Sustainability of Uranium Mining and Milling: Toward Quantifying Resources and Eco-Efficiency

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The mining of uranium has long been a controversial public issue, and a renewed debate has emerged on the potential for nuclear power to help mitigate against climate change. The central thesis of pro-nuclear advocates is the lower carbon intensity of nuclear energy compared to fossil fuels, although there remains very little detailed analysis of the true carbon costs of nuclear energy. In this paper, we compile and analyze a range of data on uranium mining and milling, including uranium resources as well as sustainability metrics such as energy and water consumption and carbon emissions with respect to uranium production—arguably the first time for modern projects. The extent of economically recoverable uranium resources is clearly linked to exploration, technology, and economics but also inextricably to environmental costs such as energy/water/chemicals consumption, greenhouse gas emissions, and social issues. Overall, the data clearly show the sensitivity of sustainability assessments to the ore grade of the uranium deposit being mined and that significant gaps remain in complete sustainability reporting and accounting. This paper is a case study of the energy, water, and carbon costs of uranium mining and milling within the context of the nuclear energy chain.

1. Introduction and Background

The nuclear industry has long been a controversial issue, commonly linked to issues such as nuclear weapons and nuclear waste. In Australia, the primary debate has often centered on uranium mining and milling as we have significant economic resources—seen by some as worthy of export for financial return or simply to maintain our position in the global nuclear fraternity.

At present there is vigorous global debate about the perceived potential for nuclear power to reduce greenhouse gas emissions—the central hypothesis put forward by pro-nuclear advocates being the apparent low carbon intensity of nuclear power compared to that of fossil fuels. From an environmental sustainability perspective, it is critical to accurately evaluate the true life cycle costs of all forms of electricity production, especially with respect to greenhouse gas emissions. For nuclear power, a significant proportion of greenhouse gas emissions is derived from the fuel supply, including uranium mining, milling, enrichment, and fuel manufacture. However, there are only limited data reported by uranium miners with respect to greenhouse gas emissions. Further, additional issues that need to be considered for uranium mining and milling include the extent of economic resources known and the average ore grade of these resources. These aspects are critical in assessing the long-term ability of nuclear power to reduce greenhouse gas emissions.

This paper compiles and presents the available data on uranium mining and milling, with a particular emphasis on historical production trends, known economic resources, and greenhouse gas emissions, as well as water and energy consumption. This is then placed within the context of sustainability metrics applied to uranium mining and milling.

2. Methodology and Data Sources

The various aspects of sustainability investigated in this paper are assessed through the compilation of detailed data sets on (i) uranium mining and milling - historical government series/periodicals on mining; (ii) uranium resources - historical government series/periodicals on mining as well as recent company annual financial or technical reports; (iii) energy and water consumption - recent company annual sustainability or technical reports; and (iv) carbon dioxide emissions - recent company annual sustainability or technical reports.

Select sustainability data for the last two aspects are only available for a few uranium mines, namely Rössing in Namibia, McLean Lake and Cluff Lake in Canada, and Ranger, Beverley, and Olympic Dam in Australia (the latter being a polymetallic Cu−U−Au−Ag mine). There are many aspects which remain unreported since, historically, they have not been considered necessary for financial or production reporting, including chemicals used (acid/alkali, lime, solvents, ammonia), all associated transport, explosives, the embodied energy and water in infrastructure, and the like.

2.1. Data Sources: Uranium Mining and Milling. The data on uranium mining and milling are available for Canada - 1959−2003 (*1*), 2004−2006 (*2–4*); United States-1948−2005 (*5*) (especially the 1992 report); South Africa - 1952−2006 (*6*) (including the CMSA Web site for 2006 data); Australia - 1954−2006 (*7*); Namibia - 1976−1989 (*8–11*), 1986 to 1994 courtesy of Uranium Information Centre ("Reviewing Rössing 1994"), and 1995−2006 (*12*) (some data estimated/cross-calculated between sources for verification); and Mongolia - 1988−1996 (*13*).

Additionally, data were compiled for in situ leach and byproduct derived uranium, thereby allowing a more accurate estimate of uranium production.

2.2. Data Sources: Uranium Resources. Various economic uranium ore deposits data were compiled by country, based on numerous company annual or other reports, plus the following: Australia - 1945 (*14*), ~1952 (*15*), 1958−1960 (*1*), 1987 (*16*), 2001 (*17*), 2005 company reports and ref (*7*); Canada - 1957−1963 (*1*), 2005 company reports (e.g., refs (*2*) and (*3*); United States - 1958−1960 (*1*), 1992−2003 (*5*), 2005 company reports; South Africa - 1958−1960 (*1*), 2005 company reports (incomplete country resources); Namibia - 2005 company reports (incomplete country resources); and Kazakhstan, Malawi, Mongolia, Niger, France, Zambia, Brazil, Argentina, Central African Republic and Russia - 2005 company reports (often incomplete country resources).

