Transforming Coal for Sustainability —A Strategy for China

Task Force on Energy Strategies and Technologies

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The Three E's of Sustainable Development

In October 2002 the 16th Party Congress established the goal of expanding China's economy fourfold by 2020 and defined the Three E's strategy for Economic development, Energy security, and Environmental protection. In pursuing these goals, China's energy system cannot continue to expand using the current approach. The risks are that:

- China will become overly dependent on oil imports as a result of the rapidly growing demand for liquid fuels, especially in the transportation sector,
- Severe additional public health and environmental damages will occur in China with very large economic consequences (projected to grow from over 7% of GDP to 13% of GDP in 2020), and
- Climate change impacts will become significant, and China will not be able to make its contribution to mitigating greenhouse gas (GHG) emissions under the United Nations Framework Convention on Climate Change.[1]

Can these risks be mitigated at reasonable cost? The answer is "yes". This is based on specific technical analyses and modeling of China's integrated energy economy.[2] The Task Force on Energy Strategies and Technologies (TFEST) analyzed two alternative strategies, as shown in Figure 1 using Base case technologies and Advanced case technologies through 2050. The

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[1] China, as a party to United Nations Framework Convention on Climate Change, " ...should protect the climate system...on the basis of equity and in accordance with [its] common but differentiated responsibilities and respective capabilities." (Article 3)

[2] See the list of background papers at the end of this report.

analysis indicates that there are advanced energy technology systems that can support growth objectives while dramatically reducing air pollution and without China's becoming overly dependent on imports.

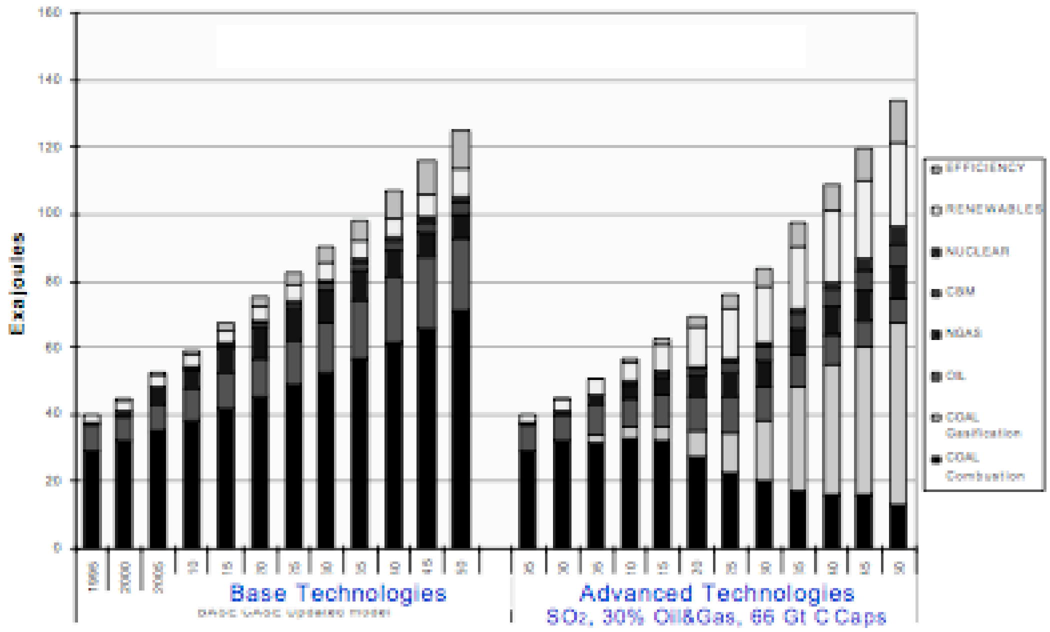

Figure 1. Total Primary Energy Supply for a Base Technologies (Business as Usual) Scenario and an Advanced Technologies Scenario with Constraints.

The Base technologies strategy, which continues to rely on coal combustion for power generation and on petroleum-derived fuels, cannot meet the same objectives, especially not the one for energy security. A recent Energy Research Institute (ERI) analysis,[3] shown in Figure 2, indicates that oil imports might exceed 60% of total consumption by 2020 under a business-as-usual scenario.

However, the TFEST analysis shows that the Advanced technologies strategy, which provides the same energy services at about the same cost as the Base technologies strategy, might limit oil and gas imports to some 30% of total supply while also meeting constraints for SO_2 and long-term carbon emissions. This strategy builds on the combination of energy efficiency, natural gas, renewable energy, and "modernized" coal. By aggressively pursuing the Advanced technology strategy now, TFEST believes China could reduce projected oil imports by up to 50 Mtoe per year in 2020, and by rapidly increasing quantities thereafter.

[3] Comprehensive Report on China's Sustainable Energy Development and Carbon Emission Scenario Analysis, Energy Research Institute of the National Development and Reform Commission, May 2003.

