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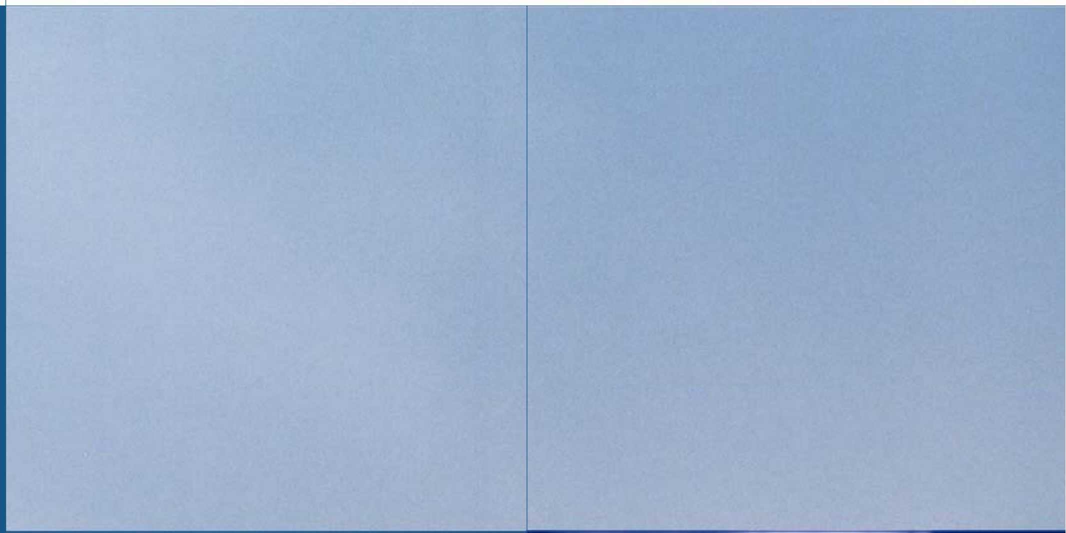
2007 Survey of Energy Resources
Executive Summary

World Energy Council 2007



Promoting the sustainable supply and use of energy for the greatest benefit of all

2007 Survey of Energy Resources
Executive Summary

Officers of the World Energy Council

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Introduction

In 1936 the World Power Conference, the organisation which eventually became the World Energy Council, published the first of a series of *Statistical Year-books.* This pioneer work represented 'an attempt to compile and publish international statistics of power resources, development and utilization, upon a comprehensive and comparable basis'. More than seventy years later, this essentially remains the objective of the Year-book's direct descendant, the twenty-first edition of the WEC's *Survey of Energy Resources*.

Despite considerable development along the way, with gradually extended coverage of energy resources (notably in the field of 'renewables') and the provision of more comprehensive tables and increasingly detailed Country Notes, the basic problems facing the compilers of the *Survey* remain much the same. They were indeed foreshadowed by a somewhat melancholy comment in the Introduction to *Statistical Year-book No. 1*: 'The work of editing the tables, and more particularly the definitions, proved even more arduous and difficult than had been anticipated'.

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 compilation is the input provided by the WEC Member Committees, completion necessitates recourse to a multitude of national and international sources and, in some cases, to estimation.

Notwithstanding the efforts of an UN/ECE Ad Hoc Group of Experts to codify and standardise the terminology of reserves and resources reporting (UN Framework Classification for Fossil Energy and Mineral Resources), it remains a fact that, at the present time, almost every country that possesses significant amounts of mineral resources still uses its own unique set of expressions and definitions. It will take some considerable time for the methodology devised by the UN to be applied globally. In the meantime, the resources and reserves specified in the present *Survey* conform as far as possible with the established definitions specified by the WEC.

This latest *Survey* is, as its full title implies, primarily concerned with energy reserves and resources - yet these terms mean different things in different countries. It is thus of paramount importance that the precise meaning attributed to such expressions in any given context is made clear. In WEC usage, *resources* refer to amounts that are known or deduced to be present and potentially accessible. Energy resources may be categorised as either finite (e.g. minerals) or perpetual, such as the so-called renewable resources (solar, wind, tidal, etc.). In the case of finite resources, *reserves* denote the amount within the designated resource that is recoverable under specified criteria.

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, The fundamental distinction is between those energies that are finite and those that are, on any human scale, effectively perpetual or everlasting.

Bioenergy is arguably the one truly renewable energy resource.

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 Executive Summary.

