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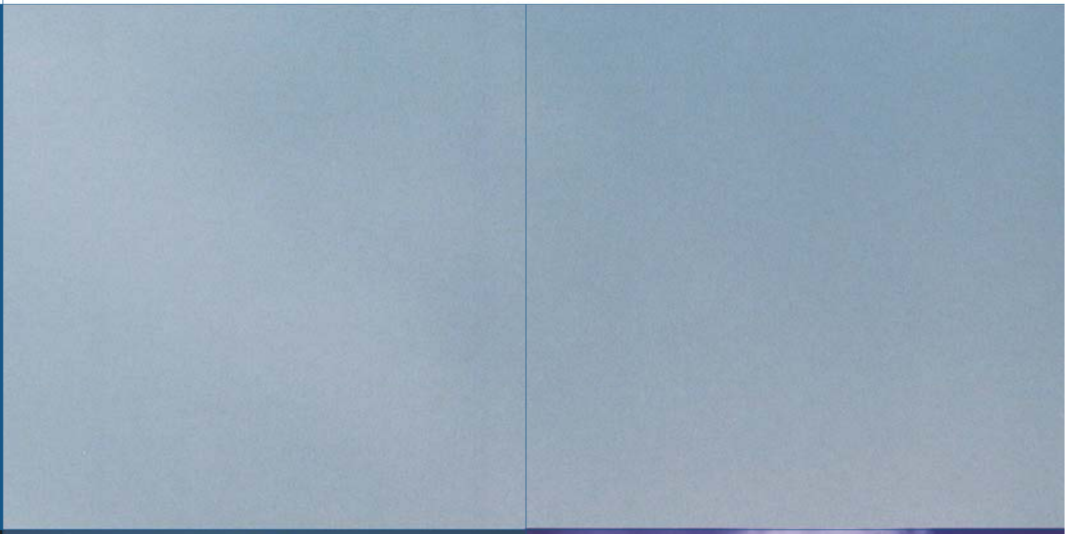
For sustainable energy.

2010 Survey of Energy Resources Executive Summary

World Energy Council



2010 Survey of Energy Resources Executive Summary

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World Energy Council

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Contents

1 Coal

2. Crude Oil and Natural Gas Liquids

3. Oil Shale

4. Natural Bitumen and Extra Heavy Oils

5. Uranium

6. Nuclear

7. Hydropower

8. Peat

9. Bioenergy

10. Solar Energy

11. Geothermal Energy

12. Wind Energy

13. Tidal Energy

14. Wave Energy

15 Ocean Thermal Energy Conversion

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Introduction

The 22nd edition of the World Energy Council's (WEC) *Survey of Energy Resources* (SER) is the latest in the series of reports on the status of the world's energy resources. It covers 15 sources of energy, and provides the most comprehensive resource and reserves assessments and other relevant information for each of them. WEC published the first *Statistical Year Book* in 1933. Already then it included information from more than 50 countries. Nearly 80 years later, the Survey remains a unique global document and a flagship publication of the World Energy Council which also is an essential tool for governments, industry, investors, academia and NGOs.

The latest edition of the *Survey* is a testament to the continued supremacy of fossil fuels and in particular oil as the price-setter in the global energy mix. The data and the commentaries in the Survey highlight the effects of higher oil prices experienced over the past couple of years but also increasing concerns about climate change and energy sector sustainability. Resources and technologies that were previously uneconomic to develop are today experiencing a renaissance and enjoying increased attention and R&D spending.

Despite the global economic crisis of 2008 and 2009, world primary energy demand has been growing and it is expected to continue its growth for decades to come. This is not surprising given the fact that more than a quarter of world's population, i.e. about 1.6 billion people still do not have access to commercial energy. The strongest growth in energy consumption comes from Asia, in particular from China and India. These two countries – according to the International Energy Agency's projections - will account for over 50% of the total growth in global energy demand to 2030. It is important to remember that both these countries are heavy coal users. Fossil fuels currently account for about 80% of primary energy demand and this figure is expected to remain largely the same through to 2030.

The expected environmental implications of the continued global energy system's dependence on fossil fuels call for urgent action across the world. Global warming and climate change are global concerns and should be treated as such. While political discussions and international negotiations continue, the industry is already working on developing more efficient and cleaner technologies. Carbon Capture and Storage (CCS) and other clean coal technologies form a vital part of global efforts to reduce CO_2 emissions. CCS is the only currently available technology that could help reduce CO_2 emissions on a large scale. Both the UN Intergovernmental Panel on Climate Change (IPCC) and the World Wide Fund (WWF) have identified CCS as a critical technology to stabilise atmospheric greenhouse gas concentrations in an economically efficient manner. The IPCC found that CCS could contribute up to 55% of the cumulative mitigation effort by 2100 while reducing the costs of stabilisation to society by 30% or more.

Although the growth in the use of renewable energy sources has been spectacular, as demonstrated in the Survey, it will take decades before renewables will be able to provide a sizeable contribution to meeting energy demand and mitigating climate change. In the meantime, the world should focus on increasing efficiency across the entire energy value chain. Improving performance of power plants around the world can make a significant contribution to the reduction of CO_2 emissions and other pollutants. A one percentage point improvement in the efficiency of a conventional pulverised coal combustion plant results in a 2-3% reduction in CO_2 emissions. Highly efficient modern coal plants emit almost 40% less CO_2 than the average coal plant in service at the present time.

Any review of energy resources is critically dependent upon the availability of data, and reliable, comprehensive information does not always exist. While the basis of the data compilation for the present *Survey* was the input provided by WEC Member Committees, a multitude of national and international sources

Reserves and Resources

In the context of finite resources and reserves, the World Energy Council distinguishes between amounts in place and quantities recoverable, and between proved and additional (i.e. non-proved). Combining these concepts, the following four categories are obtained:

- Proved Amount in Place, of which: Proved Recoverable Reserves;
- Additional Amount in Place, of which: Additional Reserves Recoverable

Whilst each major energy source has its own characteristics, applications, advantages and disadvantages, the fundamental distinction is between those that are finite and those that are, on any human scale, effectively perpetual or everlasting. This criterion is used as the basis for classifying the world's energy resources for the purposes of this *Summary Version* of the *Survey of Energy Resources*.

The Finite Resources comprise a number of organically-based substances – coal, crude oil, oil shale, natural bitumen & extra-heavy oil, and natural gas, together with the metallic elements uranium and thorium. There is one more type of energy resource – peat which is to some extent intermediate in nature, with both finite and perpetual elements in its make-up.

The principal Perpetual Resources are solar energy, wind power and bioenergy, all of which are ultimately dependent on an extra-terrestrial source, namely the Sun. Other perpetual resources are derived from geothermal heat at various depths, and from various forms of marine energy – tidal energy, wave power and ocean thermal energy conversion (OTEC).

The overall conclusion of the 22nd Survey is that there is no shortage of energy resources in the world either today or for decades to come. It is the way we are using these resources that has to change to ensure sustainable energy future.

1. Coal

Coal was the first fossil fuel to be used on an industrial scale, and remains a major force in world energy and has indeed been the fastest-growing worldwide in recent years. After centuries of mineral exploration, the location, size and characteristics of coal resources are well-established. Economically recoverable reserves are reported to exist in some 75 countries and the global total amount of coal at end-2008 of 860 billion tonnes was 1.6% higher than at end-2008. The major changes are attributable to BGR's upward re-assessment of German lignite and a downward revision of South African hard coal.

World coal reserves amount to some 860 billion tonnes, of which 405 billion (47%) is classified as bituminous coal (including anthracite), 260 billion (30%) as sub-bituminous and 195 billion(23%) as lignite.

The countries with the largest recorded coal reserves are basically unchanged from recent editions of the SER: the USA, the Russian Federation and China continue to lead the way, with nearly 60% of global reserves between them, while Australia and India are also in the top rank.

Coal Use and Demand

Coal has many uses critically important to economic development and poverty alleviation worldwide – with the most significant being electricity generation, steel and aluminium production, cement manufacturing and use as a liquid fuel

2008 Proved recoverable coal reserves: the top ten countries

Country	Million tonnes
USA	242,721
Russian Federation	157,010
China	114,500
Australia	76,600
India	56,498
South Africa	48,000
Ukraine	33,873
Kazakhstan	31,300
Serbia	13,885
Poland	7,502

Around 5.8 billion tonnes of hard coal and 953 million tonnes of brown coal were used worldwide in 2008. Since 2000, global coal consumption has grown faster than any other fuel – at 4.9% per year. The five largest coal users - China, USA, India, Japan and Russia - account for around 72% of total global coal use.

The use of coal is expected to rise by over 60% by 2030, with developing countries responsible for around 97% of this increase. China and India alone will contribute 85% of the increase in demand for coal over this period. Most of this is in the power generation sector, with coal's share in global electricity generation set to increase from 41% to 44% by 2030, according to the International Energy Agency (IEA).

The biggest market for coal is Asia, which currently accounts for 56% of global coal consumption. China, and to a lesser extent India, are responsible for a significant proportion of this

Despite the global economic downturn of 2008 and 2009, world primary energy demand is expected to continue to rise over the coming decades, largely driven by the increasing energy needs of developing countries. According to the IEA, global demand for energy is now expected to grow at a rate of 1.5% a year to 2030. China and India alone will account for over 50% of the total increase over this period. Fossil fuels currently supply around 80% of primary energy and this figure is expected to remain largely the same through to 2030.

Coal Trade

Coal is traded around the world, being shipped huge distances by sea to reach markets. Over the last twenty years seaborne trade in steam coal has increased on average by about 7% each year with seaborne coking coal trade increasing by 1.6% a year. Overall international trade in coal reached 938 million tonnes in 2008; while this is a significant amount of coal it still only accounts for about 17% of total coal consumed, as most is still used in the country in which it is produced.

Transportation costs account for a large share of the total delivered price of coal, therefore international trade in steam coal is effectively divided into two regional markets:

Australia is the world's largest coal exporter. It shipped over 252 million tonnes of hard coal in 2008, out of its total production of 332 million tonnes. Australia is also the largest supplier of coking coal, accounting for 53% of world exports.

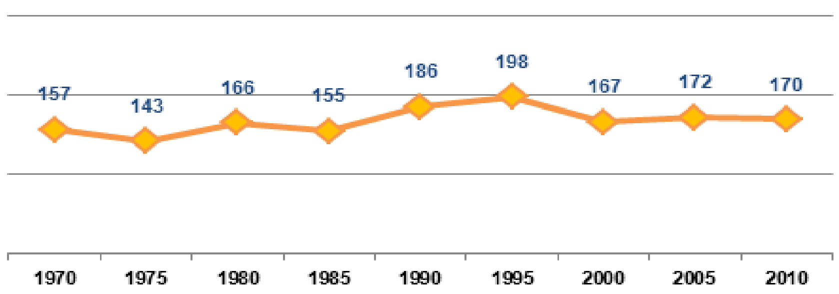
Coal and Energy Security

Coal has an important role to play in meeting the demand for a secure energy supply. As the *Survey* shows, coal is abundant and widespread, with commercial mining taking place in about 70 countries. Coal is the most abundant and economical of fossil fuels; on the basis of proved reserves at end-2008, coal has a reserves to production ratio of well over 100 years, compared with 54 for natural gas and 41 for oil.

