

The Supply of Fossil Fuels

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1. Introduction

The traditional fossil fuels – oil, natural gas and coal – continue to be the dominant sources of primary energy in the world economy. The IEA (2004) estimates that they contributed 79.8% of total primary energy supply (TPES) in 2002. This was slightly less than the 85.1% contributed in 1971, the falling share being due to the rise of nuclear energy in the 1970s and 1980s. Under the Reference Scenario, fossil fuels are expected to contribute 81.9% of TPES in 2030, the increase occurring because of a decline in the relative importance of nuclear energy.¹

The key issue in this paper is to explain how the increased demand for fossil fuels implied by this projection can be brought about on the supply side. While there is little controversy about the ready availability of coal as a growing primary source of energy, doubts have been voiced about the size of oil and gas reserves and their ability to accommodate significant growth in global demands for these primary fuels.

The key point to be made in this paper is the importance of technological change in assessing the future availability of primary energy supplies. The level of reserves of fossil fuels identified at any particular point of time is a product of assumptions about the technologies employed to define naturally occurring resources and the cost of exploiting these reserves. Over time, technological change makes possible higher rates of exploitation of given reserves and reduces the cost of exploiting resources previously regarded as being uneconomic to tap.

2. Oil

Oil Demand and Supply

Oil will continue to account for the largest share in the world's primary energy mix up to 2030 at least. Demand is expected to grow by 57% from 2002 to 2030, with only a marginal drop in today's share of the global energy mix, from 36% in 2002 to 35% in 2030. The transport sector will be increasingly important as a consumer of oil, its share of final energy consumption of oil rising from 47% in 2002 to 54% by 2030. In the developing economies, the demand for oil will rise not only because of transport needs but also because of consumption in the industrial, residential and services sectors (IEA 2004; IEA 2005a).

While oil production in aggregate will continue to rise over the projection period, conventional oil production outside of OPEC will be declining from 2010 and the rate

¹ The overall arithmetic is that power capacity has to rise by 3584GW between 2002 and 2030, representing an average annual increase of 2.4%. Nuclear power provides only 17GW extra, a rise of a mere 0.2% per annum. Hydro-power provides 415GW (up 1.5% per annum), and other renewables rise by 7.2% per annum but provide only 462GW extra. The balance, some 2690GW, has to be supplied by non-renewable resources. In addition, non-renewable resources provide the lion's share of direct use of primary energy in final consumption. Between 2002 and 2030, the demand for primary non-renewable energy is expected to increase by 63.5% (statistics derived from IEA 2004).

of increase in conventional OPEC oil production will peak by 2020, leaving an increasing importance for non-conventional oil in total production and implying higher real oil prices (IEA 2004).² According to the World Energy Outlook 2004 there are sufficient oil resources in place for the period up to 2030, provided that sufficient investments are made and that new technologies for improved oil recovery (IOR) or enhanced oil recovery (EOR) are available (IEA 2004). The IEA World Economic Outlook for 2004 projects in its Reference Scenario an unabated growth of oil supply from 77 million barrels per day (mb/d) in 2000 to 121.3 mb/d in 2030 (IEA 2004). This supply includes an increase in non-conventional oil production from 1.6 mb/d in 2002 to 10.1 mb/d in 2030. This included 6 mb/d of oil sands and tar sands, 2.4 mb/d of gas-to-liquids (GTL) and the remainder (1.7 mb/d) oil shales, coal-to-liquids and biofuels (IEA 2005b).

While the medium-term trend in the supply of crude oil can be projected, the trend in the price of oil is harder to predict. Volatility in oil prices can be occasioned by the impact of severe weather conditions on offshore supplies, industrial strife impacting on short-term supplies, the threat of terrorist strikes against oil infrastructure, and political uncertainties in producing regions like the Middle East, Russia, Central Asia, Venezuela and Africa (The Economist 2006).³

It is not clear how oil production will develop beyond 2030. Apart from the uncertainty about the resource base, there is also uncertainty about the resource development potential. Political instability may limit output growth in the Middle East, Russia and Venezuela in the very long run. On top of this, there is a divergence of opinions about how much of the original oil in place can be recovered through IOR and EOR.