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. 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 various forms of marine energy – tidal energy, wave power and ocean thermal energy conversion (OTEC). There are also two types of energy resource – peat and geothermal energy - which are to some extent intermediate in nature, with both finite and perpetual elements in their make-up.

Bioenergy is arguably the one truly renewable energy resource, in that each new crop or harvest represents a partial renewal of its resource base, which is itself subject to constant depletion through its use as a fuel or feedstock. The other perpetual energy resources are available on a continuing, albeit varying, basis, are not depleted by the utilisation of their energy content, and are therefore not subject to renewal.

Looking ahead

Energy resources are critical for the wellbeing of humankind and to our economies and social improvement. A principal issue around energy today is supplying the tremendous amounts of energy needed by the growing economies of the world, and in an economically and environmentally sustainable way. Many studies indicate that there will likely be a doubling of the world's energy demand by 2050, perhaps sooner. China alone is on a path to become the world's largest primary energy user in about five years. India is not far behind and together they make up almost 40% of the globe's population. The work represented by this careful study indicates that energy is plentiful but not always in the same place as most needed. Policies to deal with these energy challenges are the subject of the 2007 World Energy Council study: *Deciding the Future: Energy Policy Scenarios to 2050*. A critical set of data required by policymakers is where energy resources are, in what form and in what quantities. This *Survey* provides the latest information in answer to this question.

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

These four categories form the basis of the fossil fuels section of the Questionnaire sent out to WEC Member Committees requesting input for the SER. The responses to the Questionnaires reflect the Member Committees' interpretation of the WEC categories in their own context.

Other organisations, whether national (e.g. ministries, geological survey centres, etc.) or international (e.g. technical journals) have their own classifications and definitions, which generally differ to a greater or lesser extent from those employed by the WEC. The only category in which there is any substantial degree of commonality is Proved Recoverable Reserves, and it is this category which attracts the most attention worldwide. Non-WEC data on finite *resources* tend to be relatively few and far between, and not susceptible to any comparative analysis on a worldwide basis.

In discussing the subject of proved recoverable reserves, two important points should be borne in mind:

- although the terms used may be identical, the meaning attributed to each word can vary widely from one source to another; in particular, 'proved' may include 'probable' reserves and the term 'recoverable' may not be strictly adhered to, amounts being in fact 'in-situ';
- conceptually, proved recoverable reserves of any one finite resource in any particular country are not immutable, but subject to virtually constant change, due (inter alia) to shifts in economic criteria, improvements in recovery techniques and the promotion/demotion of deposits from one level of probability to another.

Data Sources

As indicated above, the data provided by WEC Member Committees have been supplemented by information culled from other sources. It should thus be noted that the resulting tabulations of reserves and resources are a compilation of existing data, not a set of specially-commissioned national assessments. The same qualification applies to all the various published annual surveys of oil and gas reserves – *Oil & Gas Journal, World Oil*, Cedigaz, OPEC, OAPEC, BP, etc.

Finite Resources

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 most countries' coal resources are well-established.** Economically recoverable reserves exist in some 70 countries, with the global total at end-2005 approximately 7% lower than at end-2002; this represents a refinement of previous assessments (particularly in relation to recoverable quantities), rather than a fundamental re-appraisal of the resource base.

Coal's future competitive stance vis-à-vis the other fossil fuels could be enhanced by the development of coal-to-liquids (CTL) facilities, which are currently under way or planned in a number of major coal-producing countries.

Environmental concerns are being addressed by the development of clean-coal technologies and their installation in new plants or via retrofit programmes. Power station efficiency is being improved by new designs operating at elevated levels of temperature and pressure, and by advanced technologies such as Integrated Gasification Combined Cycle (IGCC).

The drive to mitigate emissions of greenhouse gases is reflected in increased interest in the recovery and utilisation of coal mine methane (CMM) and in techniques of underground coal gasification, and the investigation of several different types of carbon-capture-and-storage, the successful application of which is likely to prove another key factor in coal's long-term future.

Oil

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 1 215 billion barrels (160 billion tonnes) at end-2005, some 117 billion barrels (11 billion tonnes) higher than the end-2002 level published in the previous (2004) 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-2005 assessments quoted by the other main published sources. After allowance is made for differences in definitions and coverage, the comparison reveals a reasonably high degree of consensus overall, notwithstanding many differences in detail. The Middle East remains the principal location of oil reserves, with 61% of the global total, followed by Africa with 11%, South America and Europe (including the whole of the Russian Federation) with 8% each and North America at just under 5%.

