The long-term sustainability of Nuclear Energy

- **Relative to alternatives, nuclear energy is sustainable as a long-term means of supplying most of a country's electricity.**
- **This is most clearly shown by France, which embarked on its civil nuclear program in order to achieve security of supply, and now enjoys abundant low cost electricity, is the world's largest net exporter of electricity and has minimal greenhouse gas emissions from that sector.**
- **Nuclear energy as deployed in most of the world has an impeccable safety record. Management of wastes is straightforward and the only impediments to final disposal of high-level wastes are political.**
- **The resource base for greatly expanded nuclear power generation is available**.

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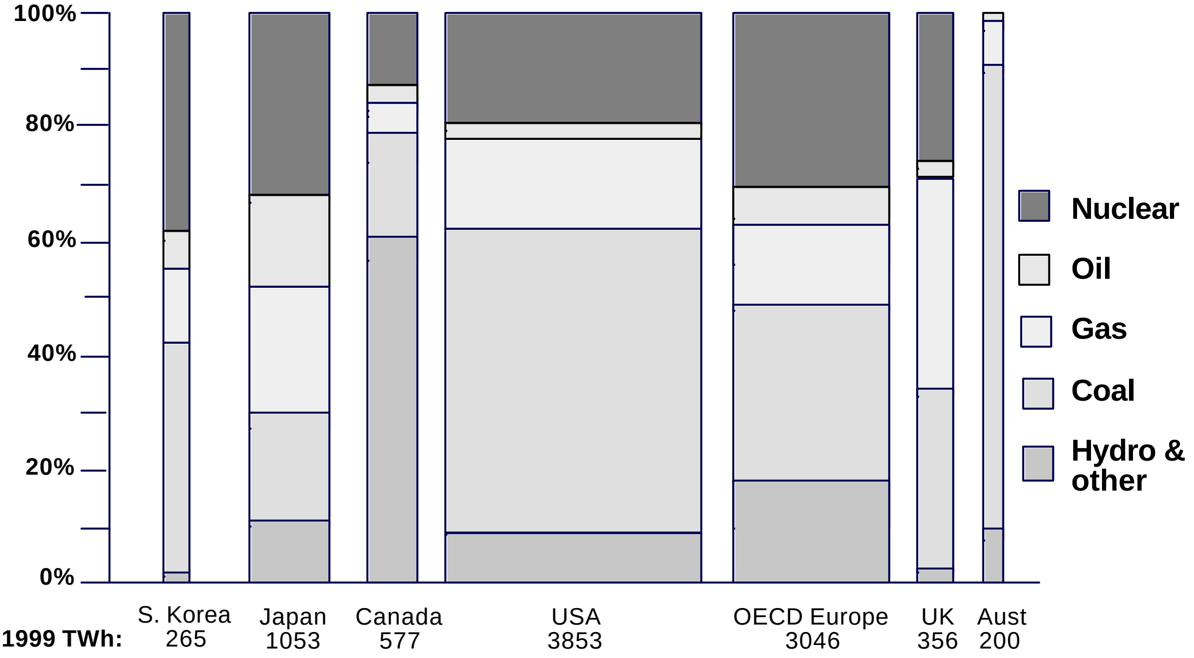
1. Nuclear Energy Today

Fifteen countries derive at least a quarter of their electricity from nuclear power. France gets more than three quarters of its electricity from nuclear energy, while Belgium, Bulgaria, Hungary, Japan, Lithuania, Slovakia, South Korea, Sweden, Switzerland, Slovenia and Ukraine get 35% or more from nuclear.

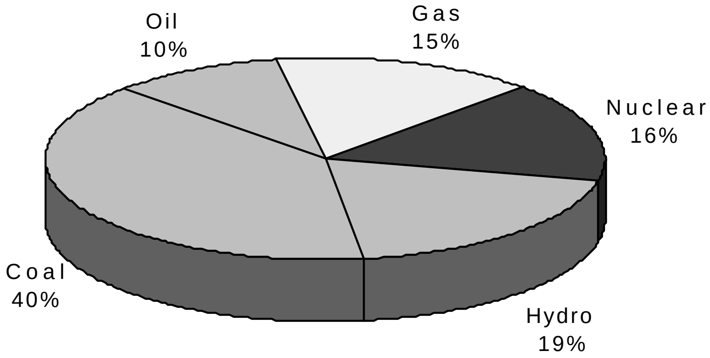
Fuel for electricity generation (percent)



Width of each bar is indicative of power generated (gross production)
Source: OECD/IAEA 2000: *Electricity Information 2000 with 1999 Data*

As of June 2001, 31 countries have a total of 437 commercial nuclear power reactors producing over 16% of the world's electricity. A further 31 commercial power reactors were under construction and six (in Canada) were undergoing major refurbishment. A list of the countries with nuclear power projects is appended (WNA reactor table). In addition, 56 countries have 284 civil research reactors operating.

World Electricity



The generating capacity of the nuclear power reactors currently operating is some 353 000 MWe. The reactors under construction total 8.6 percent of existing capacity, and those ordered or planned, a further 11.6 percent.

The economics of nuclear power

The relative costs of generating electricity from coal, gas and nuclear plants vary considerably depending on location. Coal is, and will probably remain, economically attractive in countries such as Australia and parts of China and the USA with abundant and accessible domestic coal resources. Gas is, or recently has been, also competitive for base-load power in many places, particularly with combined-cycle plants.

Nuclear energy is, in many places, competitive with fossil fuel for electricity generation, despite relatively high capital costs and the need to internalise all waste disposal and decommissioning costs. If the social, health and environmental costs of fossil fuels are also taken into account, nuclear is outstanding.

The report of a major European study of the external costs of various fuel cycles, focusing on coal and nuclear, was released in mid 2001. It shows that in clear cash terms nuclear energy incurs about one tenth of the costs of coal. The external costs are defined as those actually incurred in relation to health and the environment and quantifiable but not built into the cost of the electricity. If these costs were in fact included, the EU price of electricity from coal would double and that from gas would increase 30%. These are without attempting to include global warming.

The European Commission launched this ExternE project in 1991 in collaboration with the US Department of Energy, and it was the first research project of its kind "to put plausible financial figures against damage resulting from different forms of electricity production for the entire EU". The methodology considers emissions, dispersion and ultimate impact. With nuclear energy the risk of accidents is factored in along with high estimates of radiological impacts from mine tailings (waste management and decommissioning being already within the cost to the consumer). For external costs only, nuclear energy averages 0.4 euro cents/kWh, much the same as hydro, coal is over 4.0 cents (4.1-7.3), gas ranges 1.3-2.3 cents and only wind shows up better than nuclear, at 0.1-0.2 cents/kWh average. These all need to be added to the conventionally-quoted costs, such as those (the most recent international figures available) in the table below.

The OECD does not expect investment costs in new nuclear generating plants to rise, as advanced reactor designs become standard. The future competitiveness of nuclear power will depend substantially on the additional costs which may accrue to coal generating plants.

Without considering external costs not already included, and under current regulatory measures, the OECD expects nuclear to remain economically competitive with fossil fuel generation, except in regions where there is direct access to low cost fossil fuels. In Australia, for example, coal-fired generating plants are close to both the mines supplying them and the main population centres, and large volumes of gas are available on low cost, long-term contracts.

The most recent OECD comparative study shows that at a 5% discount rate, in 7 of 13 countries considering nuclear energy, it would be the preferred choice for new base-load capacity commissioned by 2010 (see Table below). At a 10% discount rate the advantage over coal would be maintained in only France, Russia and China, unless the external costs are brought fully into account.

Comparative electricity generating cost projections for 2005-2010

	nuclear	**coal**	**gas**
France	**3.22**	4.64	4.74
Russia	**2.69**	4.63	3.54
Japan	5.75	**5.58**	7.91
Korea	**3.07**	3.44	4.25
Spain	**4.10**	4.22	4.79
USA	3.33	2.48	**2.33** - 2.71
Canada	**2.47**-2.96	2.92	3.00
China	**2.54**-3.08	3.18	-

US 1997 cents/kWh. Discount rate 5%, 30 year lifetime, 75% load factor**.** ***OECD 1998***.

A 1997 European electricity industry study compared electricity costs from nuclear, coal and gas for base-load plant commissioned in 2005. At a 5% discount rate nuclear (in France and Spain) at 3.46 cents/kWh (US), was cheaper than all but the lowest-priced gas scenario. However at a 10% discount rate nuclear, at 5.07 c/kWh, was more expensive than all but the high-priced gas scenario. (ECU to US$ @ June '97 rates)

In 1999 Siemens (now Framatome ANP) published an economic analysis comparing combined-cycle gas plants with new designs, including the European Pressurised Water Reactor (EPR) and the SWR-1000 boiling water reactor. Capital costs for these in Germany, at 1750 and 1000 MWe respectively, were both EUR 1250/kW, compared with EUR 1375/kW for a 1550 MWe version of the EPR, and EUR 1500/kW for the 1350 MWe Advanced Boiling Water Reactor, two of which are now operating in Japan.

