EMD Uranium (Nuclear Minerals) Committee

EMD Uranium (Nuclear Minerals) Mid-Year Committee Report

Michael D. Campbell, P.G., P.H., Chair

November 18, 2010 (Revised November 26, 2010)

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Committee Activities

During the past 6 months, the Uranium Committee continued to monitor the expansion of the nuclear power industry and associated uranium exploration and development in the U.S. This information supports our updates to the Uranium Committee Public (Here) and Members-Only page (Here) of the EMD website. The Committee continues to monitor the exploration activities of the uranium in the world as well. Africa and South America have recently emerged as targets with numerous exploration projects offering considerable merit in terms of size, grade, and mineability. The Committee has initiated a new evaluation on the world uranium resources with the preliminary results included later in this report.

During the past six months, selected Committee members produced and presented a report to the Houston Geological Society (Here). Those of the Uranium Advisory Committee members who participated in the preparation of the report include: Henry M. Wise, P.G., Eagle-SWS; Bruce Handley, P. G., Consultant; William Boberg, P.G., UR-Energy, Inc., Vice-Chair, Industry, Steven

S. Sibray, Ph.D., University of Nebraska, Vice-Chair, University, and James Conca, Ph.D. New Mexico State University.

Bill Ambrose, Co-Chairman of AAPG's Astrogeology Committee, reports that the final chapters of the Astrogeology Memoir have been submitted for review and the Memoir will be "in press" in a few months. The Publication date is slipping somewhat, and is now estimated to be late 2011 or early 2012. A new development in off-world uranium exploration was identified in a report by Campbell and Ambrose (2010), which although the development does not have a current impact on uranium supplies or on other minerals resources on the Earth, it may have an impact on the international politics of the near future and of the American Space Program involving NASA and the Aerospace industry.

Status of U.S. Nuclear Industry

U.S. Uranium Production as of: 2nd Quarter 2010

Summary

Based on the current U.S. Energy Information Administration (EIA) Report (here), U.S. production of uranium concentrate was 1,055,102 pounds U_3O_8, up 20 percent from the previous quarter and up 7 percent from the second quarter 2009. During the second quarter 2010:

U.S. uranium concentrate was produced at four U.S. uranium concentrate processing facilities.

U.S. Uranium Mill in Production:

- White Mesa Mill

U.S. Uranium In-Situ-Recovery Plants in Production:

- Alta Mesa Project
- Crow Butte Operation
- Smith Ranch-Highland Operation

For the first half of 2010, U.S. uranium concentrate production totaled 1,931,186 pounds U_3O_8. This amount is 4 percent higher than the 1,862,796 pounds produced during the first half of 2009.

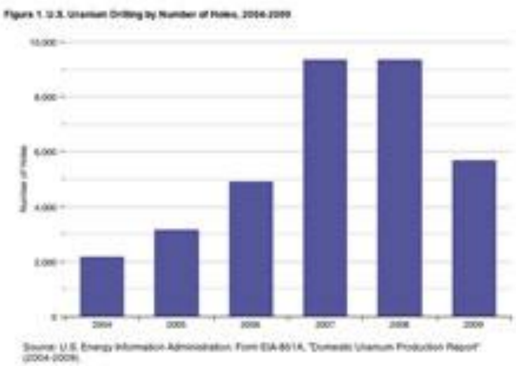
The EIA has expanded its coverage of uranium and nuclear power reporting to the general public, see, for example, U.S. EIA Report.

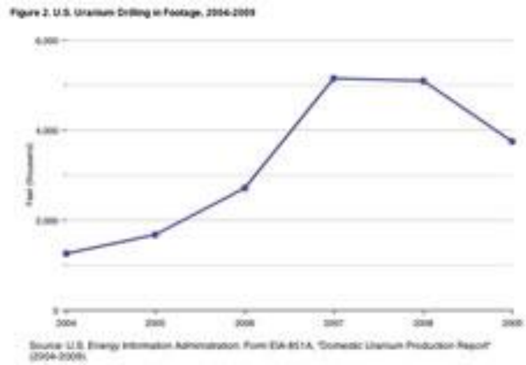
Final 2009 Production Total

Five U.S. uranium concentrate processing facilities produced 3,708,358 pounds U_3O_8 in 2009. This amount is 5 percent lower than the 3,902,383 pounds produced in 2008.

Drilling

U.S. uranium exploration drilling was 1,790 holes covering 1.1 million feet in 2009. Development drilling was 3,889 holes and 2.7 million feet. Combined, total uranium drilling was 5,679 holes covering 3.7 million feet. Expenditures for exploration activities were $24 million in 2009, and $35 million for drilling activities, down from 2008.





Click on links below to see above figures.

http://www.eia.doe.gov/cneaf/nuclear/dupr/udrillingfig1.html

http://www.eia.doe.gov/cneaf/nuclear/dupr/udrillingfig2.html

Resources

The EIA has updated its estimates of domestic uranium reserves for year-end 2008. This represents the first revision of the estimates since 2004. The update is based on analysis of company annual reports, any additional information reported by companies at conferences and in news releases, personal contacts, and expert judgment.

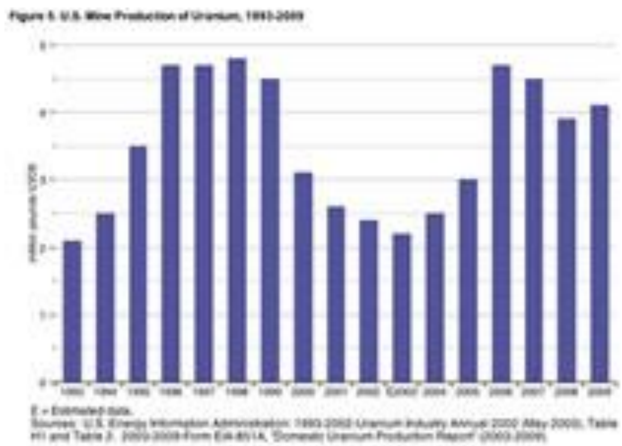
EIA indicated that at the end of 2008, U.S. uranium reserves totaled 1,227 million pounds of U_3O_8 at a maximum forward cost of up to $100 per pound U_3O_8. At up to $50 per pound U_3O_8, estimated reserves were 539 million pounds of U_3O_8. Based on average 1999-2008 consumption levels (uranium in fuel assemblies loaded into nuclear reactors), uranium reserves available at up to $100 per pound of U_3O_8 represented approximately 23 years worth of demand, while uranium reserves at up to $50 per pound of U_3O_8 represented about 10 years worth of demand. Domestic U.S. uranium production, however, supplies only about 10 percent, on average, of U.S. requirements for nuclear fuel, so the effective years' supply of domestic uranium reserves is actually much higher, under current market conditions.

In 2008, Wyoming led the Nation in total uranium reserves, in both the $50 and $100 per pound U_3O_8 categories, with New Mexico second. Taken together, these two states constituted about two-thirds of the estimated reserves in the country available at up to $100 per pound U_3O_8, and three-quarters of the reserves available at less than $50 per pound U_3O_8. By mining method, uranium reserves in underground mines constituted just under half of the available product at up to $100 per pound U_3O_8. At up to \$50 per pound U_3O_8, however, uranium available through in-situ recovery (ISR) was about 40 percent of total reserves, somewhat higher than uranium in underground mines in that cost category. ISR is the dominant mining method for U.S. production today and is likely to increase in the future. For additional current information from EIA, see (Here).

Mining

U.S. uranium mines produced 4.1 million pounds U_3O_8 in 2009, which is 7 percent more than in 2008. Fourteen underground mines produced ore containing uranium during 2009, four more than during 2008. Four in-situ-recovery mining operations produced solutions containing uranium, which are two less than during 2008. Overall, during part or all of 2009, there were 18 U.S. mines that produced uranium to be processed into uranium concentrate (yellowcake). For additional current information from EIA, see (Here).

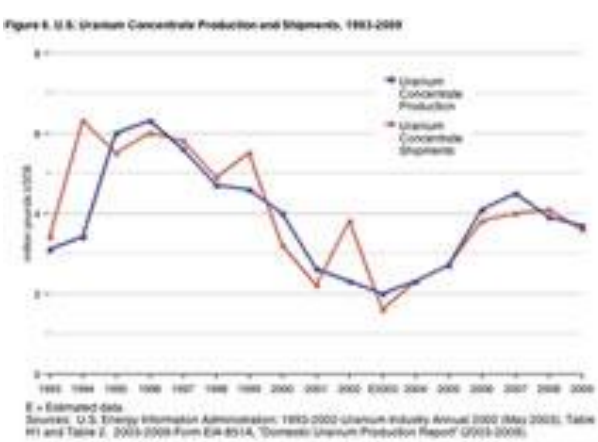
Production and Shipments



Total production of U.S. uranium concentrate (yellowcake) in 2009 was 3.7 million pounds U_3O_8, 5 percent below the 2008 level, from one U.S. mill (White Mesa Mill) and four in-situ-recovery plants (Alta Mesa Project, Crow Butte Operation, Kingsville Dome, and Smith Ranch-Highland Operation). All but one were in production for the entire year. Kingsville Dome produced uranium concentrate during the first half of 2009. Shipments of uranium concentrate from these facilities were 3.6 million pounds U_3O_8 in 2009, 12 percent below the 2008 level. For additional current information from EIA, see: (Here).

http://www.eia.doe.gov/cneaf/nuclear/dupr/uminefig5.html

Summary Production Statistics of the U.S. Uranium Industry, 1993-2009



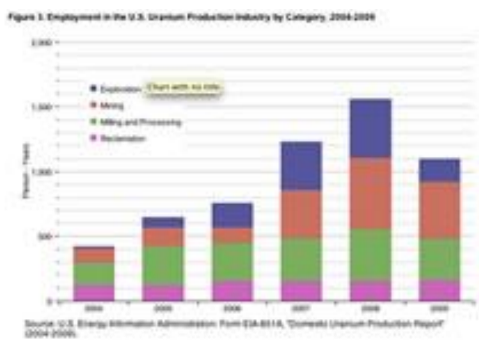
http://www.eia.doe.gov/cneaf/nuclear/dupr/uprodshipfig6.html

