaction plant, the net CO₂ emissions from coal-based transport fuels are similar to oil-based fuels. Without CCS, emissions would be significantly above those from the oil-based alternatives – roughly double current well-to-wheel emissions.

Aims of the Workshop
• Provide a CTL technology status review and update on current projects.
• Disseminate knowledge of CTL process economics, both with and without CO₂ capture and storage.
• Understand the environmental issues associated with CTL.
• Reach conclusions on the role of CTL as an alternative source of transport fuels.
• Bring CIAB advice on the subject of CTL to the attention of the IEA.

SESSION 1: Experience with Coal-to-Liquids Technologies in South Africa and Japan
CTL technologies are not widely used and are unfamiliar to many in the coal mining and power generation sectors. This session set the scene by introducing the chemical engineering behind CTL and illustrating how this has been used at pilot and commercial plants – Sasol operates CTL plants in South Africa with a combined capacity of 160 000 b/d of crude oil equivalent. Participants received a new brochure on CTL prepared by the World Coal Institute and, during 2007, the IEA Clean Coal Centre will publish a new report on the subject.

Dr John TOPPER, Managing Director of the IEA Clean Coal Centre and IEA Greenhouse Gas R&D Programme, chaired this opening session. He remarked on the renewed interest in CTL, confirmed not only by the large number of participants at the workshop, but also among Clean Coal Centre members who had given priority to a forthcoming report on CTL.

A Primer on the Technologies of Coal-to-Liquids
Mr Daniel CICERO, Technology Manager – Hydrogen & Syngas at the US DOE National Energy Technology Laboratory’s Office of Coal and Power R&D at Morgantown, WV described the three routes from coal to liquids: direct and indirect liquefaction, plus a hybrid concept. Although DOE had no specific CTL programme running, CICERO explained that many aspects of CTL were covered under its Hydrogen-from-Coal R&D programme.

Between 1975 and 2000, the USA invested $3.6 billion in direct liquefaction technologies; some are now licensed to China where production from a commercial demonstration CTL plant will start in Inner Mongolia (see below).

Maturing Direct Coal Conversion
• Originally developed in Germany in early 1900s
• Used to produce military fuel in WWII
• US spent $3.6 billion on DCL from 1975-2000
• Technologies licensed to China in 2002

Direct Conversion

Coal to Liquids Technologies
• Direct Liquefaction
  - Indirect (Gasification + Fischer-Tropsch) Liquefaction
  - Hybrid Concept

CICERO went on to describe the indirect process that benefits from being able to use a range of fuels, including coal and natural gas.
A hybrid concept combines the advantages and limits the disadvantages of both technologies by making use of the F-T tail gas from the indirect process to convert further coal using the direct process. It is potentially more efficient and offers a more flexible product slate whilst minimising refining, but...
Technology Development Department at the New Energy and Industrial Technology Development Organization (NEDO), drew on his 25 years experience in coal liquefaction to present Japanese developments in direct liquefaction for lignite and hard coal.

Simplistically, coal is dissolved with recycled hydrogenation solvent and mixed with a catalyst prior to being heated and pressurised in a reactor to produce an oil that is then hydrotreated to yield products.

**Liquefaction Development in NEDO**

NEDO developed two liquefaction processes. BCL process for brown coal, NEDOL process for sub-bituminous coal.

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WASAKA explained that NEDO had developed two direct processes following fundamental research: the Brown Coal Liquefaction (BCL) process for lignite and later, the NEDO Liquefaction (NEDOL) process for sub-bituminous and bituminous coal which was developed to pilot stage at a 150 t/d plant where eight test runs were completed over three years. Coal liquefaction development ended in Japan in 2000, although international co-operation with Indonesia and China has continued.

Using results from a BCL pilot plant in Australia, obtained over a three-year operating period, WASAKA showed that a high oil yield was achieved and an efficient lignite de-watering process was developed to deal with the very wet fuel (c.50% moisture). WASAKA then described the NEDOL process which uses an iron-based, fine powder catalyst and can convert coals ranging from lignite through to bituminous. A 1 t/d process support unit (PSU) was built in 1988. The NEDOL process was further developed at a 150 t/d pilot plant at Kashima City, Ibaraki which achieved almost 2,000 hours continuous operation.

**NEDOL Process Flow**

**BCL Process 50 t/d Pilot Plant Project in Australia**

Three coal liquefaction reactors are arranged in series, each 11 m long with an internal diameter of 1 m.
WASAKA was proud to report that the NEDOL process attains a higher yield than many competing processes (58% by weight on a dry, ash-free (daf) basis).

NEDO has also developed an installation for upgrading coal liquefaction oil at Funakawa using an improved catalyst. WASAKA reported successful results: high cetane diesel (42-43) and fuels that meet Japanese standards.

WASAKA concluded by saying that Japan was looking to co-operate with Indonesia on development of the BCL process, and also with China, since both countries have large oil requirements and plentiful coal resources. In Indonesia, low interest rate, official loans may assist. In China, WASAKA said that any co-operation plan could include technology transfer, if required.

Commercial Experience in South Africa with CTL and Coal-to-Chemicals

Mr André STEYNBERG, Technology Manager for CTL at Sasol Technology (Pty) Ltd began with Sasol’s 50 years of experience with indirect conversion processes for oil, gas and coal with five different Fischer-Tropsch (F-T) processes using both two-phase and three-phase fluid bed reactors.

Noting Sasol’s track record of technology improvement and application, STEYNBERG said that the technology development curve had not plateaued, with further scope for process intensification to give higher yields, and improved performance from catalysts that have yet to reach their intrinsic limits. However, he said that the F-T reactors themselves had been demonstrated at their maximum feasible size, such that there were no further economies of equipment scale (see photo).
When assessing potential CTL projects, STEYNBERG identified some key prerequisites sought by Sasol:

- **Large coal deposits**, sufficient to supply plants with a minimum size of 80,000 b/d.
- **Stranded coal**, due to its low-quality or location, making it unsuitable for alternative applications, such as electricity generation.
- **Government support** for the very large capital investments, on the grounds of improved energy security through decreased dependence on imported energy, and to shield developers from oil price volatility.

He noted that current conditions, in respect of oil prices, favoured CTL development and were similar to those in the mid-1970s when Sasol made its decision to invest in the Sasol Two plant at Secunda.

Beginning with Sasolburg, where the reactor is still making waxes, STEYNBERG outlined Sasol’s F-T reactor development. The world’s first commercial CTL plant, initially producing about 8,000 b/d, was the Sasol One plant opened in 1955 at Sasolburg using both German and American technologies. The Sasol Two and Sasol Three plants were commissioned in 1980 and 1983 respectively and, in 1989, Sasol unveiled its Sasol Advanced Synthol (SAS) reactor at commercial scale. In general, synthesis feed gas (syngas) from a coal gasifier is passed over (in fixed bed tubular Arge reactors), or circulated with (in circulating fluidised bed (CFB) Synthol reactors), or percolated through (in Sasol Slurry Phase Distillate (SPD) reactors and Sasol Advanced Synthol (SAS) reactors) iron- or cobalt-based catalysts at between 220°C and 350°C to produce F-T liquids.

Sasol produces almost 40% of South Africa’s liquid transport fuels, but STEYNBERG explained that Sasol’s business went far beyond CTL – from coal mining to chemicals (ammonia, nitrogrenous fertilisers and commercial explosives, waxes, phenolics such as phenol and cresols, solvents such as alcohols and ketones, polyethylene, polypropylene, alpha olefins such as 1-hexene and 1-octene, coke, tar, sulphur and noble gases).

### Variety of Industrial Processes

- **Coal processing**
- **Syngas production akin to MeOH and ammonia plants**
- **Hydrocarbon synthesis**
  - gas, liquid and solid mixtures
  - recycles and solids separation
  - large volumes flammable materials at high pressure that auto-ignite
- **Refinery operations**
- **Chemical processing**
- **Integrated utility systems**
- **Power generation**
- **Catalyst manufacture has elements of mineral processing combined with the precision found in the pharmaceutical industry**

The low temperature Sasol Slurry Phase Distillate (SPD) process, using cobalt catalyst, is now part of a three-step process to produce primarily diesel fuel and naphtha from natural gas. A full-scale, commercial slurry phase reactor was commissioned at Sasolburg by Sasol in 1993 using iron catalyst for the production of waxes and paraffins, and the proprietary technology has then been further developed for GTL plants with an advanced cobalt catalyst. During 2006, a 34,000 b/d GTL plant was commissioned in Qatar in partnership with Qatar...
Sasol Synthetic Fuels, based at Secunda, operates the world's only CTL plant, with 80 Lurgi gasifiers at the now integrated Sasol Two and Sasol Three plants.

The high temperature Sasol Advanced Synthol (SAS) reactor was developed during the 1980s as a more efficient and cost-effective successor to the CFB Synthol reactor. It operates at about 350°C with an iron-based catalyst to produce, in a single step, synthetic crude oil for downstream refining into fuels and chemicals. Nine SAS reactors (from Korea and Japan) are now operating at Secunda, having replaced the original 16 Synthol chemicals. The high temperature Sasol Advanced Synthol (SAS) reactor was developed during the 1980s as a more efficient and cost-effective successor to the CFB Synthol reactor. It operates at about 350°C with an iron-based catalyst to produce, in a single step, synthetic crude oil for downstream refining into fuels and chemicals. Nine SAS reactors (from Korea and Japan) are now operating at Secunda, having replaced the original 16 Synthol reactors in 1999, and now produce the equivalent of about 160 000 b/d of product fuels and chemicals.

Sasol uses three, fundamentally different F-T technologies: low temperature cobalt catalyst, low temperature iron catalyst and high temperature iron catalyst.

**The 3 different Sasol Fischer-Tropsch technologies**

- Cobalt low temperature Fischer-Tropsch (Co-LTFT)
- Iron low temperature Fischer-Tropsch (Fe-LTFT)
- Iron high temperature Fischer-Tropsch (Fe-HTFT)

The 3 technologies produce fundamentally different types of hydrocarbons and thus ultimately have the potential to produce different chemical products.