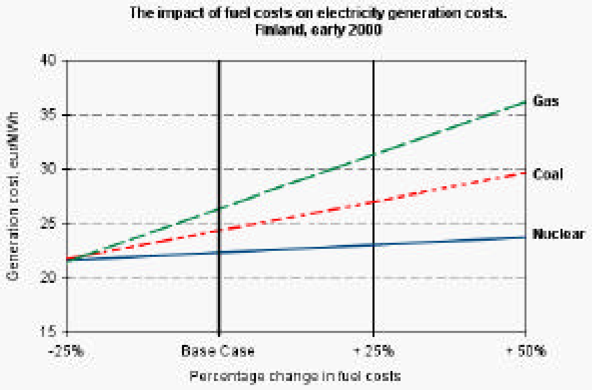
Looking at power costs, both the 1550 MWe EPR if built as a series in France /Germany and the SWR-1000 (with an 8% discount rate) were competitive with gas combined cycle, at EUR 2.6 cents/kWh. But once depreciated, their costs fall to about 1.5 cents/kWh compared with gas at 2.5 cents (capital being 60% of the nuclear plant costs but only 15% of the gas plant costs).

The current-generation Konvoi plants operating in Germany produce power at 3.0 cents/kWh including full capital costs, falling to 1.5 c/kWh after complete depreciation.

A detailed study of energy economics in Finland published in mid 2000 shows that nuclear energy would be the least-cost option for new generating capacity. The study compared nuclear, coal, gas turbine combined cycle and peat. Nuclear has very much higher capital costs than the others --EUR 1749/kW including initial fuel load, which is about three times the cost of the gas plant. But its fuel costs are much lower, and so at capacity factors above 64% it is the cheapest option. At 80% capacity factor, nuclear fuel costs are EUR 2.36 c/kWh, gas

2.69, coal 2.54 and peat 3.26. At 90% (Finland's norm for nuclear plants) the nuclear advantage increases to 2.15 c/kWh compared with 2.41 for coal and 2.61 for gas. Gas is cheapest only below about 55% capacity. A real interest rate of 4.5% was used in the study.

The Finnish study also quantified fuel price sensitivity to electricity costs:



These show that a doubling of fuel prices would result in the electricity cost for nuclear rising about 9%, for coal rising 31% and for gas 66%. These are similar figures to those from a 1992 OECD report. Gas prices have already risen significantly since the study.

The industry continues to invest and develop new reactor designs in order to improve both safety margins and economic performance. Much progress has been made towards licensing these in the USA and Japan, BNFL's Westinghouse subsidiary has been active in this, and recently an innovative development of an earlier design has been in the news – the Pebble Bed Modular Reactor (PBMR), with production costs projected at a little over 1 p/kWh. See also WNA paper on *Advanced Reactors*.

Improved Performance From Existing Reactors

Although there are not as many nuclear power plants being built now as there were during the 1970s-1980s, the plants now operating are producing more electricity. In 2000, production was 2447 billion kWh, an increase of 15% over the previous six years. This increase (317 TWh) is equal to the output from over thirty large new nuclear power plants, but in fact over 1995-2000 there was a net increase of only five reactors and 3% in capacity. The balance is due to better performance from existing power reactors.

In the Siemens study quoted above, a 50% increase in PWR burn-up (on a thermal, not electrical basis) is charted, from 30 MWd/kg U in 1974 to 45 MWd/kg in 1998. For the BWR the increase is from 23 to 40 MWd/kg over the same period, coupled with increased physical reliability of the fuel.

Two thirds of the world's nuclear reactors outside Russia and Ukraine have load factors over 75%, compared with only 39% operating at this level in 1990. For the past 15 years Finnish plants have been at the top of the performance tables, now with average load factors around 92%. Belgian, Czech, German, Hungarian, Japanese, South Korean, Spanish, Swiss, Taiwanese and US reactors range down to about 80%.

US nuclear power plant performance has shown a steady improvement over the past ten years and at 85% average load factor, has moved (from 65% in 1990) into the top bracket, with some of the best (17 of top 25) reactors. The USA accounts for nearly one third of the world’s nuclear electricity.

In 1999-2000 Japanese plants came in at 80.6% load factor and French reactors averaged 71.2% (the lower figure due to many being used in load-following mode rather than simply for base-load supply).

New Reactors under Construction

Some 31 power reactors are currently being constructed in 11 countries (see Table), notably China, the Republic of Korea and Japan. Construction is well-advanced on many of them and, based on reported progress and allowing for delays in some countries, 16 with a total net capacity of over 11,000 MWe are expected to be in operation before the end of 2004.

Power Reactors Under Construction

YEAR †	COUNTRY	REACTOR	TYPE	MWe
2001	Czech Republic	Temelin 2	PWR	912
2002	Japan	Onagawa 3	BWR	796
2002	Korea RO	Yonggwang 5	PWR	950
2002	Korea RO	Yonggwang 6	PWR	950
2002	China	Qinshan 2	PWR	610
2002	China	Lingao 1	PWR	935
2002	Argentina	Atucha 2	PHWR	692
2003	Romania	Cernavoda 2	PHWR	650
2003	Iran	Bushehr 1	PWR	950
2003	China	Lingao 2	PWR	935
2003	China	Qinshan 3	PWR	610
2003	China	Qinshan 4	PHWR	665
2004	China	Qinshan 5	PHWR	665
2004	Russia	Kalinin 3	PWR	950
2004	Russia	Kursk 5	RBMK	925
2004	Ukraine	Khmelnitski 2	PWR	950
2004	Taiwan	Lungmen 1	ABWR	1350
2004	Korea RO	Ulchin 5	PWR	950
2004	China	Tianwan 1	PWR	950
2005	Korea RO	Ulchin 6	PWR	950
2005	Japan	Higashidori 1	BWR	1067
2005	Japan	Hamaoka 5	ABWR	1325
2005	Taiwan	Lungmen 2	ABWR	1350
2005	Russia	Rostov-2	PWR	950
2005	China	Tianwan 2	PWR	950
2005	India	Tarapur 3	PHWR	450
2006	Ukraine	Rovno 4	PWR	950
2006	Japan	Shika-2	ABWR	1315
2006	India	Tarapur 4	PHWR	450
2006	Russia	Balakovo 5	PWR	950

† Latest announced year of proposed commercial operation. Onagawa-3 started up recently.

Increased Capacity of Existing Reactors

Increased nuclear capacity in some countries is resulting from the uprating of existing plants.

Power reactors in USA, Belgium, Sweden and Germany, for example, have had their generating capacity increased. In Switzerland, a program is being undertaken to increase the capacity of its five reactors by 10%.

Spain has a program to add 606 MWe (8.2%) to its nuclear capacity by 2003 through upgrading six of its nine reactors by up to 15%. For instance, the Almarez nuclear plant is being boosted by more than 5% at a cost of US$ 50 million.

Finland has recently boosted the capacity of the Olkiluoto plant by 23% to 1680 MWe. This plant started with two 660 MWe Swedish BWRs commissioned in 1978 and 1980. It is now licensed to operate to 2018. The Loviisa plant, with two VVER-440 (PWR) reactors, has been uprated by almost 100 MWe (11%).

Longer Term Plans

After about 2006 and until orders are placed or construction commenced, forecasts of installed nuclear capacity become much less certain. When the present construction programs are completed, most significant nuclear power growth has been expected to continue only in the Asian region, though with rising gas prices in Europe and North America, nuclear growth may be more widespread.

The International Atomic Energy Agency (IAEA) forecasts that the total installed nuclear capacity in 2015 will be little more than that in 2000, - 370 GWe, with the nuclear share of world electricity output decreased from 17% in 1997 to 13% in 2015.

At least six countries with existing nuclear power programs (Finland, Russia, China, India, Japan & South Korea) have plans to build new power reactors (beyond those now under construction). In addition, the program to provide North Korea with two South Korean 1000 MWe pressurised water reactors is proceeding. Of countries without any present nuclear capacity, Iran has construction well advanced on its first unit.

In all, 44 power reactors with a total net capacity of about 41,000 MWe are planned. None of these is in western Europe or the Americas.

However, rising gas prices and greenhouse constraints on coal have combined to put nuclear power back on the agenda for projected new capacity in both Europe and North America.

Some Power Reactors planned or on order

start operation	start construction	COUNTRY	REACTOR	TYPE	MWe (each)
2006	2002	India	Kudankulam	PWR (VV-1000)	950
2006-7	2002	Japan	Fukushima 7 & 8	ABWR	1325
2007-8		North Korea	Sinpo 1 & 2	PWR (KNSP)	950
2008	2003	Japan	Ohma	ABWR	1350
2007-8		Russia	Sosnovy Bor 1	PWR (VV-640)	600
2010		Russia	Balakovo 6	PWR	950
2010-11	2003?	RO Korea	Kori 1 & 2	PWR (KNSP)	950
2009-10	2003?	RO Korea	Wolsong 5 & 6	PWR (KNSP)	950
2008	2003	Japan	Tomari 3	PWR	912
2010	2003	Japan	Tsuruga 3 & 4	APWR	1500
2010	2003	Japan	Shimane 3	ABWR	1375
		India	Rajasthan 5 - 8	PHWR	450
		India	Kaiga 3 - 6	PHWR	450
		RO Korea	Kori 3 & 4	APR (KNGR)	1350
		RO Korea		APR (KNGR)	1350
2010-11	2003-5	Japan	Higashidori 1-2, 2	ABWR	1320
2012-15	2007-10	Japan	Kaminoseki 1-2	ABWR	1320

according to announcements 1998-2001

In **France**, the only western European country which has recently had an active nuclear power construction program, the national utility announced in 1994 that it will order no new generating capacity, nuclear or conventional, until about 2002. Sites have, however, been designated for new power reactors and new reactor construction is expected to resume in a few years.