Modernization of coal is a large and necessary component of energy systems that satisfy the Three Es for China's sustainable development. Modernization of coal refers to the use of gasification technology to produce synthetic gas for power, clean fuels for transportation and cooking, and heat for both domestic and industrial heating applications, to replace coal combustion technology and oil imports. This strategy is based on technologies that are mostly known and proven, many of which are already in use in China, largely in the chemicals sector. What is needed for successful implementation is to promote the integration of, and investment in, those technologies rather than the development of many new ones. Investments in new capacity should be directed to gasification-based systems, with an emphasis on co-production of multiple energy carriers and often chemicals as well at the same site, i.e., **polygeneration**. A flexible and adaptive strategy needs to be implemented step-by-step. The TFEST outlines a vision and action plan in this report.

For the Advanced Technologies Scenario SO_2 emissions are reduced from 23.7 Mt in 1995 to 16.2 Mt in 2020 and 8.8 Mt in 2050. Imports of oil and natural gas are limited to 30% of consumption of oil and gas over the long-term. The 66 Gt C cap is a cumulative carbon emission allowance for China based on atmospheric CO_2 stabilization at 450 ppmv and a year-2000 population-based apportioning of globally allowed carbon emissions.

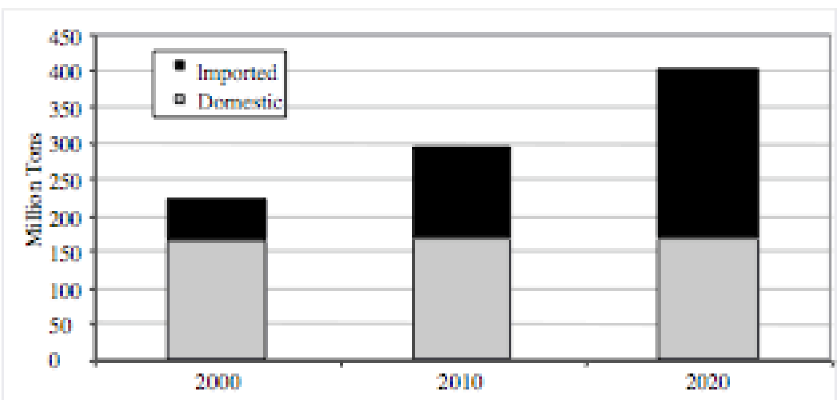

Figure 2. Projected Oil Consumption

This projection is from the Energy Research Institute's Sustainable Energy Development and Carbon Emission Scenario 3 (High Efficiency, but without Coal Gasification).[3]

Based on estimates of the Electric Power Technology Market Association of China, two-thirds of the coal plant capacity that will be operating in 2020 is yet to be built.

Time is running out to implement this strategy because large investments are planned for electricity over the next decade that will lock in the mode of coal use for meeting China's

electricity requirements through 2020 and for many decades thereafter. Figure 3 indicates that two-thirds of the coal plant capacity that will be operating in 2020 is yet to be built. The recommended strategy seeks to shift a significant portion of this new capacity onto a sustainable, modern path. Equally, decisions must be made now to allow for investments in new types of transportation fuels and infrastructure.

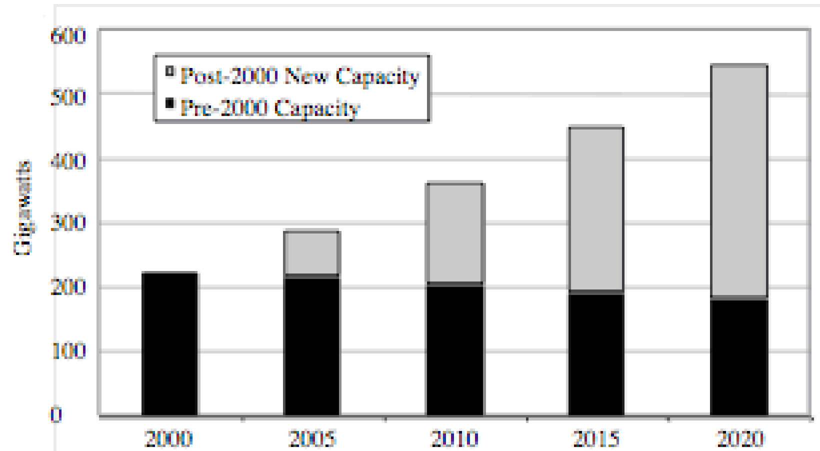

Figure 3. Projection for Coal Power Plant Capacity

Urgent Action by China's Leadership is Required

The conclusions of the analysis carried out by the TFEST over the past two years are of vital importance to energy planning for China in both the near and longer term.