Coal is also an affordable source of energy. Prices have historically been lower and more stable than oil and gas prices and coal is likely to remain the most affordable fuel for power generation in many developed and developing countries for several decades.

Both the UN Intergovernmental Panel on Climate Change (IPCC) and the WWF have identified CCS as a critical technology to stabilise atmospheric greenhouse gas concentrations in an economically efficient manner. The IPCC found that CCS could contribute up to 55% of the cumulative mitigation effort by 2100 while reducing the costs of stabilisation to society by 30% or more.

Global Coal Reserves to Production Ratio (RP years) Evolution



In addition to CCS, the increasing efficiency of coal-fired power plants around the world is contributing to emissions cuts in the power generation sector. Improving efficiency levels increases the amount of energy that can be extracted from a single unit of coal. Increases in the efficiency of electricity generation are essential in tackling climate change. A one percentage point improvement in the efficiency of a conventional pulverised coal combustion plant results in a 2-3% reduction in CO_2 emissions. Highly efficient modern coal plants emit almost 40% less CO_2 than the average coal plant in service at the present time.

The Road Ahead

There is no doubt that coal will continue to play a key role as part of a balanced global energy mix, particularly in light of China, India, and other developing countries' use of the fuel to bring millions out of poverty and generate significant economic growth. Technologies to reduce the greenhouse gas emissions associated with coal mining and power generation have been developed and are being deployed around the world.

2. Crude Oil and Natural Gas Liquids

Proved reserves of oil, as assessed for the SER, continue to show a substantial supply base for the short-medium term. The global level of proved recoverable reserves, based on information from WEC Member Committees and supplementary sources, stood at 1 239 billion barrels (163 billion tonnes) at end-2008, some 24 billion barrels (3 billion tonnes) higher than at the end-2005 level published in the previous (2007) edition of the SER.

Total proved recoverable reserves of crude oil and natural gas liquids, as compiled for the present *Survey*, stand close to midway in the range of end-2008 assessments quoted by the other main published sources. The Middle East remains the principal location of oil reserves, with 61% of the global total, followed by Africa with 11%, South America 10%, and Europe (including the whole of the Russian Federation) ~~with~~ 8%, followed by Asia and North America each at around 5%.

However, resource/reserve data categorised in terms of probability levels serve to illustrate the scope for eventual access to further oil supplies, over and above that indicated by current estimates of economically recoverable reserves.

Securing Supplies

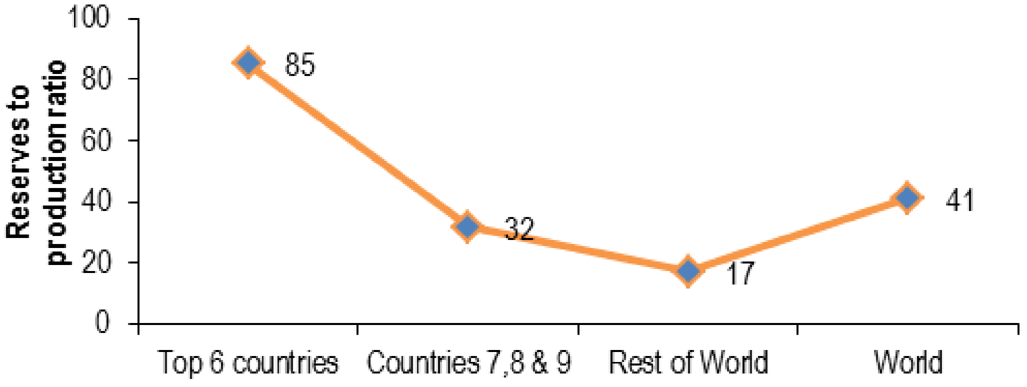
It is not known with great precision what the recoverable quantities of oil and gas are, nor how demand will grow. It is known that they are in great demand, and that they are finite. It is also known that 100% of the oil or gas in the ground cannot be recovered, and that the actual percentage will depend on the recovery processes applied.

Crude oil and natural gas liquids: proved recoverable reserves at end-2008

Country	million tonnes	million barrels
Saudi Arabia	34 518	264 063
Iran (Islamic Rep.)	17 329	137 610
Iraq	15 478	115 000
Venezuela	13 997	99 377
Kuwait	13 679	101 500
UAE	12 555	97 800
Russian Federation	10 647	79 000
Libya/GSPLAJ	5 712	44 271
Nigeria	4 953	37 200
USA	3 429	28 396
Canada	3 126	21 846
Qatar	3 094	25 405
Kazakhstan	2 907	22 762
Algeria	2 731	23 241
China	2 466	18 052

The recovery processes are for the most part physically irreversible processes. The implication is that the amount that can be recovered and used depends on the entire history of past efforts, in addition to future efforts. Flaring gas, early depressurisation of oil and condensate reservoirs, and dilution of oil by inefficient displacement fluids are all examples of this.

Comparison of reserves to production ratios in 2008 (years)



Decisions to invest for high recoveries in the long term are decisions to secure supplies. Solid partnerships are required between governments, industry and financiers that align interests in reaching the bold decisions required, strengthening the ability of the partnership to capture the opportunities and mitigate the risks that come with them.

Immediate investments to gain production in the longer term are based on the decision maker's current opinion of future wellhead values to him. The higher and the more predictable they are, the easier it is to undertake the required efforts to recover the substantial quantities of resources that are economically marginal.

This requires a comprehensive approach to address the economic and social conditions affecting prices at the wellhead, the efficiency and cost of recovery operations and the geological conditions. The international community of governments, industry and financiers all influence the recoverable quantities and can increase them substantially if they act in concert.

The world is indeed fortunate to be in a position to develop technologies to exploit these resources. They were not executed on the basis that the work had been done before – nothing similar had ever been done. They were developed on the basis that they could be modelled in the computer, in a multitude of alternatives and tested against all the conditions that they could encounter.

To secure supplies in this way becomes increasingly important as crude oil and NGL resources become scarcer and are fetched from the harsh environments of the Arctic, deep water areas, heavy oil, natural bitumen and the difficult reservoirs. The world is indeed fortunate to be in a position to develop technologies to exploit these resources.

The needs for energy are increasing as are the requirements for reduced environmental impact. The only way in which these needs can be reconciled under the second law of thermodynamics is to improve efficiencies in every respect. This must take place through improved and constructive international cooperation, inspired by the World Energy Council and informed by the *Survey of Energy Resources*.

3. Oil Shale

Definition of Oil Shale

Most oil shales are fine-grained sedimentary rocks containing relatively large amounts of organic matter (known as ‘kerogen’) from which significant amounts of shale oil and combustible gas can be extracted by destructive distillation. Included in most definitions of 'oil shale', either stated or implied, is the potential for the profitable extraction of shale oil and combustible gas or for burning as a fuel.

Deposits range from small occurrences of little or no economic value to those of enormous size that occupy thousands of square kilometres and contain many billions of barrels of potentially extractable shale oil. Total world resources of shale oil are conservatively estimated at 2.8 trillion barrels. However, petroleum-based crude oil is cheaper to produce today than shale oil because of the additional costs of mining and extracting the energy from oil shale.

Origin of Oil Shale

Oil shales were deposited in a wide variety of environments, including freshwater to saline ponds and lakes, epicontinental marine basins and related subtidal shelves. They were also deposited in shallow ponds or lakes associated with coal-forming peat in limnic and coastal swamp depositional environments. It is not surprising, therefore, that oil shales exhibit a wide range in organic and mineral composition.

Oil Shale Resources

Although information about many oil shale deposits is rudimentary and much exploratory drilling and analytical work needs to be done, the potential resources of oil shale in the world are enormous. An evaluation of world oil shale resources is made difficult because of the numerous ways by which the resources are assessed. Gravimetric, volumetric, and heating values have all been used to determine the oil shale grade. For example, oil shale grade is expressed in litres per tonne or gallons per short ton, weight percent shale oil, kilocalories of energy per kilogram of oil shale or Btu, and others. If the grade of oil shale is given in volumetric measure (litres of shale oil per tonne), the density of the oil must be known to convert litres to tonnes of shale oil.

By-products can add considerable value to some oil shale deposits. Uranium, vanadium, zinc, alumina, phosphate, sodium carbonate minerals, ammonium sulphate, and sulphur add potential value to some deposits. The spent shale obtained from retorting may also find use in the construction industry as cement. Germany and China have used oil shale as a source of cement. Other potential by-products from oil shale include specialty carbon fibres, adsorbent carbons, carbon black, bricks, construction and decorative building blocks, soil additives, fertilisers, rock wool insulating materials, and glass. Many of these by-products are still in the experimental stage, but the economic potential for their manufacture seems large.

Many oil shale resources have been little explored and much exploratory drilling needs to be done to determine their potential. Some deposits have been fairly well explored by drilling and analyses. These include the Green River oil shale in western United States, the Tertiary deposits in Queensland, Australia, the deposits in Sweden and Estonia, the El-Lajjun deposit in Jordan, perhaps those in France, Germany and Brazil, and possibly several in Russia. It can be assumed that the deposits will yield at least 40 litres of shale oil per tonne of shale by Fischer assay. The remaining deposits are poorly known and further study and analysis are needed to adequately determine their resource potential.

By far the largest known deposit is the Green River formation in the western United States, which contains a total estimated in-place resource of some 3 trillion barrels. In Colorado alone, the total in-place resource reaches 1.5 trillion barrels of oil. The Devonian black shales of the eastern United States are estimated at 189 billion barrels. Other important deposits include those of Australia, Brazil, China, Estonia, Jordan, and Morocco.

The total world in-place resource of shale oil is estimated at 4.8 trillion barrels. This figure is considered to be conservative in view of the fact that oil shale resources of some countries are not reported and other deposits have not been fully investigated. On the other hand, several deposits, such as those of the Heath and Phosphoria Formations and portions of the Swedish alum oil shale, have been degraded by geothermal heating. Therefore, the resources reported for such deposits are probably too high and somewhat misleading.

4. Natural Bitumen and Extra Heavy Oil

Natural bitumen (tar sands or oil sands) and extra-heavy oil are characterised by their high density and viscosity and high concentrations of nitrogen, oxygen, sulphur and heavy metals. In each category one country is predominant – Canada in the case of natural bitumen, 70% of worldwide reserves, and Venezuela in the case of extra-heavy oil, with about 98% of presently recorded reserves.

Natural bitumen and extra-heavy oil are the remnants of very large volumes of conventional oils that have been generated and degraded, principally by bacterial action. Chemically and texturally, bitumen and extra-heavy oil resemble the residuum generated by refinery distillation of light oil. The resource base of natural bitumen and extra-heavy oil is immense and not a constraint on the expansion of production. These resources can make an important contribution to future oil supply if they can be extracted and transformed into usable refinery feedstock at sufficiently high rates and at costs that are competitive with alternative sources.