Technology

Incremental change in reducing the cost of finding and producing oil is allowed for in the IEA's Business As Usual (BAU) scenario. Higher-than-expected rates of technological change would include: (i) advanced seismic techniques, allowing for a greatly improved identification of reservoir characteristics; (ii) faster progress in drilling and production engineering; (iii) major advances in deep-water technologies; and (iv) enhanced oil recovery techniques. Improvements in technologies associated with non-conventional oil projects, including oil sands, raw bitumen and extra-heavy oil are also possible. Current planned developments include tar sands in Canada and heavy oils in Venezuela (IEA 2004).

Enhanced Oil Recovery

Following primary and secondary oil production, tertiary production technologies, enhanced oil recovery (EOR), can be applied. A number of such technologies exist, ranging from gas injection, CO₂ injection, combustion, steam and polymer flooding.

² Between 2002 and 2030 the production of conventional oil is expected to increase by 47%, while the proportion of total oil production coming from non-conventional sources is expected to increase from 2% to 8% (IEA 2004).

³ Political uncertainty relevant to the continuity of oil production does not relate to political regime change per se but to the possibility of political dissension leading to failure to maintain production facilities, damage to such facilities and deliberate sabotage.

Their suitability and effectiveness depends on the reservoir and oil characteristics. To some extent, they are (implicitly) included in the assessment of ultimately recoverable oil reserves, and therefore in the category of conventional oil. However, EOR is not yet widely applied. Total EOR at present amounts to just 1-1.5% of global oil production. About half of this is thermal recovery of heavy oil using steam. It is estimated that by using EOR techniques, 300 billion barrels of previously inaccessible crude oil from known reservoirs could be tapped. This is equivalent to the amount of proven reserves in Saudi Arabia (IEA 2005c).

It is worthwhile discussing CO₂ EOR in more detail, as this is an emerging option that could be applied to many oil fields. Supercritical CO₂ is injected into a depleted oil reservoir alternately with the injection of water. The CO₂ and the oil mix in the reservoir, and more oil can be recovered. CO₂ that is produced with the oil is recycled into the reservoir. The additional recovery amounts to 8-15% of the total quantity of original oil in place. CO₂ EOR investment costs have been halved in the last 25 years. This cost will decline further in the future. Future use of CO₂ EOR could increase substantially if the CO₂ is stored permanently, and this storage is valued properly. The feasibility of long-term CO₂ storage in combination with EOR is currently being tested in a number of demonstration projects such as the Canadian Weyburn project (IEA 2005b).

Non-Conventional Oil

Three types of non-conventional oil can be identified: heavy oil, tar sands bitumen and oil shales. Resources of heavy oil are mobile at reservoir conditions, but those of tar sands and bitumen are not. The reserves of extra heavy oils are concentrated in Venezuela, while the tar sands and bitumen are concentrated in Canada. Recoverable reserves are in the order of the oil reserves of Saudi Arabia: 270 Ggbarrels (Ggbl) for Venezuela and 310 Ggbl for Canada.

While the recovery of potential fuel resources from oil sands is quite good using currently available technologies and direct production costs are quite low, it is energy and CO₂ intensive. Total Canadian and Venezuelan production of non-conventional oil is expected to reach 3mbpd of crude oil equivalent by 2010 which would represent 3% of world oil production. IEA (2004) projects a total production from both sources of 6mbpd by 2030. This production is based on very large multi-billion dollar projects whose planning takes time. Such projects require a stable policy environment, a situation that is given for Canada but less evident in the case of Venezuela.

The advanced processing of oil shale would yield a CO₂ emission-intensity almost five times that for conventional oil, although it may be possible to reduce this ratio to three by exploiting new technological options. The world's largest oil shale project was the Stuart project in Australia, but the plant has been closed down because of environmental objections. There are some small oil shale mining projects in Estonia, Brazil and China, but they are of secondary importance. The bulk of the global oil shale resources are located in the United States. High quality reserves amount to more than 5000 Ggbl. There are no plans as yet to develop this resource, and it is unlikely that a significant production will be achieved before 2020 (IEA 2005b).