Concentrate Production & Shipment History-1993-2009t

Facilities

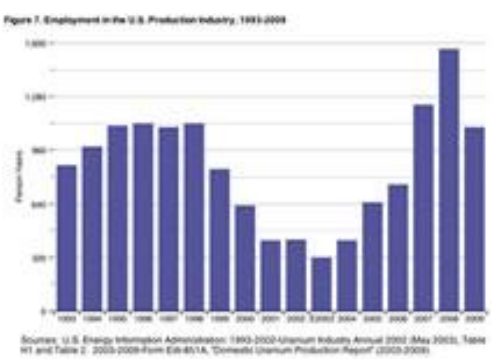
At the end of 2009, one U.S. uranium mill was operating with a capacity of 2,000 short tons of ore per day. Three other existing U.S. mills with a total capacity of 4,150 short tons of ore per day were on standby. There was one planned mill under development. Three U.S. uranium in-situ-recovery plants were operating at the end of 2009, with a combined capacity of 7.5 million pounds U_3O_8 per year. Six other existing U.S. in-situ-recovery plants with a total capacity of 4.2 million pounds U_3O_8 per year were on standby or permitted and licensed. There were eight planned in-situ-recovery plants under development or partially permitted and licensed.

Employment



Total employment in the U.S. uranium production industry was 1,096 person-years for 2009, a decrease of 30 percent from the 2008 total. Exploration employment decreased the most (62 percent). Uranium mining, milling and processing employment decreased 20 percent, while reclamation employment rose 5 percent from 2008 to 2009. Eight States (Arizona, Colorado, Nebraska, New Mexico, Texas, Utah, Washington and Wyoming) accounted for 99 percent of total employment of the uranium production industry in 2009.

http://www.eia.doe.gov/cneaf/nuclear/dupr/uemploymentfig3.html



Employment in U.S. Production History: 1993-2009

*Expenditures (**Here**)*

Total expenditures for land, exploration, drilling, production, and reclamation were $281 million in 2009, 40 percent less than in 2008. Expenditures on U.S. uranium production, including facility expenses, were the largest category of expenditures at $141 million in 2009, down 36 percent from 2008. Uranium exploration and drilling expenditures decreased 55 percent from 2008 to 2009. Expenditures for land were $17 million, a 73 percent decrease compared with 2008. The cause of this decrease is likely related to the uncertainties in the U.S. economy and in the political climate in the U.S. during 2009. These expenditures are likely to rise significantly over the next few years.

Uranium: Emphasis on Supply

Availability of U.S. Uranium Resources

MIT updated its 2003 report in 2009 to include a consideration on how long the uranium ore resource base would be sufficient to support large-scale deployment of nuclear power without reprocessing and/or breeding. Present data suggests the required resource base will be available at an affordable cost for a very long time. Estimates of both known and undiscovered uranium resources at various recovery costs are given in the NEA/IAEA "Red Book". For example, according to the latest edition of the Red Book, known resources recoverable at costs at less than \$80/kgU) and less than \$130/kgU are approximately 3 and 4 million tonnes of uranium, respectively. However, the amount of known resources depends on the intensity of the exploration effort, mining costs, and the price of uranium. Thus, any predictions of the future availability of uranium that are based on current mining costs, prices and geological knowledge are likely to be extremely conservative.

For example, the MIT update indicated that a doubling of the uranium price from its current value of about \$30/kgU could be expected to create about a ten-fold increase in known resources recoverable at costs less than \$80/kgU, i.e., from about 3 to 30 million tonnes (to 78 billion lbU_3O_8). By comparison, a fleet of 1,500 1,000 MWe reactors operating for 50 years requires about 15 million tonnes of uranium (or 40 billion lbU_3O_8), which amounts to 300,000 tU/yr (or 800 million lbU_3O_8/yr) using conventional assumptions about burn-up and enrichment.

Moreover, there are good reasons to conclude that even as demand increases, the price of uranium will remain relatively low: the history of all extractive metal industries, e.g., copper, indicates that increasing demand stimulates the development of new mining technology that greatly decreases the cost of recovering additional ore. Finally, since the cost of uranium represents only a small fraction of the busbar cost of nuclear electricity, even large increases in the former — as may be required to recover the very large quantities of uranium contained at low concentrations in both terrestrial deposits (3.5 ppm U) and seawater (3 ppb U) - may not substantially increase the latter as reported by Japanese research. They concluded that resource utilization is not a pressing reason for proceeding to reprocessing and breeding for many years to come although reprocessing remains to be considered seriously to insure that resources are available for at least the next 50 years.

The approximately 104 nuclear power plants operating in the U.S. today consume about 50 million pounds of uranium fuel per year but the U.S.'s current annual production is only about 4 million pounds per year. As is the current situation with oil, the U.S. is currently reliant on friendly foreign sources for its uranium but this is not likely to remain so for long.

Wyoming Uranium Roll-Fronts

Wyoming is particularly emphasized in this report because it has a large number roll-front uranium deposits in its sandstones and the largest known uranium reserves of any U.S. state. There is no doubt expressed by many recognized authorities that the state will be a key player in supplying the fuel to the nuclear power plants in the U.S. in order to become independent of foreign supplies.

Marion Loomis, Executive Director, of the Wyoming Mining Association, has indicated that because Wyoming is a pro-mining state, has prolific numbers of roll-front uranium deposits, and because of the rising spot uranium price in a resurgent uranium bull market, Wyoming will likely become the U.S. center for in situ recovery mining (ISR). To this must be added New Mexico, Arizona, Texas, and in frontier areas elsewhere in the U.S. because some professionals have concluded that the latter states also have significant potential for additional deposits, albeit deeper than those found to date.

Wyoming ISR uranium mines were the only ones that were able to continue operating economically in the U.S. during the 1980's and 1990's when the downturn in uranium prices occurred. Whether that was a management decision or a comment on the economic advantage of the particular operations is up to debate. The debate may well swing to the latter since there may have been no lingering capital costs involved, leaving only direct operational costs.

Solution Mining

In situ recovery (ISR) - also known as in situ leaching (ISL) - involves recovering uranium in solution from the subsurface by dissolving the ore and pumping the pregnant solution to the surface where uranium and other products can be recovered. There is little surface disturbance and no tailings or waste rock are generated. ISR comprised 36% of global uranium production in 2009 (WNA).

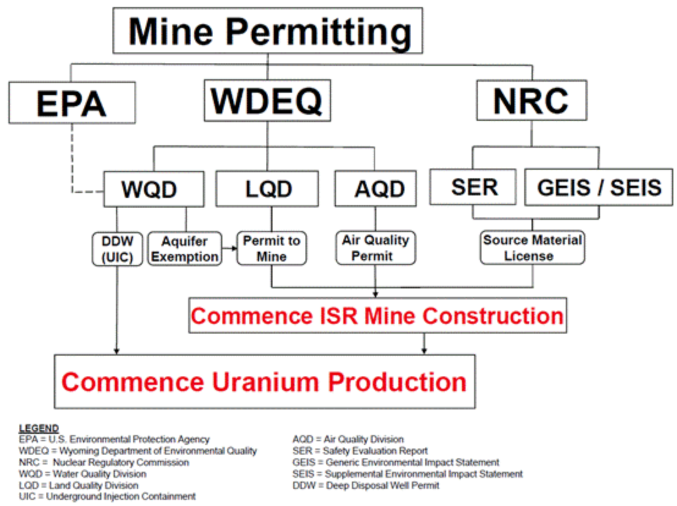
In the U.S., legislation requires that the water quality in the affected aquifer be restored after ISR mining. This means the ground water must be usable for the same purposes as it was before mining began. However, considering the ground water within the zones of mineralization never has been usable because the ground water has been naturally contaminated for millions of years, only the environment within the zones are returned to their original unoxidized condition by removing excess oxygen. This process forces the uranium (and other metals) that were in solution for production purposes, it become essentially insoluble once again. Nevertheless, the ground water within the aquifer hosting the uranium mineralization will always remain naturally contaminated and therefore unusable.

Permitting

In Wyoming, there are two major permits/licenses, plus others, required for the commencement of In-Situ Recovery (ISR) uranium recovery operations:

- The federal Nuclear Regulatory Commission (NRC) Source Material License
- The Wyoming Department of Environmental Quality (WDEQ) Permit to Mine

These two items allow for the construction of an ISR uranium operation and ultimately the commencement of uranium production. For the NRC, the Source Material License is comprised of two parts: 1) A technical review that results in a Safety Evaluation Report (SER), and 2) An environmental review which produces an Environmental Impact Statement (EIS)



The EIS is in two parts: the Generic EIS, and the Supplemental EIS.

In order to receive the WDEQ Permit to Mine, a technical review of the project must be approved and an Aquifer Exemption must be granted (to remove the areas of the aquifers containing the mineralization from potential use because of their natural contamination).

In addition to the two major permit/licenses there are two important permits that are required from the WDEQ:

Deep Disposal Well PermitAn Air Quality PermitFor the Deep Disposal Well permit and the Aquifer Exemption permit, the U.S. Environmental Protection Agency (EPA) is also involved. The EPA reviews the applications for the Deep Disposal Wells and Aquifer Exemption and gives their approval of the permits, but the issuing authority is the WDEQ since they have primacy with the EPA for Wyoming.

The Air Quality permit is required along with the Permit to Mine to begin construction of the ISR uranium facility. The Deep Disposal Well permit is not needed for construction, but is necessary for the commencement of operations for the ISR uranium facility to dispose of liquid wastes.