In eastern Europe, the **Russian** government in 1997 approved a nuclear power construction program. In addition to the three reactors presently under construction, a further 9, taking total capacity to about 29,200 MWe, are planned to be operating by 2010. Most are at existing sites. It is Russia's announced intention to replace retired nuclear capacity by new construction at the same site, to optimise the use of established infrastructure and personnel. Three advanced reactor designs are envisaged in the program.

All this is seen as a precursor to large-scale nuclear energy development after 2010. However, approval of local and regional authorities, which have been responsible for the suspension of a number of nuclear power plant projects in recent years, is required.

In **Ukraine**, much of the finance for completing two stalled but largely-built reactors has recently been pledged, and these will replace lost output from Chernobyl.

Most reactors currently planned are in the Asian region, with fast-growing economies and rapidly-rising electricity demand. Nuclear power will continue to play a major role in the future electricity supply mix in both South Korea and Japan.

In addition to the two reactors under construction, **South Korea** plans to bring a further 12, with a total capacity of 13,100 MWe, into operation by the year 2015.

Japan has plans and, in many cases, designated sites and announced timetables for a further 20 power reactors, totalling over 25,000 MWe, and some of these are negotiating the governmental approval process. Earlier this year the major utility Tepco deferred plans for 12 major fossil fuel power plants but maintained the schedules for four new nuclear plants.

China, with three operating reactors, is well into the next phase of its nuclear power program. Construction is advanced on Qinshan 2 & 3 (2 x 600 MWe, PWRs), two French 900 MWe units for Lingao, Guangdong, two 700 MWe Canadian-designed CANDU reactors at Qinshan, and two Russian 950 MWe PWRs at Jiangsu Tianwan in Lianyungang. These are expected to start up from 2002 to 2006, and to add some 6200 MWe to the existing 2167 MWe nuclear capacity. China plans to increase its nuclear capacity to 20,000 MWe by 2010.

India has announced plans for 11 power reactors (4980 MWe) of its larger reactor type, in addition to the two under construction, but financing difficulties are expected to continue to cause considerable delays. There are also plans to build two large Russian reactors there.

Nuclear power plant construction in **Iran** was suspended in 1979 but in 1995 Iran signed an agreement with Russia to complete a 1000 MWe PWR at Bushehr. Iran also has an earlier agreement with Russia for the supply of two 410 MWe power reactors and a further large one is envisaged at Bushehr also.

Indonesia has completed the feasibility study for its first 1800 MWe nuclear power station, but this is deferred indefinitely. **Egypt** and **Turkey** have for decades included a nuclear power plant in their electricity plans. A site has been selected in each country and a number of feasibility and other studies carried out. Turkey however has indefinitely deferred its first plant.

Plant Life Extension

Most nuclear power plants originally had a nominal design lifetime of up to 40 years, but engineering assessments of many plants over the last decade has established that many can operate longer. In the USA the first few reactors have been granted licence renewals which extends their operating lives from the original 40 out to 60 years, and operators of some 80 more are expected to apply for similar extensions. In Japan, plant lifetimes up to 70 years re envisaged.

When the oldest commercial nuclear power stations in the world, Calder Hall and Chapelcross in the UK, were built in the 1950s they were very conservatively engineered, though it was assumed that they would have a useful lifetime of only 20-25 years. They are now authorised to operate for 50 years, and most other Magnox plants are licensed for 40-year lifetimes.

Sweden's oldest reactor which started up in 1971, has been fully rebuilt at a cost equivalent to 8% of a replacement unit, and all Sweden's reactors are maintained so that a further 20 years of life is in prospect.

The Russian government in 2000 extended the operating lives of the country's 12 oldest reactors from their original 30 years, and recently the extension was quantified as 15 years.

The technical and economic feasibility of replacing major reactor components, such as steam generators in PWRs and pressure tubes in CANDU heavy water reactors, has been demonstrated. The possibilities of component replacement and licence renewals extending the lifetimes of existing plants are very attractive to utilities, especially in view of the public acceptance difficulties involved in constructing replacement nuclear capacity.

Case study: France

- ***France derives 75% of its electricity from nuclear energy. This is due to a long-standing policy to promote energy independence.***
- ***France is the world's largest net exporter of electricity, and gains some US$ 2 billion per year from this.***

France has 59 nuclear reactors with total capacity of over 63 GWe, supplying some 395 billion kWh per year of electricity, 75% of the total generated there.

Apart from one experimental fast breeder reactor, all of these are pressurised water reactors of three standard types: 900 MWe (34), 1300 MWe (20) and 1450 MWe (4).

The present situation is due to the French government deciding in 1974, just after the first oil shock, to expand rapidly the country's nuclear power capacity. This decision was taken in the context of France having substantial heavy engineering expertise but few indigenous energy resources. Nuclear energy, with the fuel cost being a relatively small part of the overall cost, made good sense in minimising imports.

As a result of the 1974 decision, France now claims a substantial level of energy independence and almost the lowest cost electricity in Europe. Over 90% of its electricity is nuclear or hydro and hence without greenhouse gas emissions.

France has also exported its reactor technology to Belgium, South Africa, South Korea and China. There are two 900 MWe French reactors operating at Koeberg, near Capetown in South Africa, two at Ulchin in South Korea and two at Daya Bay, near Hong Kong. China is also building two more French type 985 MWe PWR reactors at Lingao, near Daya Bay, for commissioning in 2002 and 2003.

In addition to reactors, on the front end of the fuel cycle France has a major conversion plant (14,000 t/yr), a large modern enrichment plant (10.8 million SWU/yr) and both uranium oxide and mixed oxide (MOX) fuel fabrication plants. At the back end, it has the world's largest reprocessing plant for spent fuel (1600 t/yr) and a matching vitrification plant for high-level wastes. All these facilities are operated commercially, with international customers. Together they comprise a significant export industry and France's major export to Japan.

Future French reactors will be the 1450 MWe advanced European Pressurised Water reactor (EPR) developed with Germany as a new standard design.

Economic Factors

France's nuclear power program has cost some FF 400 billion (A$ 90 billion) in 1993 currency, excluding interest during construction. Half of this was self-financed by Electricité de France, 8% (FF 32 billion) was invested by the state but discounted in 1981, and 42% (FF 168 billion) was financed by commercial loans. In 1988 medium and long-term debt amounted to FF 233 billion, or 1.8 times EdF's sales revenue. However, by the end of 1998 EdF had reduced this to FF 122 billion, about two thirds of sales revenue (FF 185 billion) and less than three times annual cash flow. Net interest charges had dropped to FF 7.7 billion (4.16% of sales) by 1998.

From being a net electricity importer through most of the 1970s, France now has steadily growing net exports of electricity, which amounted to 57 TWh and EUR 2.3 billion (A$ 3.7 billion) in 1998. France is thus the world's largest net electricity exporter, and electricity is France's fourth largest export. (Next door is Italy, without any operating nuclear power plants. It is Europe's largest importer of electricity, most coming ultimately from France.)

2. The Long-term Sustainability of Nuclear Power

Until the last ten or twenty years sustainability of energy supplies was thought of simply in terms of their abundance relative to the rate of usage. Today, in the context of the ethical framework of Sustainable Development, other aspects are equally important: the environmental effects involved, the question of wastes (even if they have no environmental effect), safety, and the broad and indefinite aspect of maximising the options available to future generations.

There are many who at the dawn of a new decade see no realistic alternative to pushing Sustainable Development criteria into the front line of energy policy. Whatever the seriousness of greenhouse matters (which have taken on a political life of their own regardless of the science), there is clearly more widespread concern than a few years ago about how we address energy needs on a sustainable basis.

Energy demand

There is little dispute that the world's population is likely to keep growing for several decades at least, that energy demand is likely to increase even faster, and that the proportion of this supplied by electricity will continue to grow. Opinions diverge as to whether the electricity demand will continue to be served predominantly by massive grid systems, or whether there will be a strong trend to generation close to the points of use. That is a fascinating question, but either way, it will not obviate the need for more large-scale grid-supplied power especially in urbanised areas over the next several decades.

The major energy question is where our electricity will come from. Today, worldwide, 64% is from fossil fuels, 16% from nuclear fission and 19% from hydro, with very little from other renewables. There is no prospect that we can do without any of these.

Energy resources

Harnessing renewable energy is an appropriate first consideration in sustainable development, but it cannot be the only option. We can certainly make much more use of solar energy, for direct application (hot water etc) and for conversion to electricity. The fact that we can enjoy our summer holidays in the sun testifies to its low intensity, while bad weather and night-time underline its short-term unreliability. It is these two aspects which provide the challenge. And it is a technological challenge of some magnitude to collect energy at a peak density of about one kilowatt per square metre when the sun is shining and then apply it to the kind of electricity demand which exists, much of it for relatively continuous and large-scale supply. Solar and wind are clearly incapable of meeting this kind of demand reliably.

Beyond renewables it is a question of what is most abundant and least polluting. Today, to a degree almost unimaginable even 25 years ago, there is an abundance of many energy sources in the ground. Coal and uranium (not to mention thorium) are available and unlikely to be depleted this century. Uranium is even available from sea water at costs which would have little impact on electricity prices. In any case the resource can be multiplied 60 to one hundredfold by adopting the kind of technology which our postwar forebears thought would be necessary by now, - fast neutron reactors. The next section considers uranium availability.

