Nuclear Energy Report

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(2007)

The Nuclear Energy Report
Ed 1 2007

Introduction

- Nuclear power is back on the menu for 20 countries as a potential base load generator
- In 2007 there are 442 nuclear power reactors in operation in 38 countries, with total generating capacity of 370,721 MW
- The first commercial nuclear power plant was commissioned in the UK in 1956 and by 2005 nuclear power provided 6.5% of the world's primary energy consumption and 9% of electricity generation
- Nuclear power has not fulfilled early expectations and there was a brown out of nuclear power in the 1970s and 1980s, stations were shut down and several countries declared moratoria on it, for various reasons, not least being public safety fears
- Nuclear power has been bedevilled by political perceptions, but other sources of power are now being subjected to similar scrutiny
- The environmental fight against fossil fuels is heating up, and informed people are starting to ask questions about what renewables will be able to achieve
- Nuclear power stations are highly efficient, being operated at higher load factors than thermal or hydro stations
- Nuclear power generates almost zero GHG emissions
- The public has always been more afraid of nuclear power than the industry, and is largely unaware of the difference between the so-called "nuclear legacy" from the 1960s and 1970s, and the sophisticated "back-end" measures being engineered into modern nuclear plants

Report Scope

- The report looks at the global nuclear energy market, past, present and future
- It looks at the countries considering Nuclear Power
- It provides country profiles
- The statistics of nuclear energy and power
- The nuclear fuel cycle and supply
- The safety and environmental issues
- The history and economics
- The nuclear power utilities and nuclear power manufacturing companies are as listed
- As are the international associations and organisations
- The report provides a global overview and comprehensive data

Key Research Findings

- Many industrialised countries are facing a shortfall in base load power as existing fossil fuel and nuclear fleets reach the end of their lives
- Environmental awareness is giving nuclear a new impetus
- There are many uncertainties about the economics and future of nuclear energy
- Nuclear power plants are expensive to build but standard designs are reducing costs
- Nuclear power plants have long lead times from concept to grid, decisions are urgent now
- The public perception of nuclear power is not a positive one but in some "anti" countries the public has turned around, e.g. Finland
- No less than 20 countries are rethinking their positions on nuclear power
- Coal has already rebounded and nuclear may well do the same

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Contents

List of Tables

List of Figures

2. Status of Nuclear Power, Past Present and Future

In 2007 there are 442 nuclear power plants in operation in 38 countries, with total generating capacity of 370,721 MW.

The first nuclear reactors to be shut down were in the US, when the CVTR station was closed in 1967, with Elk River and Bonus closing in 1968. In total 118 reactors in 83 stations totalling 40.667 MW gross (38,053 MW net) of capacity have been shut down since then. Further closures are in the pipeline, either because plants have reached the end of their design lives, they are judged to be safety risks or because political decisions have been taken to abandon nuclear power.

28 reactors, totalling 22,510 MW of capacity are currently under construction. 62 reactors with 68,021 MW are planned and a further 160 reactors with 118,825 MW of capacity are proposed.