1. Strategy for Modernization of Coal

This report highlights the need for a fundamental and urgent change of direction towards investment in coal gasification and away from investment in coal combustion. There is strong evidence from the studies carried out by the TFEST that China's energy system should evolve over time to the production of electricity, heat, clean fuels, and chemicals from various gas sources (synthesis gas from coal and biomass, natural gas, coal-bed methane). The polygeneration approach to providing these products is the most cost-effective and environmentally attractive supply option for reducing dependence on oil imports.

Polygeneration requires integrating and building flexibility into production facility siting and infrastructure planning so as to facilitate innovative approaches that optimize investments. One example would be mine-mouth siting of polygeneration facilities together with use of common rights of way for pipelines and electric transmission lines to get the products to market.

Investment decisions made over the near term for new capacity will be crucial to launching this coal modernization strategy. **Delaying the start of the transition to coal gasification-based polygeneration technology would significantly increase the costs to China of air pollution damages, of oil imports, and of reducing GHG emissions.**

In order for planning and implementation of a polygeneration strategy to move ahead fast enough to catch the investment cycle that is driven by rapid GDP growth, there is a need for creating new industries by merging traditionally separate industrial activities. There is a parallel need to integrate actions across the various government departments involved (such as chemicals; electricity generation, transmission, and distribution; petroleum refining and product distribution; natural gas; oil and gas pipelines; coal mining and transportation; renewable energy, transportation, etc.).

An important side-benefit is that if China follows the recommended approach it will inevitably drive costs down as it progresses along the learning curve and develop a uniquely valuable international competitive advantage and a capability that will eventually have export value.
The analysis has shown that a coal/synthesis gas polygeneration option must also be linked to an overall energy strategy that includes improved energy efficiency, the widespread use of renewable sources of energy and natural gas, such that developments in related energy fields are planned in a way that provides the maximum benefit to China.

2. Main Recommended Actions

The recommended merging of planning by government departments is not easily achievable. For this reason, and given the imperative of rapid decision-making by the government if the country is to enact the most efficient near- and long-term energy investment strategies, the TFEST recommends that the ideas proposed in its report be presented to top-level government officials as soon as possible.

This matter is of such strategic importance to China that:

- **a very focused "Deng's trip to the South" type of government and industry initiative should be launched, and**
- **clear direction should be given such that the relevant integrated planning bodies, capacity building activities, and enabling policies will be put into place quickly.**

In the Chinese socialist market economy the government primarily creates the environment in which this initiative can be successful. It is necessary to state the objectives and targets clearly, to keep a consistent policy for a long time, to identify and remove barriers, and to create favourable conditions that will result in the intended actions by business.
This report explains the conclusions presented above in more detail.

Modernization of Coal

Coal is abundant and cheap but is an inherently dirty resource that historically has provided energy via its combustion. In this mode coal has a limited energy market opportunity (heat and power only) and causes enormous environmental problems. Gasification to make synthesis gas provides the basis for coal modernization that enables heat and power to be made in much improved ways and also opens up vast opportunities for new liquid and gaseous fuel markets so that coal can serve essentially all energy markets.

Coal modernization based on gasification can be realized with already commercial technological components that are brought together in new kinds of energy systems that are managed in innovative ways. Modernization brings immediate economic, oil-import reduction, and air-quality benefits, and puts into place the key enabling technologies that make it possible to address later, with only minor technical modifications and at modest cost, the challenge of climate change.[4]

Figure 4 shows that modernization of coal in China would build on the already extensive Chinese experience in the chemical process industry with coal gasification and a worldwide gasification experience base that is expanding rapidly.

Figure 4. Cumulative Worldwide Gasification Capacity and Growth

Gasification is a booming activity worldwide, with a total installed synthesis gas capacity of 61 GWth and new capacity being added at a rate of 3 GWth per year.

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[4] The incremental costs are relatively modest because gasification makes it possible to recover CO_2 (for underground storage) at high concentrations prior to combustion.

1. Gasification for Power and CHP

Gasification makes it possible to exploit with coal the ever continuing advances in gas turbine technologies for both power only applications (combined cycles) and for combined heat and power (CHP) applications (gas turbines or combined cycles). Gas turbines and combined cycles offer substantial cost and thermodynamic advantages in CHP compared to the steam turbines that must be used with coal combustion. Electricity provided via gasification will have air pollutant emission levels as low as for natural gas combined cycle electricity.

Electricity via coal gasification can be provided in either an integrated gasification combined cycle (IGCC) power plant or in a polygeneration plant. At present, IGCC plants built in China cannot compete with coal steam-electric plants unless SO_2 and NO_X emissions controls are required for the latter-and even in that case IGCC plants would just barely be competitive on a lifecycle cost basis, which is not financially attractive enough to motivate power generating companies to adopt the technology for new plants. But as discussed below, electricity generated in polygeneration plants is a financially attractive option in China.