The criteria for any acceptable energy supply will continue to be cost and safety, the latter including environmental effects. Grappling with those environmental effects has cost implications, as the current greenhouse debate makes clear. But low cost electricity with acceptable safety and low environmental impact will depend substantially on harnessing and deploying reasonably sophisticated technology.

Manufacturing high-efficiency solar cells is not a cottage industry, nuclear energy has obvious high-tech requirements for reliability and safety, and even coal-burning becomes a high-tech operation under efficiency and greenhouse constraints.

Fuel cells, which promise so much in extending the utility of solar energy collection, are at an early stage of technological development with substantial R&D input still required. Certainly they promise to be an important technology of the future, but insofar as they depend on hydrogen fuel, that will need to be made from water, and so a very large increase in electricity demand is foreseeable. However, this electricity need not be continuous base-load supply, and solar or wind generation may well serve the purpose since hydrogen can be accumulated and stored. The safety implications of a hydrogen economy (such as might maximise the use of fuel cells) still need to be addressed in the public arena.

Wastes

A major concern when applying Sustainable Development considerations is wastes – both those produced and those avoided.

With solar energy wastes are mainly produced in manufacturing the conversion equipment, with nuclear energy they are operational and in decommissioning, and with fossil fuels they are primarily operational. There seems no reason why manufacturing wastes cannot be dealt with, nuclear energy contains and manages its wastes, and the focus today is on greenhouse gases from fossil fuels combustion. With nuclear energy the waste question is political, regarding final disposal, rather than technical, and all civil wastes are managed without environmental impact. **Nuclear power remains the only energy-producing industry which takes full responsibility for all its wastes, and costs this into the product - a key factor in sustainability.**

Electricity generation from fossil fuels produces substantial amounts of carbon dioxide, a greenhouse gas of prime concern. As a rule of thumb, every thousand kilowatt hours (1 MWh) of electricity generated from nuclear energy avoids the emission of one tonne of carbon dioxide, relative to generating that electricity from black coal.

Ethical issues surrounding nuclear wastes are topical. However, prominence of the issue has tended to obscure the fact that these wastes are a declining hazard, whereas other industrial wastes retain their toxicity and hence hazard indefinitely.

Regardless of whether particular wastes are nasty for centuries or millennia or forever, there is a clear need to address the question of their safe disposal. If the wastes cannot readily be destroyed or denatured, this generally means removal or isolation from the biosphere, although, the alternative view is frequently put. This asserts that indefinite surface storage of wastes under supervision is preferable to geological disposal, since progressing the latter would simply give encouragement to continued use and expansion of nuclear energy. It is often made very plain that ideological opposition to nuclear energy is more important to its detractors than dealing properly with wastes so as to achieve high levels of safety and security. The wider question of alternative low-CO_2 means of producing base-load electricity tends not to be addressed.

In a 1999 OECD article, *Long-term management of radioactive waste, ethics and the environment*, Claudio Pescatore outlines some ethical dimensions of the question. He starts on a very broad canvas by quoting four fundamental principles proposed by the US National Academy of Public Administration. This proposal followed a request from the US Government to elucidate principles to guide decisions by public administration on the basis of the international Rio and UNESCO Declarations concerning responsibilities for future generations:

- The Trustee Principle says that "Every generation has obligations as trustee to protect the interests of future generations".
- The Sustainability Principle states that "No generation should deprive future generation of the opportunity for a quality of life comparable to its own."
- The Chain of Obligation Principle says that "Each generation's primary obligation is to provide for the needs of the living and succeeding generations," the emphasis being that "near-term concrete hazards have priority over long-term hypothetical hazards."
- The Precautionary Principle is expressed as "Actions that pose a realistic threat of irreversible harm or catastrophic consequences should not be pursued unless there is some countervailing need to benefit either current or future generations."

These are then applied to the question of nuclear wastes, and in particular to geological disposal of these which is noted as having intrinsic passive safety. In the light of the IAEA and the NEA 1995 publications on the matter, Dr Pescatore summarises the principles in this context as follows:

- The generation producing the waste is responsible for its safe management and the associated costs.
- There is an obligation to protect individuals and the environment both now and in the future.
- No moral basis exists for discounting future health and risks of environmental damage.
- In particular, our descendants should not knowingly be exposed to risks which we would not accept today. Individuals should be protected at least as well as they are today.
- The safety and security of repositories should not be based on the presumption of a stable social structure for the indefinite future or on a presumption of technological progress.
- Waste should be processed in such a way as not to be a burden for future generations. However, we should not unnecessarily limit the capacity of future generations to take over management control, including the ability to recover the waste.
- We are responsible for passing on to future generations our knowledge concerning the risks related to waste.
- There should be enough flexibility in the disposal procedures to allow alternative choices. In particular information should be given to the public to enable it to take part in the decision-making process which, in this case, will proceed in stages.

He points out that "geological disposal is considered as the final stage in waste management, ensuring security and safety in such a way as not to require surveillance, maintenance, or institutional control. Although such measures are not necessary to ensure safety and security, they are not, however, excluded. Society will still be able to choose to use them as management tools."

Safety

The safety of nuclear energy has been well demonstrated, and its record is unsurpassed by any technology capable of delivering a comparable amount of power. This safety picture is notwithstanding the continued operation of a small number of reactors which are, by western standards, distinctly unsatisfactory (in particular, 11 VVER-440/230 types and 13 RBMK types have serious design deficiencies, and one of the latter type precipitated the 1986 Chernobyl disaster). Over 10,000 reactor-years of operation have shown a remarkable lack of problems in any of the reactors which are licensable in most of the world.

There is probably no other large-scale technology used worldwide with a comparable safety record, this being largely due to the fact that safety was given a very high priority from the outset of the civil nuclear energy program, at least in the west. About one third of the cost of a typical reactor is due to its safety systems and structures, including containment and back-up provisions. This is a higher proportion even than in aircraft design and construction.

Any statistics comparing the safety of nuclear energy with alternative means of generating electricity show nuclear to be the safest. In fact Chernobyl is the only event detracting from an almost impeccable record in commercial nuclear power, and Chernobyl is of very little relevance to the actual safety of most of the world's reactors.

Energy security

Particularly from a national perspective, the security of future energy supplies is a major factor in assessing their sustainability. Whenever objective assessment is made of national or regional energy policies, security is a priority.

France's decision in 1974 to expand dramatically its use of nuclear energy was driven primarily by considerations of energy security, though their economic virtues have since become more prominent. The EU Green Paper on energy security in 2000 put forward coal, nuclear energy and renewables as three pillars of future energy security for Europe.

Energy inputs to the nuclear fuel cycle and associated greenhouse gas emissions

There has been a concerted attempt recently to question the net energy benefits of nuclear energy by asserting that it requires so much energy input, and incurs so much longer-term energy debt, that it is not viable, and that the greenhouse gas emissions from those inputs and debts cancel out any advantage on that score.

This question is fully addressed in a WNA Information Paper *Energy Analysis of Power Systems*. The charge does not stand up, and in fact energy inputs on a lifetime basis are typically about 2% of the lifetime outputs. No reputable figures put the total higher than 8.7% of output, and we would want to challenge some of the components even of that. The question of greenhouse gas emissions incurred in the energy inputs depends of course on the source of energy for those inputs, but is arguably more about sophistry than science.

Opportunity costs

Nuclear energy and renewables have one important feature in common: they give us access to virtually limitless resources of energy with negligible opportunity cost, - we are not depleting resources useful for other purposes. Of course minimising opportunity cost would be very difficult if we preferred to "leave uranium in the ground", as sometimes urged. The question of the technologies involved and our willingness to harness them is central, whatever the preferred course.

Even more fundamental is the ethical consideration of resources, and opportunity costs. What preference should be given to utilising abundant rather than less abundant energy resources? Those with no significant other uses rather than those which are versatile? Those with least environmental impact from wastes?

Any attempt to answer these from a future-oriented perspective is likely to reaffirm the desirability of utilising renewable energy sources, and it may also suggest that the time is not far off when fossil carbon-based fuels are too valuable to burn on the scale we have been doing.

Recent analyses fail to come up with any 50-year scenario aligned with Sustainable Development principles which does not depend significantly on nuclear fission for large-scale, high energy-intensive needs, along with renewables for small-scale (and especially dispersed) low-intensity needs. The alternative to such a dual approach is either squandering fossil carbon resources or denying the aspirations of many billions of people in our grandchildren's generation.

Nuclear energy's detractors have yet to credibly suggest where the bulk of our future electricity will come from. Certainly all the reputable energy scenarios show the main load being carried by coal, gas, and nuclear, with the balance among them depending on economic factors in the context of various levels of greenhouse constraints.

The notion of sustainability may be expected to assert itself politically before it starts to drive the economics of fuel choice for electricity production in the way that has been seen with oil in the last three decades. The sooner substantial solar and wind capacity is operating on grid systems the sooner their advantages and limitations will become widely evident. That will help focus the public discussion on the real options for base-load electricity.

Political sustainability

While this submission concentrates on the physical and economic aspects of sustainability, it is noteworthy that public opinion in the two countries which have engaged in the most intensive discussion on nuclear power, and reflected most pointedly on the possible consequences of being without it, is more strongly pro-nuclear than elsewhere in Europe.

In Sweden, which gets about half its electricity from nuclear power, a 1980 referendum focused on three options for phasing out nuclear power and none for retaining it. Since then government policy has mellowed, one token reactor has been closed down, another is threatened with closure (though with a wide loophole) and the other ten are no longer under threat of premature closure.

