Energy Returned on Energy Invested (EROEI): A Key Indicator for Energy Policy Making
Expansion of Comments Made on 19 May, 2009
at Gray Russell's Talk on "Power Past Clean Coal"
Richard W. Franke: 12 June 2009

Summary:

- We are not running out of oil, but the easy-to-get oil is almost gone
- Oil and its by-products will likely become more and more expensive
- Coal is not a viable substitute for oil
- Coal has a low and declining Energy Returned on Energy Invested (EROEI)
- Despite coal reserves of 250 years, U.S. coal is of declining energy content
- A big investment in "clean" coal is a waste of money as well as a danger to the environment and to coal industry workers
- Nuclear reactors are of doubtful safety and most European countries are shutting theirs down
- The EROEI of (non-breeder reactor) nuclear power is only 4.0, less than wind and solar
- The US has only a 40-year supply of uranium within our borders
- Citizens need a set of consistent criteria with which to evaluate proposed energy sources

1. Energy Returned on Energy Invested in Oil – the Crisis Has Arrived

The current national debate in the US over energy costs and resources is remarkable for the absence of systematic consideration of one of the most important aspects of energy: the input/output or cost/benefit ratios of the various energy sources. Given that all energy used by humans requires some energy input to acquire it, we should routinely compare and contrast the energy expended to get other energy. Obviously the return on energy invested should be greater than the energy invested; otherwise, we are throwing away energy.

In his 2003 book *The Party's Over: Oil, War and the Fate of Industrial Societies* (Gabriola Island, British Columbia: New Society Publishers, updated and revised 2005), peak oil theorist Richard Heinberg surveys some of the available information on this important topic.

First, Heinberg notes that oil – the main energy driver of 20th century industrial civilization – went for several decades with an EROEI (Energy Returned on Energy Invested) of greater than (>) 100. This means that for each unit of energy invested in searching for, extracting and transporting oil, more than 100 units of energy were returned. This phenomenally high rate of return is in fact the measure of the reason oil became THE power source of the 20th century. The EROEI's for oil in various years are shown on Slide 1.

But note that in more recent years the EROEI of oil has been dropping rapidly: in 1996 it was only about one-tenth of its value before 1950. Why the drop in the EROEI? The main reason is that before 1950 most of the oil being pumped was easy to locate, easy to extract, and easy to

ship. As the easy oil has been depleted, remaining sources are deeper in the earth, require expensive off-shore rigs, must be pumped with assistance of steam injections, and so on that all add to the expense of the oil. We see this in the high prices of crude on the international market and the continuing high prices of gasoline at the pumps.

The declining EROEI and its consequences for oil prices tell us something very important: while oil supplies are not in danger of actually drying up, they are likely to become continuously more expensive and less advantageous in the energy input/output ratio (the EROEI). In other words, a lot of expensive, hard-to-get oil is not that different from no oil.

Slide 1: The Declining Energy Returned on Energy Invested for Oil: Before 1950 to 1996

Before 1950 each unit of energy invested in petroleum production yielded more than 100 units of energy back.