The only natural bitumen deposits presently being commercially exploited on a significant scale are those in western Canada. The three Alberta oil sands areas (Athabasca, Peace River and Cold Lake) together contain at least two-thirds of the world's discovered bitumen in place and at present furnish more than 40% of Canada's domestically-produced crude oil and bitumen.

The only deposit of extra-heavy oil large enough to have a major supply and economic impact on crude oil markets is the Orinoco Oil Belt in the Eastern Venezuela Basin. Production of upgraded extra-heavy oil from this deposit accounts for more than 20% of Venezuela's oil p roduction.

Despite their cost and technical challenges, major international oil companies have found it desirable to acquire, develop, and produce these resources in increasing volumes. Large in-place resource volumes provide a reliable long-term flow of liquid hydrocarbons and provide substantial payoff for any incremental improvements in recovery. High oil prices during 2007 and 2008 spurred new development and production which, in turn, have intensified concern about environmental effects of production increases.

Resource Quantities and Geographical Distribution

Resource quantities are based upon a detailed review of the literature in conjunction with available databases, and are intended to suggest, rather than define, the resource volumes that could someday be of commercial value. Precise quantitative reserves and oil-in-place data for natural bitumen and extra-heavy oil on a reservoir basis are seldom available to the public, except in Canada.

Natural Bitumen - is reported in 598 deposits in 23 countries. No deposits are reported offshore. It occurs both in clastic and carbonate reservoir rocks and commonly in small deposits at, or near, the earth's surface. Natural bitumen deposits have been mined since antiquity for use as sealants and paving materials. In a few places such deposits are extremely large, both in areal extent and in resources they contain, most notably those in northern Alberta, in the Western Canada Sedimentary Basin. Although these oil sands extend eastward into Saskatchewan, resource estimates for this province have yet to be published. The three Alberta oil sand areas, Athabasca, Peace River, and Cold Lake, together contain 1.73 trillion barrels of discovered bitumen in place (Energy Resources Conservation Board [ERCB], 2009a), representing two-thirds of that in the world and at this time are the only bitumen deposits being commercially exploited as sources of synthetic crude oil (SCO). More than 40% of the crude oil and bitumen produced in Canada in 2008 came from the Alberta natural bitumen deposits.

5. Natural Gas

At the end of 2008, 103 countries were reported to possess proved reserves of natural gas. Compared with the level reported for end-2005 total reserves show an increase of 9.1 trillion cubic metres or 5.1%. At the present level of 185.5 tcm (or approximately 6 550 tcf), global gas reserves are equivalent to more than 54 years' production (net of re-injection) at the 2008 rate. The countries with the largest natural gas reserves are still the Russian Federation, the Islamic Republic of Iran and Qatar, but Turkmenistan has now overtaken Saudi Arabia to take fourth place in the global ranking list. By comparison with the 2007 *Survey*, the largest changes in the level of gas reserves relate to Turkmenistan, where a major reassessment resulted in an increase of over 5.5 tcm, the Islamic Republic of Iran, and the USA, reflecting a substantial rise in proved reserves of shale gas. At end-2008, the Middle East accounted for 41% of the world's gas reserves, Europe (including the whole of the Russian Federation) for 27% and Asia for 15%.

Total proved recoverable reserves of natural gas, as compiled for the present Survey, stand close to midway in the range of end-2008 assessments quoted by the other main published sources. The dispersion around the mid-point of about 183 trillion cubic metres is relatively small (+/- 6 tcm), reflecting a high degree of consensus regarding most of the main players, notwithstanding differences in detail and in a few cases sharp disparities in definitions.

Resource/reserve data categorised in terms of probability levels, as reported by WEC Member Committees or extracted from official published sources, serve to illustrate the scope for eventual access to further gas supplies, over and above that indicated by current estimates of economically recoverable reserves.

Global Supply and Demand to 2030

Analysing the main trends in natural gas demand and supply in an energy world that is in transition is a challenging job. Moreover, the global financial and economic crisis starting in mid-2008 raised questions about the impact on gas demand and supply in the short-term, but also as to how long would the world remain in recession and what would be the implications for the future regional and global demand/supply balance. Uncertainty over the political response to climate change, as exemplified at Copenhagen in December 2009, also remains a critical influence in the energy mix.

The IGU analysis of the global gas market was conducted through regional experts, based on country data aggregated at regional level within an agreed global framework of assumptions. On the basis of this bottom-up analysis, the representatives of the gas industry in the working group performed a top-down check on the collected data, resulting in an IGU Reference Case.

The Reference Case showed that a global objective of starting to decrease CO2 emissions will not be met, at least not before 2030. Natural gas, the cleanest and most efficient fossil fuel, could play a bigger role in helping to meet the environmental challenge and to foster the mitigation of climate change. In an alternative scenario, in which there was assumed to be a global agreement at Copenhagen in December 2009 to reduce emissions in the most economic way, it is clear that 'gas can make the difference'. Indeed, increasing the share of natural gas in the global fuel mix, combined with applying more renewable energy, could still start to bend the global CO2 trend line down before 2020.

Primary Energy Demand

To frame gas supply into a wider energy context, an assessment was made of the development of the total primary energy consumption.

Primary energy demand will increase at an average annual growth rate of 1.4% from 2010 and 2030. The share of natural gas will rise from 21% at the present time to 23% in 2030. The relative gas market share varies at the regional level. The share of gas in primary energy demand is expected to grow significantly in Europe, Africa, the Middle East and Asia.

Natural Gas Demand

Natural gas demand is projected to increase by 1.6% per year between 2007 and 2030 to a total of 4.4 tcm. Compared to the previous IGU report of 2006 this projection is about 400 bcm lower. The biggest consuming regions are North America and CIS followed by Europe.

The Residential and Commercial Sector: a moderate growth is expected from 0.7 tcm at present to well over 0.9 tcm in 2030. Although all regions show some growth in this sector, a significant increase is foreseen in Asia, mainly driven by the number of households to be provided with gas. The main driver for gas consumption is the number of households: in developing countries - mainly determined by population growth, whilst in developed countries - by the decreasing number of persons per dwelling. Furthermore, comfort levels and lifestyle are also driving factors.

On the other hand gas demand is reduced by energy conservation and efficient use of resources. New, well-insulated houses with a low heat demand are increasingly using electricity for space heating, often in combination with heat pumps.

With a total projected volume of 1 600 bcm in 2030, the prospects for gas to power are impressive. However, at the same time numerous uncertainties arise. Nuclear power is more or less back on the agenda: is this a threat to the position of natural gas? How will the renewable energies develop: will they take over part of the electricity market? What will be the role of CO_2? An emission-trading scheme of CO_2 taxes will benefit natural gas, however the price of CO_2 is an uncertain factor. What will be the impact of Carbon Capture and Storage plants on gas demand in the power sector? The expected gas demand should be regarded against the background of these issues.

The Transport Sector: despite a large potential, gas consumption in the transport sector (natural gas vehicles) is expected to remain small, increasing from around 18 bcm currently to 60 bcm in 2030. Regionally this sector is currently most significant in Latin America, using about 8 bcm/yr. The main regions with growth in this sector are the Middle East and Asia.

Gas Supply

Natural gas reserves are sufficiently abundant to cover global gas demand for many decades. Moreover, technological developments and higher energy prices have increased the volumes of economic reserves as well as the diversification of sources.

Current developments in unconventional gas, especially shale gas in the United States, are spectacular and have led to upward revisions for the prospects in North America. The potential for unconventional gas in other regions is also significant.

For all regions, future gas supply has been estimated by local members of the IGU. These gas supplies were not forced to equate to regional gas demand but instead show the overall supply surplus or deficit that industry experts in every region think would occur under the common set of assumptions of the Reference Case. The difference between a region's gas demand and its gas supply indicates the need for imports from other regions and the possible volume that might be targeted as exports from the region.

Total natural gas production in North America will increase from 722 bcm in 2005 to 900 bcm in 2030. The largest producer of natural gas in the region is the United States, where depletion of the onshore lower 48 States' conventional reserves is offset by increased production from unconventional sources and from Alaska. Unconventional production increases from 244 bcm in 2006 to 374 bcm in 2030. The Alaska natural gas pipeline is expected to begin transporting natural gas in 2020 and should result in 46 bcm/yr of incremental natural gas supplies being delivered to the lower 48 States.

Gas Production in Latin America & the Caribbean almost doubles between now and 2030. Trinidad & Tobago has the highest average growth rate and Bolivia also grows strongly. Argentina is responsible for the largest share of natural gas production in Latin America; it accounts for 30% of all gas produced in the region and has a 5% average annual growth rate.

The indigenous production of natural gas in Europe (except for Norway) is in decline and from 2004 the UK has been a net importer. Domestic production in Germany, Italy and some eastern European countries is also declining, but production by Norway cannot keep up with this trend.

Currently half of the gas demand in Europe is covered by domestic production. The other half is imported from Russia (25%), Africa (20%, mainly Algeria) and the Middle East (5%). Although high energy prices may stimulate exploration and production, thus delaying the decline to some extent, European production is expected to drop to less than 20% of demand in 2030.

Liquefied Natural Gas

LNG production capacity increased by 50% during the five years prior to 2008. Against the background of global recession, growth slowed from 2008 on, for the first time in this decade. Nevertheless, production capacity will be about 380 bcm/yr during 2010.

High steel prices, high engineering costs and limited human resources (engineers) have caused an increase in the cost of LNG production, now estimated at around US$ 1 000 (and above) per tonne per year.

The expected global share of LNG is 400 bcm in 2015 and 750 bcm in 2030, corresponding to 17% of global gas demand.

Re-gasification capacity will be about twice as much as liquefaction capacity, creating downstream flexibility. LNG receiving terminal usage patterns differ by region: in the Pacific area, where LNG is generally used as a base gas source without large underground storage, seasonal demand fluctuations are absorbed by redundancy in LNG terminal capacities; in Europe and North America, with more underground storage facilities, higher utilisation rates are achieved.

Cost reduction in indigenous shale gas production in the USA has dramatically changed the future need for LNG in North America, with future supply to this region varying, depending on price differentials with shale gas as well as 7 100 km. It could be 8 000-8 500 km in 2010.

Long-term commitments in the LNG value chain are expected to continue, providing the foundation for a huge level of investment in LNG producing countries. However, long-term transactions can have flexible downstream arrangements. The share of genuine spot LNG cargoes will increase, but is not expected to grow as rapidly as the share of short-term contracts (several months or years).

Conclusion

The world is a diverse place, but natural gas will be an important part of the energy mix in all regions. Overall, both for economic and environmental reasons, natural gas remains fundamental to achieving the optimum global energy solution.

6. Uranium and Nuclear Energy

Uranium is a radioactive metallic element which has become a major contributor to world energy supplies through its use as a source of heat (through fission) in nuclear power stations.