All data above were summed to compare calculated totals with country resources reported by the 2005 edition of ref (*9*). Further data have been compiled on other uranium

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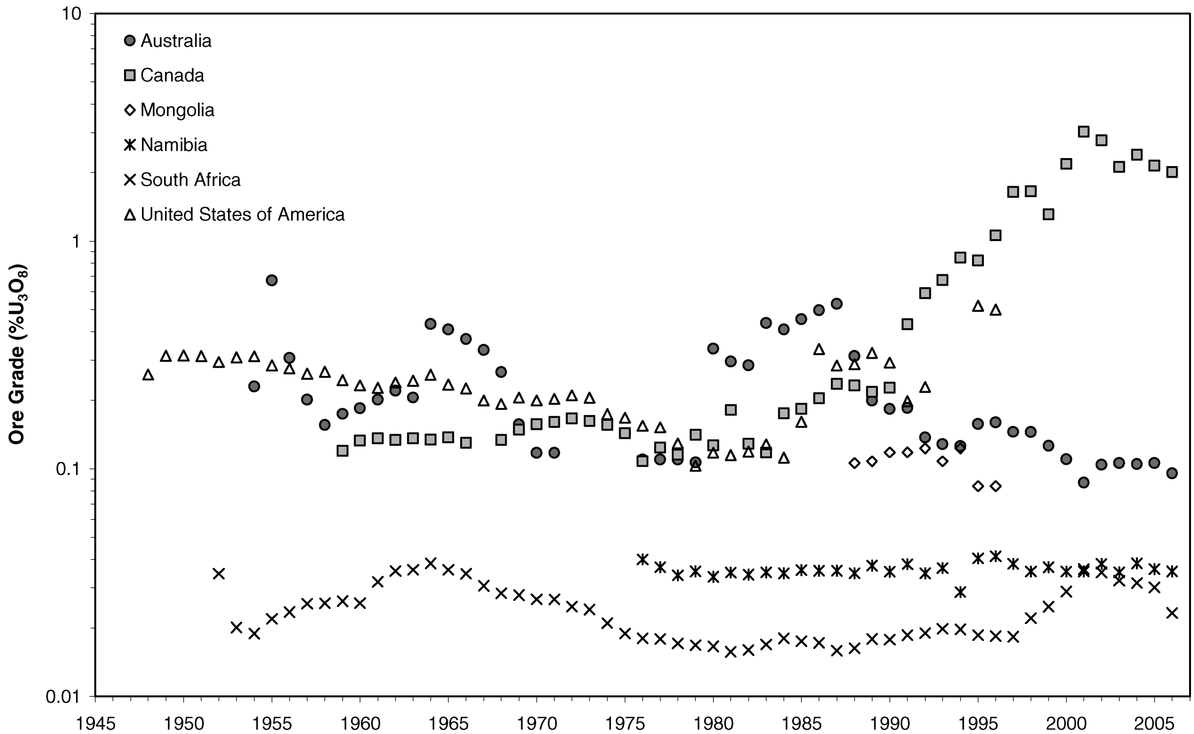

FIGURE 1. Average uranium ore grade in milling over time.

resources, such as phosphates, for comparison to conventional uranium deposits.

2.3. Data Sources: Environmental Aspects of Uranium Mining and Milling. At present, there are only limited publicly reported data on energy and water consumption in uranium mining and milling and greenhouse gas emissions. Some companies, e.g., Cameco and BHP Billiton, report company-wide totals and not site-specific data. Data available include: Rössing, Namibia - open cut mine and adjacent mill, 1995–2006 (*12*); Ranger, Australia - open cut mine and adjacent mill, 1983/84–1987/88 (*18*) (note - data are provided for 1981/82 but as the first year of operations it is excluded as an outlier) and 1996–2006 (*19*); Beverley, Australia - acid in situ leach project, 2003–2006 (*20*); Olympic Dam, Australia - underground mine, adjacent mill, and copper smelter/refinery complex, 1991–2004 (*21*) and 2004/05 (*22*) (note - Olympic Dam is a polymetallic project producing refined copper, calcined uranium oxide concentrate, and gold and silver bullion); McLean Lake, Canada - open cut mine and adjacent mill, 2002–2005 (*3*); and Cluff Lake, Canada - open cut mine and adjacent mill, 2002 (*3*) (note - closed in early 2003 and now in rehabilitation).

All data have been normalized to consumption per unit uranium oxide (U_3O_8) production. If input fuels such as diesel were reported, energy and greenhouse gas emissions were calculated using ref (*23*). All mines analyzed reported both direct and indirect energy and greenhouse gas emissions (or this could be calculated given available data).

To account for the fact that the Olympic Dam project is polymetallic (Cu–U–Au–Ag), data are presented in terms of attributing either all energy and water consumption and carbon dioxide emissions to uranium production or only 20%. Although assuming 100% is clearly unrealistic, the recent average ore grade at ~0.08% U_3O_8 is higher than the Rössing uranium mine's at ~0.04% U_3O_8. The full energy accounting for direct uranium production at Olympic Dam would need to consider a detailed analysis and breakdown of the milling, metallurgical, and smelting processes for copper, uranium, gold, and silver—which is obviously impracticable (only inputs and outputs are known, not internal aspects). The factor of 20% is adopted as this is the long-term average proportion of revenue from uranium at Olympic Dam (*7*).

Beverley is excluded from ore grade graphs due to the uncertain nature of the actual ore grade being mined by acid leaching. Prior to development, uranium resources were estimated at 9.7 Mt at 0.18% U_3O_8, containing about 21,000 t of U_3O_8 (*7*).

3. Results

3.1. Global Uranium Production. The global production of uranium began in large scale following World War II, initially to supply the nuclear weapons programs of the times, but switching to the emerging civil nuclear power industry from the late 1960s. Total production has been dominated by the United States, Canada, (former Eastern) Germany, South Africa, Australia, Czech Republic, Niger, Namibia, and France as well as smaller production from several countries (2005 edition of ref (*9*). Complete production data are not available for all of these countries, however, a significant portion is available, especially for several of these principal producers.