STEYNBERG alluded to the complexity of the CTL and F-T processes, but also pointed to opportunities for CO2 capture: at the syngas purification stage, where sulphur and CO2 are stripped using a physical organic solvent in the Rectisol process; CO2 is also removed from F-T products using the hot potassium carbonate Benfield process. CO2 is currently vented at Secunda, but STEYNBERG said that whilst CCS is not yet practiced by SASOL, the company had all the competencies needed to undertake such projects.

**CO2 application and storage opportunities**

- Geological storage in saline aquifers and depleted oil/gas reservoirs
- Enhanced oil recovery
- Enhanced Coal Bed Methane (CBM) extraction
- Competencies needed:
  - Gas treatment and compression : Sasol, Sasol Mining, Sasol Gas (Rompco)
  - High pressure transmission lines : Sasol, Sasol Gas (Rompco)
  - Gas reservoirs, gas wells: SPI
  - Coal geology : Sasol Mining
  - Oil field development : SPI and external
  - This is the type of project that Sasol can do

Finally, Sasol is engaged on a feasibility study for two CTL plants in China: one with Shenhua Corporation, focusing on a site in Shaanxi Province about 650 km west of Beijing; and the other with Shenhua Ningxia Coal Company, focusing on a site about 1 000 km west of Beijing.

**Discussion**

Opening the discussion, Dr John TOPPER remarked on the continuous technical development of these complex processes that had taken place over many years, particularly in South Africa, and helped at times by timely oil price rises.

Dr Dan LASHOF, Science Director at the Natural Resource Defense Council’s Climate Center, sought clarification on the energy efficiency of direct processes (often quoted to be 58-72%) and whether the figures included for the additional refining needed beyond the liquefaction step itself, thus allowing comparison with indirect F-T processes.

WASAKA responded that the NEDO process was 60-63% efficient with higher levels possible, but not above 70%.
CHIARO wanted to know more about resource use, he fully understood the coal demand CTL could create, but what of the quantity and quality of water?

STEYNBERG agreed that CTL plants needed to be sited near available coal and water resources. Water provides essential hydrogen and process cooling. Whilst the latter can be minimised by making best use of air cooling, STEYNBERG replied that water consumption was typically between one and two cubic metres per tonne of coal on a dry, ash-free basis.

Mr David GRAY, former Director of the British Coal Petrol and Diesel from Coal Project, asked what the yield was from the competing processes per tonne of coal, after accounting for process energy demand, energy which itself must come from coal (i.e. how much of the coal ends up in products that can displace oil products)? He was also interested to hear how much transport fuel Sasol could produce if this were the sole focus of the company?

WASAKA indicated that around 50% of the coal (dry, ash-free basis) was converted into product after upgrading, depending on the coal, process and conditions.

STEYNBERG quoted motor fuel yields from Sasol’s indirect process of about two barrels of oil products per tonne of coal on a dry, ash-free basis – plants under study in China would produce about 70% diesel and 30% naphtha. He added that for gasoline production, a high temperature F-T process with iron catalyst was the best technology.

SESSION 2: Policy Drivers for CTL in the USA, Industry’s Response and the Environmental Implications

Today’s high oil prices make coal a competitive source for transport fuels, but commercial risks remain high and only those projects that are economically viable and environmentally sound are likely to proceed. Incentives, available under the recent Transportation Act, could accelerate the conversion of the vast US coal resource into transport fuels (a 50c/gal tax credit is available under the Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2005 – equivalent to c.$20/bbl – and possible loan guarantees under the Energy Policy Act of 2005). The US Department of Energy is supporting a commercial-scale project to convert waste coal into F-T diesel and power. In addition, the US Department of Defense’s concept of a single fuel for the battlefield opens up opportunities for alternative fuels; a coal-based fuel would reduce the inherent risks and vulnerabilities associated with oil-based supplies.

Mr Steven LEER, Chairman and Chief Executive Officer at Arch Coal Inc, chaired this session, noting a shift in emphasis from the technical to the economic in three presentations on CTL developments in the USA.

Policy Implications for CTL in the USA

Dr Roger BEZDEK, President of Management Information Services Inc, began with his belief that the USA was not facing an energy crisis, but rather a liquid fuels crisis. For the last two decades or more, he said, the world has been consuming more oil than it had been finding, e.g. oil consumption in 2005 (30 billion barrels) was six times greater than oil discoveries (5 billion barrels).

He foresaw a situation more economically damaging than the 1970s energy crises, unless there was a greater effort to meet growing world energy demand. Oil imports into the USA had risen from 35% in the mid 1970s to 60% today, raising economic concerns as well as energy security concerns.

BEZDEK saw a solution in exploiting US coal, oil shale, heavy oil and biomass resources (>2-4 trillion barrels), these “alternative oil” resources being larger than the world’s conventional oil reserves (2-3 trillion barrels). He observed that the USA has more coal reserves than any other country, several hundred years even with increasing utilisation rates.
The study:
- developed a plan for the US to establish energy security and independence through the production of alternative oil and liquid fuels;
- emphasised enhanced oil recovery using CO2 and increased transport efficiency; and,
- developed policy and legislative recommendations.

To eliminate imports would require all options: coal-to-liquids (29% in 2030), biomass (24%), efficiency measures in the transport sector (16%), oil shale (16%), and enhanced oil recovery (15%). If oil imports were held steady, at the 2005 level of 13 mb/d, BEZDEK said demand growth to 25 mb/d and declining US production would open a supply gap of 5 mb/d by 2025 – five to six times more oil than Australia currently consumes. He called for early and massive action because of the 8-10 year lead time before these options would have a major impact. To establish a programme, SSEB was working with Congress and the Administration.

WHAT IS THE USA DOING?
- President Bush: U.S. is “addicted to oil” & must reduce oil imports
- Studies and plans being developed by Federal agencies: Dept. of Energy, Dept. of Defense, Unconventional Fuels Task Force, DOE labs
- Studies and plans being developed by state governments, SSEB, Western Governors Association
- Many states have passed CTL legislation & are building CTL plants
- U.S. Congress: Study mandated for GAO, Congressional Caucus formed, CTL incentives legislation passed
- Independent initiatives: National Academy of Sciences, National Coal Council, National Petroleum Council

U.S. FEDERAL GOVERNMENT
CTL INCENTIVES
- EPACT 1992: Court orders for AFVs
- EPAct 2005: Financial incentives, loans & loan guarantees, $1.4B in ITCs, Incentives for Innovative Technologies program
- SAFETEA-LU 2005 provides a $0.50/gal. excise tax credit for CTL products
- Legislation: Many Bills in U.S. Congress: Expensing of CTL equipment, loan guarantees, excise & investment tax credits, Trust Fund for CTL development, matching grants, require use of CTL fuel in SPR, R&D incentives, purchase agreements, production tax credits, mandate use of CTL fuels in Federal fleet, accelerated depreciation, cost-shared demonstrations

KEY ROLE OF CONGRESSIONAL LEGISLATIVE INCENTIVES
- As noted, U.S. Federal law SAFETEA-LU 2005 currently provides a $0.50/gal. excise tax credit for CTL products.
- However, this incentive is set to expire in 2009, before any major new CTL plants can come online.
- Its extension through 2020 will provide critically needed market incentives for the development of CTL plants.
- This extension is critical, because the tax credit will reduce CTL OPEX by $20/bbl.
- Legislation to extend this tax credit has been introduced in the U.S. Congress.

He called for an extension of the CTL tax credit from 2009 to 2020.
**U.S. DEPT. OF ENERGY INITIATIVES**

- Secretary Bodman has emphasized the need for CTL
- DOE mandated National Coal Council and National Petroleum Council to conduct independent studies
- DOE conducting a series of studies to estimate feasibility & impacts of rapid CTL development
- Unconventional Fuels Task Force: Developing commercialization plan, schedule, budget, and incentives for accelerated CTL development
- DOE labs conducting CTL R&D: NETL, Los Alamos, Oak Ridge, etc.
- Increased budgets for CTL programs

BEZDEK noted that the US Department of Defense itself consumes 400 000 b/d – more than most countries.

**STATE GOVERNMENT CTL INCENTIVES**

- State CTL incentives include: Consortia to purchase CTL fuels, tax credits, financing assistance, grants, job training, alternative fuels incentives, alternative energy portfolio standards, strategic partnerships, public vehicle fuel mandates, site assistance, accelerated permitting, public energy authorities, tax increment financing, property tax relief, alternative energy revolving loans
- Cities: Require fleets to use alternate fuels – Denver, Chicago, Oakland, Portland, San Francisco, etc.

**STATE GOVERNMENT CTL PROJECTS**

- **Illinois**: Rentech to convert fertilizer plant to CTL for gas and clean fuel
- **Mississippi**: Agreement with Rentech for $700M 10K bpd plant
- **North Dakota**: MOU with Headwaters and others for 10K – 50K bpd plant (5-7 yrs.)
- **Pennsylvania**: WMPI building $612M 5K bpd plant by 2008 (Sasol, Shell, and Nextant)
- **South Dakota**: Designing a 28K bpd plant; site planning to begin in late 2006
- **Virginia**: Planning a 10K bpd modular plant

**KELLY** saw three drivers for CTL:

- **Economics**: strong oil demand and rising real prices, versus stable coal prices, mean the price gap in favour of coal will widen. To keep oil supply and demand in balance, will require significant growth in unconventional oil production – US DOE International Energy Outlook 2006 forecasts a rise from 1.8 mb/d in 2003 to 11.5 mb/d in 2030.
- **Energy security**: large coal reserves in key industrial nations – 59% of world fossil energy reserves lies in coal, with the USA, China and India sitting on 50% of these coal reserves, countries that will all be significant oil importers over the next 20 years.
- **Environment**: CTL produces low sulphur, high cetane F-T fuels and sequesterable CO₂, responding to environmental regulations (US EPA Tier 2 sulphur levels in diesel <15 ppm by 2007) and helping reduce CO₂ emission through the better fuel efficiency of diesel-engined vehicles.

In conclusion, BEZDEK referred back to the feasibility studies that indicate the USA could produce 3-5 mb/d of CTL liquids by 2030 and again noted the activity, at all levels of government, with that objective.

**CTL Projects – key issues and economics**

Mr Robert KELLY, Executive Officer at DKRW Energy LLC, presented from a project developer’s perspective, notably on two projects with Arch Coal, but also other projects in Montana, and in Wyoming where the Medicine Bow plant is one of the first commercial CTL projects in the USA.