Table 2-1: Status of Commerical Nuclear Power Plants, Current and Planned

	Nuclear electricity generation		Reactors operable		Reactors under construction		Reactors planned		Reactors proposed		Uranium required
	2005		Sept-06		Sept-06		Sept-06		Sept-06		2,006
	TWh	% e	No	MW	No	MW	No	MW	No	MW	t U
Argentina	6.4	6.9	2	935	1	692	0	0	1	1,000	134
Armenia	2.5	43	1	376	0	0	0	0	1	1,000	51
Belgium	45.3	56	7	5,728	0	0	0	0	0	0	1,075
Brazil	9.9	2.5	2	1,901	0	0	1	1,245	0	0	336
Bulgaria	17.3	44	4	2,722	0	0	2	1,900	0	0	253
Canada*	86.8	15	18	12,595	2	1,540	2	2,000	0	0	1,635
China	50.3	2	10	7,587	5	4,170	13	12,920	50	35,880	1,294
Czech Republic	23.3	31	6	3,472	0	0	0	0	2	1,900	540
Egypt	0	0	0	0	0	0	0	0	1	600	0
Finland	22.3	33	4	2,696	1	1,600	0	0	0	0	473
France	430.9	79	59	63,473	0	0	1	1,630	1	1,600	10,146
Germany	154.6	31	17	20,303	0	0	0	0	0	0	3,458
Hungary	13	37	4	1,773	0	0	0	0	0	0	251
India	15.7	2.8	16	3,577	7	3,088	4	2,800	20	10,360	1,334
Indonesia	0	0	0	0	0	0	0	0	4	4,000	0
Iran	0	0	0	0	1	915	2	1,900	3	2,850	0
Israel	0	0	0	0	0	0	0	0	1	1,200	0
Japan	280.7	29	55	47,700	2	2,285	11	14,945	1	1,100	8,169
Kazakhstan	0	0	0	0	0	0	0	0	1	300	0
North Korea	0	0	0	0	0	0	1	950	0	0	0
South Korea	139.3	45	20	17,533	1	950	7	8,250	0	0	3,037
Lithuania	10.3	70	1	1,185	0	0	0	0	1	1,000	134
Mexico	10.8	5	2	1,310	0	0	0	0	2	2,000	256
Netherlands	3.8	3.9	1	452	0	0	0	0	0	0	112
Pakistan	1.9	2.8	2	400	1	300	2	600	2	1,200	64
Romania	5.1	8.6	1	655	1	655	0	0	3	1,995	176
Russia	137.3	16	31	21,743	3	2,650	8	9,600	18	21,600	3,439
Slovakia	16.3	56	6	2,472	0	0	0	0	2	840	356
Slovenia	5.6	42	1	696	0	0	0	0	0	0	144
South Africa	12.2	5.5	2	1,842	0	0	1	165	24	4,000	329
Spain	54.7	20	8	7,442	0	0	0	0	0	0	1,505
Sweden	69.5	45	10	8,975	0	0	0	0	0	0	1,435
Switzerland	22.1	32	5	3,220	0	0	0	0	0	0	575
Turkey	0	0	0	0	0	0	3	4,500	0	0	0

4. Nuclear Fuel Cycle and Supporting Industries

The nuclear fuel cycle, also called the nuclear fuel chain, is the progression of nuclear fuel through a series of differing stages. It consists of three steps; the **front end**, in which the fuel is prepared, the **service period** in which the fuel is used during reactor operation, and steps in the **back end**, which are necessary for safety, either to reprocess or dispose of spent nuclear fuel. If spent fuel is not reprocessed, the fuel cycle is referred to as an **open fuel cycle** (or a **once-through fuel cycle**). If the spent fuel is reprocessed, it is referred to as a **closed fuel cycle**.

Front End

The front end of the nuclear cycle encompasses uranium mining, conversion, enrichment and fuel fabrication.

Starting in uranium mines, ore is mined and milled to produce uranium in the form of uranium oxide concentrate.

Unlike coal, uranium ore cannot be fed directly into a power station; it has to be purified, concentrated (usually) and made up into special fuel rods.

Most reactors, including the common light water type (LWR), cannot run on natural uranium, so the proportion of U-235 must be increased to about 3.5%. This is called enrichment. Canadian reactors use unenriched uranium. Enrichment is a fairly high-technology physical process which requires the uranium to be in the form of a gas. The simplest way to achieve this is to convert the uranium oxide to uranium hexafluoride, which is a gas at little more than room temperature. This form of uranium is commonly referred to as UF6 or 'hex'.

The UF6 is then fed to an enrichment plant which increases the proportion of the fissile U-235 isotope. In the process about 85% of the natural uranium feed is rejected as 'depleted uranium' or 'tails' (mainly U-238) which is stockpiled. Thus, after enrichment about 15% of the original quantity is available as enriched uranium containing about 3.5% U-235.

Enriched uranium then goes on to a fuel fabrication plant where the reactor fuel elements are made. The UF6 is converted to uranium dioxide, a ceramic material, and formed into small cylindrical pellets about 2 cm long and 1.5cm in diameter. The pellets are loaded into zirconium alloy or stainless steel tubes about 4 m long to form fuel rods. These are assembled into bundles about 30 cm square to form reactor fuel assemblies. Fuel assemblies of this type are used to power the US-developed light water power reactor, currently the most popular design. A 1 MW reactor has about 75 t of fuel in it.