In total, the compiled cumulative data represents 1.27 Mt U_3O_8 and accounts for more than half of estimated cumulative global uranium production (~2.25 Mt U_3O_8) and most of the western world's total uranium production (~1.6 Mt U_3O_8) (2005 edition of ref (*9*)). The average ore grade for milling over time for the above countries is shown in Figure 1, with the estimated global data for ore milled, ore grade, and production in Figure 2. The estimated percentage of global uranium production, which the compiled data represent, is shown also, demonstrating that the data generally represent >80% of western world uranium production in the 1960s and greater than 60% since the 1970s. In situ leach mine production was excluded due to the difficulty of equivalence between solution and hard rock mining. Given the data include the current major producers, Canada, Australia, and Namibia, the data provide a reasonable representation of the global uranium industry. Two peaks of uranium production are clearly

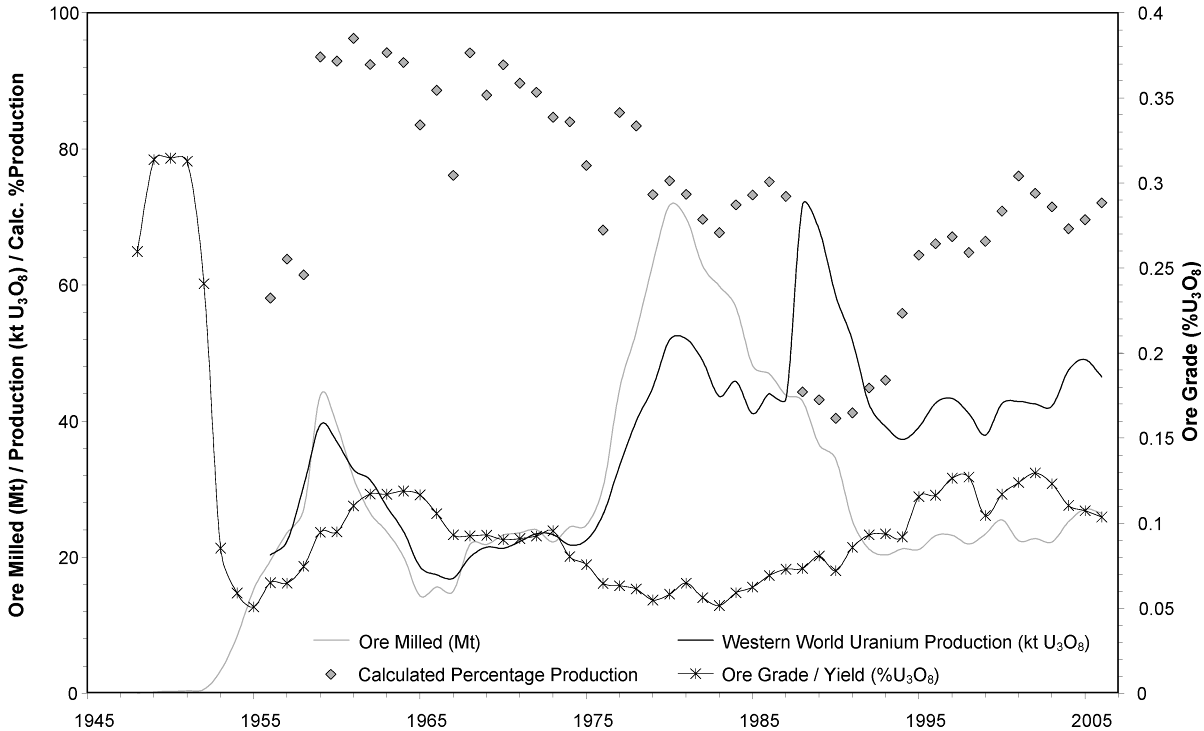

FIGURE 2. Estimated global average uranium ore grade, production, ore milled, and calculated percentage of production.

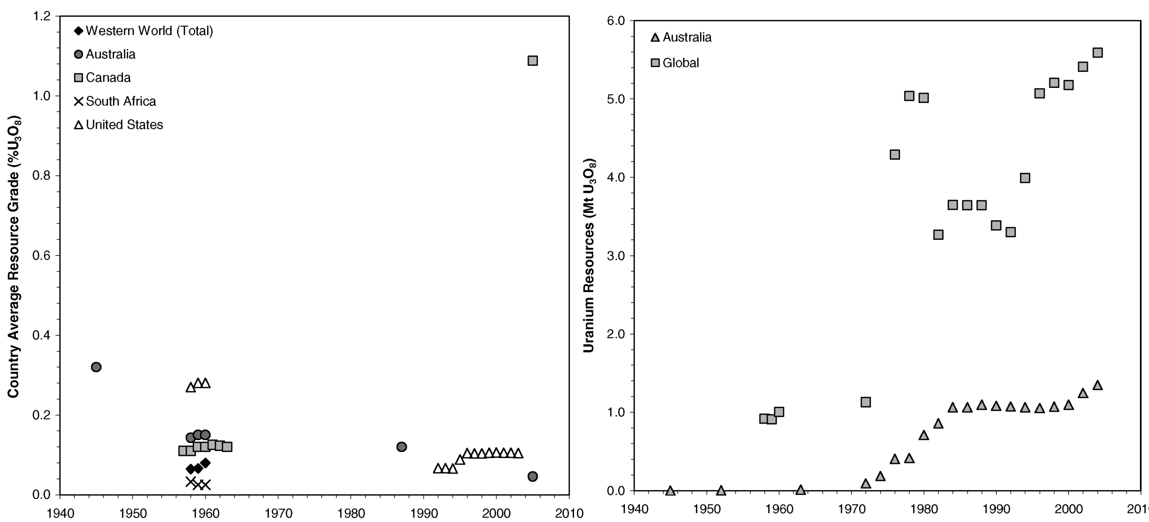

FIGURE 3. Average ore grade of select country uranium resources (left) and global and Australian known economic uranium resources (right) over time.

evident in Figure 2—the weapons phase peaking in 1959 followed by the civil phase peaking in 1988.