→

This helped keep the price of oil low

Years	Oil EROEI
Before 1950	> 100
1950–1970	40
1970s	30
1996	8.4–11.1

Source: Heinberg 2005:138; using several sources

6/5/2009

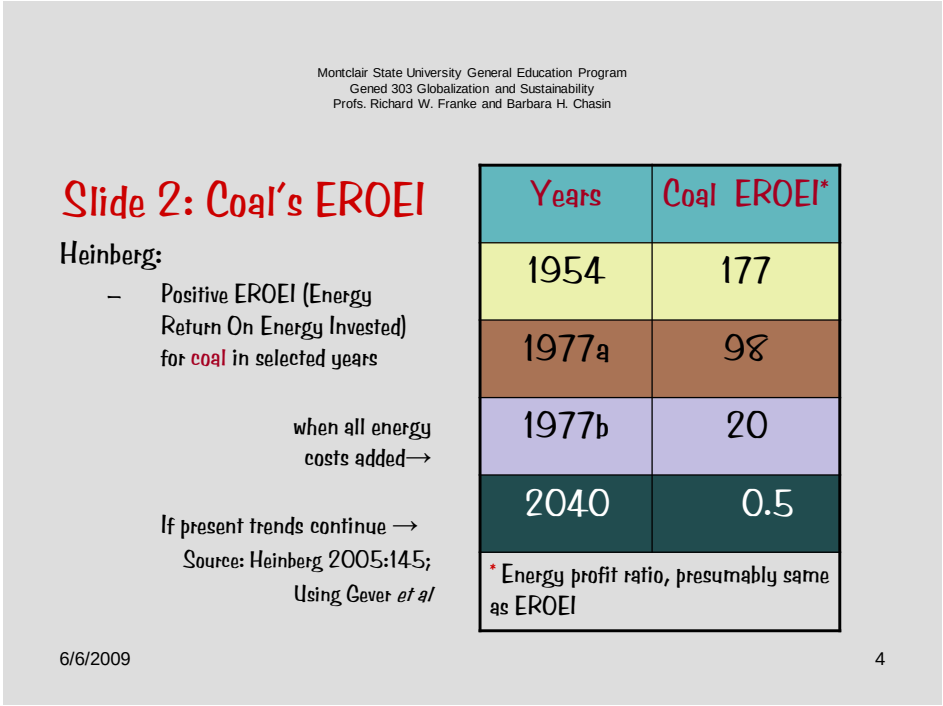
2. ("Clean") Coal – Alternative to Oil?

As the crisis over high oil prices and declining EROEI intensifies, coal is gaining ground in some circles as an appealing alternative. President Obama embraced the idea of "clean" coal throughout his presidential campaign and Democrats in Congress appear to be supporting him in the design of energy bills.

Coal has much appeal in the U.S. as an alternative oil. The U.S. Energy Information Agency estimates about 250 years worth of coal under the ground in the U.S. if present use patterns were to continue. Various gasification, liquification, and CO_2 scrubbing technologies exist or are under development. But coal remains a controversial energy source because of its sulphur content, the black lung disease minors suffer from, and the environmental side effects of mountaintop removal – the latest environmentally disastrous technique for extracting coal from the earth. The coal industry clearly hopes to convince the U.S. public that the energy crisis requires us to pay the costs of extracting coal and they also hope to develop a public relations campaign to convince people that clean, environmentally safe coal is a realistic option.

Hidden within the environmental and health debates about coal, however, is a little noted question: how energy effective is coal? In other words, what is its EROEI over time?

Slide 2 shows the data Heinberg was able to locate. These appear to come from John Gever, Robert Kaufmann, David Skole, and Charles Vorosmarty. 1991. *Beyond Oil: The Threat to Food and Foel in the Coming Decades.* University Press of Colorado. Gever *et al* got data on trends in coal EROEI up to 1977, then projected the trend out to 2040. The results appear on slide 2.



Note that in 1954 coal's EROEI was at least as good as that of oil. But by 1977 the EROEI had dropped to 98, a 45% decline in a couple of decades. The authors (Gever *et al*) argue, however, that the figure of 98 (1977a on Slide 2) is a substantial overestimate of coal's actual EROEI in 1977 because it leaves out the energy costs of energy used to build the machines for mining, to move the coal away from the mines and to process it. When those costs are added, the effective EROEI of coal drops from 98 to 20 (1977b on Slide 2). Projecting that trend out towards the year 2040 leaves us with an EROEI of 0.5. Any EROEI below 1.0 means that we are spending more energy to get energy than we are getting from the energy we got. It's a losing proposition.

If these data and their associated calculations are accurate, sometime between 1977 and 2040, the EROEI of coal will drop below 1.0. At that point, extracting coal could only be useful if heavily subsidized or if it fulfills some energy use that cannot be accomplished by another energy source. Since about 90% of coal in the U.S. is burnt to provide electricity, alternative

sources abound. These include wind, direct solar and nuclear (see below) as well as possibly geothermal, wave and tidal energy sources. Given coal's environmental and health hazards and combined with the apparent dwindling EROEI to less than 1.0 by the year 2040, what rational argument remains for society to invest heavily – even at all – in "clean" coal?

Two other considerations should be mentioned here. The costs of cleaning coal mean that the EROEI will drop even faster than projected on Slide 2 which does not consider that option. In addition, as less and less energy dense coal is mined, larger and larger amounts will be required to generate the same amount of electricity – meaning that the environmental side effects of coal will become more, not less, pronounced in future years.