As already pointed out, the coverage of the world provided by the information reported by the WEC Member Committees is necessarily incomplete, and this is particularly true of the

Proved reserves of oil continue to show a substantial supply base for the short-medium term.

Oil will not finally run out for very many years, if ever.

quantification of recoverable oil resources that are additional to proved reserves, for which the data available from WEC sources is variable and incomplete. In lieu of such a global assessment, it is apposite to quote the quantification of the 'remaining potential' for conventional oil, produced by the Federal Institute for Geosciences and Natural Resources (BGR), in Hannover, Germany, and discussed in the Oil Commentary.

The BGR's assessment of the 'Estimated Ultimate Recovery' (EUR) of conventional oil is some 387 billion tonnes, of which about 143 billion tonnes had been produced up to the end of 2005. Of the 'Remaining Potential' of 244 billion tonnes, the BGR classifies nearly 162 as 'Reserves' (broadly corresponding to WEC's Proved Recoverable Reserves) and 82 as 'Resources' (analogous to the WEC concept of Additional Reserves Recoverable). Thus, according to the BGR, there are some 625 billion barrels of additional recoverable conventional oil remaining in the world - equivalent to just over another 50% on top of the existing level of proved reserves.

It is concluded in the Oil Commentary that, with 37% of the EUR already extracted, the depletion mid-point – when half of the EUR will have been recovered – will be reached within the next 10 to 20 years. Once this point is reached, the decline of conventional oil production is described as inevitable. The accuracy of this prediction, as with that of any forecast, will depend on its underlying assumptions – the size of the EUR, the scope for further major discoveries and technological advances, and so forth. Moreover, at this point in time the depletion argument can only be applied to 'conventional' oil production: supplies from other sources (such as natural bitumen, extra-heavy oil, oil shale, derivatives of coal and natural gas), will increasingly come into play, meeting at least part of the potential deficit in liquid fuels availability.

Oil will not finally run out for very many years, if ever. **The timing of conventional oil's production peak is the subject of much debate, but is probably less important than the vision of the long decline that comes into view on its far side.**

Oil shale

Oil shales – sedimentary rocks from which significant amounts of shale oil and combustible gas can be extracted – are found in many parts of the world: global resources of shale oil are conservatively estimated at 2.8 trillion barrels. Oil shale deposits have been identified in 38 countries, with the largest resources located in the USA and the Russian Federation.

Oil shale can be burnt directly as a fuel or processed to obtain a variety of liquid fuels. Generally speaking, the production costs of conventional crude oil are lower than those involved in mining and processing oil shale. Consequently only a few deposits are presently being exploited, with oil-shale rock mining believed to be confined to Brazil, China, Estonia, Germany and Israel. Only the three first-named extract any oil from their shale, amounting to

The only natural bitumen deposits presently being commercially exploited on a significant scale are those in western Canada.

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.

only some 700 thousand tonnes worldwide, of which Estonia accounted for about half in 2005, China for just over a quarter and Brazil for the balance. Estonia burns most of its oil shale output directly as a power-station fuel.

The largest known deposit of oil shale is the Green River Formation in the western United States, with an estimated total resource of almost 1.5 trillion barrels of oil in place, of which about half might be recoverable. The recent increase in the price of crude oil has led the US Government to foster the commercial development of Green River deposits through the issue of RD&D oil shale leases, of which six were granted during 2006-2007. Early in 2007 the US Office of Naval Petroleum announced that northwest Colorado could be producing oil from shale on a commercial basis by 2015.

Natural Bitumen/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, with over 70% of worldwide reserves, and Venezuela in the case of extra-heavy oil, with about 98% of presently recorded reserves.

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 a third of Canada's domestically-produced crude oil.

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 accounted for almost 20% of Venezuela's oil production in 2005.

It has been suggested that the volume of natural bitumen and extra-heavy oil in place appears to be of at least the same order of magnitude as the volume of original oil in place in known accumulations of conventional oil.

Natural Gas

Since 1980, the world's proved reserves of natural gas have increased at an average annual rate of 3.4% (compared with 2.4% for oil), owing to a number of exploration successes and improved assessments of some existing fields. The volume of proved gas reserves has more than doubled during this period. In comparison with the level reported for end-2002 in the previous (2004) edition of the *Survey*, total reserves show an increase of 5.9 trillion cubic metres or 3.5%. At the present level, global gas reserves are equivalent to more than 56 years' production (net of re-injection) at the 2005 rate. Some 44% of total proved reserves is concentrated in about twenty mega and super-giant fields, within which

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The abundance of gas reserves already discovered, and the prospects for a large yet-to-find potential, give natural gas a lifetime probably in excess of 130 years, at the current rate of consumption.

the world's largest non-associated gas field – North Field/South Pars, which straddles Qatari and Iranian waters - accounts for very nearly half.