Current Production in Wyoming

Commercial ISR operations in the Powder River Basin have been ongoing since 1987. Cameco Resources Inc.'s Smith Ranch-Highland in situ mine in Converse County is currently the only active uranium production facility in the state. It is the largest in situ uranium facility in the country producing approximately 1.8 million pounds of uranium in 2009. Cameco plans to increase its Smith Ranch-Highland operations and undertake new operations in the Gas Hills (central Wyoming) and near Pumpkin Butte in Campbell County.

Uranium One's Christensen Ranch ISR facility in the Powder River Basin (the Powder River Basin has some of the highest grade uranium deposits in the State that are amenable to ISR operations methods is expected to resume operations in 2011. It is expected to yield about 1 million pounds of yellowcake over a period of three years.

Recently, the NRC issued an operating license for Uranium One's Moore Ranch uranium mine. It is the first new uranium mine license issued in the USA since 1998. Production of uranium bearing resins from Moore Ranch is expected to begin in 2012.

Permitting Activities

There has never been a uranium ISR operation application rejected in Wyoming. Uranerz has submitted federal and state mining applications to build and operate the Nichols Ranch ISR Uranium Project - a central processing facility at the Nichols Ranch property and a satellite facility at the Hank property.

The central processing facility is being licensed for a capacity of 2 million pounds per year of uranium (as U_3O_8). This facility will process uranium-bearing solutions from well fields of the Nichols Ranch property, as well as uranium-loaded resin transported from the Hank satellite facility, plus uranium-loaded resin from any additional satellite deposits that may be developed on the company's other Powder River Basin properties. This centralized design enhances the economics of Uranerz's potential additional satellite projects by maximizing production capacity while minimizing further capital expenditures on processing facilities.

The NRC recently issued an operating license for Uranium One's Moore Ranch ISR project. Given the proximity of Uranerz's Nichols Ranch Project/Hank properties to Moore Ranch and similar timing of both company's applications, the final Supplemental Environmental Impact Statement (SEIS) for Uranerz's Nichols Ranch Project is expected to be completed very soon. A finalized SEIS for Uranerz's Moore Ranch Project from the NRC would lead to an issuance of a source materials license that would allow Uranerz to receive, possess, use, transfer and deliver radioactive materials.

Properties and Resources

Uranerz has over 30 wholly-owned and joint-ventured projects in the Powder River Basin of Wyoming. Uranerz also has an undivided eighty-one percent (81%) interest in the NAMMCO properties, which cover approximately 67,000 acres in the central Powder River Basin The Arkose Property is located in proximity to the Company's 100%-owned properties in the Powder River Basin.

World Uranium Resources

As nuclear power has re-emerged over the past few years in the U.S. and elsewhere, concerns have been raised by pundits that the known uranium resources might be insufficient when judged in terms of current production and current rate of use. But this is the Limits-to-Growth fallacy, a major myth recycled from the 1970s, which takes no account of the very limited nature of the knowledge we have at any time of the uranium resources that are actually present in the Earth's crust. Our knowledge of geology is such that we can be confident that identified resources of metal minerals are a small fraction of what is available, at various level of cost (see WNA, (2009). Much of what follows is taken from recent summaries of conditions as considered by the "uranium press" (1, 2, and 3).

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. Economic concentrations of it are not uncommon, but significant tonnages sufficient to make a mine are not. Typical averages in concentrations are given below:

Very high-grade ore (e.g. Canada): 20% U	200,000 ppm U
High-grade ore (e.g. N. Australia): 2% U	20,000 ppm U
Low-grade ore (Roll Fronts): 0.1% U	1,000 ppm U
Very low-grade ore (Roll Fronts): 0.01% U	100 ppm U
Granite	4-5 ppm U
Sedimentary rock	2 ppm U
Earth's continental crust	2.8 ppm U
Seawater	3 ppb U

An economically viable uranium deposit depends on the concentration of uranium, the volume and geographical location of available ore, the cost of extraction and on the market price at the time of production. At present, neither the oceans nor granites are considered economic resources, but they conceivably could become so if prices were sufficient and the costs of production were favorable. At ten times the current uranium price (i.e., \$500/# U_3O_8), seawater might become a potential source of vast amounts of uranium. Uranium resources are also dependent on the intensity and effectiveness of past exploration efforts, which are basically statements about what is known rather than what may be present, and on the political climate of the host country.

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 to produce, market price, and current geological knowledge, are likely to be extremely conservative. To date, this has been proven to be the case with uranium.

Uranium Availability

With the above qualifications, Table 1 provides the uranium resource estimates made by the IAEA in 2009, 2007, and by the World Nuclear Institute (WNI) in 1999. The table shows the countries with the known major uranium resources in order of total resources, plus an estimate for 2011. It should be noted that from 1999 to 2009, the estimate of the world uranium resources increased by 84%. Of course, the actual resources didn't increase, just that which has become available based on our knowledge of what has been discovered over the past 10 years.

Fifteen countries show increasing estimates of uranium resources over the past 10 years. The common producers (i.e., Australia, Kazakhstan, Canada, Russia, South Africa, and Namibia) showing increasing resources but many other countries are also beginning to report significant uranium resources. Various countries in Africa, South America (including Brazil, Guyana, Uruguay, etc.) and central Asia and China will also likely show major increases over the next 10 years. Figure 1 illustrates the changing resource estimates and suggests that with increasing exploration, more discoveries will result.

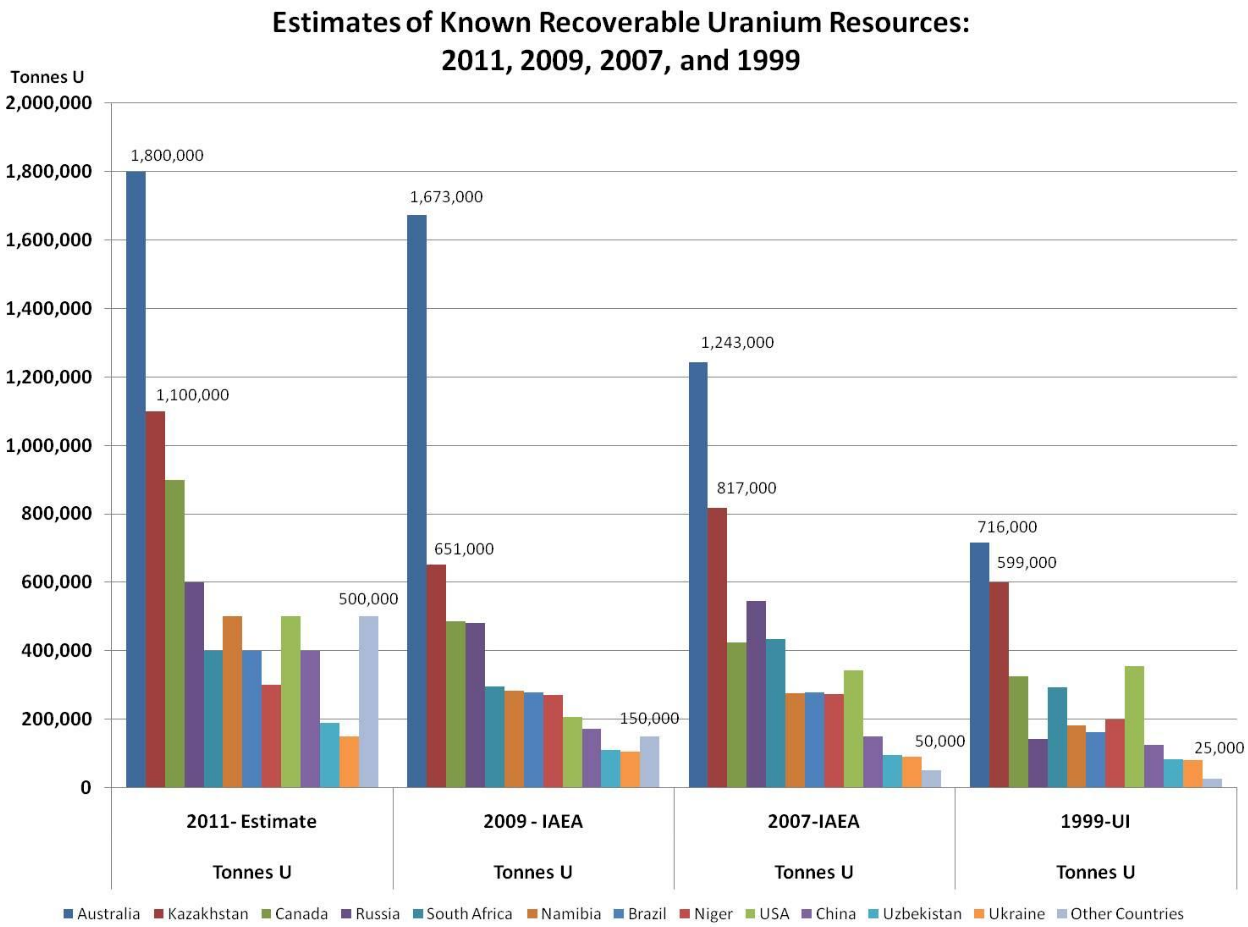
Table 1

Estimates of Known Recoverable Uranium Resources: 2011 (Est), 2009, 2007, and 1999

Note: Reasonably Assured Resources plus Inferred Resources, to US$130/kg U, 1/1/09, from OECD NEA & IAEA, *Uranium 2009 Resources, Production and Demand* ("Red Book") and earlier estimates by IAEA (2009, 2007) and WNI (1999).