Synfuels

The Fischer-Tropsch (FT) synthesis for production of synfuels is an established technology. Fossil fuels (natural gas or coal) or biomass are converted into syngas by reforming, autothermal reforming or gasification. In turn, this syngas is converted into diesel and naphtha in a catalytic reaction. South Africa has established this technology on a large scale during the past 50 years with production from a 0.15mbpd coal-to-liquids plant. China has expressed an interest in an advanced version of the process used in South Africa which could add 1.2 mbpd by 2020. A number of other, smaller scale, projects have already started operation or are under construction.

FT-synthesis from unprocessed natural gas is another established technology. Production using this technology is expected to be 1mbpd by 2010, the bulk of which being located in the Middle East (Qatar in particular). Due to the substantial energy loss associated with this technology it only makes economic sense for cheap stranded gas. As the costs of LNG transportation decline such options decline as well. IEA (2004) projects 2.3 mbpd by 2030. The bulk of the stranded gas resources are in politically less stable regions.

In recent years there has been increasing attention given to co-production of electricity and synfuels such as methanol, FT-diesel and hydrogen from coal. Co-production allows a high average load factor which reduces capital cost per unit of product (IEA 2005b).

Conclusions

The net impact of accelerated technological change in these areas would be to improve the competitiveness of oil as a source of energy over what it would otherwise be, thereby facilitating a more rapid expansion of oil refineries and some diversion of emphasis away from low-emitting sources of energy. In addition, a marked switch to the use of unconventional oil reserves would further boost GHG emissions because such reserves are usually more carbon-intensive to exploit than conventional reserves (IEA 2000).

The constraints on oil as a source of energy are twofold. Constraints on supply may begin to emerge after 2030 as low cost supplies of oil peak, or if security issues in some oil producing regions curtail production. A second constraint might be associated with climate change policies that tax the carbon content of fossil fuels. In the SD Vision Scenario of the IEA (IEA 2003) oil as a contributor to TPES drops from 37% in 2000 to 18% in 2050. Along with considerable savings in oil use by residential and commercial services and industry, oil is also progressively displaced in the long term as a transport fuel. This Scenario assumes that oil production peaks at 25% above the level reached in 2000 and then begins to slowly decline.

3. Natural Gas

Competitiveness

The use of natural gas is projected to rise by 89% from 2002 to 2030, by which time its share of the primary energy mix will have reached 25%, up from 21% in 2002

(IEA 2004). Power generation will be the principal driver of the rising gas demand, rising from 36% of total gas use in 2002 to 47% by 2030.

The long-term supply outlook for natural gas depends largely on lowering the cost of long-term transportation. Estimates of conventional gas resources suggest that there will be ample resources to support the projected growth in supply to beyond 2020 (IEA 2001a).⁴

The relatively low carbon content of gas when compared with coal ensures the lowest greenhouse gas emissions of all fossil-fuel based technologies, thereby reducing investment risk when compared with coal-fired plants. The share of natural gas in electricity generation will therefore increase under the BAU Scenario. However, the risk of higher and more volatile gas prices towards the end of the projection period may increase investment risks for gas plants in the very long run (IEA 2004).

In most of the OECD area excluding the major coal-producing regions combined-cycle gas turbine (CCGT) plants have been the preferred option for electricity generation. They have much lower capital costs than any other types of baseload plant, and relatively low construction times are a further advantage when compared with a coal-fired or nuclear plant.

The major medium-term uncertainty for gas is associated with energy security issues. Recent events in Eastern Europe indicate the possibility of disruptions to gas supplies to Europe from Russia and Central Asia. The supply of gas to key markets is vulnerable to terrorist actions and political strife in key supplying regions.

Power Generation Technologies

Efficiencies of natural gas combined-cycle (NGCC) systems are continuing to improve, with some achieving efficiencies of 52 to 55 per cent, and, in those recently built in the United Kingdom and Korea, conversion efficiencies approaching 60 per cent.

The conversion of existing coal-fired power plants to operate on natural gas can significantly increase the efficiency of power generation and reduce carbon emissions. The simplest approach is site repowering, where existing power plant site is reused with an entirely new NGCC system. This approach provides the highest cycle efficiency but requires a greater capital investment. In the more conventional approach of steam turbine repowering, a new gas turbine and heat recovery steam generator are used with the existing steam turbine and auxiliary equipment. Because of equipment age and the fact that the steam turbine was designed for linkage with a coal-fired boiler, this approach results in lower efficiency than site repowering and hence higher operating cost, but has a lower capital cost. A gas turbine can also be coupled to the existing coal boiler, with 80 per cent of the coal firing being maintained. Such an approach could reduce CO₂ emissions by 35 to 40 per cent with only minor dislocation (IEA 2000).