3.2. Global Uranium Resources. It is commonly perceived that uranium is a finite resource. The known availability of uranium has been considered to be limited in the past, with further exploration work leading to further resources being found. For example, at the start of the nuclear arms race in the 1940s, uranium was considered to be extremely scarce, yet rapid and wide-ranging exploration soon proved an abundance of uranium far in excess of that required (*24*).

The second period of uranium mining and milling (for civil nuclear power) also faced this same dilemma in the 1960s, but exploration again found additional uranium resources, particularly in Australia, Canada, Namibia, and Niger. The principal aspects of economic resources include the estimated contained uranium as well as the average ore grade of an individual deposit. Although country resources over time are compiled and analyzed by ref (*9*), the ore grades and other salient statistics of the numerous deposits are invariably never presented.

All publicly listed mining companies, at least in western-style economies, are generally bound by voluntary industry codes and/or the law to report accurately on economic ore resources they control. Given the largely western economic control of the global uranium industry, it is therefore possible to compile an up-to-date assessment of recent uranium deposit resource statistics. This can then be compared to the limited earlier data available.

In total, the compiled data totals 3.8 Mt U_3O_8 of uranium resources and accounts for more than half of estimated total global uranium resources (5.5 Mt U_3O_8, 2005 edition of ref (*9*). The ore grade of select country uranium resources over time and global and Australian known economic uranium resources are given in Figure 3, with numerous individual

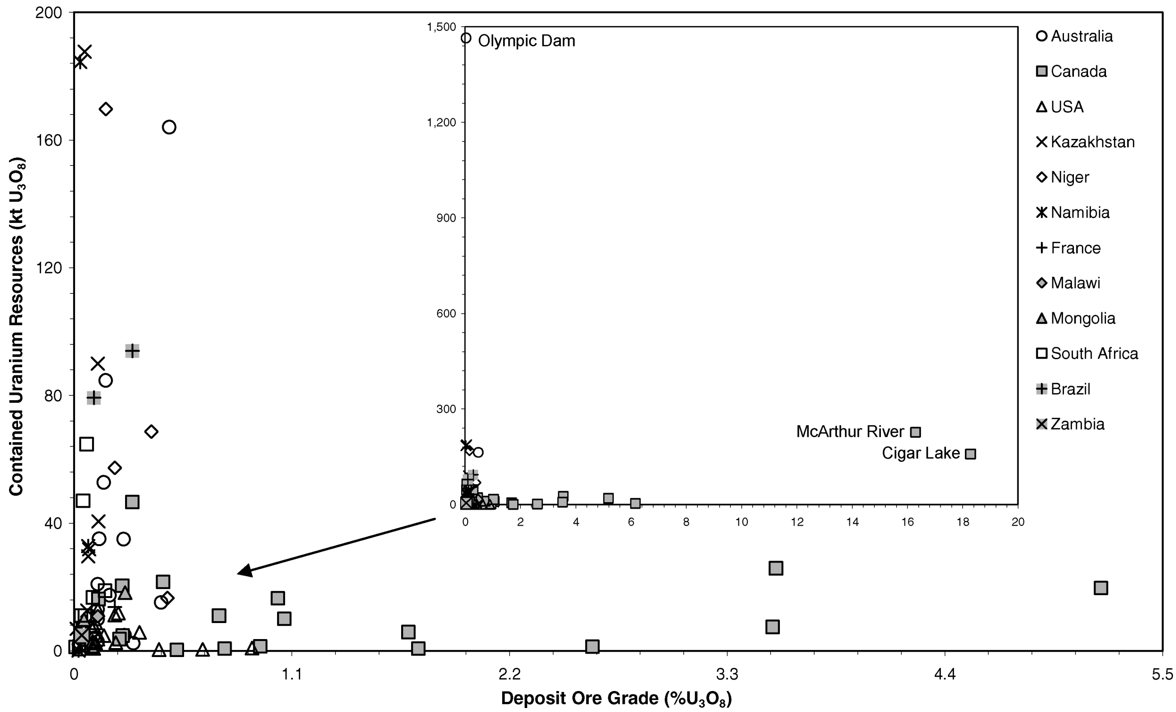

FIGURE 4. Contained uranium resources versus ore grade: individual deposits by country.