**Economics: Strong Demand & High Prices**

He explained that the price differential between coal and diesel (c.20% above the oil price shown below), provides an arbitrage opportunity for those ready to invest capital in CTL plants.
DKRW Advanced Fuels

Economics: Low Coal Feedstock Costs

![DOE Fuel Price Forecasts 2003-2030](Image 1)

Coal is Projected to Have a Significantly Lower Cost Than Oil Over the Next 25-30 Years—Blu Arbitrage

Source: US DOE Annual Energy Outlook 2006

Disadvantages of Scale in CTL Plants

- Coal Reserve Opportunities Limited
  - Larger reserve position required—2x-8x
  - Fewer mine-mouth opportunities—rail costs
- Project Financing is More Difficult
  - Limits to project financing—$1B
  - Higher WACC as scale increases
- Development costs are larger
  - Larger development costs incurred 2x-4X
  - Significant financial risks before FID complete

There are more opportunities, a lower cost of capital, and less development risk in smaller CTL projects

Source: Scully Capital Analysis for DOE 2006 2.5% Capex

Advantages of Scale in CTL Plants

- Scale — how big, or how small?
- Product mix — liquid fuels, power, chemicals, CO2.
- Contracts — cost and security of coal feedstock, and liquid fuel off-take agreements.
- Environmental — including CO2.
- Construction and permanent financing – EPC partner.

There are capital and operating cost benefits of large scale plants

Source: Headwaters ACC Presentation

(2006 dollars)

Despite these clear scale economies, KELLY argued that smaller CTL projects had attractions, particularly when it came to seeking capital – large projects carry greater upfront costs (e.g. front-end engineering and design (FEED) costs and permitting costs prior to the final investment decision (FID)) and greater financial risks. Moreover, project financing is more widely available below $1 billion (i.e. 10-15,000 b/d) at a lower weighted average cost of capital (WACC) than for, say, a $5-7 billion, 80,000 b/d CTL plant. KELLY presented details of the Medicine Bow CTL project which will use a low-temperature iron catalyst to produce ultra-low sulphur diesel and naphtha, with 275 MW of electric power generated from waste heat and tail gas, of which 60 MW would be exported — a true polygeneration plant. DKRW’s own intellectual property, in terms of gasifier / F-T process integration, brought unique added value to the project.

There are scale and development cost benefits of large scale plants

Source: Scully Capital Analysis for DOE 2006 2.5% Capex

Large scale plants incur significantly higher development costs prior to the FID

KELLY presented details of the Medicine Bow CTL project which will use a low-temperature iron catalyst to produce ultra-low sulphur diesel and naphtha, with 275 MW of electric power generated from waste heat and tail gas, of which 60 MW would be exported — a true polygeneration plant. DKRW’s own intellectual property, in terms of gasifier / F-T process integration, brought unique added value to the project.

Medicine Bow Fuel & Power

Secure Coal Resources

- Entered into Option with Arch Coal to purchase coal reserves in Carbon Basin Reserve
- Underground Continuous Coal Mine Owned
- Mine built and operated by Arch
- Permits for Surface & Continuous Mining completed
- Construction expected to commence QIV 2007

Conversion Facility

- Coal-to-Liquids Plant
- Coal Mine at plant
- Gasification (g&d)
- Fischer-Tropsch (Refinery)
- Hydrocracking (xOP)
- Permit applications to be submitted in 2006
- Expected Construction start = end of 2007
- Expected I.S.D. = end of 2010

Liquids & Other Products

- Capacity = 10,000 - 15,000 barrels / day
- Diesel (ultra low sulfur)
- Naphtha
- Long-term Purchase Contract
- Shipped via pipeline
- Export Power 65MW
- CO2 (lb EOR)
- Sulfur
- Chemicals

CO2 can be captured, liquefied and used for EOR in Wyoming where it would remain sequestered after the tertiary recovery of crude oil at rates only slightly below the CTL plant's
own output. The mine mouth design ensures a competitive coal feedstock and DKRW has acquired an option on 180 Mt of permitted bituminous coal reserves in the Carbon Basin that would support the initial plant (in-service date (ISD) end of 2010), and future expansions.

Financing the project, including the coal mine, will require $1.5-2.0 billion. A debt to equity ratio of 65:35 is proposed, the debt comprising loans backed by Federal loan guarantees, and insurance company borrowings. Equity will come from a public offering advances from the EPC turnkey contractor, and insurance debt comprising loans backed by Federal loan guarantees, $1.5-2.0 billion.

By engineering a smaller plant with a good initial return, KELLY explained that the potential then existed for greater economies of scale to be achieved during two later expansions of the project up to 30 000 b/d. He anticipated capital cost reductions of up to 25%, as experience was gained with CTL plants, and higher income from more diverse and valuable chemical products over time.

KELLY concluded by outlining the features of a successful CTL project: well structured debt/equity, key technologies and coal reserves secured early, on competitive terms, and positive public policy incentives. However, he stressed that if CTL was to succeed, then projects had to be commercially viable without state support. KELLY was optimistic of future growth prospects in a huge global market.

Sequestration of CO₂ from CTL Processes
Mr Merrick KERR, Chief Financial Officer at Rentech Inc., presented his company’s long history of F-T catalyst technology development, culminating in the first, fully-integrated CTL pilot plant of 10 b/d at Commerce City, Colorado.
KERR turned to CO2 capture where he saw three alternatives in descending order of attractiveness:

- Revenue-generating options: food-grade CO2, capture into other products (e.g. urea), EOR, and enhanced coal bed methane recovery (ECBM).
- Sequestration alternatives: salt domes, saline reservoirs, and geological strata.
- Theoretical possibilities: algae gasification, fast-growth forests, and deep-sea entrapment.

Using results from work with the State of Wyoming, KERR said that ECM needed a $5/tCO2 credit to be profitable at current natural gas prices.

In contrast, he quoted a CO2 value of $10-20/tCO2 when used in EOR projects compared with a cost of production of $7-15/tCO2, noting that this data was site specific to Wyoming.

KERR concluded with a list of Rentech’s current projects, including at East Dubuque, Illinois, where Rentech hopes that a CO2 pipeline, proposed in the Governor’s energy plan for EOR in southern Illinois, will run close enough to allow 100% sequestration. At Natchez, Mississippi, coal and petcoke would be converted, and two joint development projects with Peabody Energy in Illinois and Montana, both include CO2 capture-ready designs for EOR and ECBM.

### Rentech Projects

**East Dubuque**
- **Strategic Location**: On the Mississippi River
- **Existing Infrastructure**: Large captive load
- **CO2 Sequestration Alternatives**: Food-grade CO2
- **Mid-Range CO2 Emission Location**: Enhanced Oil Recovery
- **First US Commercial Scale CTL & FT Plant**: Currently in Front End Engineering & Design

**Peabody Energy Joint Development Agreement**
- 2 projects under study
- **BEZDEK and Arch Coal**
- Existing Ammonia Plant
- **Medicine Bowl**
- **Strategic Location**: Medicine Bowl, Wyoming
- **CO2 Sequestration Location**: Enhanced Oil Recovery
- **Currently in Feasibility and Scoping Study**

**Rentech Process Licensee**
- DKRW and Arch Coal
- **Mid-Range CO2 Emission Location**: Enhanced Oil Recovery
- **Currently in Feasibility and Scoping Study**

### Discussion

Dr. Stephan SINGER, Head of the European Climate and Energy Policy Unit at WWF, wondered if CTL would survive in a post-Bush, carbon-constrained world, because it failed to reduce CO2 emissions. He asked if the SSEC study had considered alternatives, such as coal-to-hydrogen and electric cars, and whether improving vehicle efficiency had been factored in?

BEZDEK replied that efficiency improvements did lead to a substantial demand reduction in the study. Whilst electric vehicles and hydrogen raised their own difficulties and had not been studied, he was aware of other work. BEZDEK returned to the win-win opportunity that CTL with CCS coupled to EOR offered in terms of energy supply.

KERR observed that the efficiency of new vehicle technologies was not necessarily an improvement: he quoted 55 mpg for diesel vehicles and 50 mpg for electric hybrids.

Mr. David GRAY, former Director of the British Coal Petrol and Diesel from Coal Project, asked if consumers would consider CTL fuels to be environmentally acceptable, whether oil refiners would permit blending of coal products for distribution, and whether manufacturers would guarantee vehicle engines used with coal-based fuels? He thought that the proposal to produce 5 mb/d in the USA was incredible – requiring, he believed, a doubling of US coal output.

BEZDEK agreed that the supply gap was indeed challenging at 5 mb/d, but would be bridged by energy efficiency measures, oil shale, biomass, biodiesel and electric hybrid vehicles, with coal playing a part through CTL.

KELLY confirmed that oil refiners would accept blending of F-T fuels – DKRW had spent the previous year negotiating detailed specifications and commercial terms with major refiners and marketers in the Rocky Mountain area to allow pipeline shipment to Denver of F-T fuels where they would go into commercial batch.

KERR referred to the September 2006 announcement by the US Department of Defense following the successful trials of a synthetic jet fuel (50:50 F-T:JP 8) in two engines of a B-52 Stratofortress bomber. Produced from natural gas for these trials, but with the stated aim of moving to coal-based fuels by 2009/10.
Mr Matthias HARTUNG, Executive Vice President at RWE Power AG, asked if the coal industry was engaged and contributing to the efforts to mitigate CO₂ including through CO₂ storage?

LEER explained that the industry was putting money into projects jointly supported by government, projects at utility companies and projects at national laboratories. Under almost any scenario, he saw a significant increase in coal use, in the USA, China, India and elsewhere, such that the key question was to find ways of safely storing CO₂. LEER was convinced that technology would provide the answers; the developed countries had a responsibility to develop the technologies and to share these with developing countries. This would take time, but with the forecast energy demand growth to 2030, all options would be needed including coal with CCS. He said that to exclude particular energy sources was not good public policy and that it was unrealistic to expect that any country would not exploit its indigenous coal resource.

KELLY spoke as a US-focussed project developer who, like others, was assuming that carbon would have a price in the future and that CO₂ would have to be sequestered, even though there was no current policy constraint on CO₂ emissions. Developers were motivated not only by the economic potential of projects linked to EOR, but also by the longer term need to deal with CO₂. He saw better energy efficiency as an inherent driver – developers sought the maximum output from CTL plants.

