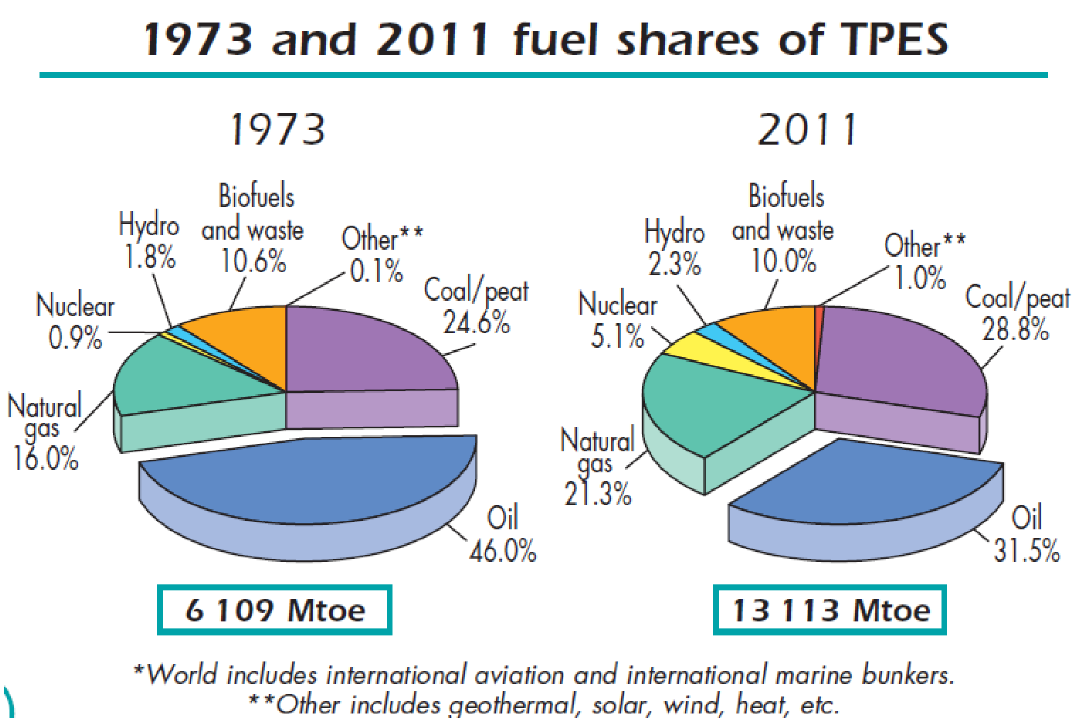
Current World Energy Demand, Ethical World Energy Demand, Depleted Uranium and the Centuries to Come.

The International Energy Agency (IEA) released last year, 2013, a free PDF brochure, available online, entitled “Key World Energy Statistics”[1] which reports total world energy consumption, comparing figures from 2011 with those of 1973. The energy unit that is used to described is the non-SI, if evocative, unit, “MTOE” which is an abbreviation for “Million Tons of Oil Equivalent,” a somewhat artificial energy unit – given that the energy content of grades of oil vary considerably depending on their source - that pretends that all the world’s energy comes from a standardized form of the dangerous fossil fuel petroleum, which, of course, it doesn’t. The conversion factor, as given in the free IEA brochure, between the SI unit, the Joule, here reported as terajoules, TJ, a trillion Joules, is 1 MTOE = 41,868 TJ.

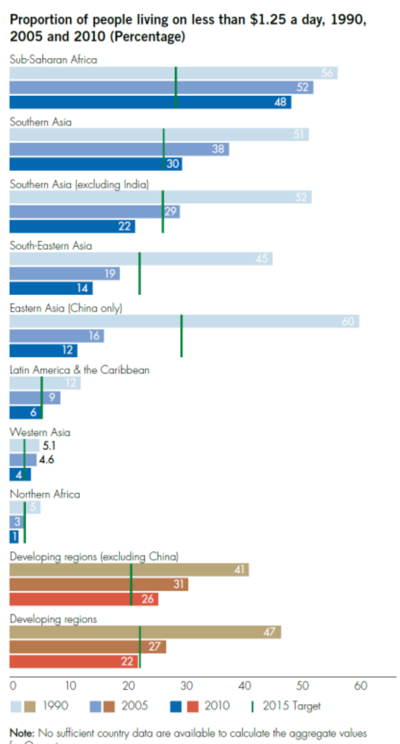
The actual forms of primary energy that the consumed energy took are shown in the following graphic from the text:



As shown in the graphic, the document reports that in 2011, world energy consumption (TPES = “Total Primary Energy Supply”) was 13,113 MTOE; in 1973, the year which those old enough to remember will recall as the year of the “oil shock” where gasoline prices in the United States surged toward the then unheard of figure of $1.00/gallon, world energy consumption was, according to the document, 6,109 MTOE. Before leaving this somewhat curious unit for the more satisfying SI units, it serves to note that it suggests, on a planet with a population in 2011 reported as 6.9 billion[2], plus or minus some 100 million human beings, that, on average, each person, as recorded in recent times, is responsible for burning the equivalent of 1.9 tons of oil equivalents per year. In 1973, the world population was something on the order of 3.9 billion people, and on average, each person on the planet was responsible for consuming 1.5 tons of oil equivalent energy each year.

In 1976, which – if I have the math right – was 3 years after 1973, the energy mystic Amory Lovins published a paper in the social science journal *Foreign Affairs*, “Energy Strategy, The Road Not Taken?”[3] that suggested that by the use of conservation and so called “renewable energy” all of the world’s energy problems could be solved. The thin red sliver on the 2011 pie chart, identified as “other” – solar, wind, etc, - obviates the grotesque failure of so called “renewable energy” to become a meaningful source of energy in the worldwide energy equation, despite consuming vast resources and vast sums of money, this on a planet that could ill afford such sums. As for conservation, in 2011 we were using 147% of the dangerous petroleum we used in 1973, 286% of the dangerous natural gas we used in 1973, and 252% of the dangerous coal we used in 1973. The rise in average figures of per capita energy consumption, as well as total energy consumed worldwide, show that energy conservation as an energy strategy has not worked either.

The reason that energy conservation as an energy strategy has failed is obvious, even divorced from population growth. According to the 2013 UN Millennium Goals Report[4], as shown in the following graphic from it, the percentage of the Chinese population that lived on less than $1.25 (US) per day fell from 60% of the population in 1990 to 16% in 2005 and further to 12% in 2010. From our knowledge of history, we would be fair to assume that the situation in China was even worse in 1976 than it was in 1990.



By the way, it ought to weigh on the moral imagination…that figure…less than $1.25 a day…less than $500 per year…for all a human being's needs…food, shelter, transportation, child care, education, health, care for the elderly…

Seen from this perspective, Lovins' writings are all marked by myopic bourgeois provincialism. The huge flaw in his 1976 conceit, and his conceits forever thereafter, was that for him, people living in the United States, and maybe Western Europe, represented the only human life that mattered. Chinese and Indians, for two examples, may as well have not existed if one reads his 1976 fantasy; he blithely assumed that they would agree to remain unimaginably impoverished while Americans pursued hydrogen HYPErcars[5] in every suburban garage and solar heated molten salt tanks[6] in every suburban backyard. Apparently, from his high perch in the überrich suburb of Aspen – Snowmass, Colorado - where he lives today in a super-efficient McMansion, he continues to issue rhetoric equally oblivious to the status of the larger fraction of humanity, this while collecting "consulting fees" from companies that among other things, mine and refine oil sands[7]. Consideration of the two to three billion people defined by the IEA ***today*** as living in "energy poverty"[8] – 1.3 billion of whom lack access to electricity for *any* purpose, never mind for the purpose of charging up their swell Tesla electric cars, and/or the 38% percent of human beings on this planet who lack access to what the IEA calls "clean cooking facilities" – is definitely not in the purview of a person who writes books with awful titles like, um, "Winning the Oil Endgame.[9]"

Out of sight, out of mind…

This raises another point:

The worldwide energy consumption averages I calculated above say *nothing* of the *distribution* of energy. On some level energy is wealth, and wealth, as most people are aware, is ever more disproportionately distributed.