⁴ Shell forecasts peak production from 2025 or later, although some analysts predict a peak as early as 2020 (Rifkin 2002, p. 125). The IEA (2004) suggests that gas reserves are adequate to support the projected demand growth out to 2030.

Technology in the Long Run

The competitive position of natural gas in energy markets would be boosted in the medium term by accelerated change in exploration, production engineering and deep-water technologies (including the use of compact technology that is installed on the sea bed and inside wells instead of expensive offshore platform structures). Major advances could also occur in high-pressure gas pipelines (improved and more resistant materials, and more effective monitoring systems), LNG processing and gas-to-liquids technology. Such advances would have mixed effects on GHG emissions from energy production. By improving the competitiveness of gas against higher-emitting sources of energy such as coal, they would tend to reduce emissions. On the other hand, to the extent that they pre-empted increased penetration of renewable energy technologies, they would have a harmful effect on GHG emissions in the very long run.

A further technological possibility in relation to natural gas is the exploitation of unconventional resources. Three sources are of particular significance. The first, coal-bed methane, has the useful side-effect of reducing methane emissions. The second, which includes tight gas, ultra-deepwater resources and arctic resources, tend to be associated with relatively low emissions of carbon dioxide, even though development costs are very high at present. The third source, gas hydrates, are solids that form under high pressure and at temperatures near the freezing point of water. They primarily occur at the base of the continental margins at depths exceeding 500 metres. They constitute the world's largest hydrocarbon reservoirs. Methods for producing gas from hydrates on a commercial scale have yet to be developed, but are on the long-term horizon as a possible development (IEA 2001a).

Conclusions

The combination of available reserves and technological progress should ensure adequate gas supplies to meet likely demands in both the medium term and long term (out to 2050). The major constraints on gas would be threefold:

1. Security concerns in some regions that are major gas exporters.
2. The high cost of establishing a transmission and distribution network for natural gas.
3. The introduction of carbon-based taxes on fossil fuels.

It should be noted that the third constraint is unlikely to be of major importance until alternative energy becomes much more competitive, since the competitive position of gas against coal and oil would be improved under a carbon taxing regime. It is only in the very long run, when renewable energy and/or nuclear energy become more competitive, that the share of gas in energy markets may come under pressure. It is noteworthy that, under the IEA's SD Vision Scenario the share of gas in TPES is actually higher in 2030 than under the BAU Scenario (27½% against 26%). Under the SD Scenario the share of gas in TPES actually peaks in 2040 (at 27.8%) before declining to 26.4% in 2050 (IEA 2003).

4. Coal

The Market for Coal

IEA (2004) projects the demand for coal in total primary energy supply (TPES) to rise by 51% between 2002 and 2030. This implies a slight decline in its share of TPES over this period – down from 23% to 22%. The growth in coal consumption will be almost entirely due to increased use in power generation. In 2002 power generation absorbed 69% of the total coal supply and in 2030 it is expected to absorb 78%. Coal consumption is projected to increase by only 9% in the advanced economies over this period and by 99% in the developing economies.

Coal resources are vast and widely distributed around the world. This gives coal a major advantage, from an energy-security perspective, over other fuels. However, only some of these resources are economically recoverable using current technology. Nonetheless, using estimates of proven coal reserves (coal that is both technologically and economically recoverable), today's world reserve base represents more than 200 years of current production.

The outlook for coal production and supply costs is subject to less uncertainty than are those for oil and gas. Continued productivity gains should result in some further cost reductions. While coal plants have relatively high capital costs, fuel costs are low relative to natural gas and coal plants will remain highly cost-competitive in the most efficient coal producing regions of the advanced economies. However, in other regions within the advanced economies few new coal-fired plants will be constructed and the anticipation of future environmental regulation will continue to favour gas-based electricity generation. The biggest uncertainty for the coal industry concerns demand, which in turn is heavily dependent on how coal-combustion technologies develop in response to environmental worries. Coal currently emits twice as much CO₂ per kWh as natural gas in power generation. In addition, costly investments are needed to reduce SO_x, NO_x and particulate emissions.