Canadian CANDU (CANadian Deuterium Uranium) reactors have a different design, and run on natural, that is, unenriched uranium. Instead of a single large pressure vessel containing the core, they have multiple (for example, 300-600) horizontal pressure tubes, each containing fuel and heavy water coolant. The pressure tubes extend through the reactor vessel, or calandria, which contains the heavy water moderator. CANDU fuel bundles are only 10 cm in diameter and 50 cm long.

In a light water reactor the fuel stays in the reactor for about three years, generating heat from fission of both the U-235 and also the fissile plutonium (for example, Pu-239) which is formed there. After three years or so, the level of fission products and other neutron-absorbers has built up so that the reaction is slowing down, and the spent fuel assemblies are therefore removed. About one third of the fuel is changed each year. In a CANDU type, fuel stays in the reactor only 18 months or so.

Back End

The back end of the nuclear fuel cycle, mostly spent fuel rods, often contains fission products that emit beta and gamma radiation. When removed, spent fuel is hot and radioactive. It is therefore stored under water to remove the heat and to provide shielding from radiation, pending the next step. This may be reprocessing in the case of countries such as UK, France and Japan, which have chosen to close the fuel cycle, or it may be final disposal in the case of countries such as US, Canada and Sweden, which have chosen the 'open fuel cycle'.

High Level Waste (HLW)

HLW is produced by nuclear reactors. It contains fission products and transuranic elements generated in the reactor core. It is highly radioactive and often thermally hot. HLW accounts for over 95% of the total radioactivity produced in the process of nuclear electricity generation.

High Level Waste flasks are transported by train in the UK. Each flask is constructed of 3 feet thick solid steel and weighs in excess of 50 t.

High-level radioactive waste is stored temporarily in spent fuel pools and in dry cask storage facilities. This allows the shorter-lived isotopes to decay before further handling.

Long-term storage of radioactive waste requires the stabilisation of the waste into a form which will not react, nor degrade, for extended periods of time. One way to do this is through vitrification. The 'calcine' generated is fed continuously into an induction heated furnace with fragmented glass. The resulting glass is a new substance in which the waste products are bonded into the glass matrix when it solidifies. This product, as a molten fluid, is poured into stainless steel cylindrical containers (cylinders) in a batch process. When cooled, the fluid solidifies or ‘vitrifies’ into the glass. Such glass, after being formed, is very highly resistant to water. According to the ITU, it will require about one million years for 10% of such glass to dissolve in water.

After filling a cylinder, a seal is welded onto the cylinder. The cylinder is then washed. After being inspected for external contamination, the steel cylinder is stored, usually in an underground repository. In this form, the waste products are expected to be immobilised for many thousands of years.

Transuranic Waste (TRUW)

Elements that have an atomic number greater than uranium are called transuranic or ‘beyond uranium’. TRUW as defined by US regulations is, without regard to form or origin, waste that is contaminated with alpha-emitting transuranic radionuclides with half-lives greater than 20 years, and concentrations greater than 100 nCi/g (3.7 MBq/kg), excluding High Level Waste. Because of their long half-lives, TRUW is disposed more cautiously than either low level or intermediate level waste. In the US it arises mainly from weapons production.

Spent Fuel Management

The following approaches are being pursued in relation to spent fuel management:

Reprocessing followed by vitrification of high-level reprocessing wastes with a view to eventual deep underground disposal. This is the policy in the UK, France, Japan, China, and India. As of mid-2005, German nuclear utilities no longer sent spent fuel to France or the UK for reprocessing.

Treating spent fuel as high-level waste with a view to eventual direct disposal. This is the policy in the US, Canada, and Sweden. However, the US intends to recommence reprocessing.

A number of countries operating nuclear power plants have yet to choose between reprocessing, direct disposal or long-term storage.

Table 4-2: World Commercial Reprocessing Capacity, t per year

LWR fuel:	France, La Hague	1,700	
	UK, Sellafield (THORP)	900	
	Russia, Ozersk (Mayak)	400	
	Japan	14	
	Approximate total		3,000
Other nuclear fuels:	UK, Sellafield	1,500	
	India	275	
	Approximate total		1,750
Total civil capacity			4,750

Source: World Nuclear Association

A range of alternative technologies, such as transmutation or sea-bed disposal, have been discussed for decades. However, all are seen to be non-starters for economic, technological or political reasons. Hence the 'international consensus' on the wisdom of placing high-level waste in deep underground repositories.