Since the 1980 referendum, public opinion has been largely positive towards nuclear energy. For instance in 1996 a survey conducted by the Confederation of Swedish Industries found 80% in favour of nuclear power. Of those in favour, two thirds thought the nuclear plants should continue full term and thought that any premature closure was unjustifiable. The other third favoured replacing decommissioned reactors with new ones.

After a political deal of early 1997 the favourable view strengthened. In 1998 two thirds said that nuclear power plants should be used for as long as they complied with safety standards, that the Barsebäck nuclear plant should not be closed if this involved increasing fossil fuel use and that the most important consideration was avoiding any increase in greenhouse gas emissions. Protecting remaining rivers from hydro works was seen as most important by 14%, while only 13% gave top priority to phasing out nuclear energy.

In June 1999 a further poll in the same series showed 82% of Swedes wanted the country's 12 nuclear plants to continue in operation, with only 16% supporting early closure of any. One in four of the 82% were in favour of building new nuclear plants. Overall 74% said that the highest government priority should be curbing greenhouse gas emissions, compared with 14% nominating protection of unspoiled rivers and 8% nuclear phase-out as top priority.

Germany's official government anti-nuclear stance is well known. It is less well realised that the policy today is an enormous backdown on its original form. Ideology has been tempered by reality, including the fact that the country depends on nuclear energy to provide a third of its power. But more significantly, public opinion has not supported the anti nuclear position where people have had a chance to reflect on its possible consequences.

In Germany, public sentiment in the last few years has swung strongly towards support of nuclear energy. A poll late in 1997 showed that some 81% of Germans wanted existing nuclear plants to continue operating, the highest level for many years and well up from the 1991 figure of 64%. The vast majority of Germans expected nuclear energy to be widely used in the foreseeable future. The poll also showed a sharp drop in sympathy for militant protests against transport of radioactive waste.

A major poll carried out after the October 1998 election confirmed German public support for nuclear energy. Overall 77% supported the continued use of nuclear energy, while only 13% favoured the immediate closure of nuclear power plants. Then late in 1999 opposition to nuclear energy dwindled to 12%, its lowest point for many years. The figure for 14-29 year-olds was 17% opposing, just over half the level at the start of the decade. Asked about the government's phase-out policy, 38% opposed it, 23% supported it and 39% were undecided.

A poll early in 2000 and showed that 38% wanted Germany's nuclear plants to continue in service for the foreseeable future, while a further 25% supported the replacement of older units with more modern reactors (ie 63% positive).

The lesson for UK from Germany and Sweden is that where citizens are faced with real consequences of possibly abandoning the use of nuclear energy, support for it is strong, despite entrenched ideology within government and popular support for developing renewables. In other countries where the question is merely academic and emotional, it is possible to find greater support for anti-nuclear sentiment.

3. Uranium availability

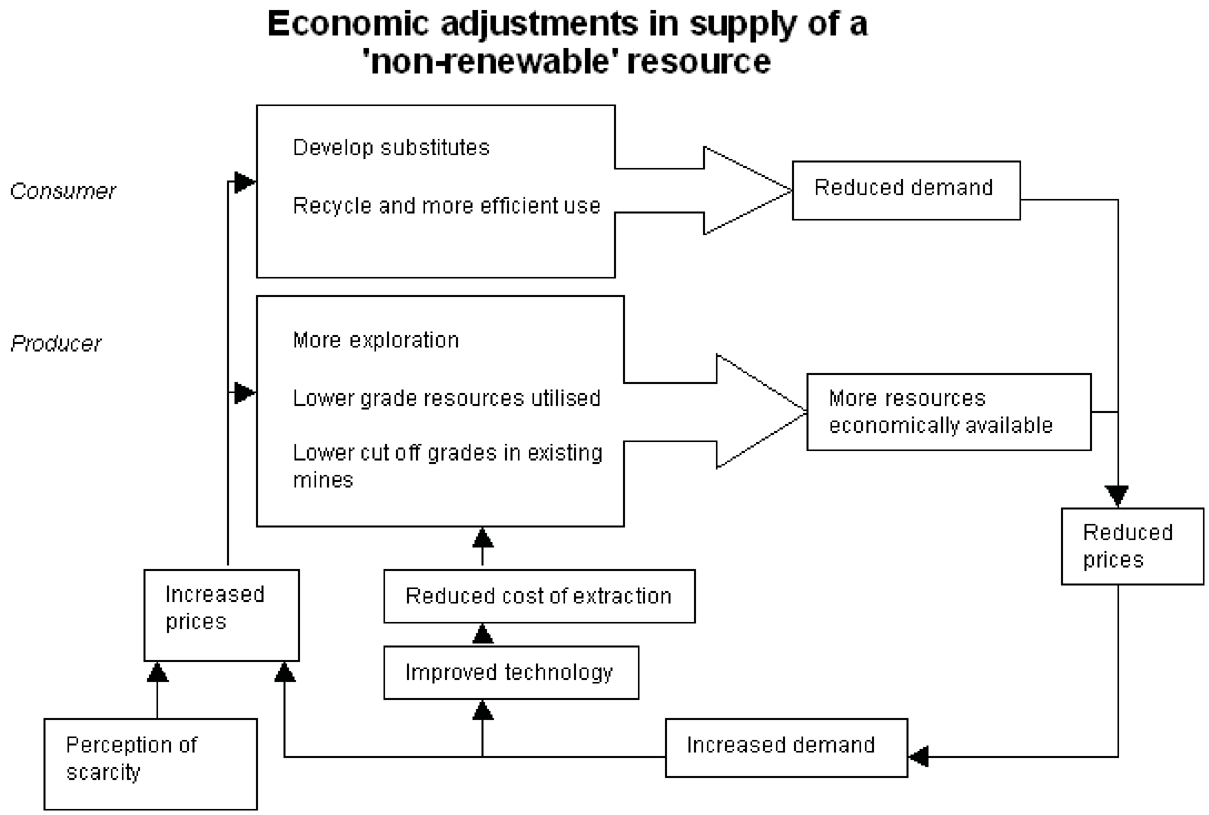
Uranium is ubiquitous on the earth. It is a metal approximately as common as tin or zinc, and it is a constituent of most rocks and even of the sea. Some typical concentrations are:

High-grade orebody	2% U,	20,000 ppm U
Low-grade orebody	0.1% U,	1,000 ppm U
Granite		4 ppm U
Sedimentary rock		2 ppm U
Average in earth's continental crust		1.4 ppm U
Seawater		0.003 ppm U

(ppm = parts per million).

An orebody is, by definition, an occurrence of mineralisation from which the metal is economically recoverable. It is therefore relative to both costs of extraction and market prices. At present neither the oceans nor any granites are orebodies, but conceivably either could become so if prices were to rise sufficiently.

Measured resources of uranium, the amount known to be economically recoverable from orebodies, are thus also relative to costs and prices. They are also dependent on the intensity of exploration effort. Changes in costs or prices, or further exploration, may alter measured resource figures markedly. Thus, any predictions of the future availability of any mineral, including uranium, which are based on current cost and price data and current geological knowledge are likely to be extremely conservative. The following diagram illustrates the dynamic interactions involved, and these are discussed further in Appendix 2:



With the above major qualifications the following Table gives some idea of our present understanding of uranium resources. It can be seen that Australia has a substantial part (about 27 percent) of the world's low-cost uranium, and Canada 15 percent.

World Uranium Resources (known and recoverable)

	tonnes U	percent of world
Australia	754,000	27%
Kazakhstan	474,000	17%
Canada	433,000	15%
South Africa	300,000	11%
Namibia	240,000	8%
Brazil	197,000	7%
Russian Fed.	133,000	5%
USA	106,000	4%
Uzbekistan	106,000	4%
World total	3,002,000	

Reasonably Assured Resources plus Estimated Additional Resources - category 1, to US$ 80/kg U, at 1/1/99. Brazil, Kazakhstan and Russian figures above are 75% of in situ totals.

Uranium: Resources, Production and Demand 1999, OECD NEA & IAEA, July 2000.

The world's present measured resources of uranium, in the lower cost category and used only in conventional reactors, are enough to last for well over 45 years. This represents a higher level of assured resources than is normal for most minerals. Further exploration and higher prices will certainly, on the basis of present geological knowledge, yield further resources as present ones are used up. A doubling of price from present levels could be expected to create about a tenfold increase in measured resources.

Widespread use of the fast breeder reactor could increase the utilisation of uranium sixty-fold or more. This type of reactor can be started up on plutonium derived from conventional reactors and operated in closed circuit with its reprocessing plant. Such a reactor, supplied with natural uranium for its "fertile blanket", very quickly reaches the stage where each tonne of ore yields 60 times more energy than in a conventional reactor.

Reactor Fuel Requirements

The world’s power reactors, with combined capacity of some 350 GWe, require about 75,000 tonnes of uranium oxide concentrate from mines (or the equivalent from stockpiles) each year. While this capacity is being run more productively, with higher capacity factors and reactor power levels, the uranium fuel requirement is increasing but not necessarily at the same rate. The factors increasing fuel demand are offset by a trend for higher burnup of fuel and other efficiencies, so demand is steady. (Over the 18 years to 1993 the electricity generated by nuclear power increased 5.5-fold while uranium used increased only just over 3-fold.) It is likely that the annual uranium demand will grow only slightly to 2010.