By reference to the free IEA energy brochure, summing its figures for produced and imported "MTOE" energy, (see page 56 of the report) one can calculate that an "average" citizen of the United States, as of 2011, where the midyear population was 312,000,000, was consuming 7.2 MT tons of oil "equivalents" each year, almost 4 times the world average for such consumption. In comparison, an "average" consumption for a citizen of Zambia, (also on page 56 of the report) where the population was 13.4 million midyear 2011, was 0.6 tons of oil equivalent, less than a third of the world average.

As I am one of a family of four living in a single house, and I am also somewhere, I suspect, near "average" as Americans go, I am compelled to imagine where I might put 28.8 MT of oil I would need each year were this figure reflected by an actual case of the "distributed energy" that one hears so often is supposed to be so wonderful. That is, were I compelled to generate all of my energy demands at home, keeping my yearly share, perhaps as "biofuel," if not petroleum, on my property, this would be the amount of oil I would need to either grow (in the biofuel case) or have delivered and store in the dangerous fossil fuel case. In real life, of course, I don't need to do this; other people and organizations do it for me. Happily, I have yet to live, my car excepted, to live in a *total* nightmare of "distributed energy."

Of course, not all the energy involved in my family's imagined 28.8 tons of oil "equivalents" is consumed directly by my family to power our refrigerators, our TV sets, our computers and our automobiles; some of it is used elsewhere, to manufacture materials for instance. About 3% of the world's electricity is assigned, for example, to producing aluminum for cans, window frames, engine blocks and, for that matter, for Tesla cars. Some metals are even more energy intensive to refine than aluminum is. For example, the metal neodymium in wind turbines and many electric and hybrid cars involves a laborious process of extraction from lanthanide ores using nitric acid, itself made using natural gas, and copious amounts of petroleum derived solvents or complexing agents for solvent extraction separations, or ion exchange resins made from dangerous petroleum, lots of pumps and other energy consuming forms of mass transfer. (When wild catted at its sources in China – China dominates the world supply of lanthanides - as it sometimes is, lanthanide production can be and often ***is*** an environmental nightmare.[10])

Out of sight, out of mind…

Even if I really don't need to store it myself, the image of 28.8 tons of oil in my backyard is illustrative, I think. I will have more below about what it might look like, in size, were it "plutonium equivalent" rather than "oil equivalent," but before going there, let's move to SI units, the units in which science is largely spoken today.

Translated into SI units, converting from the figures to the free brochure, world energy consumption in 2011 was 549 exajoules (exa- = 10^{18}); in 1973 it was 256 exajoules. From these figures one can calculate that in 2011, the average continuous power output of all the world's energy generation systems of all types was 8.1 trillion watts, or, in more familiar power units, 8.1 million megawatts. The per capita average continuous power demand overall for all people on the planet was 2500 watts, roughly the power output of a small American suburban lawn mower; in 1973 that figure was roughly 2000 watts. Billions of people of course, had much less than a lawn mower's worth of power on average in 2011 (and for that matter in 1973), whereas other people got to use several orders of magnitude more power than a "lawn mower's worth" of power, driving, for instance, in swell Tesla electric cars by which they express, in unconscious drollery, their "concern" for the environment.

If Amory Lovins has completely ignored, and continues to ignore, the issue of the billions who live in "energy poverty," others have noted it. The Nobel Peace Prize winning former head of the International Atomic Energy Agency, Mohammed El Baradei, for one example, used to make speeches in which he indicated that his drive to bring nuclear power to Nigeria was informed by his understanding that the average power consumption of a Nigerian was 8 watts,[11] although in saying this, he may have been referring to electricity alone, and not total energy demand.

Out of sight, out of mind…

Too often, discussions about energy, be they technical arguments that are either conservative or creative and dynamic, realistic or wish based, seem to divorce themselves from ethics, if not from people like El Baradei, then from many – maybe even *most* – others. When atheists like me discuss ethics, we are often accused of casuistry, but I think this ungenerous. Valid ethical axioms exist, I argue

- they have been called, not without some irony, “self-evident” – axioms that are sometimes articulated, even advanced, by religious ideologies or principles, although, I also argue, independent of them and sometimes even in conflict with them. When we discuss energy and energy technology however, we must also keep in the back of our minds the ethical question of what a human being is worth, and thus what any particular system of energy is *physically* capable of providing for and measuring that worth. Surely we can agree that a human being is worth more than $1.25 a day, can we not? I will speak more of this at the end of this diatribe.