The latest biennial joint report of the OECD Nuclear Energy Agency and the International Atomic Energy Agency provides data for 47 countries, with resources classified by the level of confidence in the estimates and by production cost-categories.

Total Reasonably Assured Resources (taken as comparable to proved recoverable reserves of other finite energy resources) increased by 5.6% 4% between end-2006 and end-2008, to reach over 3.5 million tonnes of uranium recoverable at less than US$ 130/kgU. In addition to conventional tonnages estimated to be available at lower levels of confidence, unconventional uranium resources and deposits of thorium, another radioactive metallic element, add to the resource base. Thorium is three times as abundant as uranium in the Earth's crust; current estimates of global thorium resources quoted by the NEA/IAEA range up to more than 6 million tonnes. World output of uranium in 2008 amounted to 43.9 thousand tonnes, with eight countries accounting for almost 93% of the total. Several countries (e.g. Argentina, Bulgaria, Chile, Finland and Spain), which had discontinued production for economic reasons, are considering re-opening closed mines or stepping-up exploration. Others are exploring the possibility of embarking on uranium production for the first time.

Since the early 1990s, the uranium market has been characterised by a substantial disparity between global reactor requirements and mined production, which has been covered by a variety of secondary supplies: reactor fuel derived from warheads and the drawing-down of military and commercial inventories; reprocessing of spent nuclear fuel to produce mixed-oxide (MOX) fuel; recycling of uranium to produce reprocessed uranium (RepU); re-enrichment of depleted uranium tails (left over after enrichment); and enriching at lower tail assays.

There were 437 nuclear power reactors in operation at the beginning of 2010, with an aggregate generating capacity of 370 GW_e. Eleven construction starts were made in 2009, ten of them in Asia. A number of countries uprated existing plants by up to 20%, a highly effective way of bringing new capacity on-line. During 2009, the US Nuclear Regulatory Commission approved eight licence renewals of 20 years each, bringing the number of approved renewals to 59. Licence renewals were either granted or being processed in several other countries.

Higher world prices for fossil fuels have put nuclear power on the agenda of many countries currently with no nuclear generating capacity and have revived interest in many countries with stagnating or declining nuclear capability. Nuclear power has a good and lengthening track record, reflected in over 13 900 reactor-years of experience to date.

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As for almost all commodities, uranium market conditions abruptly changed with the onset of the financial and economic crises in 2008. At the close of 2009 spot prices were about 35% below their mid-2007 peak of US$ 350/kgU. Yet compared with other commodities, the uranium market weathered the storm fairly well. Uranium is generally better protected against aberrations than other markets. For one thing, short run reactor uranium requirements are relatively stable as existing nuclear power plants are usually the lowest-cost generators on the grid. Hence, stagnating or declining electricity demand does not usually affect nuclear generation. However, the level of global nuclear electricity generation has been slipping slightly during recent years owing to reactor closures, decommissioning and lengthy shutdowns for maintenance and repairs (e.g. the Kashiwazaki Kariwa units in Japan, owing to an earthquake). Lower nuclear generation, longer refuelling cycles and higher burn-ups caused annual global reactor uranium requirements to fluctuate between 59 000 tU and 66 000 tU over recent years.

The longer-term market prospects for uranium remain bright. Between 2007 and 2009 construction started on 29 nuclear power plants representing 29.1 GWe of new installed capacity, bringing the total number under construction to 55 reactors at the end of 2009, the largest number since 1992. The post-2000 trend of licence renewals or extensions for many operating reactors continued, especially in the USA. Licence extensions are usually accompanied by replacements of aged plant components, e.g., by more efficient or larger steam generators, turbines, pumps or generators, which can result in power uprates of up to 20%. Nuclear power phase-out policies were moderated in several European countries. Sweden will now allow its existing reactors to operate to the end of their economic lifetimes and to be replaced by new reactors once they are retired. Italy ended its ban on nuclear power and will now allow new construction.

Reactor uranium requirements, therefore, are set to grow. To meet demand, stepped-up investment in uranium exploration and mine development must be made, especially if the supply of secondary sources declines after 2013, when the Russian downblending programme of highly enriched uranium to reactor fuel grade expires as planned that year.

The uranium market remains subject to political conditions. Most prominent still are the 1994 HEU Agreement (often referred to as the Megatons-to-Megawatts programme), which was implemented through a 1994 contract between the USA and Russia, and the antidumping suspension agreement between the USA and Russia plus five central Asian uranium-producing countries.

After almost eight years of ascent to US$ 350/kgU, spot uranium prices fluctuated erratically around a general downtrend beginning in mid-2007, with spot prices amounting to about US$ 115/kgU by the end of 2009 – in large part due to the overall uncertain economic and financial prospects, but also to much reduced ‘paper’ transactions with selling exceeding buying. Note: the decline of spot prices started in mid-2007 well before the financial and economic crises of 2008. Two factors were chiefly responsible for this turnaround - the return (or expected return) into service of large mining capacities that had previously encountered technical problems, and the market’s response to the additional capacities resulting from the accelerated investment in new mines and a general perception of now looser market conditions.

Production

By end-2008, uranium had been produced commercially in 17 countries. In May 2009 Malawi became the 18th producer. Three further countries produce minute amounts as part of mine rehabilitation programmes.

The market continued to rely on secondary uranium sources to close the gap between reactor requirements and mined uranium. In 2008, secondary supplies continued to consist of strategic stockpiles and fissile material from nuclear weapons programmes of Russia and the USA, sold after HEU to LEU (highly enriched uranium to low enriched uranium) conversion as reactor fuel (about 50%), utility held stocks, re-enrichment of tails, reprocessed uranium and mixed oxide fuel closing.

The top three producers also dominate the resource situation. Together Canada, Kazakhstan and Australia hold 50% of global economically recoverable uranium resources (current conditions and at production costs of less than US$ 130/kgU). Through the inclusion of the less than US$ 260/kgU category, Russia now ranks as the country with the third largest identified uranium resources, slightly ahead of Canada.

Conclusion

Like all commodity markets, uranium has encountered a good deal of turbulence and volatility. Unlike most commodities, investments in the nuclear sector are of a long-term nature with extended lead times and are thus less susceptible to short-term economic events. Despite a steep decline from the peak levels in 2007, uranium spot prices today are substantially higher than 10 years ago and are expected to remain at the levels necessary to attract investment in new mining capacity in line with future reactor requirements. Nuclear fuel resources are plentiful but they need the mobilisation of above-ground investment funds to unlock their below-ground potentials.

Nuclear Power Plants in Operation and Under Construction

During the first decade of the new millennium, annual electricity production from the global fleet of nuclear power plants ranged between 2 544 TWh and 2 661 TWh. The 2009 production of 2 568 TWh translates into a market share of 14%, i.e., every seventh kilowatt-hour produced in the world was generated by nuclear power. The market share has been declining slowly but consistently since the turn of the millennium, as overall electricity generating capacity has grown faster than nuclear power and also because of the temporary unavailability of several reactors, such as those at the 8.2 GW_e Kashiwazaki-Kariwa nuclear power plant in Japan, which was shut down in July 2007 after a major earthquake. After in-depth safety inspections and seismic upgrades, two of the seven units were restarted and connected to the grid in 2009.

Current expansion, as well as near-term and long-term growth prospects, remain centred on Asia. Of the eleven construction starts in 2009, ten were in Asia. As shown in Table 6.5, 36 of the 55 reactors under construction are in Asia (including the Middle East), as were 30 of the last 41 new reactors to have been connected to the grid. China's target is 40 GW_e of nuclear power capacity in 2020, compared to 8.4 GW_e today. Indian Prime Minister Manmohan Singh, in opening the International Conference on Peaceful Uses of Atomic Energy in New Delhi in September 2009, said India could potentially install 470 GW_e by 2050.

In Europe, nuclear power phase-out policies were moderated in several countries. Sweden will now allow its existing reactors to operate to the end of their economic lifetimes and to be replaced by new reactors once they are retired. Italy ended its ban on nuclear power and will now allow new construction. Belgium decided to postpone the first phase of its planned phase-out by ten years. Closure of its reactors had been scheduled to take place between 2015 and 2025. In Germany, following the change of Government, discussions to postpone the phase-out were started.

Economics

Generally, existing operating nuclear power plants continue to be highly competitive and profitable. The low share of fuel costs in total generating costs makes them the lowest-cost base load electricity supply option in many markets. Uranium costs account for only about 5% of total generating costs and thus protect plant operators against resource price volatility. Recently the prices of energy resources, materials used in power plants and commodities have been high, but generating costs of nuclear power plants have been barely affected, despite record-level uranium spot prices of US$ 350/kgU in 2007 (compared with US$ 20-30/kgU during 2000 to 2003).

On a levelised cost of electricity basis (LCOE), new nuclear build is generally competitive with other generating options. The 'front-loaded' cost structure of nuclear plants (i.e. the fact that they are relatively expensive to build but inexpensive to operate) has always been an investment risk factor and a financial challenge, especially in liberalised electricity markets.

The 2005 OECD report *Projected Costs of Generating Electricity* (NEA and IEA, 2005), prepared by a diverse group of experts from vendors, utilities, research organisations and national and international governmental institutions, showed an investment cost range for nuclear power of US$ 1 000-2 500/kW_e, and found that nuclear power fared well compared to alternative generating options[1].

However, investment costs for all power plants began to climb steeply around 2006 and by 2008 had more than doubled, both for conventional coal technology and, especially, for nuclear power

Projected growth for Nuclear Power

Each year the IAEA updates its low and high projections for global growth in nuclear power. In 2009, despite the financial and economic crisis that started in late 2008, both the low and high projections were revised upwards. In the updated low projection, global nuclear power capacity reaches 511 GW_e in 2030, compared to a capacity of 370 GW_e at the end of 2009. In the updated high projection it reaches 807 GW_e. These revised projections for 2030 are 8% higher than the projections made in 2008 (IAEA, 2009b). The upward shift in the projections is greatest for the Far East, a region that includes China, Japan and the Republic of Korea. Modest downward shifts in the projections were made for North America and for Southeast Asia and the Pacific.

Conclusions

Nuclear power is back on the agenda of many countries, essentia**lly for three reasons: predictable and stable** long-term generating costs, energy security, and its climate-change mitigation benefits. Its economic competitiveness depends on local conditions including available alternatives, market structures and government policy. Nuclear power is not the ‘silver bullet’ to solve all the energy challenges before us. Deployment of nuclear energy should be preceded by comparative analyses of all available options. It also requires a strong and long-term commitment on the part of governmental institutions and utilities as well as public acceptance. Good governance, transparency and stakeholder involvement in the decision process are therefore key for a decision to invest in the nuclear option.