Fuel burnup is measured in MW days per tonne U (MWd/t), and many countries are increasing the initial enrichment of their fuel (eg from 3.3 to 4.0% U-235) and then burning it longer or harder to leave only 0.5% U-235 in the fuel. This might mean that burnup is increased from 33,000 MWd/t to 45,000 MWd/t. On the other hand low uranium prices mean that enrichment plants are being operated so as to reduce energy requirements and leave more U-235 in the enrichment tails.

Reprocessing of spent fuel from conventional light water reactors also utilises present resources more efficiently, by a factor of up to 1.3 overall.

Nuclear Weapons as a source of fuel

An increasingly important source of nuclear fuel is the world's nuclear weapons stockpiles. Since 1987 the United States and countries of the former USSR have signed a series of disarmament treaties to reduce the nuclear arsenals of the signatory countries by approximately 80 percent by 2003.

The weapons contain a great deal of uranium enriched to over 90 percent U-235 (ie about 25 to 100 times the proportion in reactor fuel). Some weapons have plutonium-239, which can be used in diluted form in either conventional or fast breeder reactors. From 2000 the dilution of 30 tonnes of military high-enriched uranium is displacing about 11 000 tonnes of uranium oxide per year from mines, representing about 17% of the world's reactor requirements.

Details of the utilisation of military stockpiles are available in WNA Information paper on *Military Warheads as a Source of Nuclear Fuel.*

Thorium as a nuclear fuel

Today uranium is the only fuel supplied for nuclear reactors. However, thorium can also be utilised as a fuel for CANDU reactors or in reactors specially designed for this purpose. Neutron-efficient reactors, such as CANDU, are capable of operating on a thorium fuel cycle, once they are started using a fissile material such as U-235 or Pu-239. Then the thorium (Th-232) captures a neutron in the reactor to become fissile uranium (U-233), which continues the reaction.

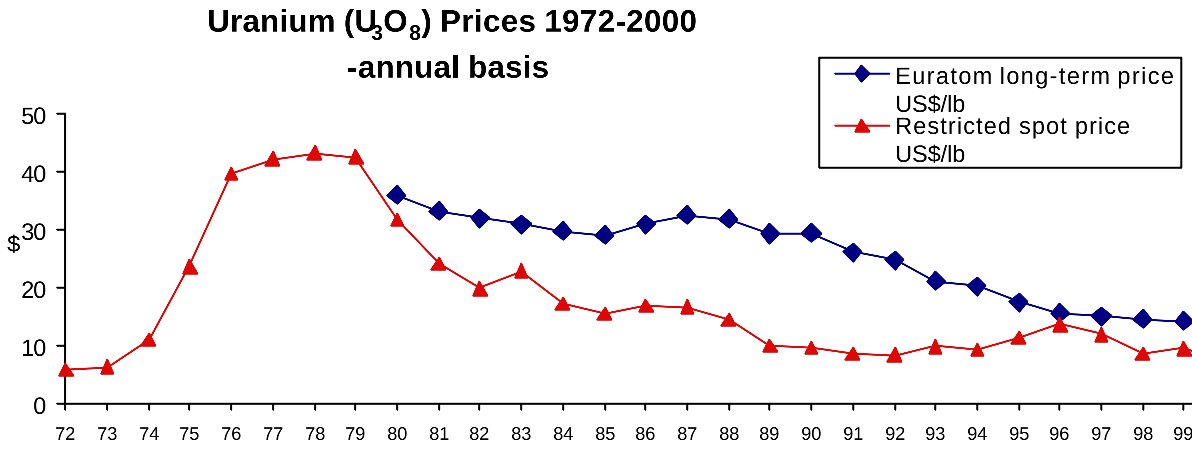
The thorium fuel cycle has some attractive features, though it is not yet in commercial use. It is outlined further in WNA Information paper on *Thorium*. Thorium is about three times as abundant in the earth's crust as uranium.

4. The Uranium Market

All mineral commodity markets tend to be cyclical, ie, prices rise and fall substantially over the years, but with these fluctuations superimposed on long-term decline in real prices. In the uranium market, very high prices in the late 1970s gave way to very low prices in the 1990s, the spot prices initially being below the cost of production for most mines. In 1996 spot prices recovered to the point where most mines could produce profitably, though they then declined again.

"Spot prices" apply to marginal trading from day to day and in 2000 represented about 10% of supply. Most trade is long term contracts with producers selling direct to utilities.

The reasons for fluctuation in mineral prices relate to demand, and perceptions of scarcity. The price cannot indefinitely stay below the cost of production, nor will it remain at very high levels for longer than it takes for new producers to enter the market.

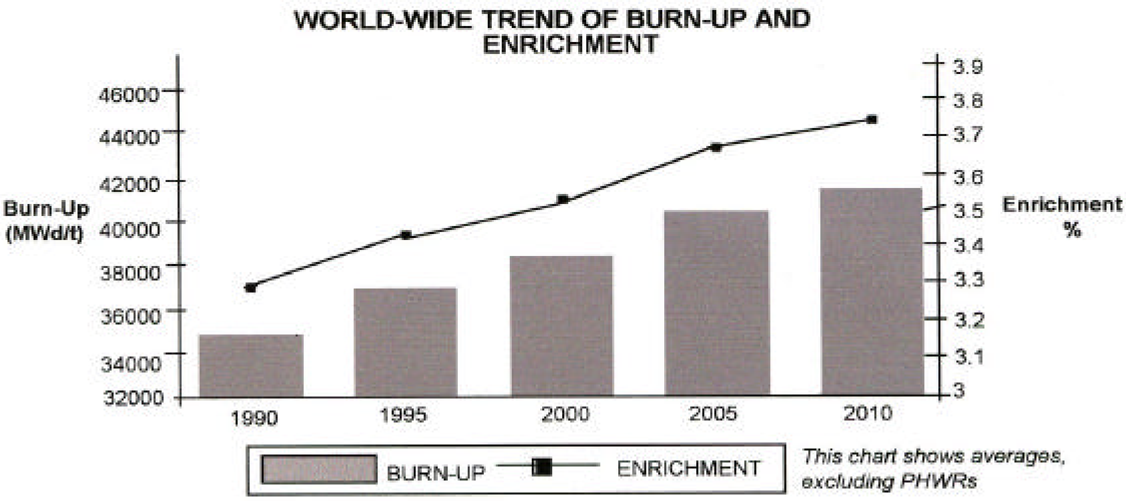


Uranium Demand

About 430 reactors with combined capacity of some 350 GWe, require about 61,000 tonnes of uranium from mines (or the equivalent from stockpiles or secondary sources) each year. The capacity is growing slowly, and at the same time the reactors are being run more productively, with higher capacity factors, and reactor power levels. However, these factors increasing fuel demand are offset by a trend for higher burnup of fuel and other efficiencies, so demand is dampened. It is thus likely that the annual demand will grow only slightly to 2010.

Fuel burnup is measured in MW days per tonne U, and many utilities are increasing the initial enrichment of their fuel (eg from 3.3 to more than 4.0% U-235) and then burning it longer or harder to leave only 0.5% U-235 in it. This might mean that burnup is increased from 33,000 MWD/t to 45,000 MWD/t. The net result is a very small reduction in the amount of uranium required ex-mine to fuel each kWh output.

Because of the cost structure of nuclear power generation, with high capital and low fuel costs, the demand for uranium fuel is much more predictable than with probably any other mineral commodity. Once reactors are built, it is very cost-effective to keep them running at high capacity and for utilities to make any adjustments to load trends by cutting back on fossil fuel use. Demand forecasts for uranium thus depend largely on installed and operable capacity, regardless of economic fluctuations. For instance, when South Korea's overall energy use decreased in 1997, nuclear energy output actually rose, to replace imported fossil fuels.



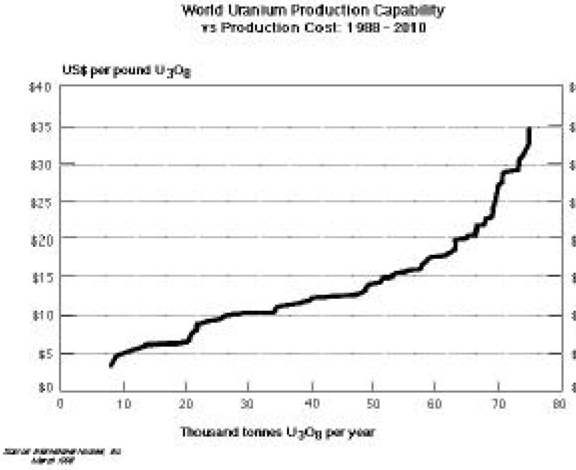
Looking ten years ahead, the market will maintain present levels or grow slightly. Demand thereafter will depend on new plant being built and the rate at which older plant is retired. Licensing of plant lifetime extensions and the economic attractiveness of continued operation of older reactors are critical factors in the medium-term uranium market. However, with electricity demand by 2020 expected (by the World Energy Council) to almost double from that of 1990, there is plenty of scope for growth in nuclear capacity in a greenhouse-conscious world.

Uranium Supply

Mines in 2000 supplied 34,746 tonnes of uranium, far less than utilities' annual requirements. The balance is made up from secondary sources or stockpiled uranium held by utilities, but those stockpiles are now largely depleted.

For this reason the "spot price" for uncontracted sales rose strongly to US$ 16.40 per pound U_3O_8 in mid 1996. Due to uncertainty about secondary supplies, the spot price then declined to around US$ 7. Most uranium however is supplied under long-term contracts and the prices in new contracts reflect a premium above the spot market.