However this all may be, let us now return to some technical arguments: The neodymium and aluminum to which I referred above are just two examples of materials that require significant quantities of energy to obtain: Our modern industrial culture relies on the separation and refining of significant quantities of some sixty to seventy elements from their sources, be they rocks, gases, or liquids; all of these processes of separation from ores and refining require energy.

One element that has been mined and processed on a grand scale – and has proved essential to our way of life - is the radioactive element uranium. For use in most nuclear reactors – heavy water reactors excepted - an additional refining process beyond chemical isolation of the element itself is generally required; one of its rarer isotopes, ^{235}U, must be enriched in the final product. Isotopic enrichment processes are generally more energy intensive than simple chemical separations. In the case of enrichment of ^{235}U from around 0.7% in natural uranium to roughly 3%, sometimes more, in fuel grade uranium, the energy invested in this concentration process is easily overcome by the incredible energy density of ^{235}U isotope when it is fissioned. Nevertheless as a result of process - the vast majority of nuclear reactors that have operated over the last half a century use this “enriched fuel” – most of the mined, refined and isolated uranium is left behind, even though considerable energy has been invested in mining and refining it from its ores.

This uranium left behind, of course, is the famous, or infamous, “depleted uranium.” Many people consider this uranium to be “nuclear waste,” although it has found some use as ballast in aircraft and in ships, as a shielding agent for x-rays, gamma rays and other radiation, and, also infamously, in armor piercing tank shells used in both of the US-Iraq *oil* wars. “Depleted uranium” is nonetheless *less* radioactive, gram of uranium for gram of uranium, than the natural uranium found in ores, the seas, and in common household items like granite countertops, since the more radioactive ^{235}U isotope in it has been partially removed.

How much depleted uranium is there? According to the World Nuclear Association, the world inventory of depleted uranium is about 1.5 *million* tons.[12]

As for what we should do with it…well…speaking only for myself, I’m not fond of war, especially resource wars, the most common kind of resource war that we have seen over the last century being the aforementioned kind of war, the *oil* war. So leave me out on the tank shell thing, putting uranium in a tank shell seems like a waste of perfectly good uranium. In addressing those who consider depleted uranium to be so called “nuclear waste,” I can say I have no idea what they’re talking about, since I personally consider that nothing that is useful can be considered “waste” at all. As it happens, I argue, there are few radioactive atoms on this planet that cannot be made to do something useful[13] and in many cases there are things that radioactive atoms can do that nothing else can do as well. Depleted uranium represents just such a case. I believe that *all* of the depleted uranium, for which the energy for isolation has already been expended and is thus, more or less, essentially available for the taking, should be converted into plutonium and fissioned in nuclear reactors, this to eliminate the necessity for any kind of energy mining in the immediate future. In this way coal mining, horizontal drilling for oil and gas ("fracking"), offshore oil drilling, and even uranium mining might be completely eliminated on a time scale of centuries.

This, of course, is not a new idea. The men and women who first harnessed nuclear energy – some of the best minds the world has known - understood this almost immediately upon uncovering its potential. In fact, the very first reactor to produce electricity in the world, this in 1951 – it was part of an experiment and not a commercial enterprise – was a *breeder* reactor, a reactor that made more fissionable material, this in the form of plutonium, than it consumed. The reactor, EBR-1, Experimental Breeder Reactor 1, was built because of the "enthusiasm" of Enrico Fermi,[14] who might well have been the greatest scientist to bridge both experimental and theoretical science since Newton, or maybe even Archimedes.