Pounds # 2009	**Country**	**Tonnes U** 2011- Estimate	**Tonnes U** 2009 - IAEA	**Tonnes U** 2007-IAEA	**Tonnes U** 1999-UI
3,346,000,000	Australia	1,800,000	1,673,000	1,243,000	716,000
2,045,000,000	Kazakhstan	1,100,000	651,000	817,000	599,000
970,000,000	Canada	900,000	485,000	423,000	326,000
960,000,000	Russia	600,000	480,000	546,000	141,000
590,000,000	South Africa	400,000	295,000	435,000	293,000
568,000,000	Namibia	500,000	284,000	275,000	181,000
558,000,000	Brazil	400,000	279,000	278,000	162,000
544,000,000	Niger	300,000	272,000	274,000	200,000
414,000,000	USA	500,000	207,000	342,000	355,000
342,000,000	China	400,000	171,000	150,000	125,000
224,000,000	Jordan	150,000	112,000	75,000	25,000
222,000,000	Uzbekistan	190,000	111,000	95,000	83,000
210,000,000	Ukraine	150,000	105,000	90,000	81,000
160,000,000	India	200,000	80,000	50,000	25,000
98,000,000	Mongolia	500,000	49,000	20,000	10,000
300,000,000	Others	500,000	150,000	50,000	25,000
11,551,000,000	**Totals**	**8,590,000**	**5,404,000**	**5,163,000**	**3,347,000**

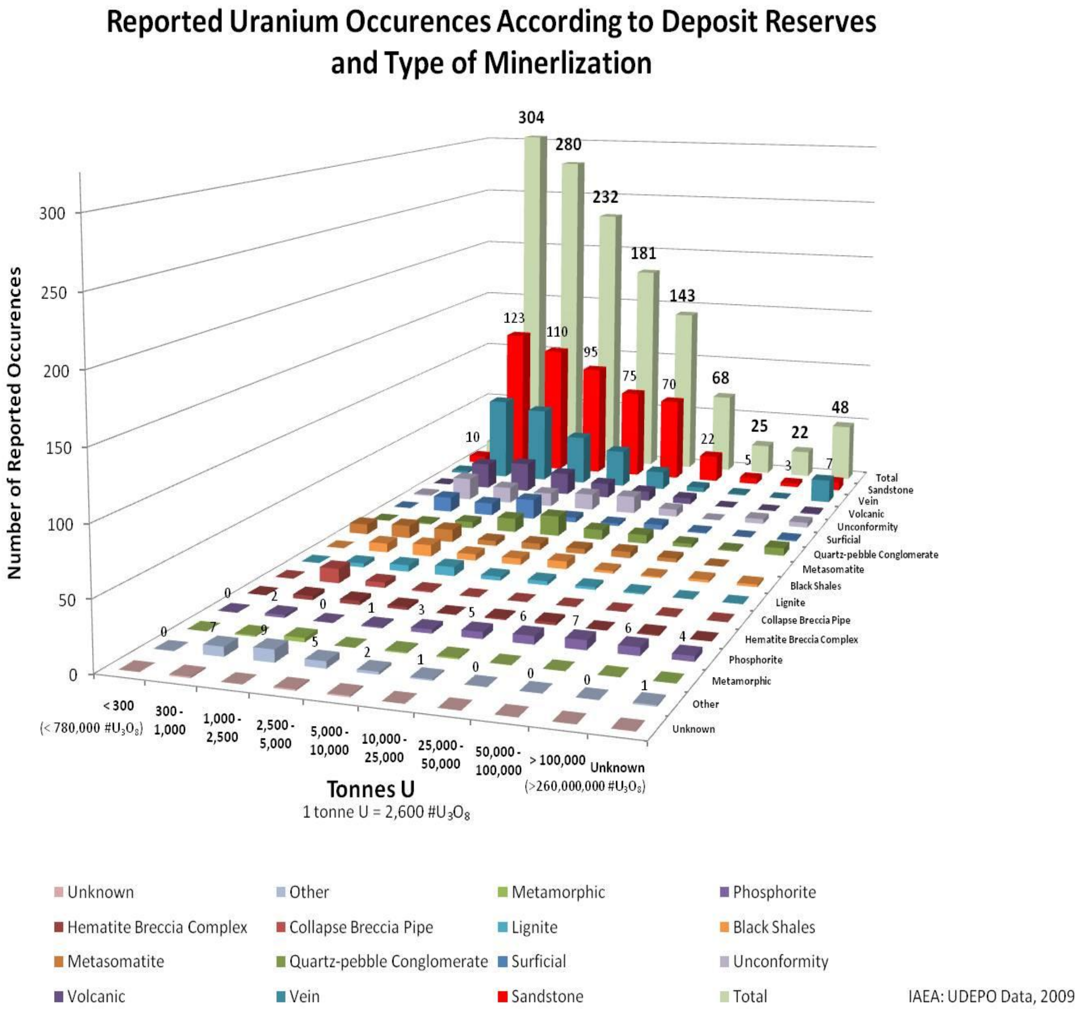
Figure 1



Current World uranium consumption (in conversion to yellowcake) is about 68,000 tU/yr. Thus, the world's present measured resources of uranium (5.4 Million tonnes – see Table 1- 2009 Estimate) in the cost category slightly above present spot prices and used only in conventional reactors, are enough to last for about 80 years. This represents a higher level of assured resources than is normally estimated for most strategic commodities. Further, exploration and higher prices will, on the basis of present geological knowledge, certainly yield additional resources as current resources are consumed.

As indicated above, exploration targets are now known in many parts the World. IAEA data on the location and type of uranium mineralization are summarized in Figure 2. This illustrates that the most common types of mineralization are found in sandstone and in veins, and which produce the largest orebodies. These have been the most predominant types explored over the past 75 years, but other types, with potential for producing substantial reserves, are beginning to be explored in other areas gone unexplored in past uranium exploration cycles.

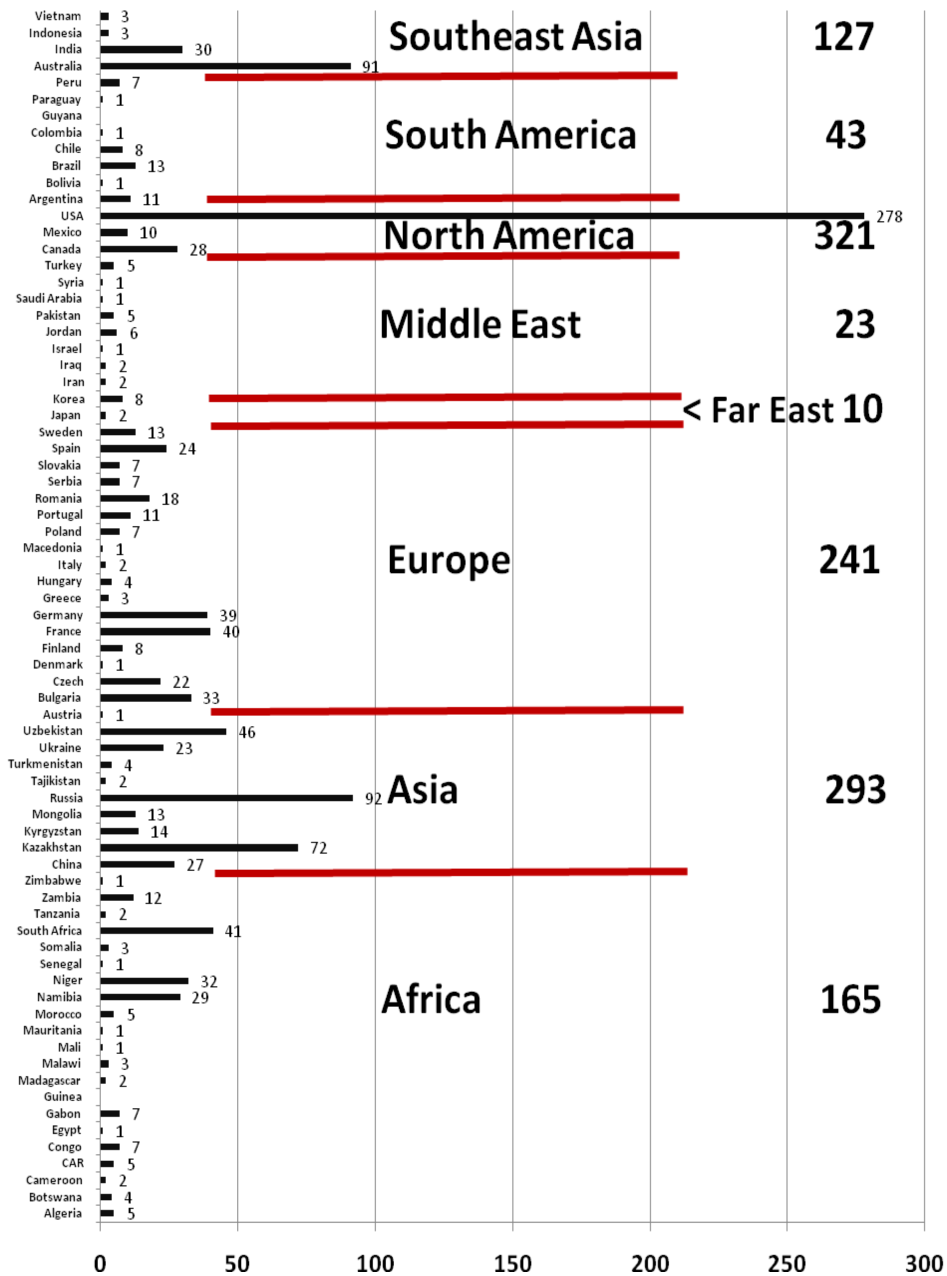
Figure 2



The geographical locations of the orebodies are of major importance. Now that new discoveries are being explored in Africa and South America, new production may come from these regions sooner than previously expected. No longer will Canada and Australia be the sole source of uranium at a low price, but continuity of delivery comes into play which may complicate the supply to the new and old nuclear power plants of the World.

The geographical distribution of current and past exploration in the World has been summarized in the Figure 3 according to regions and countries. The number of known deposits is indicated for each country and associated regions. These data are further documented in a table based on IAEA-UDEPO, 2009 research that includes the deposit names and locations where uranium has been discovered to date (Here).