Dr Atul ARYA, Vice President of Group Strategy at BP plc, suggested that given the scale and complexity of future CO₂ management, the coal industry should collaborate with the oil industry, although he was unsure on precisely how. He thought it better to incentivise energy diversity rather than energy independence. ARYA then posed this dilemma: if the USA achieved greater energy independence through successful CTL projects, then oil prices would presumably fall, making the projects uneconomic.

HEZDEK believed the goal of energy independence was worthy, if only to reduce the rate of growth of imports. It would require many diverse measures, including a commitment to energy efficiency, demand reduction and alternative fuels, and other measures not yet considered. The impact on world oil markets would be positive, but with Chinese demand growth, he thought the price impact might be relative modest.

Mr Eric FORD, Chief Executive Officer of Anglo Coal Australia Pty Ltd, began this session by welcoming participants from China, noting the important CTL developments that were well underway.

**SESSION 3: CTL Projects in China and the Developing World**

Shenhua Group is constructing the first process train of a USD 3 billion, 60 000 b/d (3.2 mtpa), direct coal liquefaction plant at Ordos in Inner Mongolia Autonomous Region, with a planned expansion to 5 mtpa. The company plans further CTL projects, including two plants in Ningxia Hui Autonomous Region (each 60-80 000 b/d) and a USD 5 billion, 80 000 b/d plant in Shaanxi Province, which are progressing using well-proven, indirect liquefaction technologies from Sasol and Shell. China aims to produce 50 mtoe annually by 2020, from 200 million tonnes of coal. In response, Yankuang Group has two coal-to-chemicals plants under construction at Yulin in Shaanxi Province, one Fischer-Tropsch and one based on methanol synthesis. Xingao Group has funding for a major dimethyl ether (DME) project in Inner Mongolia, and Lu’an Group has a small CTL project at Tunliu, Shanxi Province. Many other proposals for polygeneration projects, producing electricity, hydrogen, liquid fuels and chemicals, are also under consideration, although China’s National Development and Reform Commission set new capital thresholds in July 2006, thus limiting future development to projects >3 mtpa.

Dr Don ELDER asked if the Jerntech project economics treated CO₂ as a credit of $5/CO₂ or as an avoided cost? He also asked a more fundamental question on the feasibility of constructing as many as one hundred 50 000 b/d CTL projects in the USA. Had the economic analysis considered the inflationary pressures of such a large programme on costs of materials, labour, technology, coal, water, etc.?

KERR responded that the CO₂ credit assumed a plant already running with an established baseline such that the avoided CO₂ would have a value.

BEZDEK replied that Nth plant costs had been assessed with different capital costs assumptions. However, he believed that there would be huge demand from all energy sectors which would therefore all be faced with similar inflationary pressures. He did have a concern about a shortage of labour, especially following the downsizing during the 1990s when the US oil and gas industry lost half a million people.

Mr Daniel CICERO pointed to the similar CO₂ emissions from CTL fuels and petroleum fuels, such that CTL, even with CO₂ sequestration, would make no contribution to the 80% CO₂ reduction targets called for. He wondered if the SSEB study had considered other alternatives, specifically coal-to-hydrogen with CCS?

Dr ZHANG Yuzhuo, Chairman of China Shenhua Coal Liquefaction Corporation and Vice President of Shenhua Group Corporation Ltd, began by explaining why China needed to develop CTL: in the previous 7-8 years, the Chinese economy
had doubled and oil supply was now a critical issue. Having been a net oil importer since 1993, China’s oil import dependence could reach 60%-62% by 2020.

ZHANG showed that China’s energy resources are relatively small, given the size of its population. Coal accounts for almost 90% of China’s total proven energy reserves, although less than 60% of its remaining exploitable resources, whilst oil accounts for only 2.8% of proven reserves and 3.4% of exploitable resources.

Turning to energy consumption patterns, ZHANG showed that China was much more dependent on coal than other countries, almost 70% of total demand, and less dependent on oil. He noted how quickly coal use had grown since 2000, to 2.1 billion tonnes per annum, underpinning economic growth, but contributing to severe pollution problems.

ZHANG believed that CTL could add value to western China’s, low-cost coal resources by supplying affordable energy and allowing easier transport of smaller volumes of higher value products. He noted that the rail system was already overloaded with coal movements which accounted for over 40% of all rail freight in China.

With an annual production of 220 Mt, Shenhua Group is China’s largest coal producer. It also owns 13 GW of coal-fired power plants, 1,500 km of railways and two ports with a combined capacity of 80 mtpa. ZHANG reported that Shenhua’s CTL and coal-to-chemicals developments were in full progress, strongly supported by the Group’s other activities. He explained that...
Shenhua had adopted three process routes: direct and indirect coal liquefaction (DCL and IDCL) to produce oil products, and the methanol intermediate route to produce olefins that typically have been derived from oil in China.

The Shenhua DCL process, ZHANG explained, uses a new, highly-efficient, synthetic catalyst developed in China which has very high activation and low cost. More than 90% by weight of the coal is converted and oil yield reaches 57% on a dry, ash-free basis.

The process has been proven on a 6 t/d Process Development Unit (PDU) in Shanghai, operational since May 2004 with support from Japanese, German and US equipment suppliers. The third test run was still in progress as ZHANG spoke, having achieved 1 400 hours continuous operation.

ZHANG moved on to describe Shenhua’s commercial-scale DCL demonstration project that will produce a little over 25 000 b/d (1.1 mtoe per year). He said that this first, demonstration process train was intended to eliminate any technical risks with the remaining trains of the first and second phases.

Shenhua’s DCL demonstration project is an important component of China’s oil substitution strategy. It’s the first large-scale direct coal liquefaction plant in the world after the World War II.

Construction Site: Inner Mongolia
Planned Scale: 5 million tons of oil products per year (in two phases)
Demonstration Scale: one million tons of oil products per year (the first train in Phase I)

The product slate was biased towards diesel because China is short of this fuel:

<table>
<thead>
<tr>
<th>Product</th>
<th>Tonnes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>102 100</td>
</tr>
<tr>
<td>naphtha</td>
<td>249 900</td>
</tr>
<tr>
<td>diesel</td>
<td>714 600</td>
</tr>
<tr>
<td>phenol</td>
<td>3 600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 070 200</strong></td>
</tr>
</tbody>
</table>

The construction of Shenhua DCL demonstration project will be completed in 2007. In 2008, the plant will be put into demonstration test run.
ZHANG said that the first plant was 68% complete with two reactors already lifted and installed on site, including the world’s largest single reactor (2 250 tonnes). Ground breaking took place on 25 August 2004, pre-commissioning is scheduled during 2007, with final commissioning, test run and start-up in 2008. Turning to Shenhua’s IDCL projects, ZHANG stated that his company was working with Sasol and Shell on the feasibility of CTL projects at two locations in western China to produce fuels (naphtha and diesel) and chemicals (oxygenates).

In addition, three parallel IDCL projects are underway in China, one of which is run by Shenhua – a 4 000 b/d (170 000 toe per year) demonstration plant.

The third coal conversion route being exploited by Shenhua is coal-to-olefins via coal gasification, methanol synthesis and methanol dehydration using mature processes: methanol-to-propylene (MTP) developed by Lurgi and methanol-to-olefins (MTO) developed by UOP and the Dalian Institute of Chemistry and Physics at the China Academy of Sciences. ZHANG reported that a rapid construction programme was underway and that, in the next 2-3 years, total methanol production would reach 10 mtpa from a number of plants such as the MTP project at Ningxia Coal Area that converts 4.7 mtpa of coal, firstly into 1.8 mtpa of methanol and than into 600 ktpa of polypropylene (PP) and other chemicals using Institut Français du Pétrole (IFP) technology licensed from Lurgi. ZHANG briefly mentioned a feasibility study with DOW Chemical for a large-scale MTO project.
By 2020, ZHANG said that China’s strategy was to produce 1 mb/d (50 mtpa) of products from CTL to limit oil imports below 50% of demand. To achieve this, he referred to incentives that were being discussed among different government departments. He acknowledged that CTL was not applicable everywhere, but in western China, with its low-cost coal ($8-10/tonne) and access to a reliable water supply from the Yellow River, CTL was viable, especially when compared with the alternative of transporting coal from Xinjiang in the west 2 500 km to the coastal area.

ZHANG presented comparative, techno-economic data from the China Coal Research Institute for the three different coal conversion technologies that Shenhua was employing, data which includes the capital investment required for on-site power generation.

He noted the high efficiency of DCL that resulted in 40% lower CO\textsubscript{2} emissions compared with IDCL. He saw both coal gasification and liquefaction as important components in China’s strategy to derive electric power, heat, transport fuels and chemicals cleanly from coal.

Overall, this contributed to China’s energy security strategy of using western China’s rich coal resource to reduce the country’s dependence on imported oil and to avoid the economic impacts of high oil prices. In adding some further conclusions, ZHANG praised the many equipment suppliers to Shenhua’s CTL projects, companies from Japan, USA, France and Germany, and extended a welcome to those who wished to make a site visit.

Conclusions

- Different technological routes can be adopted for oil substitution. New DCL process, F-T synthesis process, MTO/MTO processes may be suitable in China for large scale fuel/feed-stock production.
- It can only be competitive for CTL business when oil price keeps relatively high and coal-derived-oil be produced with low cost.
- Environmental impacts of CTL need further studied.
- We are looking forward to the wide and extensive exchanges and cooperation with friends both at home and abroad.
CTL Technology in China and Polygeneration Opportunities

Prof Li Zheng, Director of the Tsinghua-BP Clean Energy Research and Education Centre, presented on the general energy situation in China and on how alternative fuels and polygeneration could add to energy security, environmental protection and sustainable mobility. To ensure sufficient energy supply during a period of rapid economic growth, Li outlined the energy challenges that China faces, many related to coal use:

- huge demand, but limited resources and supply capacity;
- shortage of liquid fuels and high dependency on imports;
- severe pollution;
- clean energy needed for rural and urbanising areas; and,
- huge and increasing CO₂ emissions.

Since 1990, oil demand has trebled and recent growth in energy consumption has outstripped economic growth due to strong demand from heavy industry (e.g. ferrous & non-ferrous metals, construction materials and chemicals).