3. Nuclear Power – Safe? Clean? Abundant?

After coal, the most heavily lobbied alternative to oil is nuclear power. About 103 nukes are operational in the US today (442 worldwide) and they supply about 20% of our electricity – up to 77% in France, 56% in Belgium and 49% in Sweden. European nations, however, except for France, are shutting down their nuclear capacity and replacing it mostly with conservation and with wind power. For example:

- Italy has shut down all five of its nuclear reactors following a referendum
- Sweden is phasing out all twelve of its reactors following a referendum
- Belgium will phase out its seven nuclear reactors between 2015 and 2025
- The Netherlands is closing down its two nuclear reactors
- Germany pledged to shut its nineteen reactors by 2021

(European shut down data from Cavanagh, John and Jerry Mander, Editors. 2004. *Alternatives to Economic Globalization: A Better World Is* Possible. San Francisco: Berret-Koehler. Second edition. page 170.)

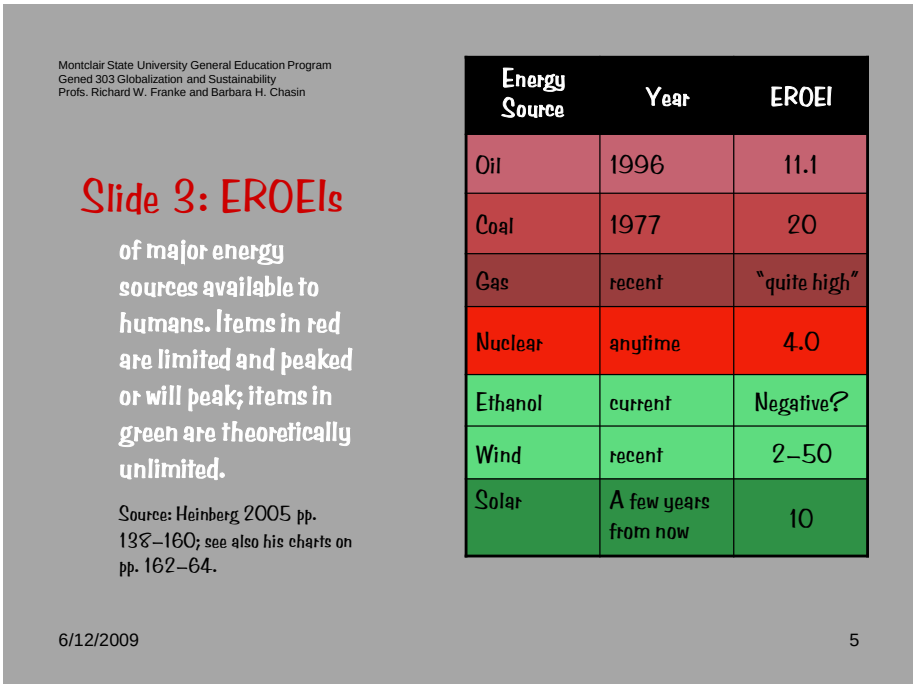
Apparently the main international and US concern with nuclear reactors is safety. Despite assurances from the nuclear power industry over the years that reactors are safe, accidents and malfunctions have occurred. Many recall Three Mile Island and Chernobyl. The potential for earthquakes and human error to activate an even more catastrophic disaster has kept the public wary of this source. And, despite the repetitious assurances of safety, Congress passed a special Price-Anderson Act in 1957 and renewed several times after to limit the liability of nuclear power plant operators in the event of a major accident. The act commits the federal government to insure all costs above $10 billion (http://en.wikipedia.org/wiki/Price-Anderson_Nuclear_Industries_Indemnity_Act; http://www.ans.org/pi/ps/docs/ps54-bi.pdf). Need more be said?

Is nuclear power clean? In a sense, yes. Former Vice President Dick Cheney told CNN on May 8, 2001, that nuclear energy "doesn't emit any carbon dioxide at all." This is true of the nuclear chain reaction that is used to heat water into steam and turn the electricity generators in a nuclear power plant. However, large amounts of CO_2 are generated in mining uranium, refining it and concentrating it. Cheney ignored these important factors in his remark.