Figure 3
World Uranium: Number of Known Deposits by Country and Region – 2009
([IAEA-UDEPO Data, 2009](#))



The data for Figure 2 and Figure 3 were substantially derived from 2003 WNA Symposium paper by Colin MacDonald, *Uranium: Sustainable Resource or Limit to Growth?* - supplemented by his 2005 WNA Symposium paper ([Here](#)) and including a model "Economic adjustments in the supply of a 'non-renewable' resource" from Ian Hore-Lacy.

A review of the sustainability of mineral resources with reference to uranium supplies has been included at the end of this report.

Characteristics of Uranium Exploration Cycles

The initial uranium exploration cycle was military-driven, over 1945 to 1958. The second cycle was about 1974 to 1983, driven by civil nuclear power and in the context of a perception that uranium might be scarce. There was relatively little uranium exploration between 1985 and 2003, so the significant increase in exploration effort since then could conceivably double the known economic resources despite adjustments due to increasing costs. In the two years 2007 to 2009, the world's known uranium resources tabulated above increased by 17%.

World uranium exploration expenditure in 2006 was US$705 million, in 2007 $1,328 million, and in 2008 $1,641 million, an increase of almost 25%. In the third uranium exploration cycle from 2003 to the end of 2009, about US$5.75 billion was spent on uranium exploration and deposit delineation on over 600 projects. In this period, over 400 new junior companies were formed or changed their orientation to raise over US$2 billion for uranium exploration. About 60% of this was spent on previously-known deposits. All this was in response to increased uranium price in the market, which recently has turned markedly upwards (See Figure 4).

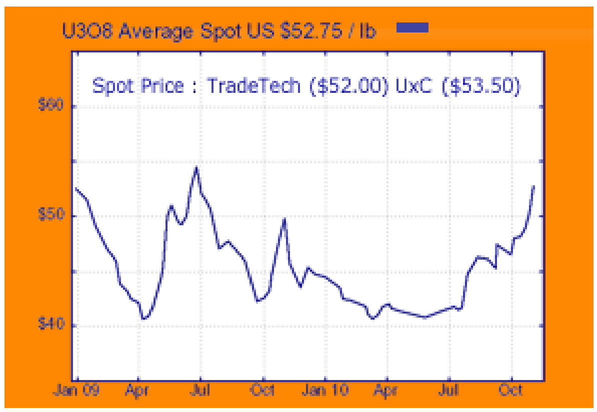
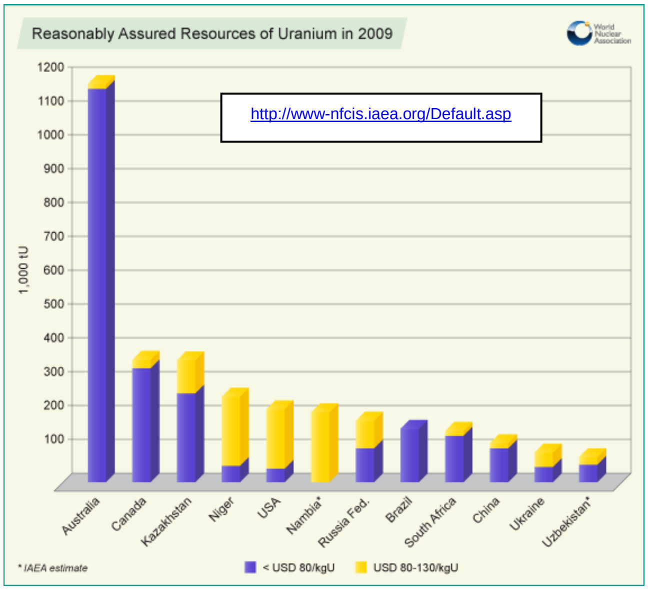


Figure 4
UxC November 1, 2010

The price of uranium, and almost any other mineral commodity, also directly determines the amount of known resources that are economically recoverable. On the basis of analogies with other metal minerals, a doubling of price from present levels could be expected to create about a tenfold increase in measured economic resources, over time, due both to increased exploration and the reclassification of resources regarding what is economically recoverable. The World Nuclear Association (WNA) monitors these activities. Figure 5 illustrates the resource base currently known for the two market-price levels.

By adding a price increase of US$130/kgU to all conventional resources considered in Figure 5, another 5.5 million tonnes (beyond the 5.4 Mt of known economic resources, which would provide 160 years of yellowcake supply (and its equivalent fuel) at today's rate of consumption. This omits unconventional resources such as phosphate/phosphorite deposits (22 Mt U recoverable as by-product) and seawater (up to 4,000 Mt), but which would, as indicated earlier, likely be uneconomic in the foreseeable future under current prices.

Figure 5



About 20% of U.S. uranium came from central Florida's phosphate deposits to the mid 1990s, as a by-product, but it then became uneconomic as the price fell. With higher uranium prices today the resource is being examined again, as is another lower-grade one in Morocco. Plans for Florida extend only to 400 tU/yr at this stage. for additional on uranium in phosphates, see ([Here]).

Coal ash is another easily-accessible though minor uranium resource in many parts of the world. In central Yunnan province in China, the coal uranium content varies up to 315 ppm and averages about 65 ppm. The ash averages about 210 ppm U (0.021%U) - above the cut-off level for some uranium mines. The Xiaolongtang power station ash heap contains over 1000 tU, with annual contributions of approximately 190 tU. Recovery of this product by acid leaching is about 70%.

Indirect Utilization of Fuel Supply

Widespread use of beryllium and thorium in with the uranium has been found to significantly increase fuel burn life and reduce reactor-load requirements. The primary interest in developing the breeder reaction is because the "fast breeder" reactor design could increase the utilization of uranium 50-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 or depleted uranium for its "fertile blanket", can be operated so that each tonne of ore yields 60 times more energy than in a conventional reactor. For more on this subject, see the (WNA).

Reactor Fuel Requirements

The world's power reactors, with combined capacity of some 375 GWe, require about 68,000 tonnes of uranium from mines or elsewhere each year. While this capacity is being increased each year, with higher capacity factors and reactor power levels (larger plant designs), the uranium-fuel requirement is also increasing, but not necessarily at the same rate. Therefore, the factors of increasing fuel demand are offset by a trend for higher rate of burn-up of fuel and related matters, so demand is steady. Over the years 1980 to 2008, the electricity generated by nuclear power increased 3.6-fold while uranium used increased by a factor of only 2.5.

Reducing the tails assay in enrichment reduces the amount of natural uranium required for a given amount of fuel. Reprocessing of used fuel from conventional light water reactors also utilizes present resources more efficiently, by a factor of about 1.3 overall.

Today's reactor fuel requirements are met from primary supply (direct mine output - 78% in 2009) and secondary sources: commercial stockpiles, nuclear weapons stockpiles, recycled plutonium and uranium from reprocessing used fuel, and some from re-enrichment of depleted uranium tails (left over from original enrichment). These various secondary sources make uranium unique among energy minerals.

Nuclear Weapons as a Source of Fuel

An 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.

The weapons contained a great deal of uranium enriched to over 90 percent U^{235} (i.e. up to 25 times the proportion in reactor fuel). Some weapons have plutonium^{239}, which can be used in mixed-oxide (MOX) fuel for civil reactors. From 2000, the dilution of 30 tonnes of military high-enriched uranium has been displacing about 10,600 tonnes of uranium oxide per year from mines, which represents about 15% of the world's reactor requirements. Details of the utilization of military stockpiles are described in some detail in the coverage by WNA (Here).

Other Secondary Sources of Uranium

The most obvious source is civil stockpiles held by utilities and governments. The amount held is difficult to quantify, due to commercial confidentiality. As of January 2009, some 129,000 tU of total inventory was estimated for utilities, 10,000 tU for producers and 15,000 tU for fuel-cycle participants, making a total of 154,000 tU (see the above WNA Market Report). These reserves are expected not to be drawn down, but to increase steadily to provide a stockpile for energy security and continuity for utilities and governments.

Recycled uranium and plutonium is another source, and currently saves 1500-2000 tU per year of primary supply, depending on whether just the plutonium or also the uranium is considered. In fact, plutonium is quickly recycled as MOX fuel, whereas the reprocessed uranium (RepU) is mostly stockpiled. For additional information on the processing of used nuclear fuel for recycle paper, see the WNA (here)

Re-enrichment of depleted uranium (DU, enrichment tails) is another secondary source. There is about 1.5 million tonnes of depleted uranium available, from both military and civil enrichment activity since the 1940s, most at tails assay of 0.25 - 0.35% U^{235}. Non-nuclear uses of DU are very minor relative to annual increase of over 35,000 tU per year. This leaves most DU available for mixing with recycled plutonium on MOX fuel or as a future fuel resource for fast neutron reactors. However, some that has relatively high assay can be fed through under-utilized enrichment plants to produce natural uranium equivalent, or even enriched uranium ready for fuel fabrication. Russian enrichment plants have treated 10-15,000 tonnes per year of DU assaying over 0.3% U^{235}, stripping it down to 0.1% and producing a few thousand tonnes per year of natural uranium equivalent. This Russian program treating Western tails has now finished, but a new U.S. program is expected to start when surplus capacity is available, treating about 140,000 tonnes of old DU assaying 0.4% U^{235}.

Thorium as a Nuclear Fuel

Today, uranium is the only fuel supplied for nuclear reactors. However, thorium can also be utilized as a fuel for the Canadian 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}) atom captures a neutron in the reactor to become fissile uranium (U^{233}), which continues the reaction. Some advanced reactor designs are likely to be able to make use of thorium on a substantial scale.

The thorium fuel cycle has some attractive features, though it is not yet in commercial use. IAEI reports that thorium is about three times as abundant in the earth's crust as uranium. The 2009 IAEA-NEA "Red Book" lists 3.6 million tonnes of known and estimated resources as reported, but points out that this excludes data from much of the world, and estimates about 6 million tonnes overall. For additional information on thorium, see the WNA.