Further industrialisation will ensure demand for energy continues to rise, although the economy’s energy intensity should pass a peak and then decline as structural changes take effect.

Li presented this energy flow chart for China, showing that of the 2.1 billion tonnes of coal equivalent (tce) total energy supplied in 2004 (excluding biomass), the useful heat and work used totalled just 0.7 billion tonnes. He drew attention to industry’s 69% share of total final energy consumption, this being much greater than in OECD countries.

China’s future energy demand depends not only on continued industrialisation, but also on urbanisation trends; an urban dweller uses 3.5 times more energy than a rural inhabitant and Li explained that the current urbanisation rate of 41% would rise by one percentage point each year to 2020 as China develops some of the most populous cities in Asia.

He gave examples of urban planning in Shanghai and Chongqing where population densities are very much higher in urban areas than in US and European cities.

NOx pollution from cars was already a major problem in metropolitan areas, and Li predicted that this would become worse as demand for personal transport grows.
LI saw an important role for alternative fuels in China. In the near term, they could supplement oil supply to minimise oil import costs and, together, could provide China with a strategic reserve to ensure energy security. In the longer term, they offer sustainable transport solutions with improved environmental performance, giving time for renewable energy options to become technically practical and economically affordable.

He did not suggest a unique solution existed; of the many alternative fuel options, LI believed the most likely to be:

- CNG/LNG – mature and relatively easy, but market led by imports
- Bio-ethanol – policy led and 1 Mt produced in 2005, but expensive
- GTL – limited by resources and price
- Bio-diesel – only a small production
- Coal derived fuels – CTL, DME and methanol

All needed to be developed, but LI expected that CTL, with its large potential, may be the main solution. However, it is very capital intensive and LI noted the one trillion Yuan investment already announced as project developers, especially coal producers, responded to incentives and high oil prices in what has become an overheated sector. Nevertheless, he quoted Premier Wen who said, “Shenhua’s CTL projects are an important part of national energy security strategy” and acknowledged that CTL was one way to reduce coal transport bottlenecks. With NDRC’s recent bar on CTL projects below 3 mtpa, LI believed that the future success of CTL depends on improved economics flowing from the current demonstration projects.

LI introduced polygeneration – combining the production of fuels with power generation – as an important solution to China’s energy challenge. The gasification process is clean and efficient, allowing high sulphur coal to be used for power generation, CTL fuels, town gas, LPG and hydrogen. It facilitates up to 90% CO₂ capture, but is flexible enough to allow different configurations depending on the product demand and CO₂ capture requirement.

He listed the many active or proposed DME projects in China and noted that the use of DME in vehicles is being promoted in Shanghai.
Polygeneration offers the potential for CO₂ reduction at a lower incremental cost: compared to supercritical plant, it can reduce CO₂ by 11%, with further reductions possible as more hydrogen is produced.

As a starting point, LI favoured large-scale methanol production coupled with small-scale electricity generation.

LI reported that polygeneration was a strategic element of China's medium- and long-term science and technology planning, with fundamental research projects already underway with coal gas and coke oven gas. As a demonstration programme, MOST has solicited three or four IGCC plants of 120 MWe and 200 MWe, plus one or two polygeneration plants of 100 000 toe per year / 60 MWe.

In conclusion, LI made the following points:

- China's energy demand will continue increasing due to rapid industrialisation and urbanisation.
- Alternative fuels could supplement dwindling oil supplies and act as a buffer to minimise oil import costs in the short term and ensure sustainability in the long term.
- Polygeneration is an important solution to China's energy challenges: by decreasing conventional pollutants; producing alternative fuels for ensuring oil security; and, providing future CO₂ reduction options at a lower incremental capital cost.
- Large-scale methanol production with small-scale power generation could be a reasonable first step for the demonstration of polygeneration and can accommodate fluctuating power demand.

The Shell Perspective on Coal-to-Liquids

Mr Nicolás XIMÉNEZ BRUIDEGOM, General Manager: Clean Coal Energy Europe at Shell Gas & Power International, fleetted over coal's abundance and recent high demand growth as countries, led by China, sought alternatives for oil and gas, to concentrate on the operational and CO₂ challenges of CTL plants – familiar territory for Shell which offers turn-key plants based on the Shell Coal Gasification Process (SCGP) and the Shell Middle Distillate Synthesis Process (SMDS). Noting the low emissions of conventional pollutants from CTL plants and the potential to capture CO₂ efficiently, he said that the latter was a necessary step if coal was to move forward as an environmentally-friendly fuel of the future, rather than back to the dirty ways of the Industry Revolution.

XIMÉNEZ explained that Shell's coal gasification developments stemmed from the 1970s oil crises, but slowed when natural gas became briefly abundant and cheap. Since the mid-90s, Shell has concentrating on scaling up the technologies, notably in China and Qatar, with China leading the way having taken 15 commercial licences over the previous five years. He stressed Shell's belief that only CTL plants of 70 000 b/d or above made economic sense, hence its careful selection of projects to pursue. In addition, he felt that only the largest companies could manage CTL projects given their sheer size and complexity.

Shell's gasification project list is dominated by chemical plant applications, but includes two CTL plants and a number of IGCC projects.
For a CTL project to be successful, XIMÉNEZ identified these key factors:

- low-cost, stranded feedstock supply, which might also be of poor quality – hence Shell’s partnerships with coal producers Shenhua and Anglo;
- technology choice;
- marketing of the premium products, which often have greater value than products from conventional refining, e.g. ultra-low sulphur diesel;
- operational excellence; and
- CO₂ management – 16 mtpa of CO₂ is emitted from a 70 000 b/d plant, equivalent to a 3 GW coal-fired utility plant.

XIMÉNEZ claimed Shell had the experience and know-how to capture and store CO₂, referring to projects in Norway and Australia, where the company’s ability to characterise suitable storage sites added considerable value. He then presented this long list of hurdles that any CTL project developer must clear. On economics, he noted the huge differences in capital and operating costs between different locations, e.g. California and China, despite similar product values. XIMÉNEZ saw great uncertainty in the future framework for CO₂ management, yet CTL projects with CCS demanded an economic driver for CO₂ sequestration over a 30-40 year operational period. Finally, he recommended that resource holders without oil refining experience needed partners with expertise in the development and operation of large (petro)chemical plants - given the operational complexity of these projects.

Discussion

Dr Roger BEZDEK thought the Chinese 1 mb/d target for 2020 rather ambitious and enquired if there was a detailed, bottom-up assessment of how many plants this implied?

ZHANG replied that Shenhua’s target in the next 5 years was four plants producing a little over 10 mtoe per annum; after that, another five projects were planned in the following 5-6 year period. He said many other companies had projects in planning that would proceed soon.

KERR asked what catalyst technology Shenhua used at its large-scale F-T demonstration plant?

ZHANG said an iron catalyst developed by the Chinese Academy of Sciences.

Mr Yoshihiko NAKAGAKI, President of the Electric Power Development Company, also acknowledged China’s ambitious CTL commercialisation plans and asked if there were any significantly more than the 3.5 mtpa emitted from a similar sized GTL plant.

Shell’s CO₂ projects

XIMÉNEZ offered these details of Shell’s CTL project in China, whilst the Monash CTL project is described below.

Shell’s participation in China CTL

In February 2006, Shenhua Ningxia Coal Ltd, (Ningxia), Shell (China) Limited and Ningxia Hui Autonomous Region People’s Government signed a Memorandum of Understanding (MOU) for a coal-to-liquids project in Ningdong.

This was followed in June 2006 by the signing of a Joint Study Agreement (JSA)

Ningxia Autonomous Region
Has rich reserves of coal and a well-developed infrastructure including sound water, power and transportation facilities.

Ningxia
The largest company in Ningxia and a joint venture under the Shenhua Group, China’s largest coal producer.

Shell
A leader in clean coal technology.

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Has rich reserves of coal and a well-developed infrastructure including sound water, power and transportation facilities.

Ningxia
The largest company in Ningxia and a joint venture under the Shenhua Group, China’s largest coal producer.

Shell
A leader in clean coal technology.
estimates of the impact on CO₂ emissions, with and without CCS. He wondered if China’s energy demand growth, especially in the transport sector, might be reduced through efficiency measures.

ZHANG was able to quote from a comparison of life-cycle CO₂ emissions:

<table>
<thead>
<tr>
<th></th>
<th>gCO₂/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>conventionally refined diesel</td>
<td>929</td>
</tr>
<tr>
<td>DCL diesel</td>
<td>2 163</td>
</tr>
<tr>
<td>IDCL diesel</td>
<td>2 615</td>
</tr>
</tbody>
</table>

He went on to explain that Shenhua was investigating CO₂ storage in a project with the US DOE. The demonstration plant lay near PetroChina’s mature Changqing oil field where EOR was being discussed. Shenhua also had a number of adjacent coal mines which might be suitable for CO₂ injection and ZHANG saw this as a cost effective solution.

ZHANG also mentioned China’s energy conservation measures with the ambitious target of achieving a 20% reduction in emissions per unit of GDP over 5 years. LI added that the Communist Party wished to double GDP per capita by 2010 whilst decreasing energy intensity. The measures being taken could be broadly split three ways: improved technology, an economic trend towards less energy intensive activity, and influencing consumer behaviour.

Mr Masaki TAKAHASHI, Senior Power Engineer at the World Bank, asked if conversion of coal to liquid fuels would really alleviate pressures on the Chinese rail system since most coal was transported for power generation – a demand that would remain. He also wanted to know what plans China had to deploy IGCC.

ZHANG replied that the bottlenecks were in moving coal to eastern China. Coal movements would continue to grow because, each year, over the next 5 years, China would add an average of 50 GW of new coal-fired plant meaning that coal from central China would certainly be required in the east. However, the plan is to build CTL plants in the far west – in Ningxia where an existing PetroChina oil pipeline infrastructure has sufficient capacity to transport the additional 10 mtoe of products proposed. Regarding IGCC plans, ZHANG could not speak for the Chinese government, but noted Shenhua’s IGCC proposals at Shanghai and Wenzhou, and expected the government to approve several other IGCC projects. He added that MOST was supporting an IGCC pilot that would be used to test the integration of different technologies prior to going ahead with a large, commercial 600-800 MW plant.