14. Country Profiles

North America

Canada

General Overview

The energy sector is an important part of Canada's economy. It employs just under 300,000 Canadians, or about 1.8% of the Canadian labour force, and accounts for about 6.2% of Canada's GDP. However, there are marked regional differences in energy production and consumption. The Canadian energy sector enjoys a strong presence in all primary energy commodities and strong electricity and energy efficiency industries. Canada has more lakes and rivers than any other country in the world. Electricity accounts for about 15% of domestic energy requirements. Canada's total hydropower potential is estimated at approximately 600 TWh. Canada is also well endowed with oil, natural gas, coal and uranium. It produces a surplus of crude oil above its domestic needs. In 2002, remaining established reserves of conventional crude oil amounted to 4.3 billion barrels. Proven reserves of natural gas were 1.7 trillion m3, about 3% of global reserves. Canada has extensive coal reserves estimated at 6,578 million tonnes (Mt) representing about 1% of the world's coal resources. They represent about 90 times the 2002 Canadian production. Alberta, British Columbia and Saskatchewan account for over 95% of total output. Close to half of Canada's coal production is exported. Canada produces a wide range of metals and minerals and is the world's leading producer of uranium. As of January 1st 2003, its proven uranium deposits amount to 288,000 Mt. Table 3 shows the energy resources in exajoules.

Canada has been a net exporter of most energy forms since 1969. In 2002, Canadian energy exports were valued at CAD$50 billion. The US is by far Canada's largest customer, with over 90% of Canada's energy exports. Virtually all of Canada's exports of oil, natural gas and electricity and 41% of uranium exports go to the US.

Table 14-1: Estimated Energy Reserves in Canada

Estimated energy reserves (Exajoule)						
	Solid	Liquid	Gas	Uranium (1)	Hydro (2)	Total
Total amount in place	174.21	33.15	64.29	178.21	124.26	574.12

(1) This total represents essentially recoverable reserves.
(2) For comparison purposes a rough attempt is made to convert hydro capacity to energy by multiplying the gross theoretical annual capability (World Energy Council - 2002) by a factor of 10.

Source: IAEA.

Energy Policy

Canada's energy policy supports a variety of energy sources, including nuclear energy, in order to ensure a secure and "sustainable" energy future for Canadians. There are three major areas of active federal energy policy development: conventional and renewable energies, nuclear energy and environment.

The federal government's approach to energy policy has gradually evolved over the last two decades to a stronger market-driven and less interventionist approach to energy development. In recent years environmental pressures are shaping the energy policy agenda. Environmental protection, energy efficiency and the development of new alternative sources of energy remain high on the list of federal objectives for the energy sector. The focus now is on achieving a balance between economic, environmental and security objectives, that is, sustainable development. In December 2002, Canada ratified the Kyoto Protocol reaffirming its commitment to work with the international community to address this global problem. Meeting Kyoto targets is high on the federal government agenda.

With respect to nuclear energy, the federal government is supportive of the nuclear energy option for Canada and views nuclear energy as an important component of a diversified energy mix. The federal government provides funding for Atomic Energy of Canada Limited's (AECL) nuclear R&D programme. The federal government also regulates the development and application of nuclear energy in Canada. Decision-making responsibility for planning, construction and operation of nuclear plants reside with the provinces and provincial electric power utilities. There are currently no firm plans to build additional

nuclear plants in Canada although there is growing recognition that nuclear energy will be required to meet future demand and at the same time meet climate change and air quality commitments. Servicing of existing reactors and the refurbishment of some of the units is the present focus of the nuclear utilities.