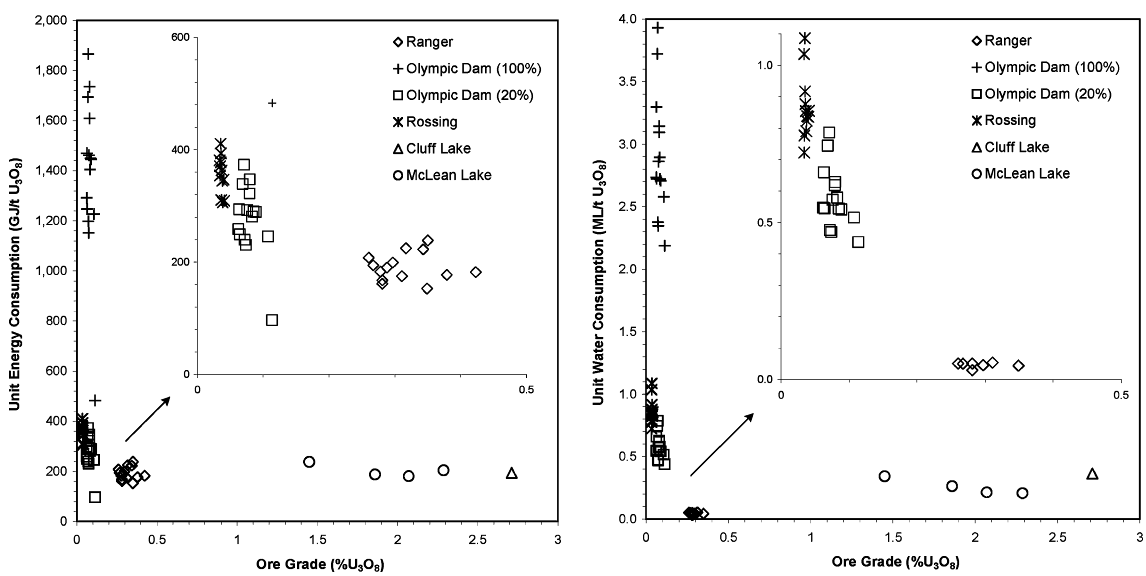

FIGURE 5. Energy and water consumption per uranium oxide produced versus ore grade.

deposits by ore grade and contained uranium compiled in Figure 4 by country.

3.3. Energy and Water Consumption in Uranium Mining and Milling. The compiled data for energy and water consumption per unit of uranium oxide production with respect to ore grade are shown in Figure 5, and with respect to time in Figure 6. As can be seen, using a 20% factor places the unit energy consumption of Olympic Dam within the same order of magnitude as Rössing. The higher water consumption of Beverley in Figure 6 is due to the fact it is an in situ leach mine. The data are summarized in Table 1.

3.4. Carbon Dioxide Emissions From Uranium Mining and Milling. The compiled data for carbon dioxide emissions per unit of uranium oxide production with respect to ore grade and over time are shown in Figure 7. As can be seen, using a 20% factor places Olympic Dam within the same order of magnitude as Rössing. The data are summarized in Table 1.

4. Discussion

The data compiled and presented within this paper provide support for a number of key aspects of uranium mining and milling, centered around known economic resources, ore grades of resources and production, energy and water consumption per uranium oxide production, and greenhouse gas emissions (carbon dioxide) per uranium oxide production.

The extent of economic uranium resources has generally increased over time, coincident with the major periods of exploration. In Canada, the Elliot Lake region of Ontario provided most resources during the 1950s−1960s, switching to Saskatchewan from the 1970s. The extremely high grade

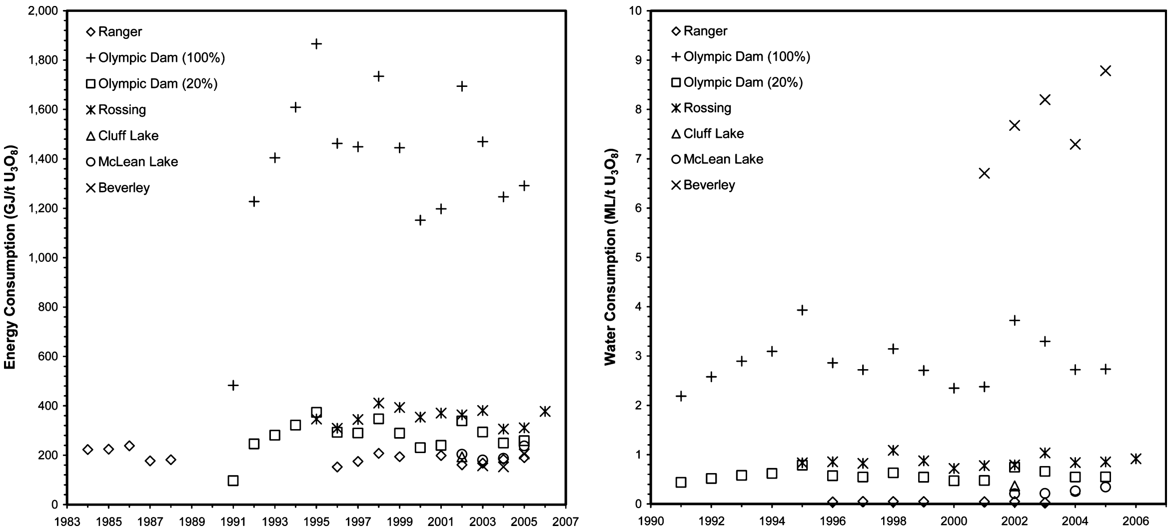

FIGURE 6. Energy and water consumption per uranium oxide produced versus time.