While breakthrough technologies in coal mining are unlikely, there is ongoing scope for significant productivity gains. Where conditions are economically attractive for new investment, there is no shortage of unexploited supply opportunities. The open and competitive nature of the coal supply chain and the steady growth of international trade mean that these opportunities could be readily exploited. Prices could remain highly competitive, especially if oil and gas prices rise in the long term, although coal may be penalised by its high carbon content (IEA 2001a).

Within the power generation sector, natural gas remains coal's main competitor in regions where gas is available and natural gas combined cycle (NGCC) plants offer certain environmental benefits, notably half the CO₂ emissions at the point of use and negligible air polluting emissions in comparison with coal; although supply chain emissions, particularly where liquefied natural gas is used, complicates this simplistic comparison. Yet, bringing more distant reserves of gas to market is proving expensive. So, despite its environmental challenges, coal often has a substantial cost advantage which translates into lower power prices (IEA 2005d).

Energy Efficiency

Accelerated technological change could increase the competitiveness of coal through a number of avenues. Major improvements in coal mining can lower the cost of coal extraction and preparation. Advanced technologies in coal mining include the use of sensors and instruments in controlling operations and automation in the extraction process. A second area offering great potential is clean coal technologies in energy production. A range of technologies offer the prospect of increased production efficiencies in coal-based energy generation (IEA 2004; Australian Coal Association 2004).

The average efficiency of coal-fired generation in the OECD is 36% in 2002 compared with 30% in developing countries. There are many options for improving plant performance and reducing emissions. Low to medium cost improvements can increase fossil-fuelled plant efficiency by 2 to 3.5 percentage points. Current and emerging re-powering technologies can achieve larger reductions in CO₂ emissions, but are only cost-effective in plants close to the end of their technical life. They include: co-firing and re-powering with biomass; re-powering with super critical boiler; re-powering with CHP or gasification. Refurbishment of older thermal power stations gives up to a 12% reduction in greenhouse intensity as well as significant increases in power generation at a significantly lower unit cost than that of a new power plant.

New installations can differ markedly with respect to CO₂ intensity. The latest full-size state of the art plants in industrialised countries rely on supercritical technology with efficiency exceeding 45% with favourable cooling water conditions, while new sub-critical plants can reach an efficiency of 38-39%. Increased working temperatures will further raise the efficiency of supercritical plants, with efficiencies of more than 50% being envisaged. Current demonstration plants based on gasification have an efficiency of 42-43%. Further deployment and development indicate that this could exceed 50% in a similar time frame for advanced forms of supercritical pulverised coal firing. Where demand for heat exists, either for some industries or for district heating, combined heat and power (CHP, or cogeneration) can increase the energy efficiency of coal plants to much higher levels – 80% or more (IEA 2005e).

The consequence of introducing clean coal technologies would be lower emission rates for coal technologies as final energy outputs rise in relation to energy inputs. At the same time, by increasing the competitiveness of coal against lower-emissions sources of energy such as gas and renewable energy, such changes would tend to increase emissions-intensity in the aggregate (IEA 2001b).

Clean Coal Technologies

The majority of the coal used in electricity production is burned in pulverised fuel (PF) boilers heating water to drive steam turbines. However, these PF turbines are inefficient in conversion to energy and give rise to high levels of emissions. These disadvantages have encouraged research into efficiency improvements (better turbines, higher boiler temperatures), alternative methods of combusting coal (gasification, fluidised bed combustion), co-firing with other fuels, and even conversion of coal into alternative types of fuel (such as liquefaction or pyrolysis).

Environmental control technologies have been developed to remove or prevent the formation of SO₂, NO_x and particulates when coal is burned to generate electricity at conventional, coal-fired power stations. These clean coal technologies include coal washing, advanced combustion techniques, and end-of-pipe techniques.

Coal washing reduces the amount of ash in raw coal to facilitate combustion and increase the energy content per tonne. At the other end of the process, particulate control often relies on electrostatic precipitators. The objective is to remove SO₂ and reduce NO_x.