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7. Peat

Peat consists of partially decomposed organic material, derived mostly from plants, that has accumulated under conditions of waterlogging, oxygen deficiency, acidity and nutrient deficiency. It is an intermediate fuel, part way between the biomass of which it was originally composed and the fossil fuel (coal) that it would eventually become, given appropriate geological conditions. It is still being formed in many parts of the world, and is therefore to a certain extent 'renewable'. Peat's intermediate status has been recognised by the IPCC, which has reclassified it from a fossil fuel to a separate category ('peat') between fossil and renewable fuels.

The world's peat resources are enormous: the total area of peatlands is about 4 million km^2, or some 3% of the total land surface. The main deposits are in North America and the northern parts of Asia, together with northern and central Europe and Indonesia. An indicative estimate of the amount of peat in situ is in the order of 6 000-13 800 billion m3.

Peat has many applications. In the energy field, it is used as a fuel for the generation of electricity and heat, and directly as a source of heat for industrial, residential and other purposes. At the present time, the principal producers (and consumers) of fuel peat are Finland, Ireland, Belarus, Sweden and the Russian Federation. Despite the widespread distribution of peat resources, consumption for energy purposes outside Europe is essentially negligible. Global consumption is around 17 million tonnes per annum, derived from a very small proportion of the total area of peatland: in the EU, only some 1 750 km^2 (0.34% of total peatland) is used for energy peat production.

Uses of Peat

Peat has a large number of uses, which may be classified under three headings:

- Energy (as fuel for electricity/heat generation, and directly as a source of heat for industrial, residential and other purposes;
- Horticultural and agricultural (e.g. as growing medium, soil improver, cowshed/stable litter, compost ingredient);
- Other (e.g. as a source of organic and chemical products such as activated carbon, resins and waxes, medicinal products such as steroids and antibiotics, and therapeutic applications such as peat baths and preparations).

Future Developments in the Use of Peat for Energy

VTT Technical Research Centre of Finland is experimenting with gasification equipment designed for the development of second-generation transport biofuels. In this process, synthesis gas will be refined from biomass for the production of diesel fuels. In addition to synthesis applications, the work involves development of new solutions for gas turbine and fuel cell power plants, as well as for the application of hydrogen for transport purposes. The gasification plant will be able to utilise any carbonaceous raw material, including forest industry residues, bark, biomass from fields (including peat fields), refuse-derived fuels and peat.

Peat from a Climate Impact Point of View

The Intergovernmental Panel on Climate Change (IPCC) changed the classification of peat from fossil fuel to a separate category between fossil and renewable fuels (25th session of IPCC, Port Louis, Mauritius, 2006). Peat now has its own category: ‘peat’. The emission factor of peat is similar to fossil fuels.

Wise Use of Peat

The International Peat Society (IPS) joined with the International Mire Conservation Group (IMCG) to develop a procedure for the reasoned and wise use of peat and peatlands globally (Joosten and Clarke, 2002). This contains sound advice for the peat industry to adopt the ‘wise use’ approach and will mean that most of the remaining peat bogs in Europe and North America will not be utilised (less than 0.4% of the total peatland area in Europe is currently used in this way) and those that are will have after-use plans, to be implemented at the industry’s expense once the extraction work has ended. In most cases, former extraction sites are destined to become CO_2 sinks once again.

8. Hydropower

Hydro-electric power is currently easily the largest of the perpetual or so-called Renewable energy resources. There is one sense in which part of the hydro resource is indeed 'Renewable', in that it is quite common for a series of power plants on the same watercourse to 're-use' the same flow of water, thus effectively increasing the utilisation of its technical potential.

Hydro contributes to electricity generation in 160 countries. Five (Brazil, Canada, China, Russia and the USA) account for more than half of global hydropower production.

The least-cost way to increase hydro generating capacity is almost always to modernise and expand existing plants, where this is an option. Most of the hydro plant presently in operation will require modernisation by 2030. While capacity expansions are generally made at existing hydro stations, there are sometimes opportunities for installing generators at non-hydro dams. There are 45 000 large dams in the world and the majority do not possess a hydro component.

Development of hydro capacity has a long-term economic advantage: annual operating costs are very small in comparison with initial capital costs, to a large extent insulating hydro from fuel price rises. Another advantage stems from the flexibility of storage hydro (using reservoirs) and, where appropriate, pumped–storage schemes, which helps to ensure total system security and quality of supply in hybrid power systems, whether in conjunction with fossil fuels or with the growing army of Renewables – initially mainly wind and geothermal, but in due course also solar, bioenergy and marine power.

Major challenges for the hydro sector include developing more appropriate financing models and finding optimum roles for the public and private sectors. Investor confidence is a vital factor: in developing markets, such as Africa, interconnection between countries and the creation of power pools should assist in this regard. Feasibility and environmental impact assessments carried out by the public sector, prior to inviting tenders from developers, would help to promote greater private-sector interest in future projects.

The Potentials Debate

There is considerable debate regarding the quantification and classification of the world's hydropower resources.

Worldwide technical potential, estimated by the World Atlas at 14 604 GWh/yr, is increasingly challenged as it tends to be based only on specific sites that have been studied at some point in the distant past. It thus tends to exclude other sites that could be developed.

Economically feasible potential, estimated by the World Atlas at 8 771 GWh/yr, is also questioned on the basis that much of the evaluation is based on energy prices at different times in the past, again tending to underestimations

Notwithstanding the above, the IHA estimates that, if the global level of deployment were to equate to the level already realised in Europe, only one-third of the realistic hydro potential has been developed to date. This estimate, in itself, is considered to be conservative, given that considerable new development continues in the European region. It is clear that the growth potential within the hydropower sector remains significant.

Development, especially in the less-developed regions such as Africa and Asia, will rely heavily on the availability of long-term funding mechanisms and partnerships.

Orders for hydropower equipment clearly demonstrate that hydro development continues to show strong growth well into the future.

As the use of renewable energy expands, the flexibility of hydropower will assume greater importance. By matching the other renewable energies with hydropower, synergies develop from hydro's capacity to supply power on demand, which allows for the balancing out of variability, as well as supplying the peak load. Unless the incentives are in place to capitalise on this flexibility, the substantial benefits it offers will be lost.

The increasing need for storage

Most hydropower projects were developed to provide base load to the power system, and this pattern will continue in developing countries.

Currently, there are more than 127 GW of pumped storage throughout the world[2]. Recent reporting in the technical press indicates that at least 15 projects are under construction in nine countries, and that these will add a further 8.8 GW of capacity. The power plants range in size from 150 to 1 353 MW.

It is anticipated that the market for pumped storage will increase by 60% over the next four years.

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[2] HRW, Dec 2009, www.hydroworld.com, accessed 26/01/2010.

9. Bioenergy

The term Bioenergy denotes the use of vegetable matter as a source of energy; it covers a variety of fuels (wood, crops grown for fuel, agricultural residues, municipal solid waste, landfill gases, etc.), with applications in all the major sectors of energy consumption – power generation, transportation, industry, households, etc.

The largest category under the Bioenergy heading is Wood, which in its various forms accounts for about half of the estimated total world supply of combustible Renewables and waste (some 48 exajoules). Wood fuels comprise three main commodities: fuelwood, charcoal and black liquor (a by-product of the pulp and paper industry). Global wood consumption for energy purposes in 2005 was approximately 22 EJ, comprising 17.9 EJ of fuelwood, 1.4 EJ of charcoal and 2.7 EJ of black liquor.

Fuelwood consumers are of two very different types: in industrialised countries, the present-day wood user is likely to use a highly-efficient combustion appliance under strict regulations regarding emissions, whereas the typical developing-world consumer uses small, inefficient and highly-polluting fires and stoves. Indoor air pollution is a major health problem in less-developed countries.

After charcoal production, the next largest secondary transformation of biomass is electricity generation. CHP plants have been operated by biomass-processing industries such as sugar, wood products and chemical pulping for many years, with some producing a surplus which is exported to national or regional networks. In more recent times, they have been joined by biomass-fired CHP linked to district heating schemes (fuelled by straw in Denmark and by wood residues in Finland and Sweden). Co-firing biomass with coal has also been successfully introduced in some locations. The estimated worldwide generation of electricity from biomass amounted to about 183 TWh in 2005, of which nearly three-quarters was produced from solid biomass, 14% from biogas and 12% from municipal solid waste.

Interest in biofuels – ethanol and biodiesel – is at an all-time high. The continued increases in the price of crude oil in 2005 and 2006 resulted in a reversal of the traditional relationship of the price of bioenergy to that of crude oil. For the first time since the 1930s, the price of oil imported into the USA exceeded that of domestically-grown corn (maize). Many countries have raised their targets for biofuels and large production gains have been achieved, notably in the USA and Brazil. It is estimated that world production of ethanol in 2006 was equivalent to about 1.1 EJ, of which the USA accounted for 40% and Brazil for 37%.

The other significant biofuel is biodiesel, which is currently derived from vegetable oils, animal fats and grease by esterification. The resulting product is blended with conventional diesel oil, in proportions ranging from 5% to 20%. The expansion of biofuels is not without controversy, as the production of ethanol from corn is only marginally energy-positive at about 1.4:1, while that from Brazilian sugar-cane has a ratio of about 8 units of Renewable liquid fuel to 1 unit of fossil-fuel input. Moreover, production of corn and ethanol is heavily subsidised in the USA and EU countries, whereas Brazil has foregone most agricultural subsidies to its sugar industry.

Given the existing large-scale use of forest resources for fuel, the future expansion of biomass supply for energy purposes will come primarily from two streams: agricultural residues and energy crops, such as switchgrass in the USA and miscanthus in Europe, planted on the land available, which will predominantly be in countries with large land areas and relatively low population densities.

Biomass Resources

At present, forestry, agricultural and municipal residues, and wastes are the main feedstocks for the generation of electricity and heat from biomass. In addition, very small shares of sugar, grain, and vegetable oil crops are used as feedstocks for the production of liquid biofuels. Today, biomass supplies some 50 EJ globally, which represents 10% of global annual primary energy consumption.

There is significant potential to expand biomass use by tapping the large volumes of unused residues and wastes. The use of conventional crops for energy use can also be expanded, with careful consideration of land availability and food demand. In the medium term, lignocellulosic crops (both herbaceous and woody) could be produced on marginal, degraded and surplus agricultural lands and provide the bulk of the biomass resource. In the longer term, aquatic biomass (algae) could also make a significant contribution. Based on this diverse range of feedstocks, the technical potential for biomass is estimated in the literature to be possibly as high as 1 500 EJ/yr by 2050, although most biomass supply scenarios

Whatever is actually realised will depend on the cost competitiveness of bioenergy and on future policy frameworks, such as greenhouse gas emission reduction targets. Growth in the use of biomass resources in the mid-term period to 2030 will depend on many demand and supply side factors. Strong renewable energy targets being set at regional and national level (e.g. the European Renewable Energy Directive) are likely to lead to a significant increase in demand.

Other factors that may affect biomass potential include the impact of biotechnology, such as genetically modified organisms, water availability, and the effects of climate change on productivity.