Environmental Considerations

Nuclear power's life-cycle emissions range from 2 to 59 gram-equivalents of carbon dioxide per kilowatt-hour. Only hydropower's range ranked lower at 2 to 48 grams of carbon dioxide-equivalents per kilowatt-hour. Wind comes in at 7 to 124 grams and solar at 13 to 731 grams. Emissions from natural gas fired plants ranged from 389 to 511 grams. Coal produces 790 to 1,182 grams of carbon dioxide equivalents per kilowatt hour. The IAEA (2001) produced a report on this subject.

Groups opposing uranium exploration and development (and nuclear power in general) focus on the potential impact to local ground water supplies. Campbell and Wise (2010) continue to deal with such issues. The WNA indicates that nuclear power is an essential part of the energy picture in the future if the impact of climate change is to be reduced.

Big Picture

By far the biggest use for uranium is to produce electricity - the U.S. produces close to 20 percent of its electricity via nuclear power. One pound of yellowcake (U_3O_8 - the final product of the uranium milling process) has the energy equivalence of 35 barrels of oil. One 7 gram uranium fuel pellet has an energy-to-electricity equivalent of 17,000 cubic feet of natural gas, 564 liters of oil or 1,780 pounds of coal.

Today, there are some 441 nuclear power reactors operating in 30 countries and nuclear energy provides approximately 15% of the world's electricity. These 441 reactors, with combined capacity of over 376 Gigawatts (One GWe equals one billion watts or one thousand megawatts), require approximately 69,000 tonnes of uranium oxide (U_3O_8), otherwise known as yellowcake, end product of current uranium recovery operations.

According to the WNA, about 58 power reactors are currently being constructed in 14 countries. In all, there are over 148 power reactors planned and 331 more proposed. Each GWe of increased capacity will require about 195 tU per year of extra uranium production - three times this for the first fuel load. A $4 to $6-billion dollar investment in a new reactor requires that more than one year's of fuel supply are available.

In 2008, uranium recovery operations supplied 51,600 tonnes of uranium oxide concentrate containing 43,853 tU, which means mining supplied roughly 75% of nuclear utility power requirements. The remaining supply deficit used to be made up from stockpiled uranium held by nuclear power utilities, but their stockpiles are nearing depletion. Production is now primarily supplemented by ex-military material - the "Megatons to Megawatts" program which ends in 2013 - the Russians have stated that the agreement will not be renewed.

The approximately 104 nuclear power plants operating in the U.S. today consume about 50 million pounds of uranium fuel per year but the U.S.'s current annual production is only about 4 million pounds per year, as indicated earlier in this report. As is the current situation with oil, the U.S. is highly reliant on foreign sources for its uranium albeit Canada and Australia are politically stable, market forces may restrict supplies. Numerous alternative sources will need to be developed throughout the World wherever such resources are made available to the World market at "reasonable" prices.

There is also a new development in the size of nuclear reactors in the range of 25MW to 100 MW. A number of groups are designing small, modular reactors that can be trucked in to supply electricity for a population 25,000 to 50,000 in emergency circumstances or for use in remote areas, on the Earth and off-World. For WNA's summary of the current status the small reactors, see (here).

Vice-Chair Reports:

I. Uranium-Related University Research Activity

By Steven N. Sibray, P.G., (Vice-Chair: University), University of Nebraska, Lincoln, NE

Summary

Uranium-related research activities at the major United States universities were limited in scope in 2010. Funding sources were primarily from private sources, usually uranium mining companies. The Society of Economic Geologists provided four student grants related to uranium ore deposits, which are listed at the end of this report. The U.S. Geological Survey also provided a limited amount of funding.

Two faculty members of the Colorado School of Mines had active research projects related to uranium ore deposits. Dr. Thomas Monecke and a PhD graduate student (Julie Leibold) were investigating the mineralogy and geochemistry of the Three Crows roll front uranium deposit in Nebraska. Dr. Monecke was also conducting research on the mineralogy and geochemistry of the Lost Creek roll front deposit in Wyoming. Funding for the Three Crows study was provided by Cameco while the Lost Creek study was funded by UR Energy and the U.S. Geological Survey. Dr. Murray Hitzman and Sophie Hancock (PhD graduate student) were studying the hydrogeology of the Lost Creek deposit and were funded by UR Energy. Sophie Hancock presented a talk, "In Situ Recovery: Hydrologic Aspects of Producing a Deposit with a Fault System", at the Rocky Mountain section meeting of AAPG at Durango, Colorado. Dr. Samuel Romberger of the Colorado School of Mines also presented a one day short course, "Geology and Geochemistry of Uranium Deposits" at the Rocky Mountain section meeting of AAPG. Two faculty members (Linda Figueroa and Jim Ranville) of the Colorado School of Mines are also involved in studying microbially mediated removal of radionuclides.

Two faculty members at the University of Wyoming, Dr. Kevin Chamberlain and Ken Sims, are studying the potential applications of isotope geochemistry to ISR mining of uranium. Their study is funded by Cameco. Dr. Peter Stahl and graduate student Lisa Cox are studying in-situ methods of remediating radium contaminated soils. Funding is provided by the State of Wyoming and the Wyoming Mining Association.

At the University of Nebraska, the author of this report, made a presentation on the "Revised White River Group Stratigraphy and Uranium Mineralization in the Nebraska Panhandle" at the Rocky Mountain section of AAPG at Durango, Colorado. In this presentation, I speculated that the source of the uranium at the Crow Butte deposited was a sequence bounding paleosol in the lower part of the White River Group. During the last thirty years, there has been a great deal of change in the way that geologists look at sedimentary rocks. Sequence stratigraphy and paleopedology (study of fossil soils) have given geologists new tools that can help interpret the paleohydrogeology of clastic sequences that contain sandstone uranium deposits. Detailed studies of the Tertiary White River Group, the Jurassic Morrison Formation, and the Triassic Chinle Formation have been conducted by academic geologists interested in reconstructing past climates and environments. With renewed interest in uranium as a fuel, there is the potential for developing a better understanding of the genesis of the sandstone uranium deposits. Improved conceptual models should lead to better exploration programs.

Recipients of Research Grants

Students receiving research grants related to uranium from Society of Economic Geologists in 2010:

Elizabeth Bloch, $2,000, University of Texas at Austin, USA, Ph.D., Nature and origin of the Be-U-REE-rich fluorspar deposits associated with the Round Top laccolith, Trans-Pecos, Texas, USA.

Alina V. Kuptsova, $1,500, St. Petersburg State University, Russia, Ph.D., Geochemistry and alteration of sandstone and basement rocks of the East-AnBasin with high potential for unconformity-type uranium deposits.

Alex Moyes $2,500, University of Utah, USA, M.S.; Porosity and Permeability characterization of Gas Hills uranium roll-front deposit with application to hydraulic fracturing.

Jim Renaud, $2,500, University of Western Ontario, Canada, Ph.D.; Mineralogical zoning of the U_3O_8 Corp. basement-hosted Archeng uranium deposit, Roraima Basin, British Guyana, South America.

II. Uranium-Related Industry Research Activity

By William Boberg, P.G., (Vice-Chair: Industry), Ur-Energy Inc., Denver, CO

Summary - TBA

Recipients of Research Grants - TBA

III. Uranium-Related Government Research Activity

By Robert W. Gregory, P.G., (Vice-Chair: Government), Wyoming State Geological Survey, Laramie, WY

Summary - TBA

Recipients of Research Grants – TBA

The Sustainability of Mineral Resources with Reference to Uranium Supplies

The following is taken directly from Appendix 2 of the IAEA 2009 Redbook and included in this report because of its importance in the understanding of the concepts involved as they relate to the world uranium supply. We have, therefore, not attempted to summarize this information and present it in whole in the following:

“It is commonly asserted 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 (Club of Rome 1972 popularized by Meadows et al in *Limits of Growth* at that time. (A useful counter to it is W Berckerman, *In Defense 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%.) fashionable in the early 1970s, which was substantially disowned by its originators, the Club of Rome, and shown up as nonsense with the passing of time. 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 if the scale of the Earth's crust is ignored, it lacks empirical support in the trend of practically all mineral commodity prices and published resource figures over the long term. In recent years some have promoted the view that limited supplies of natural uranium are the Achilles heel of nuclear power as the sector contemplates a larger contribution to future clean energy, notwithstanding the small amount of it required to provide very large amounts of energy.

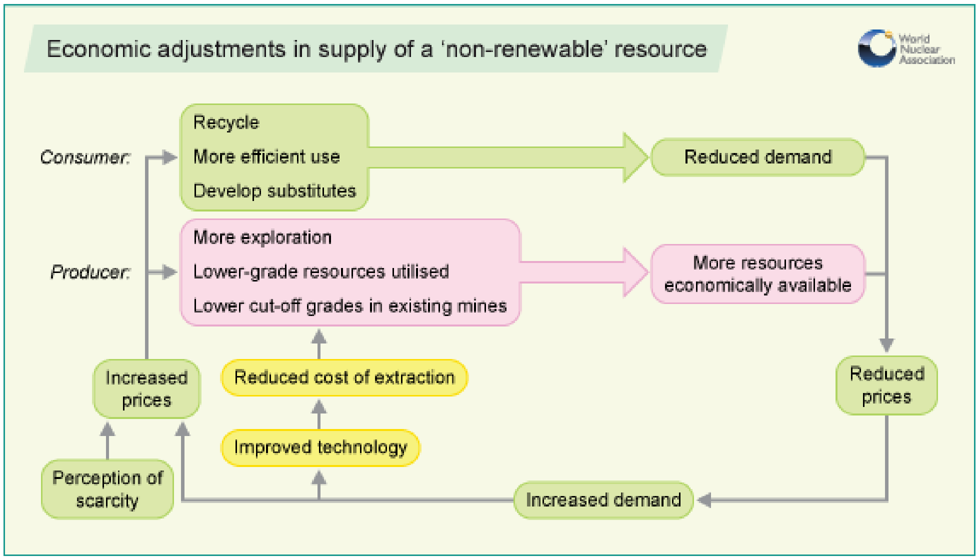
Uranium supply news is usually framed within a short-term perspective. It concerns who is producing with what resources, who might produce or sell, and how does this balance with demand? However, long-term supply analysis enters the realm of resource economics. This discipline has as a central concern the understanding of not just supply/demand/price dynamics for known resources, but also the mechanisms for replacing resources with new ones presently unknown. Such a focus on sustainability of supply is unique to the long view. Normally-functioning metals markets and technology change provide the drivers to ensure that supply at costs affordable to consumers is continuously replenished, both through the discovery of new resources and the re-definition (in economic terms) of known ones.