Noting this, and having some small insight as to who Fermi was, I cannot avoid some sarcasm: In the 1970's Amory Lovins, who was, for reasons that leave me cold, awarded the "MacArthur Prize," and thus was thus declared by some in the media to be a "genius." Such a declaration, when Fermi has existed, the same Fermi whose work Lovins has the unparalleled hubris insipidly to dismiss[15] with silly speculations, innuendo, and frankly, gross ignorance, is the equivalent of declaring a tone deaf third grader seated as a second cellist in a musically weak elementary school orchestra to be the peer of Yo-Yo Ma.

Unfortunately for humanity, Lovins' "Road Less Traveled" is now the "Road Most Traveled" even though, as the graphic at the opening of this piece shows, neither conservation or so called "renewable energy" has not, cannot, and will not accommodate the energy traffic required for a decent lifestyle for the overwhelming majority of human beings. Lovins' road represents the daydream of the unconscionable and indifferent elite with scant attention paid to the relatively impoverished and absolutely impoverished bulk of humanity. There was a *reason* that reliance on diffuse forms of energy, so called "renewable energy," for all of humanity's needs was abandoned around the beginning of the 19th century and all the reactionary rhetoric in the world cannot change that fact. That reason, even more so than today, was that the overwhelming majority of human beings lived short miserable lives of dire poverty.

Nuclear energy, and *only* nuclear energy, has the energy to mass density to be sustainable indefinitely at levels of energy production that involve a balance of human decency coupled to environmental justice.

Fermi – who despite his vast intellect is said to have been no elitist - understood, way back in the 1940's, that we would require depleted uranium to be made into energy, and well more than half a century later, as we are in crisis whether we see it or not, it is very clear that he was, in recognizing this, handing us a key by which we might save what *can* still be yet saved at this point.

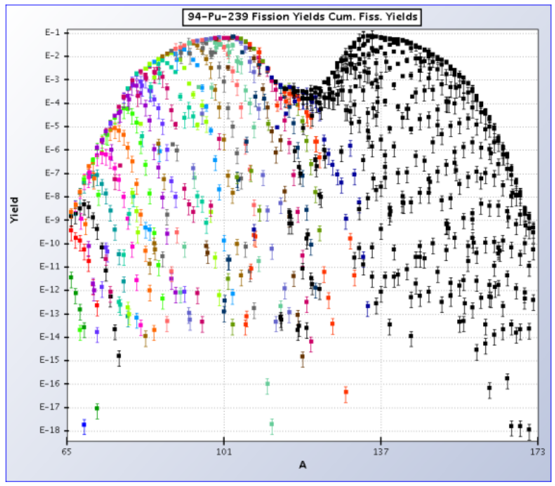
So how much energy is there in the isolated and refined “depleted uranium” now available for the taking? As stated, before the energy content of this uranium can be recovered, it needs to be converted into plutonium. I have prepared a spreadsheet, using the nuclear data tables available at the website of the Brookhaven National Laboratory,[16] showing the breakdown of the types of energy released when an atom of plutonium – the ^{239}Pu isotope – fissions. The table below is from that spreadsheet:

Pu-239 Fission energy yield	Energy (eV)
Kinetic energy of the fragments	1.76E+08
Kinetic energy of the prompt neutrons	6.13E+06
Kinetic energy of the delayed neutrons	2.99E+03
Kinetic energy of the prompt gammas	6.74E+06
Kinetic energy of the delayed gammas	5.17E+06
Total energy released by delayed betas	5.31E+06
Energy carried away by the neutrinos	7.14E+06
Total energy release per fission (sum)	2.06E+08
Total energy less neutrino energy	1.99E+08
J per fission	3.1867E-11
Fissions per sec per watt of power.	3.1380E+10

In the calculations below, I will include all of the forms of energy except neutrinos – which represent energy that cannot be recovered owing to the weak interaction of neutrinos with matter - assuming that all of these forms can be converted into thermal energy, thus claiming 199 MeV from each fission as recoverable as heat which may be converted to electricity, to fluid fuels (or other chemicals), to drivers of industrial processes: ***All*** the things for which we use energy.