Total proved recoverable reserves of natural gas, as compiled for the present *Survey*, stand close to midway in the range of end-2005 assessments quoted by the other main published sources. The dispersion around the mean level of about 177 trillion cubic metres is not great (+/- 4.5), 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.

The amount of natural gas remaining to be discovered has been consistently and significantly underestimated. Moreover, gas exploration is at a less mature stage than that for crude oil. Many territories have been only partially explored, if at all. Moreover, improvements in the economics of transportation are opening-up access to hitherto 'stranded' deposits, while advances in technology will enable exploration and production activities to be undertaken in deeper and more complex horizons. Conventional sources of natural gas are already augmented by substantial quantities of coal-bed methane (CBM), and other non-conventional sources (e.g. tight gas sands, gas shales and possibly gas hydrates) will come to play a part in gas supply.

Cedigaz, the natural gas industry's international information centre, believes that the abundance of gas reserves already discovered, and the prospects for a large yet-to-find potential, give natural gas a lifetime probably in excess of 130 years, at the current rate of consumption.

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.

A biennial joint report of the OECD Nuclear Energy Agency and the International Atomic Energy Agency provides data for 50 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 4% between 2003 and 2005, to reach very nearly 3.3 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; the estimate of 4.5 million tonnes for reserves (plus additional resources) is considered to be conservative, as exploration has so far been on a limited scale.

World output of uranium in 2005 amounted to 41.7 thousand tonnes, with nine countries accounting for almost 95%. Several 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.

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(e.g. Argentina, Bulgaria, Chile and Finland), 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 435 nuclear power reactors in operation at the beginning of 2007, with an aggregate generating capacity of 367 GW_e. A number of countries uprated existing plants by up to 20%, a highly effective way of bringing new capacity on-line. During the year, the US Nuclear Regulatory Commission approved eight licence renewals of 20 years each, bringing the number of approved renewals to 47 by the end of 2006. 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 12 400 reactor-years of experience to date, improved capacity factors, lower generating costs and an excellent safety record – the one major accident, at Chernobyl in 1986, has resulted in the founding of a 'safety culture' based on constant improvement, thorough analysis of experience and sharing of best practices.

The world uranium market is rapidly adjusting to nuclear's rising expectations, as witness the ten-fold price increase since 2000 and the beginning of the correction of a persistent market anomaly, in which reactor fuel requirements have exceeded uranium mine production.

Uranium resources are seen to be plentiful and not to constitute in themselves a constraint on nuclear power development. The limiting factor is timely investment in new production facilities. As the lead-time required to turn uranium in the ground into nuclear reactor fuel is considerable, global reactor requirements will have to continue to rely upon secondary sources for another decade.

Intermediate Resources

Peat

Peat 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 approaches 3 million km^2, or about 2% 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. The total volume of peat in situ is in the order of 3 500 to 4 000 billion m^3.

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 Ireland, Finland, Belarus, the Russian Federation, Sweden and Ukraine. 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.

Geothermal

Although geothermal energy is conventionally classed as a renewable energy resource, and even as a 'new renewable', it is not such a clear-cut example of a perpetual source of energy as are solar, wind and marine energy. On the one hand, it is to a certain extent subject to attrition – individual geothermal wells are liable to decline and eventual exhaustion – but on the other hand, the supply of geothermal energy can be boosted, e.g. by water-injection. Moreover, geothermal has a long history of human utilisation, notably through the use of hot springs, and is by no means a 'new' renewable. For the purposes of this Executive Summary, it has been classed as an intermediate energy resource, although for most practical purposes it can be regarded as perpetual.

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 (>150^{o}C) are mostly confined to the former group, and generally occur along

‘Direct use’ of geothermal energy encompasses a multitude of different applications. Overall, ground-source heat pumps account for nearly one-third of recorded direct geothermal utilisation.

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 in 2005 was nearly three times the level recorded for 2000. 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%.

Major Perpetual Resources

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.