LI offered his perspective on IGCC in a country where the limited supplies of natural gas are needed by the domestic sector, and are not generally used for electricity generation. IGCC could convert coal cleanly, perhaps making use of existing CCGT plant, whilst the co-production of power and chemicals, such as methanol, could improve plant economics.

### SESSION 4: Prospects for CTL in Europe, Australasia and Globally

The world’s biggest lignite or brown coal reserves lie in Australia, some 38 billion tonnes. India and the USA have similarly large reserves, whilst substantial reserves exist in many other countries, including Germany where annual production of 180 million tonnes underpins one quarter of the country’s electricity production. Despite their low calorific value and often high moisture content, all these reserves are suitable for converting to liquid fuels, providing appropriate technologies are available. Globally, brown coal resources are similar in magnitude to non-conventional oil resources, and hard coal resources exceed the combined total of all types of oil and gas resources. What then is the oil industry’s view on the future of coal as a source of alternative fuels?

Before introducing the speakers, Dr Don ELDER, Chief Executive Officer of Solid Energy New Zealand Ltd, drew on previous sessions to observe that some huge changes were likely in the energy business; he calculated that if CO₂ were to trade at a price of, say, $15-30/tCO₂, then emissions from coal use alone would have a tradeable value of $150-300 billion, turning the management of CO₂ emissions into a larger business than mining coal.

### Prospects for Coal-to-Liquids in Australasia

Mr Jeff COCHRANE, Chief Executive Officer of Monash Energy, presented the Monash Energy project, located in the Latrobe Valley, Victoria, south-east Australia, as part of a response to Australia’s widening oil supply/demand gap. Anglo Coal created Monash Energy in 2005 when it acquired the CTL project from a local entrepreneur, following a wider corporate strategy review, dating back to 2002, that had looked to more sustainable ways of using coal.

The proposed Monash project will sit adjacent to a large, 30 mtpa brown coal (lignite) mine with a 300 m thick seam. Monash Energy has a mining licence for 13 billion tonnes, although the Latrobe Valley has over 150 billion tonnes of accessible coal resources. 25 mtpa of this low-cost, low-quality, wet coal (calorific value of 7 GJ/t) will be dried and gasified to yield a syngas that will be converted to liquid fuels by F-T synthesis and electricity – 1.2 t of brown coal produces one barrel of high-quality diesel or 1 000 kWh of electricity. Syngas will be used to generate the plant’s own electricity needs and potentially some exports. Water requirements are
reduced significantly because of the high moisture content of the brown coal. Captured CO₂ will be stored in offshore depleted oil and gas fields in the Gippsland Basin which have been well characterised over the years. COCHRANE noted that other companies were also looking at prospects in the Latrobe Valley. He stressed that the technologies – from bucket wheel excavators, through drying and gasification, to F-T synthesis – were all proven and CTL based on gasification offered a flexible solution, citing the 25% co-feeding of biomass at Buggenum and the potential to use wastes and sewage sludge to supplement the coal feedstock.

COCHRANE believed that CTL had a future – it was just a question of when, because waiting until market conditions were overwhelmingly right placed a major strategic risk on communities who would otherwise face supply disruptions and high costs. He believed it was time to fully establish the technology and begin the process of capital and operating cost improvements, with early-movers building plants in the locations having the best competitive advantages (low-cost coal resource, product market and geology for CCS). With their high capital cost, he saw CTL projects being driven by large coal and oil companies, possibly in partnership. COCHRANE called for stable policy frameworks and government incentives to offset the commercial risks being taken by early movers, especially for those projects with CCS. He was confident that, like the analogous LNG projects on Australia’s NW shelf, which faced the challenges of high capex and low oil prices when originally proposed, CTL projects can succeed.

Across the Tasman Sea, Solid Energy New Zealand Ltd and L&M Group are promoting CTL projects using the South Island’s vast lignite reserves to boost indigenous energy production.

Lignite’s main use is in power generation and he saw this continuing in the long term with technological improvements. The efficiency of RWE’s new BoA 2/3 1000 MW units is 35% higher than the old units they will replace, and RWE’s unique fluidised bed drying technology (WTA) will see a further 10% gain. Beyond that, new materials will allow 700°C steam temperatures and efficiency >50%. Simultaneously, RWE is following two routes to zero-CO₂ coal-fired power plant – scrubbing CO₂ from existing plant and IGCC with CCS. The latter route gives RWE the option of lignite hydrolquefaction.

With some 90 billion tonnes of classified lignite reserves in Europe, exploitable under internationally-competitive conditions, HARTUNG believed it to be an indispensable element to guarantee a sustainable and competitive energy mix.
RWE believes that IGCC meets several basic requirements: it can use a domestic energy resource, it allows CO₂ capture, it is cost effective, and it can be implemented now. HARTUNG explained that the size chosen for this commercial project reflects the size of the largest available gas turbines.

The RWE zero-CO₂ coal-fired power plant project includes carbon storage as the response to central tasks of the future:

- Use of a readily available, domestic energy source
- Significant cut in CO₂ emissions
- Cost-efficient electricity generation
- Rapid implementation of technology

HARTUNG went on to explain that CO₂ capture requires the H₂/CO syngas to be shifted to H₂/CO₂. After CO₂ scrubbing, the hydrogen fuel is combusted in a gas turbine – the only component unproven for this IGCC application at this scale.

IGGCC with carbon capture is based on largely tried and tested technology:

- Carbon capture is relatively elegant and efficient in this process
- Nearly all IGCC carbon capture components have been trialed on a commercial scale
- Remaining development tasks:
  - Gas turbine for H₂-rich fuel gas
  - Optimum overall concept

RWE has a long history in coal gasification, most recently with a High-Temperature Winkler (HTW) gasifier for methanol production that ran commercially for ten years during which time two million tonnes of CO₂ were scrubbed from the syngas.

RWE: 30 years of experience in coal gasification, carbon capture tested as well

In addition to its proven status, HARTUNG saw other advantages with IGCC: fuel flexibility and the option to produce chemical products from the syngas, including synthetic natural gas (SNG) and high quality diesel.
HARTUNG presented the economics of producing these fuels and hinted at the volumes of lignite needed to meet German motor fuel and natural gas demand.

Production costs of coal-to-liquid products: syngas and Fischer-Tropsch diesel

Example – SNG production from lignite

Example – Diesel production from lignite

ARYA showed that conventional oil reserves are plentiful and that industry is investing to raise future production, but he recognised that the world was looking at alternatives to bring energy diversity – quoting Sheikh Yamani, “the Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil”. He pointed to Saudi Arabia’s massive reserves, and to investments in production expansion in Nigeria and Angola, as well as in non-OPEC countries, such as Russia and Azerbaijan.

Future oil supply projections

By 2020, non-conventional oil supplies, including CTL, could be 7.7% of the total 104.1 mb/d oil supply. BP’s own analysis indicates slightly higher growth in non-conventional production, driven by energy diversity considerations rather than any perceptions of oil shortages. CTL is shown to account for 0.9 mb/d or 9% of non-conventional supply and <1% of total supply. ARYA distinguished between oil sands and heavy oil projects, where investments were being made, and the other non-conventionals, including CTL, which would not be economic if oil prices fell from current highs.
ARYA warned against assuming that, among the non-conventional resources, coal would be preferred – the prospects for extra heavy oil, bitumen and oil shale, in Canada, the USA and Venezuela, might be better. In fact, he showed that these resources were geographically diverse, often in large, energy-consuming countries, and that their exploitation was ripe for technological development.

Similarly, he cautioned against basing long-term investment decisions on the current “perturbation” in oil prices. These had been >$40/bbl for just 2 years and >$60/bbl for less than a year, whilst the historical average was <$30/bbl.

ARYA noted that CTL economics also depended on coal prices, themselves subject to market pressure.

He concluded with the following:

- Oil demand would continue to grow – particularly in the USA, China and India.
- Sufficient resources exist to meet future demand growth.
- Consumer nations want security of supply and one option is to increase diversification.
- Opportunities are growing to diversify into non-conventional supplies, including CTL where success may depend on collaboration and cooperation between coal and oil companies.
- Economics depend on long-term future oil and coal prices and capital costs (plant location).
- Carbon footprint may increase CTL costs when compared to other non-conventionals (e.g. biofuels) – ARYA saw this as a real policy challenge for the IEA, DOE, EU and governments everywhere.
- CTL and biofuels production require large volumes of scarce water, limiting their long-term sustainability.

**Discussion**

Dr Don ELDER led the discussion, noting two, very different perspectives on future CTL production: 3-5 mb/d in the USA by 2030, according to speakers in Session 2, but maybe only 1 mb/d globally by 2020, according to Dr Atul ARYA from BP.

Mr David GRAY asked if sufficient oil refining capacity existed, including capacity to process heavy oils, and what the underlying cost of oil supply would then be when this is factored in.

ARYA saw no refining constraints and believed there would be enough capacity through to 2020, although with some product mismatches in Europe (gasoline surplus) and the USA (long on diesel, short on gasoline). He added that China was building enough new capacity, India already had a surplus, and that OPEC was keen to build their own refineries to capture more of the oil supply value chain. He observed that industry was investing in Canadian heavy oil processing capacity. However, he did foresee competition for capital in the refining industry if biofuels developed strongly in response to policy incentives. On oil production costs, ARYA responded that whilst these are low in Saudi Arabia, they rise significantly offshore and especially in the deeper waters now being explored by Western oil companies – not helped by the inflationary pressures seen over the previous few years, citing the six-fold increase in drilling rig costs.

Dr Roger BEZDEK queried the accuracy of figures for conventional oil reserves, particularly in the Middle East which might be overstated, and whether the oil industry could meet demand over the next 30-40 years?
ARYA responded with BP’s view that plenty of oil remained in the ground, outside of mature provinces such as the USA and North Sea, and enough new projects existed to meet the 1.7% average demand growth forecast by IEA over the next 5-10 years. Beyond that, the challenge would be to convert resources into viable projects and he reminded participants that, for many years, there had been no oil shortages – industry had delivered.

Mr Justin MUNDY, Special Advisor to the UK Government’s Foreign & Commonwealth Office, observed that many of the projects presented depended on a carbon price and wondered if there was enough depth and liquidity in the carbon market to capitalise this. ELDER suggested that certainty was more important than price.