TABLE 1. Summary of Normalized Energy and Water Consumption and Carbon Dioxide Emissions for Uranium Mines (Average ± Standard Deviation, Number of Years in Brackets)

			consumption		emissions
			water	energy	carbon dioxide
uranium project	typical ore grade $\%U_3O_8$	annual production t U_3O_8	kL/t U_3O_8	GJ/t U_3O_8	t CO_2/t U_3O_8
Ranger	0.28–0.42	~5,000	46.2 ± 8.2 (7)	191 ± 25 (14)	14.1 ± 2.3 (15)
Olympic Dam (x%)			2,888 ± 487 (15)	1,382 ± 325 (15)	252 ± 65 (15)
Olympic Dam (x%)	0.064–0.114	~4,300	578 ± 97 (15)	276 ± 65 (15)	50.4 ± 13.0 (15)
Rössing	~0.034–0.041	~3,700	868 ± 104 (12)	356 ± 34 (12)	45.7 ± 4.2 (12)
Cluff Lake	2.71	(closed)	365 (1)	194 (1)	12.1 (1)
McLean Lake	1.45–2.29	~2,750	257 ± 62 (4)	202 ± 25 (4)[a]	8.4 ± 1.2 (4)
Beverley	~0.18	~1,000	8,207 ± 1,370 (6)	198 ± 57 (4)[b]	10.3 ± 3.0 (4)
Niger[c]	~0.2–0.5	~3,100	no data	~204	no data
Cameco[d]	~0.9–4.0	~8,500	no data	~178	no data

[a] Different data for 2000 are given by ref (*26*) as 313 GJ/t U_3O_8, although this is also the first year of full production and may not be representative compared to data compiled above (for years 2002–2005). [b] Different data for 2004–2005 are given by ref (*26*) as 187 GJ/t U_3O_8, compared to data reported by ref (*20*) and used in graphs and table above. [c] Data for 2000 for Areva's (formerly Cogema) two mine/mill complexes (Somair and Cominak) (*26*). [d] Data average over 1992–2001 for "Cameco Saskatchewan mines" (*26*).

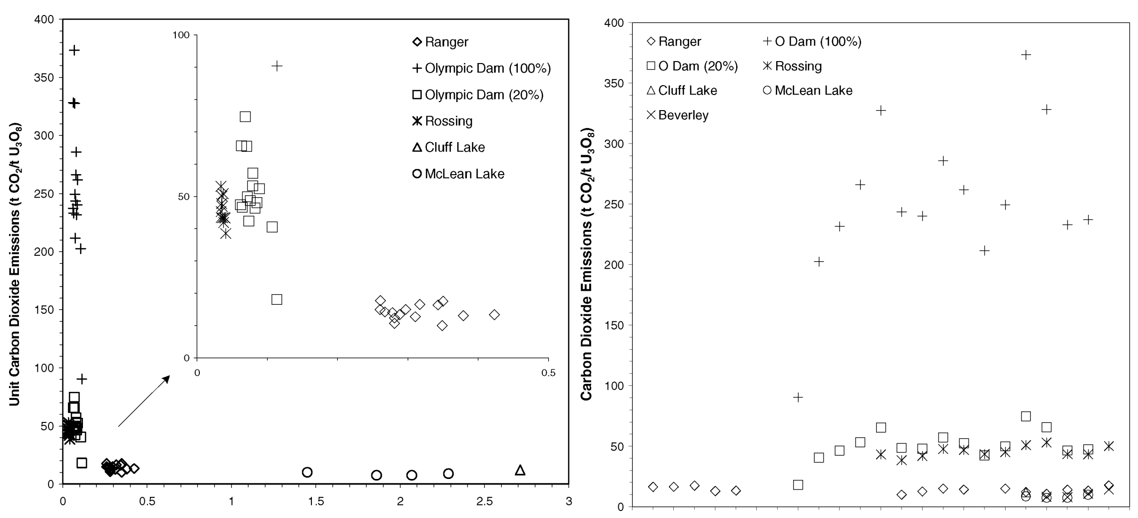

FIGURE 7. Carbon dioxide emissions per uranium oxide produced versus ore grade and time.

deposits of Cigar Lake and McArthur River were discovered in 1981 and 1988 with grades of 18.3% and 14.3% U_3O_8, respectively (prior to development) (*2*). Although new prospects are being found, only the Millenium prospect from late 2002 has to date proven substantive (about 26 kt U_3O_8 at ~3.55% U_3O_8; 2005 edition of ref (*2*). No deposits of the significance of Cigar Lake and McArthur River have been found since 1988.

In Australia, despite broad-ranging exploration in the 1970s with associated spectacular results, there have only been two new economic deposits discovered since 1975: the modest Kintyre in 1985 and the new Beverley 4 Mile in 2002 (although an economic mineral resource was not confirmed until early 2007). All increases in uranium resources between 1985 and 2005 have resulted from increased drilling and new assessments at known deposits, mainly Ranger and Olympic Dam. This pattern of no "world-class" discoveries greater than 50 kt U_3O_8 in the past two decades is thought to be similar in other countries (e.g., see ref (*9*)