Drivers for increased bioenergy use (e.g. policy targets for renewables) can lead to increased demand for biomass, leading to competition for land currently used for food production, and possibly (indirectly) causing sensitive areas to be taken into production. This will require intervention by policy makers, in the form of regulation of bioenergy chains and/or regulation of land use, to ensure sustainable demand and production. Development of appropriate policy requires an understanding of the complex issues involved and international cooperation on measures to promote global sustainable biomass production systems and practices. To achieve the bioenergy potential targets in the longer term, government policies and industrial efforts need to be directed at increasing biomass yield levels and modernising agriculture in regions such as Africa, the Far East and Latin America, directly increasing global food production and thus the resources available for biomass.

Different technologies exist or are being developed to produce electricity from biomass. Co-combustion (also called co-firing) in coal-based power plants is the most cost-effective use of biomass for power generation. Dedicated biomass combustion plants, including MSW combustion plants, are also in successful commercial operation and many are industrial or district heating CHP facilities

In the transport sector, first-generation biofuels are widely deployed in several countries, mainly bioethanol from starch and sugar crops and biodiesel from oil crops and residual oils and fats.

First-generation biofuels face both social and environmental challenges, largely because they use food crops which could lead to food price increases and possibly indirect land-use change. While such risks can be mitigated by regulation and sustainability assurance and certification, technology development is also advancing for next-generation processes that rely on non-food biomass (e.g. lignocellulosic feedstocks such as organic wastes, forestry residues, high-yielding woody or grass energy crops and algae). The use of these feedstocks for second-generation biofuel production would significantly decrease the potential pressure on land use, improve greenhouse gas emission reductions when compared to some first-generation biofuels, and result in lower environmental and social risk. Second-generation technologies, mainly using lignocellulosic feedstocks for the production of ethanol, synthetic diesel and aviation fuels, are still immature and need further development and investment to demonstrate reliable operation at commercial scale and to achieve cost reductions through scale-up and replication. The current level of activity in the area indicates that these routes are likely to become commercial over the next decade. Future generations of biofuels, such as oils produced from algae, are at the applied R&D stage, and require considerable development before they can become competitive contributors to the energy markets.

Further development of bioenergy technologies is needed, mainly to improve the efficiency, reliability and sustainability of bioenergy chains. In the heat sector, improvement would lead to cleaner, more reliable systems linked to higher-quality fuel supplies. In the electricity sector, the development of smaller and more cost-effective electricity or CHP systems could better match local resource availability. In the transport sector, improvements could lead to higher quality and more sustainable biofuels.

Bioenergy Markets

The predominant use of biomass today consists of fuel wood used in non-commercial applications, in simple inefficient stoves for domestic heating and cooking in developing countries, where biomass contributes some 22% to the total primary energy mix. This traditional use of biomass is expected to grow with increasing world population. However, there is significant scope to improve its efficiency and environmental performance and thereby help reduce biomass consumption and related impacts .

Globally, the use of biomass in heat and industrial energy applications is expected to double by 2050 under business-as-usual scenarios, while electricity production from biomass is projected to increase, from its current share of 1.3% in total power production to 2.4 – 3.3% by 2030 (corresponding to a 5 – 6% average annual growth rate).

10. Solar

The Sun is the most abundant permanent source of energy for its planet Earth. Solar energy is available both directly as solar radiation and indirectly in the form of power from wind, biomass, hydro, and marine sources. The Solar chapter of the *Survey of Energy Resources* is concerned exclusively with the direct use of solar radiation.

The annual solar radiation reaching the earth is over 7 500 times the world's annual primary energy consumption of 450 exajoules; it varies from place to place, with some parts of the earth receiving a much greater irradiance than the average annual level of 170 W/m^2. However, there is a useable solar resource in virtually all parts of the world, and economically attractive applications are not confined to the sunniest regions.

There are two basic types of device currently used to capture and utilise solar radiation:

- solar thermal collectors, which are used to heat air, water or other liquids, depending on the application;
- photovoltaic (PV) collectors, which convert sunlight directly into electricity.

Within the first category, non-concentrating (or flat-plate) solar collectors, commonly installed as roof-mounted panels, can produce temperatures up to about 100^{o}C, with applications in the heating and cooling of buildings, and the provision of domestic hot water and industrial process heat. Medium-temperature concentrating collectors such as parabolic troughs/dishes provide temperatures of 100-500^{o}C, with applications in process heat, refrigeration and electricity generation; much of the heat used in industrial processes is required at less than 250^{o}C. Central-receiver types of solar concentrating collectors can produce temperatures as high as 1 000^{o}C or more, and are used to generate electricity and in industrial furnace applications.

PV panels are solid-state and are therefore very rugged, with a long life. Currently, the commonest panels are based on crystalline and polycrystalline silicon solar cells. Their efficiency has gradually increased, while costs have declined. A major advantage of PV devices is that they can be installed as stand-alone systems, providing power ranging from microwatts to megawatts. In 2009, sales of PV modules for terrestrial applications exceeded 7 2001 700 MWp. The global market has been is growing at a phenomenal rate: an average of 47% per annum over the past five years.

There is a growing trend towards the use of passive solar in conjunction with Building Integrated Photovoltaics. Passive solar building designs can reduce the conventional energy consumption by as much as 75%. Such designs use knowledge of the position of the sun either to allow sunlight to enter the building for heating or to shade the building for cooling, and employ natural ventilation and daylighting.

Solar Collectors

Solar thermal collectors are used to heat air, water or other fluids, depending on the applications, while solar photovoltaic (PV) collectors are used to convert sunlight to electricity directly. High-temperature solar thermal collectors are also used to produce electricity indirectly via thermodynamic cycles. Non-concentrating (or flat-plate) types of solar collectors can produce temperatures of about 100°C or less, which is applicable for many uses such as building heating and cooling, domestic hot water and industrial process heat. Medium-temperature concentrating collectors such as parabolic troughs or parabolic dishes may be used to provide temperatures from about 100°C to about 500°C. Such collectors may be used for various applications from refrigeration to industrial process heat and electricity generation. Central-receiver types of solar concentrating collectors are able to produce temperatures as much as 1 000°C or even higher. Therefore, they are used to produce electrical power and as high-temperature furnaces in industrial processes.

PV panels are solid-state and are therefore very rugged, with a long life. At present, panels based on crystalline and polycrystalline silicon solar cells are the most common. However, thin-film solar panels, especially cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) are gaining market share because of their lower costs. Their efficiencies have gradually increased, while costs have decreased. For example, the efficiencies of multijunction cells and concentrating PV have been reported to be as high as 40%, and most panels available in the market have efficiencies of the order of 15%. The retail price of PV panels came down from about US$ 30/W about 30 years ago to about US$ 2/W in 2010. Thin-film solar cells based on CdTe which use much less material, have production costs less than US$ 1/W. Because of lower cost and therefore lower retail prices, they have steadily increased their global market share.

Solar Energy Applications

The energy in solar radiation can be used directly or indirectly for all of our energy needs in daily life, including heating, cooling, lighting, electrical power, transportation and even environmental cleanup. Many such applications are already cost-competitive with conventional energy sources, for example, PV in remote applications is replacing diesel generator sets. Some applications, such as photovoltaics and solar heating are better known and popular, while others such as solar detoxification of contaminated waters or solar distillation are less known.

Solar water heating is the most developed solar technology and is very cost-effective when life-cycle costs are considered. However, the initial costs (capital investment) of solar water heaters are many times higher than those for electric water heaters. Therefore, most people opt for electric water heaters. In many countries, governments have adopted policies and financing mechanisms that make it easier for consumers to buy solar water heaters. For this reason the adoption of solar water heating worldwide is growing at a rate of more than 25% per yea.

Adoption of solar water heating can have a great impact on the reduction of peak electrical load and thus greenhouse gas emissions. For example, if all the electric water heaters in the USA (approximately 100 million) were replaced by solar water heaters, it would reduce the peak load by about 100 GW.

Solar technologies can make a substantial contribution to the energy budget of modern buildings, and consequently to the world's energy use. Buildings can be the largest collectors of solar energy and therefore the electrical appliances (light bulbs, refrigerators, washing machines, etc.) with innovative energy-efficient models, can reduce electricity demand and increase the significance of, e.g. photovoltaic electricity, to the whole energy budget.

Globally, about 8-10 million new buildings are constructed every year, most of them in developing countries. Large areas of these countries do not have access to grid electricity, thus making solar energy an attractive alternative. Even if only a tiny fraction of these buildings were served by solar, the implications for the solar and energy industry could be enormous, not only from a technological point of view but also from a cultural point of view. It would be a contributory factor to changing the way people think about conventional sources of energy and solar energy.

Solar Photovoltaic Systems (PV)

Photovoltaic conversion is the direct conversion of sunlight into electricity with no intervening heat engine. As indicated above, photovoltaic devices are rugged and simple in design and require very little maintenance. Perhaps the biggest advantage of solar photovoltaic devices is that they can be constructed as stand-alone systems to give outputs from microwatts to megawatts. That is why they have been used as the power sources for calculators, watches, water pumping, remote buildings, communications, satellites and space vehicles, and even megawatt-scale power plants. With such a vast array of applications, the demand for photovoltaics is increasing every year. In 2009, over 7 200 MW_p of photovoltaic panels were sold for terrestrial uses and the worldwide market is growing at a phenomenal rate: an average of 47% per annum over the past five years.

Solar Thermal Power Plants

Concentrating solar collectors can achieve temperatures in the range of 200^{o}C to 1 000^{o}C or even higher, which is ideal for generating electricity via thermodynamic power cycles. All of the present power plants based on fossil fuels and nuclear power work on the same principles. Therefore this technology takes advantage of the knowledge base relating to conventional power plants. Another advantage of Solar

Thermal Power is that it can easily use fossil fuels such as natural gas as a back-up fuel or store high-temperature heat to overcome the disadvantage of the intermittency of sunlight. explains the concept of a solar thermal power plant operating with storage and/or a backup fuel. shows schematic diagrams of the types of concentrating solar collector used for solar thermal power plants.

Solar Energy Storage Systems

As a result of solar energy's intermittent nature, the growth in worldwide usage will be constrained until reliable and low-cost technology for storing solar energy becomes available. The sun's energy is stored on a daily basis by nature through the process of photosynthesis in foodstuffs, wood and other biomass. The storage of energy from intermittent and random solar radiation can be achieved artificially, by using energy storage technologies (thermal storage, chemically-charged batteries, hydro storage, flywheels, hydrogen, and compressed air), some well-known and widely-applied, whilst others are still under development.

Thermal storage for solar heat and chemically-charged batteries for off-grid PV systems are the most widely used solar energy storage systems today. However, there are many who think that hydrogen produced using solar energy will provide the long-term solution for solar energy storage and much research is being undertaken around the world. Only the future will tell whether hydrogen will become cost-effective as compared with other storage options.

Other Solar Energy Applications

Availability of drinking water is expected to be the biggest problem to face mankind over the next few decades. Even though there is an abundant water resource in the oceans, it must be desalinated before use. Solar energy can play a very important role in this application. Although simple solar desalination and distillation technology has been known for a long time, there has not been much research to improve the technology for large-scale use.