2. Gasification for Synthetic Fuels Production

Gasification also makes it possible to provide clean synthetic fuels in the near term, such as town gas for cooking and heating, dimethyl ether (DME) for cooking, and methanol, Fischer-Tropsch (F-T) liquids[5] and DME for transportation. For the longer term, gasification makes it possible to provide fuel in the form of hydrogen with near zero emissions of greenhouse gases if the CO_2 co-product of hydrogen manufacture is stored underground.

Gasification makes it possible, starting with the two small molecules carbon monoxide and hydrogen that are the major constituents of synthesis gas, to design fuels that are vastly superior to hydrocarbon fuels (derived from crude oil or via direct coal liquefaction) with regards to both performance and emissions. For transportation fuels this is an important consideration because over time tightening air-quality regulations imply that meeting these regulations with conventional hydrocarbon fuels will require ever more sophisticated exhaust gas after-treatment technology and major improvements in fuel quality with concomitant large oil refinery investments.

The need for such costly continuing modifications of both production and end-use technologies can be minimized with gasification technologies. The basic approach is to first clean the synthesis gas of all the noxious materials such as sulphur, nitrogen, and mercury (as is already routinely done for most such materials in the chemicals industry in China) and then choose a chemical manufacturable from carbon monoxide and hydrogen that comes the closest to meeting

[5] Primarily synthetic hydrocarbon fuels similar to Diesel fuel and gasoline.

the performance goals (e.g., high cetane number or high octane) and emissions goals (e.g., inherently low particulate and NO_X emissions in combustion).

3. Polygeneration

Synthetic fuels and electricity can be manufactured either in separate facilities or in polygeneration plants that provide both products simultaneously. There are substantial investment cost savings associated with the polygeneration option that makes it possible to produce clean synthetic liquid fuels from coal that will be competitive at crude oil costs of about $20 per barrel or less. Because of the favorable economics of polygeneration, typical coal gasification-based systems in the future are likely to provide multiple energy products as well as chemicals. See Figure 5.

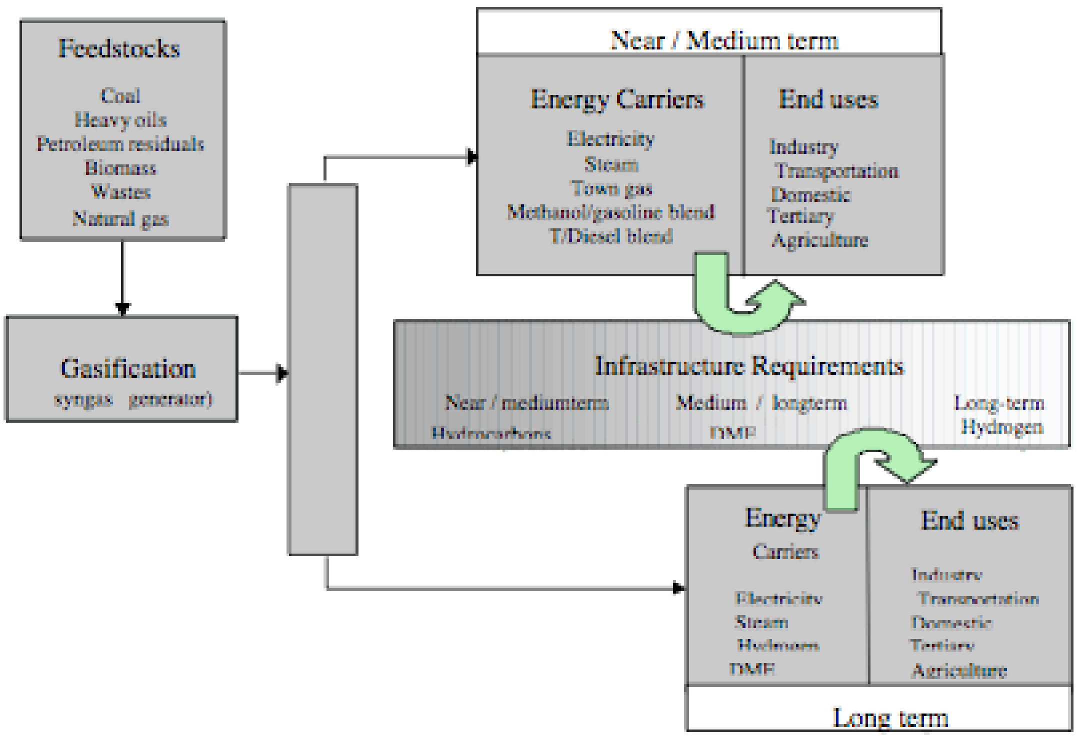

Figure 5. Vision for Modernized Coal

Gasification to modernize coal makes it possible to produce synthetic fluid fuels as well as heat and power. The least costly option is polygeneration, in which multiple energy products (as well as chemicals) are produced from coal-derived synthesis gas in the same facility. Modernized coal can provide energy carriers such as DME that are far superior to crude oil-derived hydrocarbon fuels. New infrastructures will be needed-for DME in the medium-term and for hydrogen in the long term. Eventually synthesis gas might be made from a variety of carbonaceous feedstocks at the same facility ("carbon refinery").