EROEI and supplies. But perhaps the most telling problem with nuclear power are its relatively low EROEI – 4.0 (Heinberg 2005:163) and its availability. **Current estimates are that the U.S. has a 40-year supply of uranium within our borders (Heinberg 2005:149)**. For nuclear power to replace coal as a source of electricity entirely would require construction of 250 nuclear plants in the US and all of them would become useless in approximately 40 years – unless, of course, the US took control of uranium sources in other countries, a policy that would put us right back where we are today with oil.

Caveat: the estimates just above would change dramatically if all the reactors built would be breeder reactors that create their own fuel as a by-product of nuclear fission. The issue of breeder reactors is quite complex, but a fair summary in my opinion is that they are significantly more dangerous than standard light water reactors usually built. As can be expected, the industry claims that breeder reactors are perfectly safe. Believe it if you want.

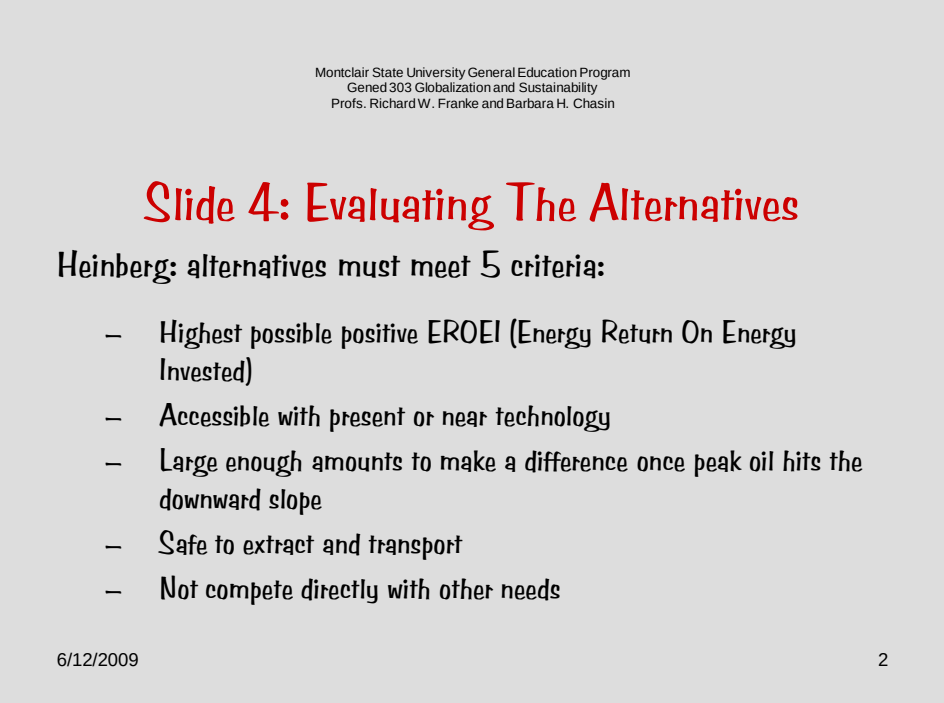
Slide 3 gives a summary of the known EROEI figures for the most common energy sources currently being debated in the US.



Energy Source	Year	EROEI
Oil	1996	11.1
Coal	1977	20
Gas	recent	"quite high"
Nuclear	anytime	4.0
Ethanol	current	Negative?
Wind	recent	2–50
Solar	A few years from now	10

4. Evaluating alternative energy sources

Richard Heinberg suggests a list of criteria by which the public should evaluate the claims of competing energy sources. This list is shown in slide 4. All of these seem common sense criteria. Here is something you can do for yourself. Take each of the resources on slide 3 and think about how each measures up to the criteria on slide 4. Which energy source(s) do you think the federal government should invest heavily in to deal with the current high price of oil and the likely decline of oil as a significant source for energy in the near and distant future?



If you find this brief overview useful, I suggest that you will be interested in reading Heinberg's book for more details.

Richard W. Franke
12 June, 2009

Heinberg, Richard. 2005 [orig 2003] *The Party's Over: Oil, War and the Fate of Industrial Societies*. Gabriola Island, British Columbia: New Society Publishers, updated and revised 2005.

http://chss.montclair.edu/anthro/franke.html

franker@mail.montclair.edu