Although beyond the scope of this paper, significant additional uranium resources are likely to be available as a byproduct from phosphate ore resources (e.g., Florida), which have produced uranium in the past. It is entirely possible that with further exploration new uranium deposits could be found, however, some issues need to be considered. First, given the broad coverage of uranium exploration globally over the past 50 years, any new deposit discovered is most likely to be deeper than most current deposits. This trend is evident in Canada, where successive deposits discovered in Saskatchewan have each been deeper, and future deposits are expected to be found even deeper still (e.g. ref (*25*)). The deeper a deposit the more energy which could be expected to be required to mine the resource. Second, the long-term trend over the past five decades has been a steady decline in most average country ore grades (even allowing for varying economic assessments of resources). This is particularly evident in Australia, where the increasing size of the Olympic Dam deposit now dominates Australia's total resources and average ore grade. The average country ore grade for the United States in the 1990s was typically 0.07–0.11% U_3O_8, which is about one-third of that in the late 1950s of 0.28% U_3O_8. Canada is the only country which has seen a substantive rise in its average ore grade, due to the rich Athabasca Basin deposits of northern Saskatchewan (e.g., McArthur River, Cigar Lake, Midwest). The average ore grade of the Elliot Lake district of northern Ontario, which generally contained more than 95% of Canada's resources in the 1950s to 1960s, was typically 0.11% U_3O_8—compared to the estimated average of 1.1% U_3O_8 in 2005 (based on resource data compiled for this paper). These trends in average ore grade of country resources are reflected in the ore grades of as-milled production (Figure 1). It is worth noting that despite the increasing ore grade in Canada, this has not significantly affected typical global average ore grade, which has remained between 0.05 and 0.13% U_3O_8 over the past five decades (even allowing for incomplete production and considering likely grades at remaining countries). Finally, based on data for 93 deposits/fields compiled for this paper (Figure 4), there is an indicative relationship between ore grade and contained uranium. As ore grade declines, there is an increasing possibility of substantial tonnage. In terms of major production capacity for any proposed nuclear power program, it is clear that these larger-tonnage, lower-grade deposits would need to be developed, thereby continuing to balance the rich Saskatchewan deposits into the future.

A common issue raised with uranium is the ability for a major contribution to production from byproduct sources such as phosphate and gold ores. Virtually all South African uranium has been derived as a byproduct from gold mining in the Witwatersrand Basin. In the United States some uranium was produced as a byproduct from phosphate mining until their permanent closure in 2000 (capacity of about 1,150 t U_3O_8 at that time; 2001 edition of ref (*9*)). The Olympic Dam project in Australia, containing copper, uranium, gold, silver, and rare earths, is the only major operating mine not solely mining a deposit for uranium, though Olympic Dam is more correctly described as a coproduct mine due to the economic importance of uranium. Over recent years, only South Africa has continued byproduct uranium production from gold ores. A detailed examination of all editions of ref (*9*) shows that byproduct uranium has been a minor component of global uranium production to date (probably of the order of less than 20%). There is very little recent data on uranium resources from byproduct operations, especially ore grades and quantity, nor information available to discern or allocate energy, water, and reagent costs and pollutant emissions to the additional effort required for this byproduct uranium.

With respect to energy, gradual increasing trends are apparent for Olympic Dam, Beverley, Ranger, and McLean Lake, although Rössing shows a slight decreasing trend over time (excluding the single year for Cluff Lake). The data reported for these select mines and compiled herein are only based on direct fuel inputs, such as diesel and/or electricity. Given the data provided, there appears to be little difference in unit energy costs per uranium oxide production above an ore grade of about 0.5% U_3O_8. Given the small number of points greater than 0.5%, however, this interpretation requires caution. A curious fact shown by the data above is that the energy cost of Beverley, an acid in situ leach project, is similar to that for Ranger, a large open cut mine/mill complex. For Beverley, a recent energy efficiency audit in 2004 showed that the well field and mill consumed 44.9% and 41.6% of electricity usage, or in terms of activities pumping consumed 80.7% of electricity usage (2004 Edition of ref (*20*)). The energy cost of drilling at Beverley remains unquantified and given the number of bores involved in acid leach mining and milling, it should certainly not be ignored in a true energy cost analysis.

Critically, the data for all mines does not account for the additional embodied energy required for reagents such as solvents (e.g., kerosene, amine), sulfuric acid, oxidants (e.g., hydrogen peroxide, manganese dioxide or MnO_2), lime, and so on. This would add further energy costs to uranium production. For example, data for the Ranger mine from 1988/1989 to 1996/1997 (*18*) suggest that each tonne of uranium oxide production requires about 320 L of kerosene, 12.7 L of amine, 460 kg of ammonia (NH_3) 1.75 t of oxidant (as t MnO_2), 15 t of acid (as t H_2SO_4), and 5.9 t of lime. For kerosene, the embodied energy is estimated as 36.6 GJ/kL (*23*), thereby adding about 60,000 GJ to Ranger's energy requirements for some 5,000 t of U_3O_8 annual production. This would add approximately 11.7 GJ/t U_3O_8 or 6% to the 191 GJ/t U_3O_8 presently reported. Unfortunately more recent annual data since the 1997 mill expansion at Ranger are not available. It is clear that full life cycle accounting and sustainability reporting needs to include reagents with major embodied energy costs.

For water, gradual increasing trends are apparent for Olympic Dam, Beverley, and McLean Lake, although Ranger and Rössing show a slight decreasing trend over time (excluding the single year for Cluff Lake). There are marked differences in water consumption, due in large part to the major differences among these various projects. For example, although Ranger and Rössing are somewhat similar in terms of uranium production and scale for open cut mining, Rössing has an ore throughput about 5-fold that of Ranger as well as an ore grade some eight times lower, thereby leading to significant demands for water. The sensitivity of normalized water consumption to ore grade is apparent. Further characterizing water consumption based on water quality and the extent of recycling is not possible based on the available reported data.