Other lesser known applications of solar energy include its environmental applications such as solar photocatalytic detoxification and disinfection. This application has been shown to clean contaminated ground water and industrial waste water. It can also be used to disinfect water for potable use.

Countries whose governments have established firm goals for the penetration of renewable energy into primary energy and electricity generation, or have adopted specific policy mechanisms, are achieving great success. Examples are the successful feed-in laws adopted in several European countries, for instance, Germany and Spain; the Renewables Portfolio Standard (RPS) adopted by the majority of the American states, which ensures that a minimum amount of renewable energy is included in the portfolio of electricity production; and city ordinances requiring solar systems to be used for water heating in residential and commercial buildings. Appropriate policy measures have shown that solar applications can be boosted with many positive side effects, from the creation of new industries, new jobs and new economic opportunities, to the protection of the environment.

11. Geothermal

Geothermal energy is, in the broadest sense, the natural heat of the Earth. This heat can be exploited as a source of energy in two basic ways. The first is to utilise the heat that is transferred (mostly by conduction) from the extremely hot interior of the earth to accessible areas at or near the surface; the second is to utilise (via heat pumps) the temperature difference between the ambient temperature and that of the ground.

Exploitable geothermal systems in the first category can be divided into two groups, depending on whether or not they are related to young volcanoes and magmatic activity. High-temperature fields (>150oC) are mostly confined to the former group, and generally occur along plate boundaries (e.g. around the Pacific 'ring of fire', in Iceland and along the East African Rift Valley).

Geothermal utilisation is commonly divided into two categories: electricity generation and direct use. Whilst the six largest producers of geothermal electricity are mostly major world economies, the six countries with the highest percentage share of geothermal in their power production are all relatively small, with three out of the top six being located in Central America, a part of the world rich in high-temperature geothermal resources.

'Direct use' encompasses a multitude of different applications. Overall, ground-source heat pumps account for nearly one-third of recorded direct geothermal utilisation. This application is based upon the use of normal ground or groundwater temperatures, which are relatively constant and are available everywhere. The World Geothermal Congress indicates that the total installed capacity of geothermal heat pumps grew at an annual rate of nearly 21% over the ten years prior to 2009. To date most installations have been in North America and Europe, although other parts of the world (e.g. China) are beginning to develop significant heat-pump capacity.

The principal other uses of (generally relatively low-temperature) geothermal heat are bathing and swimming, space heating, and horticultural/aquacultural/agricultural applications. The prominence of bathing/swimming reflects the large number of hot springs found throughout the world, particularly in Japan. Geothermally-based space heating has been developed to a high degree in Iceland, where its market penetration has reached around 90%.

Geothermal Utilisation and Characteristics

Geothermal power is generated by using steam or a hydrocarbon vapour to turn a turbine-generator set to produce electricity. A vapour-dominated (dry steam) resource can be used directly, whereas a hot-water resource needs to be flashed by reducing the pressure to produce steam, normally in the 15-20% range. Some plants use double and triple flash to improve the efficiency, however in the case of triple flash it may be more efficient to use a bottoming cycle (a small binary plant using the waste water from the main plant). Low-temperature resources generally require the use of a secondary low boiling-point fluid (hydrocarbon) to generate the vapour, in a binary or Organic Rankine Cycle (ORC) plant.

Direct Utilisation

The main advantage of using geothermal energy for direct use projects in the low- to intermediate-temperature range is that such resources are more widespread and exist in at least 80 countries at economic drilling depths. In addition, there are no conversion efficiency losses and projects can use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the fluid). Most projects can be on line in less than a year. Projects can be on a small scale, such as for an individual home, greenhouse or aquaculture pond, but can also be a large-scale commercial operation such as for district heating/cooling, or food and lumber drying.

Technical Potential

The main advantage of geothermal heating and power generation systems is that they are available 24 hours per day, 365 days a year and are only shut down for maintenance. Power generation systems typically have capacity factors of 95% (i.e. operate at nearly full capacity year round), whereas direct-use systems have a capacity factor around 25 to 30%, owing to heating not being required year round. Heat pump systems have operating capacities of around 10-20% in the heating mode and double this if the cooling mode is also included.

Within the direct utilisation sector of geothermal energy, geothermal heat pumps have world-wide application, as the shallow ground temperature is within their range anywhere in the world. Traditional direct use heating is limited to where the resource is available in economic depths and where climate justifies the demand.

At end-2008, approximately 10 700 MW_e of geothermal electricity generating capacity was installed, producing over 63 000 GWh/yr. Installed capacity for direct heat utilisation amounted to about 50 000 MW_t, with an annual output of around 430 000 TJ (equivalent to about 120 000 GWh). The annual growth in energy output over the past five years has been 3.8% for electricity production and around 10% for direct use (including geothermal heat pumps). Energy produced by ground-source heat pumps alone has increased by 20% per annum over the same period. The low growth rate for electric power generation is primarily due to the low price for natural gas, the main competitor.

12. Wind

The world's wind resources are vast: it has been estimated that if only 1% of the land area were utilised, and allowance made for wind's relatively low capacity factor, wind-power potential would roughly equate to the current level of worldwide generating capacity. Offshore wind resources are also enormous, with the European potential up to 30 km from land being enough to meet the whole of the EU's present demand for electricity.

It has been found that the integration of wind-generated electricity into regional or national supply systems can be readily achieved, up to the point when wind energy accounts for around 20% of total electricity consumption. Beyond this point, some wind power may need to be curtailed when high winds coincide with low levels of demand.

Substantial further development of wind power capacity is foreseen, although the actual rate will depend on the level of political support provided by governments and the international community, in turn reflecting the degree of commitment to achieving emissions reduction targets.

Resource and Potential

Wind energy has been utilised by man for thousands of years, initially to provide mechanical energy and now to provide electricity. It is available virtually everywhere on earth, although there are wide variations in wind strengths. The total resource is vast; one estimate (Cole, 1992) suggests around a million GW 'for total land coverage'. If only 1% of the area was utilised, and allowance made for the lower load factors of wind plant (15-40%, compared with 75-85% for thermal plant) that would still correspond, roughly, to the total worldwide capacity of all electricity-generating plant.

The rapid growth of wind energy may be demonstrated by noting that the projection for 2010 set out in the European Commission's White Paper on renewable energy (EC, 1997), was 40 GW. That was 16 times the capacity in 1995, but the target was realised by 2005 and by late 2009, European capacity was over 72 GW.

World wind energy capacity has been doubling about every three and a half years since 1990 as is doubtful whether any other energy technology is growing, or has grown, at such a rate. Total capacity at the end of 2008 was over 120 GW and annual electricity generation around 224 TWh, roughly equal to the Australia's annual consumption. The United States, with about 25 GW, has the highest capacity but Denmark with over 3 GW, has the highest level per capita, and production there corresponds to about 20% of Danish electricity consumption.

Wind energy is being developed in the industrialised world for environmental reasons and it has attractions in the developing world as it can be installed quickly in areas where electricity is urgently needed. In many instances it may be a cost-effective solution if fossil fuel sources are not readily available. In addition there are many applications for wind energy in remote regions, worldwide, either for supplementing diesel power (which tends to be expensive) or for supplying farms, homes and other installations on an individual basis.

Most wind capacity is located onshore but offshore wind sites have been completed, or are planned, in China, Denmark, Ireland, Sweden, Germany, the Netherlands, the UK and elsewhere. By end-2009, over 1 500 MW was operational. Offshore wind is attractive in locations where pressure on land is acute and winds may be 0.5 to 1 m/s higher than onshore, depending on the distance from the coast. The higher wind speeds do not presently compensate for the higher construction costs, but the chief attractions of offshore are its large resource and low environmental impact.

Several commercial types of wind turbine now have ratings over 3 MW and diameters around 60-80 m; machines for the offshore market have outputs up to 6 MW and diameters up to 126 m.

Machine sizes have increased for two reasons. They are cheaper and they deliver more energy. The energy yield is improved partly because the rotor is located higher from the ground and so intercepts higher-velocity winds, and partly because they are slightly more efficient. Energy yields, in kWh per square metre of rotor area, are now double those of 1990 (Welke and Nick-Leptin, 2006). In 2008, data from the Danish Energy Agency showed that the most productive machines delivered around 1 500 kWh per square metre of rotor area. Reliability has also improved steadily and availabilities of 95% or more are common.

Wind Energy Costs

The cost of wind energy plant fell substantially during the period from 1980 to 2004. Prices in the 1980s were around US$ 3 000/kW, or more, and by 1998 they had come down by a factor of three. During that period the size of machines increased significantly - from around 55 kW to 1 MW or more - and manufacturers increased productivity substantially. In 1992, for example, one of the major manufacturers employed over seven people per megawatt of capacity sold, but by 2001 only two people per megawatt were needed. The energy productivity of wind turbines also increased during this period. This was partly due to improved efficiency and availability, but also due to the fact that the larger machines were taller and so intercepted higher wind speeds. A further factor that led to a rapid decline in electricity production costs was the lower operation and maintenance costs.

Generation costs

No single figure can be quoted for the installed cost of wind farms, as much depends on the difficulty of the terrain, transport costs and local labour costs. Generation costs depend, in addition, on the wind speed at the wind farm site - since this determines the energy productivity - and on the financing parameters. The latter depend on national institutional factors which influence whether wind farm investments are seen as high or low risk. Although there is a broad consensus that wind turbines are now sufficiently reliable to enable depreciation over a 20-year period, the 'weighted average cost of capital' (WACC) may lie between 5% and 11%. (The WACC is a weighted average interest rate that takes into account the cost of both bank loans and equity investments).

Typical generation costs are between US 1 700/kW and US$ 2 600/kW, an 8% interest rate and a 20-year amortisation period. The estimates suggest that generation costs at US$ 2 600/kW range from just under US$ 200/MWh at 6 m/s, falling to US$ 84/MWh at 9.75 m/s. At US$ 1 700/kW, the corresponding range is US$ 125/MWh to US$ 53/MWh, respectively.

Although the largest wind turbines tend to attract most interest, there is a wide range of sizes available commercially, from small battery-charging machines with ratings of a few Watts, up to, say 100 kW for farm use. A recent review of this market (Frey, 2010) found 124 manufacturers and suggested the term 'micro SWTs' be used for machines up to 1 kW output, 'mini' up to 10 kW output and 'midi' up to 100 kW output.

One of the more obvious environmental effects of wind turbines is their visual aspect, especially that of a wind farm comprising a large number of wind turbines. There is no measurable way of assessing the effect, which is essentially subjective. As with noise, the background is important. Experience has shown that good design and the use of subdued neutral colours – ‘off-white’ is popular - minimises these effects. The subjective nature of the question often means that extraneous factors come into play when acceptability is under discussion.