Unlike the situation for IGCC power plants, there is a strong financial incentive to produce electricity via polygeneration because by so doing the cost of synthetic fuel production can be significantly less than if only synthetic fuel is produced. However, essential to reaching attractive synthetic fuel costs is that the fuel producer must be able to sell the electricity co-product into the electric grid at a remunerative price. A TFEST analysis shows that such a price could correspond approximately to the cost of making electricity from a coal steam-electric plant equipped with SO_2 and NO_X controls.

4. Carbon Refineries in the Long Term

Modernization of coal via gasification puts coal on a path that is also being pursued for other carbonaceous feedstocks. At refineries around the world synthesis gas is being made by gasification of petroleum residuals for the polygeneration of hydrogen, electricity, and steam. (See Figure 4.) There is worldwide interest in F-T liquids derived from natural gas that is also based on first making synthesis gas from natural gas. A leading option for making synthetic fuels from biomass is via gasification; in Sweden, for example, activity is underway to make DME from biomass wastes in the pulp and paper industry.

In the future "carbon refineries" might provide a panoply of energy and chemical products from synthesis gas that is derived from a variety of *carbonaceous* feedstocks-various combinations of coal, heavy oils, petroleum residuals, natural gas,[6] biomass, and even municipal solid waste, (See Figure 5). Rural carbon refineries based on agricultural residues might become important in China-e.g., producing via polygeneration DME (for cooking fuel) and electricity close to where the energy is needed.

Vision for Modernized Coal-by End Use

As shown in Figure 5, modernized coal would evolve from one set of technological options in the near/medium term (2006—2020) to a modified set of options in the long term (beyond 2020).

1. Near/Medium Term

In the medium term, town gas, methanol, F-T liquids, and DME would be produced in polygeneration facilities that make co-product electricity. The markets served would be:

- Domestic heating and cooking in urban areas: town gas as coal replacement
- Cooking fuel for rural areas and small towns: DME, which would augment LPG using the existing LPG infrastructure and would be derived from both coal (2006—2020)

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[6] Including small reserves of natural gas and coal-bed methane far from markets for which it is not cost-effective to develop pipelines.

and biomass (beyond 2015)

- ❖ Industrial heating: town gas as coal replacement
- ❖ Motor vehicle fuel substitutions that require no new infrastructures beyond refineries:
  - o Methanol in blends with gasoline (as gasohol)[7]
  - o F-T liquids in blends with Diesel fuel.
- ❖ Motor vehicle fuel substitution that requires a new infrastructure: DME introduced during 2006—2015-starting with buses and trucks but later also in cars along with a shift to compression-ignition engines.
- ❖ Urban electricity: coal polygeneration facilities co-producing methanol and DME
- ❖ Rural electricity: biomass polygeneration facilities co-producing DME (beyond 2015)

Although in this period coal would not be decarbonized for climate reasons, partial decarbonization and underground CO_2 storage can be carried out as an acid gas management strategy in conjunction with synfuel production. Removal of the acid gases H_2S and CO_2 from synthesis gas is a necessary part of making these fuels. Removing them together and storing these acid gases underground can sometimes be a less costly option than the conventional approach of separating out the H_2S and reducing it to elemental sulfur (see Appendix A). This strategy can make liquid fuels produced from coal in the near term less GHG emissions intensive than petroleum-derived hydrocarbon fuels and provide near term experience with underground storage of H_2S and CO_2 to facilitate a transition later to higher levels of fuels decarbonization.

2. Long Term

In the longer term, when global climate change considerations will have a powerful influence on energy planning in all countries, it is likely that the major energy carriers will be hydrogen, electricity, and one or more carbon-based energy carrier provided in ways such that GHG emissions for the global energy system will be about 50% or less than at present. Such low emissions can be realized from coal via gasification at relatively low incremental costs if CO_2 is removed from synthesis gas and stored underground.

Producing hydrogen from coal with near zero GHG emissions will not be technologically challenging for China, and may turn out to be the least costly way to make hydrogen with near zero emissions (see Appendix B). The major challenges relating to hydrogen are: ◯ scientific uncertainties relating to underground CO_2 storage (many mega-scale demonstration projects are

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[7] Gasohol can be provided to gasoline engine vehicles without significant modification of the engine and fuel system with the methanol blending fraction up to 15% by volume (M15). One liter of methanol used in gasohol can displace 25%~30% more gasoline (by enhancing gasoline performance) than it can as M85 fuel. Therefore, oil import reduction can be maximized if the M15 limit is reached for gasoline before a shift is made to M85 vehicles to achieve further reductions of oil imports. Without M15, gasoline consumption in 2020 would be 170 billion liters/year. If M15 became the norm for gasoline by 2020, some 21 billion liters/year of gasoline could be displaced annually.

needed), and ◯ development of markets for hydrogen - there is intensive ongoing worldwide development of hydrogen fuel cells for vehicles.