The direct emission of carbon dioxide (and equivalents) is an issue of critical importance, especially in the context of the current debate over greenhouse gas emissions from the nuclear chain. As with energy and water consumption, gradual increasing trends for normalized emissions are apparent for all mines (excluding the single year for Cluff Lake). The data in terms of carbon dioxide emissions per tonne of ore milled, although not presented within the space of this paper, show that Olympic Dam and McLean Lake are gradually declining over time while Ranger and Rössing are increasing. The declining trends are most likely related to the recent expansion of Olympic Dam and increasing throughput at McLean Lake.

In summary, the extent of economically recoverable uranium, although somewhat uncertain, is clearly linked to exploration effort, technology, and economics but is inextricably linked to environmental costs such as energy, water, and chemicals consumption, greenhouse gas emissions, and broader social issues. These crucial environmental aspects of resource extraction are only just beginning to be understood in the context of more complete life cycle analyses of the nuclear chain and other energy options. There still remains incomplete reporting however, especially in terms of data consistency among mines and site-specific data for numerous individual mines and mills, as well as the underlying factors controlling differences and variability. It is clear that there is a strong sensitivity of energy and water consumption and greenhouse gas emissions to ore grade, and that ore grades are likely to continue to decline gradually in the medium- to long-term. These issues are critical to understand in the current debate over nuclear power, greenhouse gas emissions, and climate change, especially with respect to ascribing sustainability to such activities as uranium mining and milling.

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Literature Cited

(1) NRC. *Canadian Minerals Yearbook, Mining Sector*; Natural Resources Canada (NRC), var., years 1944−2005.
(2) Cameco. *Annual Report*; Cameco Corporation, var., years 1997−2006.
(3) Cogema. *2005 Annual Review*; Cogema Resources Inc. (subsidiary of Areva Group, France), 2005.
(4) Denison. *Annual Report*; Denison Mines Ltd, var., years 2004−2006.
(5) EIA. *Uranium Industry Annual*; Energy Information Administration (EIA), U.S. Department of Energy (USDoE), var., years 1992−2005.
(6) CMSA. *Facts and Figures 2005*; Chamber of Mines of South Africa (CMSA), 2005.
(7) Mudd, G. M. *Compilation of Uranium Production History and Uranium Deposit Data Across Australia*; SEA-US Inc, 2007; last updated July 2007.
(8) Freeman, G. M.; Vernon, P. N. In *13th Congress of the Council of Mining and Metallurgical Institutions (CMMI) and Australasian Institute of Mining and Metallurgy (AusIMM)*; Berkman, D. A., Ed.; Singapore, 1986; Vol. 5, pp 153–161..
(9) OECD-NEA; IAEA. *Uranium: Resources, Production and Demand*; Nuclear Energy Agency, Organisation for Economic Cooperation and Development (OECD-NEA) and International Atomic Energy Agency (IAEA), var., years 1977−2006.
(10) USBoM. *Minerals Yearbook*; U.S. Bureau of Mines (USBoM), var., years 1933−1993.
(11) Johnson, C. C. *J. South African Inst. Mining Metall.* **1990**, *90*, 141–147.
(12) Rössing. *Annual Social and Environmental Report to Stakeholders*; Rössing Uranium Ltd, var., years 1999− 2006.
(13) Mays, W. M. In *23rd Uranium Institute Annual Symposium*; Uranium Institute: London, UK, 1998; p 4.
(14) Dickinson, S. B. Part I - General Statement - Uranium Investigation, Mount Painter, South Australia. In *Report on Investigation of Uranium Deposits at Mt Painter, South Australia, June 1944 to September 1945 - Undertaken at the request of the British Government by the Government of the Commonwealth of Australia in conjunction with South Australian Government, November 8, 1945*; Dickinson, S. B., Ed.; SA Department of Mines: Adelaide, SA, 1945; *Report Book 40*, 334 pp.
(15) Cawte, A. *Atomic Australia 1944–1990*; UNSW Press: Kensington, NSW, 1992.
(16) Battey, G. C.; Miezitis, Y.; Mackay, A. D. *Australian Uranium Resources*, Bureau of Mineral Resources, Geology and Geophysics (BMR), 1987.
(17) McKay, A. D.; Miezitis, Y. *Australia's Uranium Resources, Geology and Development of Deposits*; Geoscience: Australia (GA), 2001.
(18) OSS. *Annual Report*; Office of the Supervising Scientist (OSS), var., years 1978−2006.
(19) ERA. *Annual Social and Environment Report*; Energy Resources of Australia Ltd (ERA), var., years 2001−2006.
(20) HR. *Annual Environment Report*; Heathgate Resources Pty Ltd (Heathgate)/General Atomics Corporation, var., years 2001−2005.
(21) WMC. *Annual Environmental Progress/Sustainability Report*; Western Mining Corporation Ltd (WMC), var., years 1995−2004.
(22) BHPB. *Interim Environmental Management and Monitoring Report 1 July 2004 to 30 June 2005*; BHP Billiton Ltd (BHPB), 2005.
(23) AGO. *AGO Factors and Methods Workbook*; Australian Greenhouse Office (AGO), Department of the Environment and Heritage, Australian Government, December 2005.
(24) Mogren, E. W. *Warms Sands: Uranium Mill Tailings Policy in the Atomic West*; University of New Mexico Press: Albuquerque, NM, 2002.
(25) Macdonald, C. In *26th Uranium Institute Annual Symposium*; World Nuclear Association (formerly the Uranium Institute): London, UK, 2001; p 8.
(26) WNA. *Energy Analysis of Power Systems*; World Nuclear Association (WNA), 2006; last updated March 2006; accessed August 19, 2007.

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