Note that at current prices only a quarter of the cost of the fuel loaded into a nuclear reactor is the actual ex-mine (or other) supply. The balance is mostly the cost of enrichment and fuel fabrication.



The above graph, from International Nuclear Inc., shows a cost curve for world uranium producers, and suggests that for 40,000 t/yr U_3O_8 production from mines, US$12/lb is a plausible price (or at 50,000t, $15/lb).

As well as existing and likely new mines, nuclear fuel supply may be from **secondary sources** including:

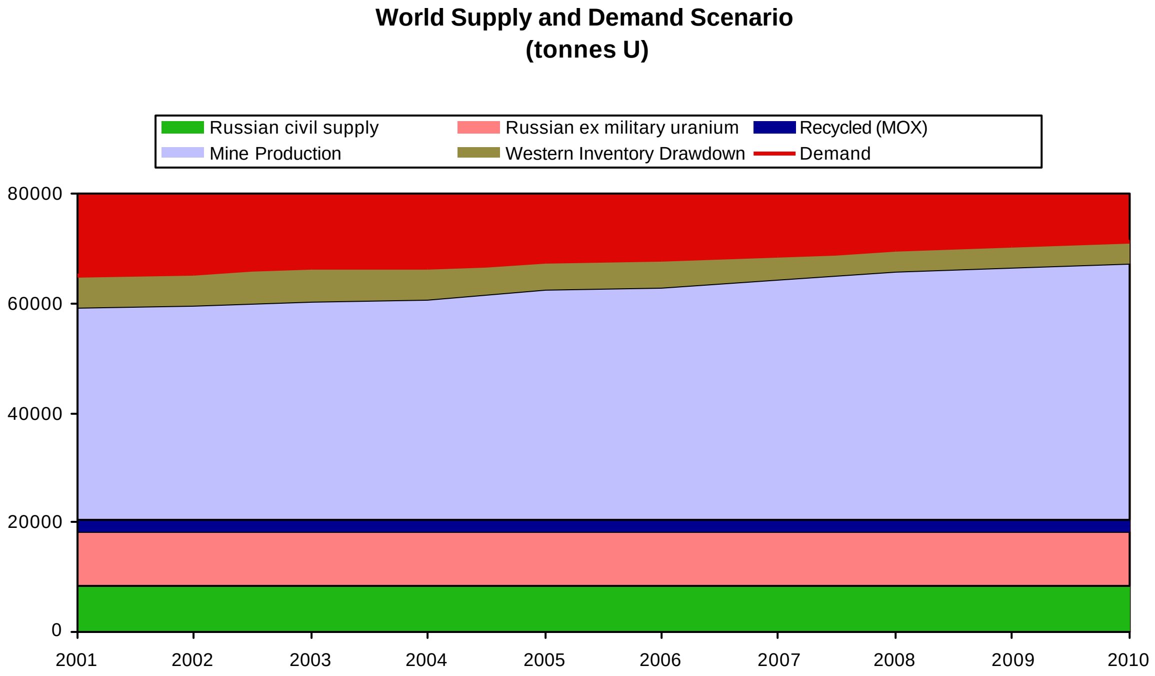
- recycled uranium and plutonium from spent fuel, as mixed oxide fuel,
- re-enriched depleted uranium tails,
- ex military weapons-grade uranium,
- Russian-owned stockpiles,
- ex military weapons-grade plutonium.

Major commercial reprocessing plants are operating in France and UK, with capacity of over 4000 tonnes of spent fuel per year. The product from these re-enters the fuel cycle and is fabricated into fresh mixed oxide (MOX) fuel elements. About 200 tonnes of MOX is used each year, equivalent to less than 2000 tonnes of uranium from mines.

Military uranium for weapons is enriched to much higher levels than that for the civil fuel cycle. Weapons-grade is about 97% U-235, and this can be diluted about 25:1 with depleted uranium (or 30:1 with enriched depleted uranium) to reduce it to about 4%, suitable for use in a reactor. From 1999 the dilution of 30 tonnes such material is displacing about 10,600 tonnes per year of mine production.

As a result of the 1994 "Megatons to Megawatts" agreement between USA and Russia, Russia owns a considerable amount of natural uranium which corresponds with the diluted high-enriched uranium it has supplied as described above since January 1997. In 1999 an agreement was signed which restrains this material from entering the market in the short term. Some other supply from Russian and other CIS stockpiles is possible in the short term.

No schedule for disposal of military plutonium has yet been agreed, but most of it is likely to be used as plutonium feed for MOX plants and thus progressively burned in civil reactors.



Sources: Demand for reactors: World Nuclear Associaton 2001 (reference scenario for demand)
Other data: Industry estimates

World uranium production from mines in 2000 was about 35,000 tonnes uranium, with Canada as the leading producer at 10,682 tU, and Australia next at 7578 tU. (See also WNA Information paper *World Uranium Mining*)

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Appendices.

1. Summary of Nuclear Power Reactors

COUNTRY	Nuclear generation 2000		REACTORS OPERATING at June 2001		REACTORS BUILDING* at June 2001		REACTORS ON ORDER or PLANNED		TOTAL REACTORS	
	TWh	%	No.	MWe	No.	MWe	No.	MWe	No.	MWe
Argentina	5.7	7.3	2	935	1	692	0	0	3	1627
Armenia	1.8	33	1	376	0	0	0	0	1	376
Belgium	45	57	7	5728	0	0	0	0	7	5728
Brazil	5.6	1.5	2	1855	0	0	0	0	2	1855
Bulgaria	18	45	6	3538	0	0	0	0	6	3538
Canada*	69	12	14	9998	6	3598	0	0	20	13596
China	16	1.2	3	2167	8	6370	2	1800	13	10337
Czech Rep.	13.6	19	5	2560	1	912	0	0	6	3472
Egypt	0	0	0	0	0	0	1	600	1	600
Finland	21	32	4	2656	0	0	1	1000	5	3656
France	395	76	59	63203	0	0	0	0	59	63203
Germany	160	31	19	21141	0	0	0	0	19	21141
Hungary	15	42	4	1755	0	0	0	0	4	1755
India	14	3.1	14	2548	2	900	11	4980	27	8428
Indonesia	0	0	0	0	0	0	1	600	1	600
Iran	0	0	0	0	1	950	1	950	2	1900
Japan	305	34	53	43505	4	4492	12	15858	69	63855
Korea DPR (N)	0	0	0	0	0	0	2	1900	2	1900
Korea RO (S)	104	41	16	12970	4	3800	8	9200	28	25970
Lithuania	8.4	74	2	2370	0	0	0	0	2	2370
Mexico	7.9	3.9	2	1364	0	0	0	0	2	1364
Netherlands	3.7	4	1	452	0	0	0	0	1	452
Pakistan	1.1	1.7	2	425	0	0	0	0	2	425
Romania	5.1	11	1	655	1	620	0	0	2	1275
Russia	120	15	30	20793	3	2625	5	4050	38	27468
Slovak Rep.	16	53	6	2472	2	840	0	0	8	3312
Slovenia	4.5	37	1	679	0	0	0	0	1	679
South Africa	13	6.7	2	1842	0	0	0	0	2	1842
Spain	59	28	9	7345	0	0	0	0	9	7345
Sweden	55	39	11	9460	0	0	0	0	11	9460
Switzerland	24	36	5	3170	0	0	0	0	5	3170
Taiwan	37	24	6	4884	2	2600	0	0	8	7484
Ukraine	72	47	13	11195	2	1900	0	0	15	13095
UK	78	22	33	12528	0	0	0	0	33	12528
USA	754	20	104	98060	0	0	0	0	104	98060
=										
WORLD	**2,447**	**16**	**437**	**352,629**	**37**	**30,299**	**44**	**40,938**	**518**	**423,866**

Source: Reactor data: ANSTO, based on information to 1 June 2001,
% e = % of total electricity from nuclear (source: IAEA)
Operating = Connected to the grid; Construction = First concrete poured;
Planned = Relatively firm plans. Mwe: nett
** Canadian construction figures are for 4 laid up Pickering A reactors likely to re-enter service by 2003, plus two Bruce A units which are very likely do so later.*

2 A Minerals Industry Perspective on the Sustainability of Mineral Resources

It has become fashionable to assert that because "the resources of the earth are finite", therefore we must face some day of reckoning, and will need to plan for "negative growth". All this, it is pointed out, is because these resources are being consumed at an increasing rate to support our western lifestyle and to cater for the increasing demands of developing nations. The assertion that we are likely to run out of resources is a re-run of the "Limits to Growth" argument (1) fashionable in the early 1970s, which was substantially disowned by its originators, the Club of Rome, subsequently. It also echoes similar concerns raised by economists in the 1930s, and by Malthus at the end of the 18th Century.

In recent years there has been persistent misunderstanding and misrepresentation of the abundance of mineral resources, with the assertion that the world is in danger of actually running out of many mineral resources. While congenial to common sense, it lacks empirical support in the trend of practically mineral commodity prices over the long term.

An anecdote brings this home: In 1980 two eminent professors, fierce critics of one another, made a bet regarding the real market price of five metal commodities over the next decade. Paul Ehrlich, a world-famous ecologist, bet that because the world was exceeding its carrying capacity, food and commodities would start to run out in the 1980s and prices in real terms would therefore rise. Julian Simon, an economist, said that resources were effectively so abundant, and becoming effectively more so, that prices would fall in real terms. He invited Ehrlich to nominate which commodities would be used to test the matter, and they settled on these (chrome, copper, nickel, tin and tungsten). In 1990 Ehrlich paid up - all the prices had fallen.