Hydrogen would be used mainly in cities. For rural areas carbon-based fuels would be needed, because hydrogen infrastructure is very costly at low energy use densities. Although only partial decarbonization of coal can be realized with carbon-based fuels, total GHG emissions coming from rural areas would be so small that climate mitigation goals for the entire energy economy could still be realized.

Infrastructure Issues

Modernization of coal via gasification will pose new infrastructure challenges for China, but it will provide opportunities as well.

1. Easing the Rail Infrastructure Problem

Modernization of coal could provide opportunities for alleviating the formidable challenges of getting coal to market by rail, which presently accounts for about 70% of rail utilization capacity in China. Polygeneration plants located close to the coal mine could export electricity by wire and liquid fuels by pipeline as an alternative to getting coal to market by rail. Such "minemouth" siting would preclude the option of providing town gas as a polygeneration product, but town gas could be replaced by DME, a safer fuel because it contains no carbon monoxide.

2. Infrastructure for Electricity

Minemouth siting of polygeneration facilities might lead to greater electricity transmission requirements than would otherwise be the case. It will be important for China to keep abreast of and incorporate advances in transmission technology that are being continually made, especially for DC transmission technology, which offers cost advantages for long-distance transmission relative to AC technology.

3. Minimizing the Number of Carbon-Based Energy Carriers

The number of new carbon-based energy carriers should be minimized because infrastructure costs are huge. Thus it is desirable to try to find new carbon-based energy carriers to introduce in the near term that society will want to have even in the longer term. Ideally, there should be only one carbon-based energy carrier in the long term. DME is an outstanding "third" energy carrier candidate (the carbon-based complement to electricity and hydrogen) that can be introduced in the near-term. It can serve many alternative fuel markets, it is virtually non-toxic, and air-pollutant emissions from DME-fueled vehicles are low even without exhaust gas after-treatment.

4. Infrastructure for DME

Introducing DME as a new coal-derived energy carrier requires a new energy infrastructure, because this fuel must be mildly pressurized in canisters, as is the case for LPG. This infrastructure challenge is the main reason why most industrialized countries are not pursuing DME despite its outstanding performance and emissions characteristics. However, Japan is pursuing DME intensively - in part because it is the only industrialized country that widely uses LPG for domestic applications, and it recognizes that future LPG supplies may not be adequate to meet its domestic needs.

China, other developing countries, and Japan have extensive LPG infrastructures that can easily be adapted to DME. For these countries, bringing about a shift to DME will be far easier than for industrialized countries that lack extensive LPG infrastructures.

With respect to DME applications in transportation, China has an advantage relative to most other countries in that its hydrocarbon transport fuel infrastructure is at an early stage of development. However, this advantage would be largely lost if there is a long delay in introducing DME as a transport fuel. Thus there is an urgency to launch a DME economy for transportation during 2006－2015.

5. Infrastructure for Hydrogen

In the case of hydrogen, there is not an urgency for establishing an infrastructure for widely distributed applications, because hydrogen fuel cells and other end use devices are not yet close to being commercially viable. However, in the near term, limited hydrogen infrastructure development might be pursued for applications involving hydrogen refueling of dedicated vehicle fleets-such as for hydrogen-fueled hybrid electric/internal combustion engine buses and also for fuel cell vehicle demonstration projects. Such applications could typically use hydrogen available as a result of excess production capacity at ammonia plants and other chemical process plants.

Recommended Actions by Government

The National Development and Reform Commission (NDRC), especially the Energy Bureau, should clearly articulate the long-term energy strategy for sustainable development, including large-scale coal gasification and polygeneration.

- Develop a detailed cross-sectoral plan for gasification-based coal modernization.
- Identify and remove legislative and regulatory barriers to modernization of coal.
- Given the high rate of investment needed for any strategy to meet China's energy needs, remove barriers for rapid investment of Chinese funds, perhaps through a fast-track mechanism.

Establish the obligation by the power grid to buy gasification-based electricity.

- For an introductory (5~10 year) period offer remunerative prices for qualifying gasification-based projects.
- A date (e.g., in the period 2015—2020) should be set by which all new coal electric generation capacity should be gasification based.
- Establish a mechanism such as a portfolio standard to manage the transition from the introductory period in a manner that promotes competition in gasification power generation.

Establish the obligation by transportation fuel providers to use gasification-derived fuels (such as F-T liquids, methanol, and DME)[8] designed with an emphasis on reducing oil imports.

- By 2020 most gasoline sold should be M15, with a step-by-step implementation from the present.
- By 2020 most Diesel fuel sold should be blended with F-T liquids, with a step-by-step implementation from the present.
- For an introductory (5~10 year) period offer remunerative prices for DME used in transportation, followed by incentives to progressively replace oil imports.