ARYA agreed that a long-term policy framework was needed to allow a carbon price to develop, otherwise clean investments, such as BP’s own projects at Peterhead in the UK and at Carson in California, would not proceed.

HARTUNG added that a CO₂ value was a pre-condition of RWE’s CO₂-free IGCC power project, yet under the EU ETS, this value was uncertain and unknown beyond 2012. Nevertheless, his company was committed to developing a response to the threat posed by greenhouse gas emissions and would press ahead with projects in anticipation of post-2012 legislation leading ultimately to large cuts in CO₂ emissions.

Mr Robert KELLY asked about the size of the Monash project and how lignite liquefaction costs compared with those for hard coal?

COCHRANE replied that Monash was a 60 000 b/d project and that the key advantage of lignite was price stability over 20 or more years. Since the low CV brown coal reserve had no alternative market, its price was equal to its extraction cost and not some other opportunity cost, as would be the case with high CV hard coal which can be traded.

**SESSION 5: Coal Market and Policy Implications of a Growing CTL Demand**

Mr Preston CHIARO, Chief Executive – Energy at Rio Tinto and CIAB Chairman, returned to the chair and posed a series of searching questions to the six panellists. He asked panellists to raise their own questions before inviting a wider discussion among participants.

**Dr Victor K Der, Director – Office of Clean Energy Systems, US Department of Energy**

Chair: Are we moving in the wrong direction with CTL – trying to develop a technology that will be obsolete by the time it is up to scale because of increasing concerns over CO₂ and hence efforts to reduce emissions? For example, the Stern Review calls for a 25% reduction below current emission levels in the face of growing demand for power and transport fuels – when CTL is fully developed, there may be no demand for CTL fuels.

DER did not see liquid fuels disappearing, the issue was how they would be produced and how the CO₂ issue would be addressed by regulation or other means. In the near term, EOR opportunities give some comfort in the market place that CTL fuels can be introduced to bring diversity without a CO₂ penalty. The long-term future of CTL depends on the success of zero-emission projects such as FutureGen and others. DER said that a unique aim of the DOE’s R&D effort was to develop low-cost technologies that allow CO₂ capture and hydrogen use without having to place a value on the avoided carbon emissions. CTL could then be emission free, at least at the point of production. With many billions invested in CTL over 30 years, DER felt that it was now down to industry to take it forward as a business, responding to the right incentives. How far and how quickly the transportation sector would evolve was unclear to DER: improved efficiency, the use of hybrids, and electric vehicles supplied from zero-carbon sources were all possible, although solar-powered cars were surely a more distant prospect.

**Mr Roger Bezdek, President, Management Information Services Inc**

Chair: If CTL is driven by the price differential between oil and coal, what price gap is needed to secure investments in the face of the technical risks and the need for a long-term coal supply?

BEZEK replied that the gap needed to be substantial and semi-permanent, unless a floor price for CTL fuels existed through government intervention. Oil price cycles, as seen in the late 1970s and early 1980s, and carbon pricing – whether through cap-and-trade or CCS regulation – would influence decisions. BEZDEK warned that a switch to alternative sources, whether coal, oil shale, EOR or biomass, might result in lower oil prices that benefit the economy, but these low prices would perversely hurt the new developers of crucial infrastructure – unless support mechanisms were in place. On the other hand, he noted that new conventional oil projects were themselves often only profitable at oil prices at which CTL was already competitive, citing $40-50/bbl for the Jack No.2 project in deep waters off the US Gulf Coast. He concluded that perhaps oil prices would remain at a level that left CTL competitive.

BEDEK reflected on how CTL might be incentivised and suggested that an empirical answer may lie in the development of Canadian oil sands where 1 mb/d was now produced with the potential to double or quadruple production. Since the late 1960s, through periods of high and low oil prices, with the support of Federal and provincial governments, the Canadians had responded to the imperative to develop successful oil sands projects.

**Dr Jeff Cochrane, Chief Executive Officer, Monash Energy**

Chair: The boom in China and trends elsewhere have created a huge demand for skilled labour; for example, Rio Tinto has difficulty finding people to work on conventional coal mining projects in Australia, whilst university graduates are not attracted into mining. Where will Anglo and other companies around the world recruit the skilled chemical and process engineers needed for complex CTL projects?

COCHRANE recognised this difficulty, but thought that CTL itself would make the industry more attractive for graduates who could then be part of a new, cleaner energy future rather than simply working in an industry seen by some as old fashioned. The skills shortage was more acute in industries with a poor image. He drew a comparison with the nuclear industry that faced a similar problem – so few had learnt nuclear engineering over the last 20 years that new nuclear build programmes would struggle. COCHRANE foresaw multi-national teams of scientists and engineers working on projects in all parts of the world, and was even hopeful of recruiting people back from the oil industry.

COCHRANE explored how risks were being managed at the Monash project to secure long-term capital investment. Coal mining, drying and gasification each involved technology risks that Anglo had assessed and eliminated through design and knowledge from experience elsewhere. Reducing regulatory risk meant that CCS was an integral part of the project. He foresaw CTL becoming an important source of clean fuels in Australia, extending to renewable fuels should biomass be co-fed (20-40%) with coal.

**Mr André Steynberg, Technology Manager for CTL, Sasol Technology (Pty) Ltd**

Chair: In the 1970s, a rush to develop many energy and coal projects was followed by a slack period. How do companies
Mr Bill Senior, Senior Advisor – Technology, BP Alternative Energy

Chair: The US government has moved to encourage CTL, but what is the optimum government policy? If there should be encouragement, what form should it take and how should it link to carbon pricing, whether set by trading or tax?

SENIOR painted a picture of trade-offs between the three key drivers: energy, environment and economics. In Europe, he saw climate as the strongest driver, but even there, energy security was never far behind. The carbon intensity of CTL meant that incentives, such as fiscal support, designed to mitigate high oil prices could be at odds with climate policy. For example, SENIOR noted that the specific incentives in the USA supported alternative, coal-derived fuels which may have a carbon footprint much greater than crude oil, i.e. the current baseline as determined by the market. He quoted CO₂ emissions from coal, on a mine-to-well basis versus well-to-wheel basis, of some 1.8-2.0x those of oil, if CO₂ capture and storage was not employed. CCS allows a substantial reduction at a relatively low cost (from 16 MtCO₂ to 3 MtCO₂ in the case of the Monash project). However, SENIOR observed that CCS only takes emissions towards the crude oil baseline and he felt governments would have to look seriously at any incentives for CTL whilst pursuing policies to reduce emissions – raising challenges for governments and corporations. SENIOR was encouraged that most CTL project developers included CCS. He remarked on the scale of CO₂ storage required. In the USA, c.30 MtCO₂ each year is used for EOR, BP’s In Salah project in Algeria re-injects 1 MtCO₂/yr. At 13 MtCO₂/yr, the Monash project was a huge jump in scale; if CTL plants were deployed to produce say 5 mb/d, then 1 250 MtCO₂/yr would have to be stored underground. BP advocates a carbon market policy approach, through expanded emissions trading, as the primary policy measure to mitigate CO₂ emissions; for CCS to become eligible, enabling policy on licensing, storage integrity, monitoring and liabilities must be developed. SENIOR’s opinion was that power generation may be a much better opportunity to deploy CCS because emissions can be reduced below current baselines.

SENIOR reflected on the baseline question: a CTL plant had large abatement potential at low cost in absolute terms, but not when compared with a conventional oil refinery producing the same products. He did not believe that any public discussion on baselines for CTL plants had occurred. Whilst today’s CDM would not support CCS at CTL plants, a post-Kyoto framework that included developing countries with price similar to the EU ETS ($20-30/TCO₂) could be a source of value to CTL developers. SENIOR saw a complicated and uncertain landscape ahead.

Finally, he offered some insight into the skills issue. Since BP set up its Alternative Energy business in 2005, it has proved to be a magnet for engineers interested in working in hydrogen power (i.e. fossil power with CCS), solar and other renewables. SENIOR believed that zero-emission coal offers an appealing future that should attract young engineers. With so many talented engineers and scientists in China, he expected that multiple-national companies would respond to capitalise on this resource, but wherever the skills lay, he suggested that greater collaboration between industries was vital.

Discussion

CHIARO asked if Sasol had been approached by anyone interested in earning value by reducing the CO₂ emissions from its long-established CTL projects?

STEYNBERG replied that South Africa unfortunately had no oil fields and so no EOR opportunities. However, there were possibilities with enhanced coal bed methane (ECBM) which Sasol was exploring, although this was complicated by coal resource ownership issues – Sasol does not own coal resources
suitable for ECBM production. In China, Sasol was involved in projects designed to be CO₂ “capture ready”.

On skills, CHIARO asked if China was training enough people in the right disciplines to service the growing CTL industry?

LI spoke of the traditionally strong teaching of coal chemistry, combustion and power engineering at many Chinese universities which now offer tailored courses, building on these fundamentals, such that demand for skills would be met. ZHANG added that Shenhua had anticipated the need for many more trained people, so had signed an agreement with the China University of Petroleum to switch third year undergraduates from refinery courses to courses in CTL. With many graduates currently unable to find jobs, ZHANG reported that this initiative had worked to the extent that skills shortages would not be an issue.

Dr Stephan SINGER, Head of the European Climate and Energy Policy Unit at WWF, spoke strongly against CTL because it fell short of carbon-free coal use, unlike coal in power generation with CCS where gains compared to current baselines were real. He believed that coal’s role in the transport sector could only be through hydrogen production when CCS could reduce emissions far below baselines. He politely suggested that China, with its rapid economic development, had the opportunity to establish an infrastructure that responded to the climate challenge. His suggestion was a huge pilot demonstration of coal-to-hydrogen for transport in a major city. Within a generation, such a demonstration would allow many outstanding issues to be addressed by engineers who, he felt, were bored by traditional nuclear and fossil engineering.

SENIOR queried how transport infrastructure would evolve in the long term – many believed that hydrogen looked expensive. He acknowledged that achieving a sustainable solution through the progressive improvement of current infrastructure was a great challenge. SENIOR pointed to hybrid cars, electric vehicles and the trend towards DME and methanol fuels in China, but offered no clear view on the future of transport except that coal would almost certainly be a feedstock.

CHIARO broadened the question to include plug-in electric hybrids.