In 2005, renewables accounted for one-fifth of total power generation, of which hydro held the major share, at 87%. During 2005, 18 GW of new hydro capacity came into operation, bringing total world hydro capacity to nearly 778 GW. Hydro-electric generation during the year was in excess of 2.8 TWh, representing some 17% of the technically exploitable capability of the world’s actual or potential hydro sites. Generally speaking, the economically exploitable capability (as currently assessed) is considerably less than the corresponding technical potential; the International Hydropower Association estimates that only one-third of the realistic potential has so far been developed.

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.

After charcoal production, the next largest secondary transformation of biomass is electricity generation.

Interest in biofuels – ethanol and biodiesel – is at an all-time high.

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%. A second-generation biodiesel (‘renewable diesel’)

Solar energy is available both directly as solar radiation and indirectly in the form of power from wind, biomass, hydro, and marine sources.

There is a growing trend towards the use of passive solar in conjunction with Building Integrated Photovoltaics.

is produced by treating vegetable oil with hydrogen over catalysts and is either blended (5% to 50%) or co-processed with 'fossil diesel'. Biodiesel output in 2005-2006 was approximately 0.3 EJ.

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.

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.

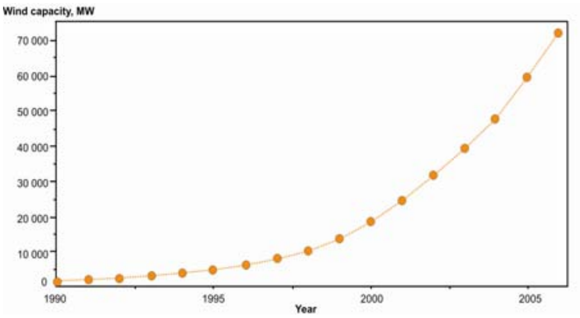
There are two basic types of device currently used to capture and utilise solar radiation:

- 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 100-400^{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 2 000^{o}C or more, and

Wind energy capacity has grown rapidly since 1990, doubling every three and a half years.

Growth of world wind capacity
Source: Milborrow and 'Windpower Monthly'



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 2005, sales of PV modules for terrestrial applications exceeded 1 700 MW_p and the global market is growing at about 35% per annum.

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.

Novel applications of solar energy are being developed, some with particular relevance to developing countries, such as solar detoxification of contaminated waters and solar distillation apparatus.

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.

Wind energy capacity has grown rapidly since 1990, doubling every three and a half years, to reach some 72 000 MW by end-2006, with annual output of around 160 TWh. Although most of the current capacity is located on land, offshore wind farms have been established in a number of locations and other schemes are under construction or at the planning stage. Moreover the size of wind turbines being installed continues to grow, with many new onshore machines in the 2 MW bracket, and offshore turbines substantially larger (up to 5 MW, with blade diameters up to 110 m).

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.

Other Perpetual Resources

Tidal

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.

Wave

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

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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 the 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.

OTEC

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^{o}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.

Key data on reserves, resources and production

	2002*	2005*	% Change 2005/2002
Coal, billion tonnes			
Proved Recoverable Reserves	909	847	-6.8
Production	4.8	5.9	+22.4
Crude Oil & NGL, billion barrels			
Proved Recoverable Reserves	1 099	1 215	+10.6
Production	26.7	29.6	+11.1
Shale Oil, billion barrels			
In-Place Resources	3 328	2 826	-15.1
Production	0.004	0.005	+18.1
Natural Bitumen, billion barrels			
Reserves	247	246	-0.6
Production	0.28	0.37	+33.1
Extra-Heavy Oil, billion barrels			
Reserves	48	60	+23.7
Production	0.21	0.23	+13.7
Natural Gas, trillion cubic metres			
Proved Recoverable Reserves	171	176	+3.5
Production	2.6	2.8	+9.0
Uranium, thousand tonnes			
Proved Recoverable Reserves	3 169	3 297	+4.0
Production	36.0	41.7	+15.7
Nuclear			
Installed Generating Capacity, GW_e	359	371	+3.2
Electricity Generation, TWh	2 573	2 625	+2.0
Geothermal			
Installed Generating Capacity, GW_e	8	9	+9.9
Electricity Generation, TWh	51	58	+14.7
Hydropower			
Technically Exploitable Capability, TWh/year	15 899	16 494	+3.7
Installed Generating Capacity, GW_e	732	778	+6.4
Electricity Generation, TWh	2 640	2 837	+7.5
Wind			
Installed Generating Capacity, GW_e	31	59	+89.0
Electricity Generation, TWh	58	106	+82.3

* reserves and resource data are as at end-year

Source: SER 2004, 2007

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