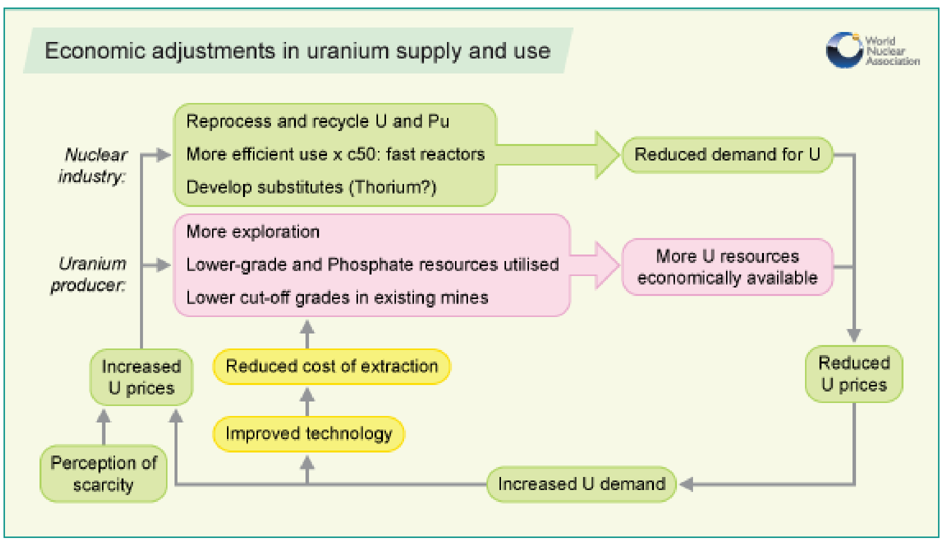
Of course the resources of the earth are indeed finite, but three observations need to be made: first, the limits of the supply of resources are so far away that the truism has no practical meaning. Second, many of the resources concerned are either renewable or recyclable (energy minerals and zinc are 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.

There are three principal areas where resource predictions have faltered:

- predictions have not accounted for gains in geological knowledge and understanding of mineral deposits;
- they have not accounted for technologies utilized to discover, process and use them;
- economic principles have not been taken into account, which means that resources are thought of only in present terms, not in terms of what will be economic through time, nor with concepts of substitution in mind.

What then does sustainability in relation to mineral resources mean? The answer lies in the interaction of these three things which enable usable resources (Some licence is taken in the use of this word in the following, strictly it is reserves of minerals which are created) effectively to be created. They are brought together in the diagram below.





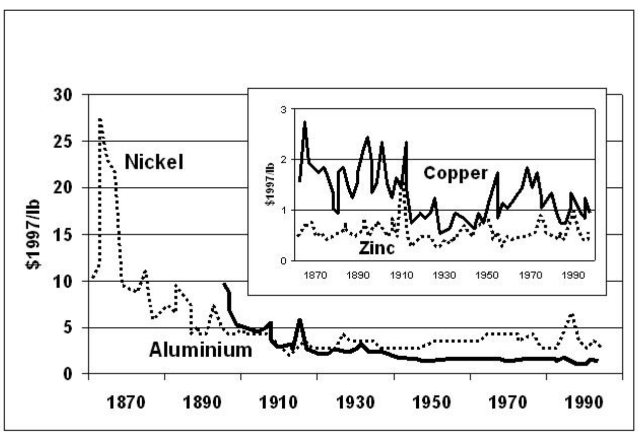
Numerous economists have studied resource trends to determine which measures should best reflect resource scarcity (Tilton, J. *On Borrowed Time? Assessing the threat of mineral depletion*, Resources for the Future, Washington DC 2002). Their consensus view is that costs and prices, properly adjusted for inflation, provide a better early warning system for long-run resource scarcity than do physical measures such as resource quantities.

Historic data show that the most commonly used metals have declined in both their costs and real commodity prices over the past century. Such price trends are the most telling evidence of lack of scarcity. Uranium has been a case in point, relative to its late 1970s price of US$40/lb U_3O_8.

An anecdote underlines this basic truth: 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.

However, quantities of known resources tell a similar and consistent story. To cite one example, world copper reserves in the 1970s represented only 30 years of then-current production (6.4 Mt/yr). Many analysts questioned whether this resource base could satisfy the large expected requirements of the telecommunications industry by 2000. But by 1994, world production of copper had doubled (12 Mt/yr) and the available reserves were still enough for another 30 years. The reserve multiple of current production remained the same.

Another way to understand resource sustainability is in terms of economics and capital conservation. Under this perspective, mineral resources are not so much rare or scarce as they are simply too expensive to discover if you cannot realize the profits from your discovery fairly soon. Simple economic considerations therefore discourage companies from discovering much more than society needs through messages of reduced commodity prices during times of oversupply. Economically rational players will only invest in finding these new reserves when they are most confident of gaining a return from them, which usually requires positive price messages caused by undersupply trends. If the economic system is working correctly and maximizing capital efficiency, there should never be more than a few decades of any resource commodity in reserves at any point in time.



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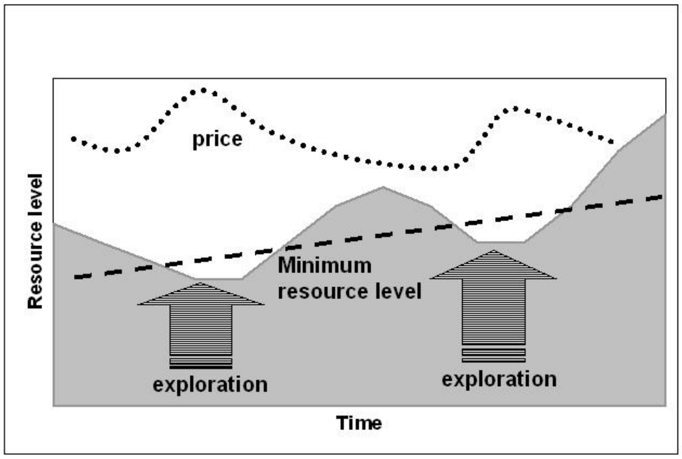

The fact that many commodities have more resources available than efficient economic theory might suggest may be partly explained by two characteristics of mineral exploration cycles. First, the exploration sector tends to over-respond to the positive price signals through rapid increases in worldwide expenditures (which increases the rate of discoveries), in particular through the important role of more speculatively-funded junior exploration companies. Exploration also tends to make discoveries in clusters that have more to do with new geological knowledge than with efficient capital allocation theory. As an example, once diamonds were known to exist in northern Canada, the small exploration boom that accompanied this resulted in several large discoveries - more than the market may have demanded at this time. These patterns are part of the dynamics that lead to commodity price cycles. New resource discoveries are very difficult to precisely match with far-off future demand, and the historic evidence suggests that the exploration process over-compensates for every small hint of scarcity that the markets provide.

Another important element in resource economics is the possibility of substitution of commodities. Many commodity uses are not exclusive - should they become too expensive they can be substituted with other materials. Even if they become cheaper they may be replaced, as technology gains have the potential to change the style and cost of material usage. For example, copper, despite being less expensive in real terms than 30 years ago, is still being replaced by fiber optics in many communication applications. These changes to materials usage and commodity demand provide yet another dimension to the simple notion of depleting resources and higher prices.

In summary, historic metals price trends, when examined in the light of social and economic change through time, demonstrate that resource scarcity is a double-edged sword. The same societal trends that have increased metals consumption, tending to increase prices, have also increased the available wealth to invest in price-reducing knowledge and technology. These insights provide the basis for the economic sustainability of metals, including uranium.

Geological Knowledge and Exploration

Whatever minerals are in the earth, they cannot be considered usable resources unless they are known. There must be a constant input of time, money and effort to find out what is there. This mineral exploration endeavor but must extend to comprehensive investigation of orebodies so that they can reliably be defined in terms of location, quantity and grade. Finally, they must be technically and economically quantified as mineral reserves. That is the first aspect of creating a resource. See IAEA Redbook (2009) for mineral resource and reserve categories.

For reasons outlined above, 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 in the 1970s, and this is especially so for uranium.

Simply put, metals which are more abundant in the Earth's crust are more likely to occur as the economic concentrations we call mineral deposits. They also need to be reasonably extractable from their host minerals. By these measures, uranium compares very well with base and precious metals. Its average crustal abundance of 2.7 ppm is comparable with that of many other metals such as tin, tungsten, and molybdenum. Many common rocks such as granite and shales contain even higher uranium concentrations of 5 to 25 ppm. Also, uranium is predominantly bound in minerals which are not difficult to break down in processing.

As with crustal abundance, metals which occur in many different kinds of deposits are easier to replenish economically, since exploration discoveries are not constrained to only a few geological settings. Currently, at least 14 different types of uranium deposits are known, occurring in rocks of a wide range of geological age and geographic distribution. There are several fundamental geological reasons why uranium deposits are not rare, but the principal reason is that uranium is relatively easy both to place into solution over geological time, and to precipitate out of solution in chemically reducing conditions. This chemical characteristic alone allows many geological settings to provide the required hosting conditions for uranium resources. Related to this diversity of settings is another supply advantage. The wide range in the geological ages of host rocks ensures that many geopolitical regions are likely to host uranium resources of some quality.