ZHANG shared his experience as a member of the National Energy Experts Group. The Minister of Science and Technology had asked the Group for data on providing a major city in China with hydrogen rather than gasoline. One conclusion was that 1.6 tonnes of coal could yield enough hydrogen for a fuel cell car travelling 20,000 km per year. After several seminars and workshops, the national view was that whilst China could leapfrog other countries and build a new hydrogen infrastructure, especially in areas where gasoline distribution was sparse, this would not happen because fuel cell cars are currently too expensive and there is no viable means of transporting hydrogen 800-1,000 km from mine mouth plants. ZHANG reported that Shenhua and Shell were already building a few hydrogen filling stations in Beijing and Shanghai, but that it would be 20 years before one could talk of a “hydrogen age”. He contrasted this analysis with the use of coal for power generation where China had no alternative – power demand would double in the next 15 years and 70% would be coal-fired.

Dr Kelly THAMBIMUTHU, Chief Executive Officer of the Centre for Low Emission Technology in Australia, noted that if the carbon footprint of CTL with CCS was no different than fuels refined from crude oil, then the energy security value of using coal should make this route attractive in some countries. He went on to explore the climate challenge and felt that solutions demanded the wholesale replanning of energy infrastructures, yet the debate rarely went beyond the energy efficiency of existing infrastructure.

CHIARO contrasted countries, mainly interested in energy security, with companies, mainly interested in profits, and asked who should be responsible for designing and putting in place new energy infrastructure when the boundaries of responsibility were rarely clear?

COCHRANE suggested that rather than “CTL”, the industry should talk of “CTX” or coal-to-X, where X was the chosen product from which the infrastructure follows. Coal was the important starting point and investment in technology would allow an optimum energy vector to be chosen.

Mr Robert KELLY returned to the question of whether CTL or power generation was an appropriate use of coal. He said that if CO₂ mitigation with, for example, EOR was included, then, for transportation, decisions depended simply on the preferred primary energy source used to produce the secondary fuel, alongside the associated costs. He noted that DOE and EIA projects included significant conservation efforts of 1-2% per year, yet demand from the transport sector would continue to grow and CTL was a reaction to that growth. Responding to THAMBIMUTHU, he agreed that all externalities needed consideration: a carbon price and markets would lead to carbon abatement strategies in response to the environmental externality; whilst in China, India and the USA, geopolitical externalities had an impact on national security and economic security through high oil prices.

Mr Roger WICKS, Head of Energy at Anglo American, started from the premise of a carbon-constrained world with two competing imperatives: energy security and climate protection. If security was the predominant driver, then WICKS sensed that enough competing activity in different fields was taking place at a sufficient pace to meet the imperative. However, to address the climate imperative demanded a much greater level of urgency as detailed in the Stern Review and elsewhere. He saw CCS on a massive scale as being the key mechanism that would buy time and ultimately secure a long-term future for the coal industry. As part of the CIAB’s role to inform the IEA, he wanted to know what could be done to radically accelerate CCS technology deployment, certainly in a much shorter timescale than, for example, the development of Canadian oil sands referred to by BEZDEK. In this respect, WICKS asked if there was something to be learnt from the Chinese: “What is it that Shenhua is doing that enables research to be carried out, technology proven and projects built at such a pace? Perhaps the political system or private companies free of the constraints “found in Western boardrooms”?

ZHANG replied by outlining a long-term strategy that flowed from China’s mix of natural resource: small oil reserves and abundant coal. Thirty years ago, China had started research into CTL, learning from Japan, Germany and USA. A turning point came in 1993 when China became a net oil importer, resulting in a foreign currency deficit (unlike today). The government responded by using coal in place of fuel oil. Another turning point came in 1996 when Premier Li Peng said that a CTL plant must be operational within the next 5 years, a goal that is now being realised.

Mr Justin MUNDY, Special Advisor to the UK Government’s Foreign & Commonwealth Office, reflected on energy security and climate security, but asked again what could be done to make coal part of the solution rather than part of the problem. He was not entirely convinced that an agreement on this had been reached at the workshop. Analogous to national security, which could be broken down into hard security (e.g. deployment of troops and counter-terrorism) and soft security (e.g. resolving tensions that would otherwise lead to the need for hard security), MUNDY split climate security into a combination of energy security, water security, agricultural security, rural security and soft security. All three had to be in balance from a public policy perspective and he believed that CTL without CCS was such a massive imbalance that the coal industry would fail in its ambition to
be part of any solution. He called on the industry not to rely on normal solutions and normal technologies, but to leapfrog to new solutions, perhaps hydrogen, whilst avoiding any economic assessments that ignored the cost of carbon.

Mr Yoshihiko NAKAGAKI, President of the Electric Power Development Company, noted the strong relationship between CTL and IGCC, such that plant economics could be improved by designing for flexible production of liquid fuels and electricity. He explained that Japan was expediting the development of coal gasification with the flexibility to supply hydrogen for IGCC. In the longer term, he thought CTL may have limited impact on oil supply because of a scarcity of viable projects and a lack of CO₂ emission benefits, even with CCS. NAKAGAKI believed that hydrogen production from coal could be a cleaner and more economic route than CTL.

Dr Dan LASHOF, Science Director at the Natural Resource Defense Council’s Climate Center, continued on the security theme when he stated that energy and climate issues needed to be addressed simultaneously and urgently, not separately. Many options were available in the transportation sector: vehicle efficiency, biofuels and part electrification, but he was not persuaded that CTL was a sensible option, even with CCS, since its emission performance was no better than gasoline. He thought that other products could be important, such as hydrogen, but noted that the GTX concept only applied to IDCL and not DCL, so investors should be wary of projects without product flexibility. He spoke vehemently against the 50c tax credit in the USA for CTL fuels and anticipated much greater public scrutiny, and better alignment with climate policy, if its renewal was ever debated, noting that an emission performance standard should be built into any measures to incentivise alternative fuels.

Dr Rolf LINKOHR, Director of the Centre for European Energy Strategy and Special Advisor to Andris Piebalgs, European Commissioner for Energy, wondered how the day’s debate would have sounded in, say, 1895. Most would have suggested using coal in steam engines for transport, modernists might have preferred electric cars, only a few would have picked liquid fuels. LINKOHR pointed to the difficulty of predicting the future, but economics and the environment would drive outcomes. Briefly noting the EC’s developing hydrogen strategy, LINKOHR moved on to speak about how CDM could help the coal industry following the decision at COP-11 that CCS should be on the agenda at COP-12 in Nairobi. A workshop in Bonn held in May 2006 brought together signatories to the Kyoto Protocol and all agreed that clean coal with CCS should be integrated into CDM – a move that could put climate policies back on track by alleviating the burden of CO₂ from coal use. Finally, LINKOHR called for greater international cooperation aimed at developing innovative technologies in response to economic and environmental needs. He believed the energy industry lacked an international body with the stature to achieve this.

Dr Don ELDER offered some concluding remarks from the industry. He felt that it was easy for industry critics to exploit the climate challenge and dismiss the steps that the coal industry is taking. CTL with CCS yields an emission performance equivalent to conventional oil, and coal-to-hydrogen is substantially better. The coal industry is moving forward with projects, ELDER said, while others, mainly governments, are talking about issues that they could and should be addressing. For example:

- If CO₂ was recognised as an issue, not a pollutant, then governments would make regulation of its storage easier, yet he observed a worrying trend in the opposite direction. ELDER wanted CCS to become a commodity, not something that needs $50 million for research before a project can start.
- If the hydrogen economy was so desirable, those talking would be making it happen. In New Zealand, the marginal cost of producing hydrogen at a proposed CTL project with CCS was below that of gasoline, but ELDER observed that the $150 000 cost of a hydrogen car made it an impossibility.

ELDER concluded by saying that the coal industry was doing a lot and that it was time for others to do what they needed to be doing.

Summing up:

Mr Ian CRONSHAW, Head of the Energy Diversification Division, spoke on behalf of the IEA, an organisation that values its contacts with industry through the CIAB. He welcomed the information-rich presentations and vigorous debate during the day’s workshop. With energy security back at the top of the agenda and carbon emissions rising, he believed governments and industry needed to maintain a healthy collaboration. He was particularly pleased to see unanimity among participants on the need to tackle CO₂ emissions and that the coal industry could be part of a solution. In his vote of thanks, he made special mention of the speakers and delegates from China, noting how important it was to share knowledge and experience within what had become a truly global industry.

Mr Preston CHIARO sensed much interest in coal-to-liquids – companies hoping to profit from it and some governments hoping that it would enhance energy security. It was clear to him that a huge amount of expertise already existed to execute large CTL projects. Resource demands would be significant: low-cost coal, water, power, skilled people and capital investors willing to face new risks. CHIARO understood that environmental challenges remained, especially in relation to CO₂ where the volumes captured and stored today would need scaling by 1 000×10 000× to have an impact on atmospheric concentrations. For CTL to be successful, he believed that collaboration and co-operation between industrial sectors was essential. CHIARO warned that CTL would face strong competition from the traditional oil supply industry, a growing renewable industry, and even from the nuclear industry. In answer to his own earlier question, CHIARO saw CTL as neither a dead-end technology nor an essential technology, but a technology that was likely to play a part in the future fuel supplies of countries endowed with rich coal resources.

CHIARO thanked the IEA staff, speakers, session chairs, participants, CIAB Members, guests and CIAB Associates, especially those involved in the organisation of a stimulating workshop.
# Annex – Workshop Participants

## CIAB MEMBERS ATTENDING:

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Organising Committee

Notes
1 See, for example, information provided by the National Mining Association [www.futurecoalfuels.org] and Coal: America’s Energy Future, Washington DC: The National Coal Council, March 2006.
3 Coal: Liquids Fuels, London: World Coal Institute, October 2006, [www.worldcoal.org].
6 Typically, about 15 MJ of coal energy is needed to make one barrel of liquid fuel product. Conversion efficiency can be improved by using more modern but also more expensive technologies e.g. IGCC to provide process steam and electricity needs.

Coal Industry Advisory Board
For more information about the IEA Coal Industry Advisory Board, please refer to www.iea.org/ciab, or contact Brian Ricketts at the IEA (brian.ricketts@iea.org) or Brian Heath, CIAB Executive Co-ordinator (mail@ciab.org.uk).

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