Table 14-2: Energy Statistics in Canada

Average annual Growth rate (%)	1970	1980	1990	2000	2001	2002	1970 to 1990	1990 to 2002
Energy consumption								
- Total (1)	6.53	9.31	10.79	14.58	14.65	14.68	2.54	2.60
- Solids (2)	0.83	1.15	1.35	4.87	4.73	4.66	2.48	10.90
- Liquids	2.94	3.65	3.29	2.97	2.97	2.94	0.58	-0.96
- Gases	1.27	1.96	2.62	2.97	3.13	3.28	3.68	1.87
- Primary electricity (3)	1.50	2.55	3.52	3.77	3.82	3.81	4.37	0.65
Energy production								
- Total	7.09	10.23	13.44	20.59	20.52	20.31	3.25	3.50
- Solids	0.53	1.19	1.91	5.17	5.06	4.89	6.59	8.15
- Liquids	2.92	3.45	3.81	4.90	4.95	4.91	1.34	2.13
- Gases	2.11	2.79	4.20	6.40	6.35	6.37	3.49	3.53
- Primary electricity (3)	1.52	2.81	3.53	4.12	4.15	4.14	4.30	1.35
Net import (Import - Export)								
- Total	-0.32	-0.52	-2.38	-5.98	-6.12	-6.30	10.59	8.43
- Solids	0.32	-0.05	-0.49	-0.36	-0.27	-0.15	-2.11	-9.28
- Liquids	0.17	0.37	-0.38	-1.83	-1.85	-1.87	-4.16	14.20
- Gases	-0.81	-0.84	-1.51	-3.78	-4.00	-4.27	3.17	9.04

(1) Energy consumption = Primary energy consumption + Net import (Import - Export) of secondary energy.

(2) Solid fuels include coal, lignite and commercial wood.

(3) Primary electricity = Hydro + Geothermal + Nuclear + Wind.

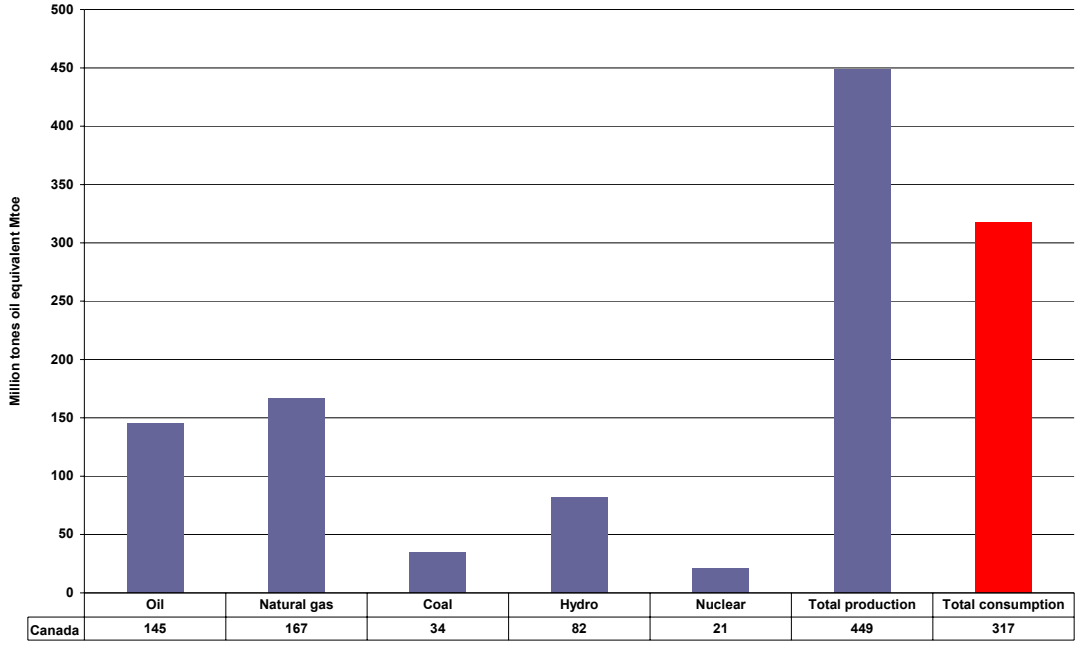
(*) Energy values are in Exajoule except where indicated.

Source: IAEA.

Ratio of Energy Production and Consumption

Nuclear energy accounted for 4.6% of primary energy supply in 2005.

Figure 14-1: Production of Energy by Source and Total Consumption in Canada, Mtoe, 2005



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