Provide market guarantees to introduce DME for expanding access to clean fuels in rural areas and small towns, primarily for cooking.
Facilitate financing for the modernization of coal.

- Support/promote private-sector investment in polygeneration, e.g., by reduced taxes, low-interest loans, making risk capital available.
- Develop appropriate policy for attracting foreign investment.

Promote multi-sector capacity building and education (e.g., NDRC, MOST, State Environmental Protection Administration, National Natural Science Foundation, electric power utilities, chemical industry association).

- Increase public awareness of the benefits of coal modernization.
- Organize seminars and courses of different levels (for government officials, leaders of enterprises, local government officials, engineering companies, and even students).
- Arrange site visits to already launched projects (and feasibility study projects) for above-mentioned organizations and personnel.
- Involve the concept and technology of modern coal utilization in appropriate courses for university students and technicians.
- Promote the formation of industry associations for targeted areas (e.g., polygeneration association, DME association).

[8] In the transportation sector, this could build on the experiences of Shanxi Province and some cities where there exist strong local incentives and appropriate infrastructure for implementation of such a policy.

Fund and actively engage in more intensive RD&D and studies (NDRC, MOST, and others) in areas such as the following:

- Key technologies for polygeneration, such as gasification technology, large-scale gas turbines, liquid-phase reactors, and new catalyst systems.
- Application of DME as alternative fuel for compression-ignition engines.
- Application of methanol at high concentrations for high compression ratio spark-ignition engines.
- Infrastructure development needs and optimal investment plans required for coal modernization, e.g., understanding optimal siting[9] of polygeneration facilities in the large-scale (post demonstration) phase.
- Role of polygeneration in sustainable urbanization.
- Support/promotion of gasification-based coal modernization projects that have already been approved (Yanzhou, Ningxia, Chongqin, Yantai, etc.).
- Support for additional polygeneration demonstration projects to come on line during 2006—2010, especially in regions with large resources of high-sulfur coal and/or with opportunities for CO_2 utilization or storage.
- International collaborations and demonstrations aimed at improving the understanding of the viability of underground storage of CO_2 (e.g., Carbon Sequestration Leadership Forum).

Support actions that will facilitate the proposed strategy but which are likely to be taken by government for reasons that are not specific to polygeneration:

- More emphasis on including health and environmental costs in the price of fuels.
- Introduction of more ambitious emission standards for electric generation and chemical process plants and for automobiles.
- Introduction of more ambitious standards for urban air quality.
- Liberalization of energy markets with regulations to protect public benefits.
- Freeing up of Chinese funds for investment.
- More emphasis on equal, transparent, and predictable conditions for domestic and foreign investment.
- Facilitation of joint ventures.
- Harmonization of international and Chinese design and construction standards.
- Improvement of the protection of intellectual property rights.
- Streamlining and speeding up of project approval process.
- Modernization of coal mining to reduce significant health, safety, and environmental problems.

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[9] For example, coal rail transport to city-gate conversion plants vs. remote siting with pipelines and electric transmission.

Appendix A: Acid Gas Management in Synfuel Manufacture

In the process for making synthetic fuel via gasification, the acid gases H_2S and CO_2 must be removed from the synthesis gas ahead of the synthesis reactor (see Figure A). The synthesis gas must be cleaned of H_2S to ppb levels to protect the catalysts in the synthesis reactor. Much of the CO_2 must be removed to maximize synthetic fuel production. The recovered CO_2 might be vented, but the H_2S cannot be vented because it is highly toxic. Typically, at plants around the world that make methanol via gasification of coal or petroleum residuals, the H_2S is recovered and reduced to elemental sulfur, which might be sold as byproduct. Once a large gasification-based fuels industry is established, the by-product value of sulfur will be negligible in many cases.

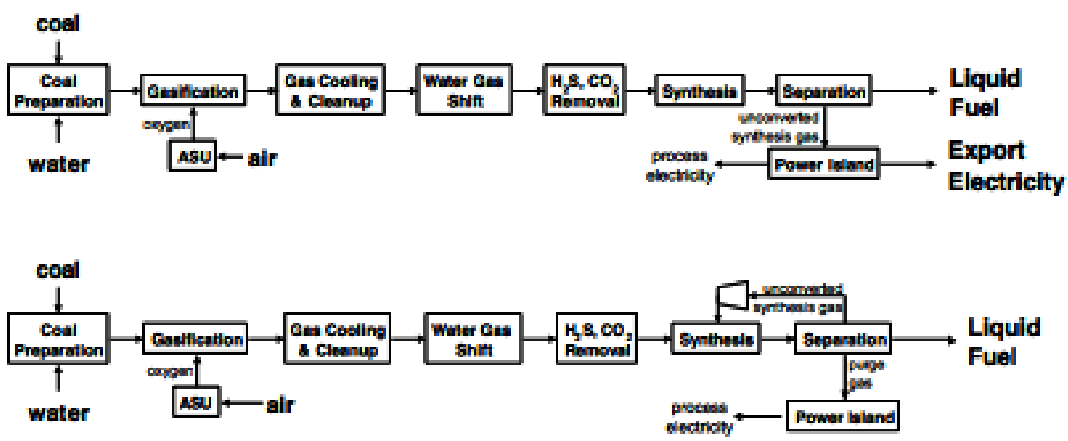

Figure A General System Layout of Making Synthetic Fuels from Coal via Gasification