Numerous utility studies have indicated that wind can readily be absorbed in an integrated network at modest cost. Several studies have been reviewed by the International Energy Agency (2005). More recent estimates suggest 10% wind energy is likely to incur extra costs in the range GBP 2.5-5/MWh (US$ 4-8/MWh) and 20% wind energy in the range GBP 3-6/MWh (US$ 5-10/MWh), approximately (Milborrow, 2009). Beyond 20%, some wind power may need to be curtailed on a few occasions if high winds coincide with low demand, but there are no ‘cut-off’ points. Practical experience at these levels is now providing a better understanding of the issues involved.

Projections of future capacity vary. Taking the IEA’s cautious estimate of 422 GW for the installed capacity in 2020 and assuming an installed cost of US$ 2 000/kW suggests investments of around US$ 522 billion will be required over the next 10 years.

13. Tidal Energy

The tides – cyclic variations in the level of the seas and oceans – give rise to water currents which constitute a potential source of power. There are two basic approaches to tidal energy exploitation: one exploits the cyclic rise and fall of the sea level through entrainment, whilst the other harnesses local tidal currents.

There are many sites at which local geography induces large tidal movements, particular examples being the Bay of Fundy in eastern Canada, the Severn Estuary in western England and the mouth of the River Rance in northern France. In these locations, and at a number of others, tidal-power schemes have been proposed, but very few have so far been implemented; the only one of any real significance is the 340 MW La Rance plant in Brittany, which has operated successfully since 1966. The basic approach is always the same: an estuary or bay with a large tidal range being enclosed by a barrier, often planned to include a rail and/or road crossing, in order to maximise the economic benefits. Electricity is generated by allowing water to flow from one side of the barrier to the other, through low-head turbines. Various configurations have been proposed, utilising single or multiple basin layouts.

As tidal barrage systems are likely to cause substantial environmental change, artificial lagoons have been proposed as an alternative, with their principal advantage being a greatly reduced impact on the coastline and intertidal zone. This concept, however, requires further research.

A different way of harnessing the tidal potential is to utilise the energy in tidal currents; various experimental/demonstration schemes have been implemented or are planned, in Europe and the USA.

The high capital costs of tidal barrage systems are likely to restrict their development in the near future. However, with interest in entrainment schemes higher than in the past, it is increasingly likely that new barrage and lagoon developments will emerge in due course, especially where they can be combined with new transport infrastructure. If the currently-deployed prototype tidal-current systems prove successful, commercial installations could begin to appear during the present decade, providing electricity to some rural, coastal or island communities.

Using the tides as energy sources is not a new idea. Small tidal “mills” were used in Southern England and Northern France in the Middle Ages. Tidal flows in bays and estuaries offered the potential to drive cereal-grinding apparatus in areas that were too low-lying to allow the use of conventional water wheels. The Eling Tide Mill, for example, is still operational, largely as an educational and tourist facility. This is a very early example of a tidal entrainment system, i.e. an artificial barrier or barrage used to interfere with the natural movement of water under tidal influences. Entrainment is a more general term than “barrage”, as it allows consideration of alternative engineering methods such as lagoons.

There are two fundamentally different approaches to the exploitation of tidal energy. The first is to exploit the cyclic rise and fall of the sea level through entrainment. This includes “traditional” barrage methods as well as tidal lagoons and fences. The second approach is to harness local tidal currents in a manner somewhat analogous to wind power.

Tidal barrages

Principles and History: - there are many places in the world in which local geography results in exceptionally large tidal ranges. Sites of particular interest include the Bay of Fundy in Canada, which has a mean tidal range of 10 m; the Severn Estuary between England and Wales, with a mean tidal range of 8 m and northern France with a mean range of 7 m. A tidal barrage power plant has, indeed, been operating at La Rance in Brittany since 1966 [2]. This plant, which is capable of generating 240 MW, incorporates a road crossing of the estuary. It has recently undergone a major ten-year refurbishment programme.

Tidal current technology

*Principles and History***.** The development of a tidal entrainment system represents a substantial investment of time and money, and many planners and engineers favour the development of tidal current systems which could be developed incrementally. Indeed, it possible that a step-by-step development of the tidal current resource might allow subsequent advances in technology or understanding of the resource to be incorporated in later stages. The most thoroughly documented early attempt to prove the practicality of tidal current power was conducted in the early 1990s in the waters of Loch Linnhe in the Scottish West Highlands [6]. This scheme used a turbine held mid-water by cables, which stretched from a sea-bed anchor to a floating barge.

The mid to late 1990s was primarily a time of planning and development as far as tidal current power was concerned and it was not until the beginning of the 21st century that further systems became ready to test. In 2000 a large vertical-axis floating device (the ENERMAR project [7]) was tested in the Strait of Messina between Sicily and the Italian mainland. Between May 2003 and October 2009, Marine Current Turbines (MCT) Ltd. [8] of Bristol, England, demonstrated a 300 kW pillar-mounted prototype system, called SeaFlow, in the Bristol Channel.

14. Wave Energy

The Resource

Wave energy can be considered as a concentrated form of solar energy, where winds generated by the differential heating of the earth pass over open bodies of water, transferring some of their energy to form waves. The amount of energy transferred and, hence, the size of the resulting waves, depends on the wind speed, the length of time for which the wind blows and the distance over which it blows (the 'fetch'). Hence, solar energy can be 'stored' in waves so that original solar power levels of typically ~100 W/m^2 can be magnified into waves with power levels of over 1 000 kW per metre of wave crest length.

Waves lying within or close to the areas where they are generated (storm waves) produce a complex, irregular sea. These waves will continue to travel in the direction of their formation even after the wind dies down. In deep water, waves lose energy only slowly, so they can travel out of the storm areas with minimal loss of energy as regular, smooth waves or 'swell' and this can persist at great distances from the point of origin. It is these 'swell waves' that are utilised by most wave energy devices and coasts with exposure to the prevailing wind direction and long fetches tend to have the most energetic wave climates, such as the western coasts of the Americas, Europe, Southern Africa and Australia/New Zealand

Benefits

In addition to the large size of the resource and the lack of associated greenhouse gas emissions, wave energy has several important advantages:

Outside the tropics, storms are usually more intense and frequent during winter, which results in wave power levels being higher in that season. Therefore, wave energy provides good seasonal load-following for those regions where peak electricity demand is produced by winter heating and lighting requirements (e.g., northern Europe, western Canada and north-west USA);

Wave energy is a concentrated manifestation of solar energy, whereby winds generated by the differential heating of the earth pass over open stretches of water, transferring some of their energy to create waves. Regions with the most energetic wave regimes include the western coasts of the Americas, Europe, Southern Africa and Australasia. The global wave power resource in water depths of over 100 m has been estimated as between 1 and 10 TW, while the economically exploitable resource ranges from 140-750 TWh/yr for current designs when fully mature, and could be as high as 2 000 TWh/yr if the potential improvements to existing devices are achieved.

The generating costs of the first wave energy devices are high, as all fixed costs must be defrayed against the output of a single installation. However, follow-on schemes should exhibit efficiency improvements and cost savings, as a result of design-optimisation and series-production. In order for generating costs to be reduced to levels comparable with those of other Renewable energy resources, some form of interim subsidy would be required.

Out of a plethora of proposals, there are several promising technologies that are ready for deployment. In order to realise their full potential, these devices will require some support, and this is becoming available from a number of governments. Given a continuance of this situation, wave energy could start to make a significant contribution to energy supply within 5 to 10 years.

15. OCEAN THERMAL ENERGY CONVERSION

The Resource

Ocean Thermal Energy Conversion (OTEC) is a means of converting into useful energy the temperature difference between the surface water of the oceans in tropical and sub-tropical areas, and water at a depth of Japproximately 1 000 metres, which comes from the polar regionshe temperature differences in various parts of the ocean, and for OTEC a temperature difference of 20°C is adequate, which embraces very large ocean areas, and favours islands (Gauthier & Lennard, 2001) and many developing countries (Lennard 2007).

Types of OTEC Plant

Depending on the location of the cold and warm water supplies, OTEC plants can be land-based, floating, or - now not such a longer-term development - grazing. Floating plants have the advantage that the cold water pipe is shorter, reaching directly down to the cold resource, but the power generated has to be brought ashore, and moorings are likely to be in water depths of, typically, 2 000 metres. The development of High Voltage DC transmission offers substantial advantage to floating OTEC, and the increasing depths for offshore oil and gas production over the last decade mean that mooring can now be classed as 'current technology' - but remains a significant cost item for floating OTEC. Land-based plants have the advantage of no power transmission cable to shore, and no mooring costs. However, the cold water pipe has to cross the surf zone and then follow the seabed until the depth reaches approximately 1 000 metres - resulting in a much longer pipe which has therefore greater friction losses, and greater warming of the cold water before it reaches the heat exchanger, both resulting in lower efficiency.

Further OTEC Applications

An especial benefit of OTEC is that, unlike most renewable energies, it is base-load - the thermal resource of the ocean ensures that the power source is available day or night, and with only modest variation from summer to winter. It is environmentally benign, and some floating OTEC plants would actually result in net CO_2 absorption. And a further unique feature of OTEC is the additional products which can readily be derived - food (aquaculture and agriculture); pharmaceuticals; potable water; air conditioning; etc. Many of these arise from the pathogen-free, nutrient-rich, deep cold water. OTEC is therefore the basis for a whole family of Deep Ocean Water Applications (DOWA), which can additionally benefit the cost of generated electricity. Potable water production alone can reduce electricity generating costs by up to one-third, and is itself in very considerable demand in most areas where OTEC can operate.

Ocean Thermal Energy Conversion (OTEC) is a means of converting into useful energy the temperature difference between the surface water in tropical and sub-tropical seas and cold water at a depth of about 1 000 metres, which emanates from the polar regions. A temperature difference of 20°C is adequate for OTEC: this level is encountered over wide ocean areas, particularly near islands and off the coast of certain developing countries. As well as the level of the ocean thermal differential, a host of other factors have to be considered before selecting a particular country or location as suitable for an OTEC project.

Depending on the location of the cold and warm water, OTEC plants may be land-based, floating, or 'grazing'. Compared with fixed onshore installations, floating plants have the advantage of a shorter cold-water pipe, but incur mooring and power-transmission costs. The concept of a grazing OTEC plant has been linked to the production of liquid hydrogen and liquid oxygen, which would be offloaded into shuttle tankers for delivery to energy-importing countries. Some of the hydrogen could, in turn, be used to produce ammonia fertilisers.

Unlike most Renewable energy technologies, OTEC has the advantage of providing base-load power, available at a constant rate throughout the 24 hours, and varying very little with the seasons. OTEC plants can also be designed to produce additional products: foodstuffs, through aquaculture and agriculture; pharmaceuticals; potable water; air conditioning; etc. The resulting family of Deep Ocean Water Applications (DOWA) can significantly improve the overall economics of an OTEC scheme.

The economic commercialisation of OTEC/DOWA will require the successful operation of a number of demonstration plants. Efforts are presently being concentrated on lining up suitable funding sources to enable the demonstration stage to go ahead.

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