Unlike the metals which have been in demand for centuries, society has barely begun to utilize uranium. As serious non-military demand did not materialize until significant nuclear generation was built by the late 1970s, there has been only one cycle of exploration-discovery-production, driven in large part by late 1970s price peaks (MacDonald, C, *Rocks to reactors: Uranium exploration and the market.* Proceedings of WNA Symposium 2001). This initial cycle has provided more than enough uranium for the last three decades and several more to come. Clearly, it is premature to speak about long-term uranium scarcity when the entire nuclear industry is so young that only one cycle of resource replenishment has been required. It is instead a reassurance that this first cycle of exploration was capable of meeting the needs of more than half a century of nuclear energy demand.

Related to the youthfulness of nuclear energy demand is the early stage that global exploration had reached before declining uranium prices stifled exploration in the mid 1980s. The significant investment in uranium exploration during the 1970-82 exploration cycle would have been fairly efficient in discovering exposed uranium deposits, due to the ease of detecting radioactivity. Still, very few prospective regions in the world have seen the kind of intensive knowledge and technology-driven exploration that the Athabasca Basin of Canada has seen since 1975. This fact has huge positive implications for future uranium discoveries, because the Athabasca Basin history suggests that the largest proportion of future resources will be as deposits discovered in the more advanced phases of exploration. Specifically, only 25% of the 635,000 tonnes of U_3O_8 discovered so far in the Athabasca Basin could be discovered during the first phase of surface-based exploration. A sustained second phase, based on advances in deep penetrating geophysics and geological models, was required to discover the remaining 75%.

Another dimension to the immaturity of uranium exploration is that it is by no means certain that all possible deposit types have even been identified. Any estimate of world uranium potential made only 30 years ago would have missed the entire deposit class of unconformity deposits that have driven production since then, simply because geologists did not know this class existed.

Impact of 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. Uranium was not a resource in any meaningful sense before 1940.

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.(aluminum can mass was reduced by 21% 1972-88, and motor cars each use about 30% less steel than 30 years ago)

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 45 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.

Just over a hundred years ago aluminum 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 aluminum 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.

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.

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, and with uranium it is also demonstrable. 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.

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 continue to 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 aluminum. During World War II, Germany and Japan recovered aluminum from kaolinite, a common clay, at slightly greater cost than it could be obtained from bauxite.

Due to the operation of these three factors the world's economically demonstrated resources of most minerals have risen faster than the increased rate of usage over the last 50 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.

Replacement of Uranium

A characteristic of metals resource replacement is that the mineral discovery process itself adds a small cost relative to the value of the discovered metals. As an example, the huge uranium reserves of Canada's Athabasca Basin were discovered for about US$1.00/kgU (2003 dollars, including unsuccessful exploration). Similar estimates for world uranium resources, based on published IAEA exploration expenditure data and assuming that these expenditures yielded only the past uranium produced plus the present known economic resources categories at up to US$80/kg (*Uranium 2003: Resources, Production and demand.* Nuclear Energy Agency and IAEA, OECD Publications 2004) yields slightly higher costs of about US$1.50/kgU. This may reflect the higher component of State-driven exploration globally, some of which had national self-sufficiency objectives that may not have aligned with industry economic standards.

From an economic perspective, these exploration costs are essentially equivalent to capital investment costs, albeit spread over a longer time period. It is, however, this time lag between the exploration expense and the start of production that confounds attempts to analyze exploration economics using strict discounted cash flow methods. The positive cash flows from production occur at least 10-15 years into the future, so that their present values are obviously greatly reduced, especially if one treats the present as the start of exploration. This creates a paradox, since large resource companies must place a real value on simply surviving and being profitable for many decades into the future; and, without exploration discoveries, all mining companies must expire with their reserves. Recent advances in the use of real options and similar methods are providing new ways to understand this apparent paradox. A key insight is that time, rather than destroying value through discounting, actually adds to the option value, as does the potential of price volatility. Under this perspective, resource companies create value by obtaining future resources which can be exploited optimally under a range of possible economic conditions. Techniques such as these are beginning to add analytical support to what have always been intuitive understandings by resource company leaders - that successful exploration creates profitable mines and adds value to company shares.

Since uranium is part of the energy sector, another way to look at exploration costs is on the basis of energy value. This allows comparisons with the energy investment cost for other energy fuels, especially fossil fuels which will have analogous costs related to the discovery of the resources. From numerous published sources, the finding costs of crude oil have averaged around US$6/bbl over at least the past three decades. When finding costs of the two fuels are expressed in terms of their contained energy value, oil, at US$1050/MJ of energy, is about 300 times more expensive to find than uranium, at US$3.4/MJ. Similarly, the proportion of current market prices that finding costs comprise are lower for uranium. Its finding costs make up only 2% of the recent spot price of US$30/lb ($78/kgU), while the oil finding costs are 12% of a recent spot price of US$50/bbl.

By these measures, uranium is a very inexpensive energy source to replenish, as society has accepted far higher energy replacement costs to sustain oil resources. This low basic energy resource cost is one argument in favor of a nuclear-hydrogen solution to long-term replacement of oil as a transportation fuel.

Forecasting Replenishment

Supply forecasters are often reluctant to consider the additive impacts of exploration on new supply, arguing that assuming discoveries is as risky and speculative as the exploration business itself. Trying to predict any single discovery certainly is speculative. However, as long as the goal is merely to account for the estimated total discovery rate at a global level, a proxy such as estimated exploration expenditures can be used. Since expenditures correlate with discovery rate, the historic (or adjusted) resources discovered per unit of expenditure will provide a reasonable estimate of resource gains to be expected. As long as the time lag between discovery and production is accounted for, this kind of dynamic forecasting is more likely to provide a basis for both price increases and decreases, which metals markets have historically demonstrated.

Without these estimates of uranium resource replenishment through exploration cycles, long-term supply-demand analyses will tend to have a built-in pessimistic bias (i.e. towards scarcity and higher prices), that will not reflect reality. Not only will these forecasts tend to overestimate the price required to meet long-term demand, but the opponents of nuclear power use them to bolster arguments that nuclear power is unsustainable even in the short term. In a similar fashion, these finite-resources analyses also lead observers of the industry to conclude that fast breeder reactor technology will soon be required. This may indeed make a gradual appearance, but if uranium follows the price trends we see in other metals, its development will be due to strategic policy decisions more than uranium becoming too expensive.

The resource economics perspective tells us that new exploration cycles should be expected to add uranium resources to the world inventory, and to the extent that some of these may be of higher quality and involve lower operating cost than resources previously identified, this will tend to mitigate price increases. This is precisely what has happened in uranium, as the low-cost discoveries in Canada's Athabasca Basin have displaced higher-cost production from many other regions, lowering the cost curve and contributing to lower prices. Secondary uranium supplies, to the extent that they can be considered as a very low-cost mine, have simply extended this price trend.

The first exploration and mining cycle for uranium occurred about 1970 to 1985. It provided enough uranium to meet world demand for some 80 years, if we view present known resources as arising from it. With the rise in uranium prices to September 2005 and the concomitant increase (boom?) in mineral exploration activity, it is clear that we have the start of a second such cycle, mid 2003 to ??. The price increase was brought about by diminution of secondary supplies coupled with a realization that primary supplies needed to increase substantially.

Several significant decisions on mine development and increased exploration by major producers will enable this expansion of supply, coupled with smaller producers coming on line. The plethora of junior exploration companies at the other end of the spectrum which are finding no difficulty whatever in raising capital are also a positive sign that a vigorous new exploration and mining cycle is cranking up. From lows of around US$55 million per year in 2000, world uranium exploration expenditure rose to about US$110 million in 2004 and is expected to be US$185 million in 2005, half of this being from the junior exploration sector. The new cycle is also showing considerable regional diversification. Measured from 1990, cycle 2 totals US$1.5 billion to 2005, compared with a total of about three times this figure (uncorrected) for the whole of the first cycle.

Depletion and Sustainability

Conversely, the exhaustion of mineral resources during mining is real. Resource economists do not deny the fact of depletion, nor its long-term impact - that in the absence of other factors, depletion will tend to drive commodity prices up. But as we have seen, mineral commodities can become more available or less scarce over time if the cost-reducing effects of new technology and exploration are greater than the cost-increasing effects of depletion.

One development that would appear to argue against economic sustainability is the growing awareness of the global depletion of oil, and in some regions such as North America, natural gas. But oil is a fundamentally different material. This starts with geology, where key differences include the fact that oil and gas were formed by only one process: the breakdown of plant life on Earth. Compared with the immense volumes of rock-forming minerals in the Earth's crust, living organisms on top of it have always been a very tiny proportion. But a more important fact is that the world has consumed oil, and recently natural gas as well, in a trajectory of rapid growth virtually unmatched by any other commodity. Consumption growth rates of up to 10% annually over the past 50 years are much higher than we see for other commodities, and support the contention that oil is a special depletion case for several reasons: its geological occurrence is limited, it has been inexpensive to extract, its energy utility has been impossible to duplicate for the price, and its resulting depletion rates have been incredibly high.

This focus on rates of depletion suggests that one of the dimensions of economic sustainability of metals has to do with their relative rates of depletion. Specifically, it suggests that economic sustainability will hold indefinitely as long as the rate of depletion of mineral resources is slower than the rate at which it is offset. This offsetting force will be the sum of individual factors that work against depletion, and include cost-reducing technology and knowledge, lower cost resources through exploration advances, and demand shifting through substitution of materials.

An economic sustainability balance of this type also contemplates that, at some future point, the offsetting factors may not be sufficient to prevent irreversible depletion-induced price increases, and it is at this point that substituting materials and technologies must come into play to take away demand. In the case of rapid oil depletion, that substitute appears to be hydrogen as a transport fuel. Which raises the question of how the hydrogen is produced, and nuclear energy seems the most likely means of that, using high-temperature reactors.

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 humankind."

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