Advanced combustion technologies offer an alternative approach to the above conventional emission abatement measures. The two main technologies are Fluidised-Bed Combustion (FBC) and Integrated Gasification Combined Cycle (IGCC).

FBC reduces air polluting emissions of SO₂ and NO_x by the controlled combustion of crushed coal in a bed fluidised with jets of air. It can be used for a wide range of fuels, slurries, sludge, biomass, coal, coal rejects, refuse-derived fuels, or mixtures of these. The FBC is particularly suited to poorer quality fuels although it is complex to operate. The advantages of burning in a fluidised bed are (i) the ability to burn a wide range of low-grade and difficult fuels as well as mixed fuels; (ii) lower NO_x emissions; and (iii) in-process sulphur capture. The technology is now being used in many countries, including the United States, Australia, China and India (IEA 2005c).

IGCC systems involve gasification of coal, cleaning the gas produced, and combusting it in a gas turbine to produce electricity. Residual heat in the exhaust gas from the gas turbine is recovered in a heat recovery boiler as steam, which can be used to produce additional electricity in a steam turbine generator. IGCC systems are among the cleanest and most efficient of the emerging clean coal technologies.

While efficiency improvements and advanced combustion technologies tend to reduce all polluting emissions, the removal of local pollutants has an energy cost and thus tends to slightly increase CO₂ emissions (IEA 2005e).

SC/USC Technology

Most subcritical boilers have a steam drum where a mixture of water and steam from the boiler is separated into water and steam. The water is recirculated to the boiler while steam passes to the superheater. Supercritical (SC) boilers are based on the 'once through' principle – an arrangement where the water flow matches the rate of evaporation, and allows steam pressure to be increased beyond the point where the density of steam and water are equal. This allows steam conditions with much higher temperature and pressure. As the technology evolved, the development of new ferritic steels permitted boilers to be specified with steam conditions of even higher temperatures at a given steam pressure – ultrasupercritical (USC) boilers.

SC and USC boilers offer the advantage of significantly higher thermal efficiency than similar sized subcritical units. Efficiencies of 40% to 45% have been achieved with SC units while USC units have reached 47%. This represents an increase over

typical PC subcritical units and permits electricity generation with less fuel input and lower emissions of greenhouse gases (IEA 2001b).

Zero Emissions Technologies for Fossil Fuels

The IEA's Working Party on Fossil Fuels (WPFF) has coined the term 'Zero Emissions Technologies' (ZET) for technologies that integrate carbon capture and storage with a variety of energy systems. These technologies will be discussed in greater detail in a later chapter of this report. The ZET concept implies a shift of industry away from methods in which wastes are the norm, and towards integrated systems in which everything has its use. All input streams entering an industrial complex are put to use, either as final products or converted in value-added inputs for other industries or processes. Clusters of industries may thus work in synergy through back and forth exchange of waste or by-products against inputs. The concept also extends to new types of technology for the oil and gas industries and high-efficiency conversion of fossil fuels into electricity or other products, using processes emitting virtually no carbon or other pollutants. It also covers techniques, already deployed around the world, to enhance recovery of oil and gas, and thus extend the cost-effective exploitability of deposits (IEA 2005a).

Moving from existing technologies to ZET equivalents that incorporate a carbon capture stage will clearly have cost implications for coal-based energy systems. It has been estimated that plant capital costs could be between 27 and 82% greater than current systems. Future technological advances will play an important role in the economics of a particular system, and there is potential for considerable cost reductions in more advanced PCC- and IGCC-based technologies coupled with a range of candidate carbon capture technologies.

Conclusions

Unlike oil and natural gas, coal does not face significant long-term supply constraints. The main constraint on coal in the long term is associated with its environmental impacts, particularly in relation to its contribution to greenhouse gas emissions. Clean coal technologies (especially carbon sequestration) provide the means of maintaining coal's competitiveness in the long run in the context of taxes on emissions. The SD Vision Scenario projects the share of coal in TPES falling below 10% by 2050, with most of the decline occurring after 2030. This projection occurs despite carbon sequestration being assumed to take place for 20% of coal utilised (IEA 2003).

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