Of course the resources of the earth are indeed finite, but three observations need to be made: first, the limits of the supply of resources are so far away that the truism has no practical meaning. Second, many of the resources concerned are either renewable or recyclable (energy minerals and zinc are the main exceptions, though the recycling potential of many materials is limited in practice by the energy and other costs involved). Third, available reserves of 'non-renewable' resources are constantly being renewed, mostly faster than they are used.

What then does sustainability in relation to mineral resources mean? The answer lies in the interaction of three things which enable usable resources[*] effectively to be created.

Geological Knowledge

Whatever minerals are in the earth, they cannot be considered usable resources unless they are known. Therefore there must be a constant input of time, money and effort to find out what is there. This mineral exploration endeavour is not merely fossicking or doing aerial magnetic surveys, but must eventually extend to comprehensive investigation of orebodies so that they can reliably be defined in terms of location, quantity and grade. They must be technically and economically quantified as mineral reserves. That is the first aspect of creating a resource.

For instance, measured resources of many minerals are increasing much faster than they are being used, due to exploration expenditure by mining companies and their investment in research. Simply on geological grounds, there is no reason to suppose that this trend will not continue. Today, proven mineral resources worldwide are more than we inherited. (2)

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[*] Some licence is taken in the use of this word in the following, strictly it is reserves of minerals which are created.

The corollary of this for the future is that access for mineral exploration should be open virtually everywhere, including national parks. To take the view that we shouldn't know what resources exist is, as a former Australian Senator put it, "to make a declaration for ignorance and against knowledge. It is tantamount to book burning". (3) Any properly rational land use decision properly requires knowledge of the real, as distinct from the presumed, options.

Technology

It is meaningless to speak of a resource until someone has thought of a way to use any particular material. In this sense, human ingenuity quite literally creates new resources, historically, currently and prospectively. That is the most fundamental level at which technology creates resources, by making particular minerals usable in new ways. Often these then substitute to some degree for others which are becoming scarcer, as indicated by rising prices.

More particularly, if a known mineral deposit cannot be mined, processed and marketed economically, it does not constitute a resource in any practical sense. Many factors determine whether a particular mineral deposit can be considered a usable resource - the scale of mining and processing, the technological expertise involved, its location in relation to markets, and so on. The application of human ingenuity, through technology, alters the significance of all these factors and is thus a second means of "creating" resources. In effect, portions of the earth's crust are reclassified as resources. A further aspect of this is at the manufacturing and consumer level, where technology can make a given amount of resources go further through more efficient use. (4)

An excellent example of this application of technology to create resources is in the Pilbara region of Western Australia. Until the 1960s the vast iron ore deposits there were simply geological curiosities, despite their very high grade. Australia had been perceived as short of iron ore. With modern large-scale mining technology and the advent of heavy duty railways and bulk shipping which could economically get the iron ore from the mine (well inland) through the ports of Dampier and Port Hedland to Japan, these became one of the nation's main mineral resources. For the last 35 years Hamersley Iron (Rio Tinto), Mount Newman (BHP-Billiton) and others have been at the forefront of Australia's mineral exporters, drawing upon these 'new' orebodies, and creating much wealth for all Australians.

Just over a hundred years ago aluminium was a precious metal, not because it was scarce, but because it was almost impossible to reduce the oxide to the metal, which was therefore fantastically expensive. With the discovery of the Hall-Heroult process in 1886, the cost of producing aluminium plummeted to about one twentieth of what it had been and that metal has steadily become more commonplace. It now competes with iron in many applications, and copper in others, as well as having its own widespread uses in every aspect of our lives. Not only was a virtually new material provided for people's use by this technological breakthrough, but enormous quantities of bauxite world-wide progressively became a valuable resource. Without the technological breakthrough, they would have remained a geological curiosity.

The development of new technologies which are able to utilise otherwise non-usable or uneconomic iron ore 'fines' and other low grade materials which otherwise aren't quite in the category of commercial-grade ore is another good example of creating resources, by enabling materials to be reclassified as such. Incremental improvements in processing technology at all plants are less obvious but nevertheless very significant also. Over many years they are probably as important as the historic technological breakthroughs.

Improved energy efficiency in metal smelters has resulted in large savings of energy and this is another very important aspect of making resources go further.

At the level of manufacturing, research into making more cans from each kilogram of aluminium or more widgets from every tonne of iron, etc, are means of stretching resources and making what we have go further. Recycling of aluminium, lead and other metals is another aspect of this, principally in respect of energy efficiency.

To achieve sustainability, the combined effects of mineral exploration and the development of technology need to be creating resources at least as fast as they are being used. There is no question that in respect to the minerals industry this is generally so. Recycling also helps, though generally its effect is not great.

Economics

Whether a particular mineral deposit is sensibly available as a resource will depend on the market price of the mineral concerned. If it costs more to get it out of the ground than its value warrants, it can hardly be classified as a resource (unless there is some major market distortion due to government subsidies of some kind). Therefore, the resources available will depend on the market price, which in turn depends on world demand for the particular mineral and the costs of supplying that demand. The dynamic equilibrium between supply and demand also gives rise to substitution of other materials when scarcity looms (or the price is artificially elevated). This then is the third aspect of creating resources. (5)

The best known example of the interaction of markets with resource availability is in the oil industry. When in 1972 OPEC suddenly increased the price of oil fourfold, several things happened at both producer and consumer levels.

The producers dramatically increased their exploration effort, and applied ways to boost oil recovery from previously 'exhausted' or uneconomic wells. At the consumer end, increased prices meant massive substitution of other fuels and greatly increased capital expenditure in more efficient plant. As a result of the former activities, oil resources increased dramatically. As a result of the latter, oil use fell slightly to 1975 and in the longer perspective did not increase globally from 1973 to 1986. Forecasts in 1972, which had generally predicted a doubling of oil consumption in ten years, proved quite wrong.

Oil will certainly become scarce one day, probably before most other mineral resources, which will drive its price up. As in the 1970s, this will in turn cause increased substitution for oil and bring about greater efficiencies in its use as equilibrium between supply and demand is maintained by the market mechanism. Certainly oil will never run out in any absolute sense - it will simply become too expensive to use as liberally as we now do.

Another example is provided by aluminium. During World War II, Germany and Japan recovered aluminium from kaolinite, a common clay, at slightly greater cost than it could be obtained from bauxite. (6)

Due to the operation of these factors the world's economically demonstrated resources of most minerals have risen faster than the increased rate of usage over the last 40 years, so that more are available now, notwithstanding liberal usage. This is largely due to the effects of mineral exploration and the fact that new discoveries have exceeded consumption. The real prices of most minerals have actually fallen over this period. The fact that we have, in this sense, more non-renewable resources than a generation ago is a major consideration in relation to intergenerational equity.

This raises the question of what might be the annual sustainable yield of minerals. With respect to agriculture, forestry or fisheries it would be possible, at least in theory, to quantify fairly accurately the annual sustainable yield on an indefinite time scale, based on the soil and water resources supporting them. But with respect to mining, this would be a totally impossible task. Anyone who attempted to quantify the annual sustainable yield of minerals possible from the earth's crust would risk being in error not by a factor of two or three or even ten, but by many orders of magnitude. For instance, how would one factor-in the bringing on-stream of the Brockman Iron Formation in the Pilbara region of Western Australia (already referred to)? Here, in one mineralised zone, we have 3500 cubic kilometres or ten thousand billion tonnes of plus 35 percent iron material which would be valuable ore in many parts of the world (much US iron ore is of such a grade). In physical terms this would provide the world with over 4000 years supply of steel at present rates of production, or it would build enough motor cars to stretch bumper to bumper right around the equator, each day, for the next thousand years. And all these figures can be doubled if you include the Marra Mamba Iron Formation 300 metres beneath the Brockman!

From a detached viewpoint all this may look like mere technological optimism. But to anyone closely involved it is obvious and demonstrable. Furthermore, it is illustrated by the longer history of human use of the earth's mineral resources. Abundance, scarcity, substitution, increasing efficiency of use, technological breakthroughs in discovery, recovery and use, sustained incremental improvements in mineral recovery and energy efficiency - all these comprise the history of minerals and mankind.

References:

(1) Club of Rome 1972 popularised by Meadows et al in Limits of Growth at that time. (A useful counter to it is W Berckerman, In Defence of Economic Growth, also Singer, M, Passage to a Human World, Hudson Inst. 1987). In the decade following its publication world bauxite reserves increased 35%, copper 25%, nickel 25%, uranium and coal doubled, gas increased 70% and even oil increased 6%.

(2) Gibbons, D & O'Neill, D, "Sustaining our Mineral Development" in AMIC Mining Review, July 1990.

(3) Senator Peter Walsh, Australian Financial Review, June 1990.

(4) Gibbons & O'Neill note that aluminium can mass was reduced by 21% 1972-88 and motor cars each use about 30% less steel than 30 years ago.

(5) Asserting the importance of an option value of resources for some time in the future tends to ignore the dynamics of the economic process sketched here, and presupposes too much regarding future demand for particular commodities. Cobalt and tin are two metals whose use has declined sharply due to substitutes being found following scarcity and/or high prices in the last 25 years.

(6) Gibbons, D & O'Neill, D, op. cit. see note above.