Two alternative system configurations for fluid fuels production from coal via gasification are shown. The configuration at the top represents "once-through" synthesis with exportable electricity co-product. The configuration at the bottom represents "recycle" synthesis with no net exportable electricity product.

An alternative acid gas management strategy that avoids the costs of separating the H_2S from CO_2 and reducing it to elemental sulfur is to capture the H_2S and CO_2 together using an appropriate solvent, to dry and compress the mixture to liquefy it, and to transport it via pipeline to an underground storage site-e.g., a deep saline aquifer or depleted oil or gas field.

There is already some experience with co-capture of H_2S and CO_2 and co-storage in underground media (aquifers and depleted oil and gas fields) in conjunction with natural gas production from "sour" gas fields, where the natural gas is contaminated with both of the acid

gases H_2S and CO_2. There are 31 such projects in Alberta (Canada) and one in Texas (United States) (Longworth, et al., 1995; Wichert and Royan, 1997; Whatley, 2000). In these projects appropriate solvents are used to remove the acid gases before the natural gas is marketed. Environmental regulations require that the H_2S (or SO_2 if the H_2S is first burned) not be vented to the atmosphere. Originally, this activity involved reducing the H_2S to elemental sulphur, selling the sulphur, and venting the CO_2 to the atmosphere. However, sulphur prices are now so low that a less costly alternative is to not make sulphur but instead to dispose of the H_2S/CO_2 mixtures underground.

Analysis carried out for the TFEST (Williams and Larson, 2003) considered this H_2S/CO_2 co-capture, co-storage scheme (assuming 100 km pipeline transport of the H_2S/CO_2 mixture to a storage site in an aquifer 2 km underground), as well as the conventional scheme that recovers elemental sulfur for both methanol and DME manufacture. The fuel cycle GHG emissions of the H_2S/CO_2 co-capture, co-storage option were found to be no more than half as large as for the conventional scheme, at no increase in fuel cost-in essence, carbon mitigation at no increase in cost, as a byproduct of an innovative approach to acid gas management.

This finding is contingent upon the viability of large-scale underground co-storage of H_2S and CO_2. Although experience with acid gas disposal in conjunction with sour natural gas projects in North America suggests that this strategy is effective, disposal rates for those projects are modest. Many "megascale" demonstration projects (e.g, involving geological CO_2 disposal at rates of the order of one million tonnes CO_2 per year) along with appropriate monitoring, modeling, and scientific experiments, in alternative geological contexts, are needed worldwide to give a high degree of confidence in the viability of this strategy. It is desirable to find out as soon as possible if underground co-storage of CO_2 and H_2S is a viable strategy for widespread applications-both as a climate mitigation strategy and as a sulphur management strategy in synfuels production.

References for Appendix A

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Appendix B: Making Hydrogen from Coal with Near-Zero GHG Emissions

Making hydrogen from coal with venting of the CO_2 co-product is fully established commercial technology that is familiar in China, which produces 5 out of the 40 million tonnes per year of hydrogen produced worldwide-mostly to make ammonia, with a significant and rapidly growing fraction made from coal using modern coal gasification technology.

The technology required to dry, compress, transport, and inject CO_2 underground in depleted oil and gas fields or deep saline aquifers is also fully established commercially-in connection with both enhanced oil recovery operations (mostly in the US), acid gas storage in connection with "sour" natural gas exploitation (mostly in Canada), and the Sleipner Project in the North Sea. And, in contrast to the high cost associated with recovering CO_2 from stack gases of fossil fuel combustion systems and storing it underground, the incremental cost of hydrogen associated with putting CO_2 underground is modest because the CO_2 is available in a relatively pure concentrated stream (whereas it makes up only about 15% of the stack gas of a coal combustion unit). Hydrogen from coal based on commercial technology with underground storage of CO_2 stands out as potentially the least costly means of making hydrogen with near-zero CO_2 emissions-less costly probably even than hydrogen from renewable or nuclear sources based on hoped-for future innovations (Williams, 2003).

Reference for Appendix B

Williams, R.H., 2003: Decarbonized fossil energy carriers and their energy technological competitors, pp. 119-135, in Proceedings of the Workshop on Carbon Capture and Storage of the Intergovernmental Panel on Climate Change, Regina, Saskatchewan, Canada, published by ECN (Energy Research Center of The Netherlands), 18-21 November, 178 pp.