The reader who has a sophisticated understanding of nuclear engineering, nuclear physics, and nuclear chemistry might question the inclusion of gamma radiation of both types, delayed and prompt, and delayed betas in my list, even if their contribution is minor compared to the kinetic energy of fission products and neutrons. In the gamma case I argue that advances in materials science, as well as the need to provide very high temperature systems to increase energy efficiency and thus to enable the elimination of the need to mine dangerous petroleum, dangerous coal, and dangerous natural gas, imply that a much superior fast reactor coolant is pure unalloyed lead as opposed to sodium – even if the most recently built fast reactors in Russia and in India still use the historically utilized and more problematic lighter sodium coolant. (We need to think anew.) Lead’s high atomic number provides for lots of electrons and heavy atoms that absorb and thermalize gamma energy via the agency of pair production, photoelectric emissions,[17] and Auger emissions, etc. Although other elements, including sodium, also capture some gamma radiation, the most efficient elements are all heavy, with lead and the actinides being the most efficient. This said, lead cooled reactors are a small subset of the thousands of types, arguably infinite types, of possible reactors.

As for delayed betas (and gammas), it is true that some of the beta energy, that involved with long lived radioactive fission products, may be removed from the reactors when used fuel is removed, but the majority of delayed betas, will in fact, decay in situ, while still in the reactor. From the BNL Nuclear Data Center referenced above, one may obtain the full fission product profile for the fission of ^{239}Pu in either tabular or graphic form. I will reproduce the graphic – with the caveat that the live version at the BNL website which may be accessed by following the directions in the notes[18] is interactive – here:



I have accessed the table form of the graphically shown data above, imported the data in it to MS Excel, summed the fission yields from plutonium-239 fast fission for each mass number, and have shown that on the left side maximum in the two "humps" above, the most common fission product mass number is 103 – as one just about make out in the graphic above – in which all of the radioactive members of the series decay to the single stable isotope of the rare, expensive, and industrially important element rhodium (Rh). (It is interesting to note that by 2030, the world supply of rhodium found in used nuclear fuel will exceed the supply found in ores.[19]) In direct fission, the mass number 103, which is produced in 6.59% of fission events, is represented by a distribution of elements from rubidium (^{103}Rb) to palladium (^{103}Pd), all of which, with the exception of ^{103}Rh, are radioactive. (For practically every mass number, with a few exceptions, there is one, and only one, stable nuclide associated with it.) In the case of mass number 103, the most prominent nucleus among these isotopes which is formed directly in the fast fission of ^{239}Pu is ^{103}Mo, formed in 3.63% of fissions. Its half-life is just 67.5 seconds. With two exceptions, the half-lives of the others are all much shorter, ranging from nanoseconds to a second and a half. Thus while the beta emissions are "delayed" the beta energy of its decay of the isotopes in the mass 103 series will all, more or less, be released in the fuel during reactor operations. Indeed the longest lived radioactive isotope in the entire mass 103 series is ^{103}Ru, which has a half-life of 39.6 days. Since nuclear fuels may be expected to remain in the reactor for periods longer than two years, and reactor designs are either available[20] or conceivable[21] in which fuel may remain in the core for periods measurable in decades, it is clear that the overwhelming majority of this ruthenium isotope will also decay to stable rhodium during reactor operations for all kinds of reactors, both of types that have been built, or among the many thousands of unbuilt types of nuclear reactors that one might imagine, with the overwhelming majority of the energy produced by mass 103 fission products recovered as thermal energy during reactor operations. Mass number 103 in this aspect is not really unique.[22]

(As an aside, on the topic of long fuel cycle time reactors, the Sekimoto monograph, *Light A Candle*, just referenced (reference 21), includes a charming account[23] by Sekimoto of how pleased he is that the Bill Gates funded nuclear design company, Terrapower, has essentially appropriated the ideas behind his "CANDLE" reactor, rebranding it, apparently (at the time the account was written) without attribution, as the "Traveling Wave" reactor. Sekimoto discourses, quite cheerfully, about his ultimate visit to Terrapower's luxurious offices, where he feels that however unstated, his innovations are nonetheless appreciated. Sekimoto is, apparently, a gracious and generous soul who can be pleased to die with nothing more than the knowledge of his contribution to the welfare of humanity.)

While the analysis above suggests I am largely justified in claiming the full 199 MeV of plutonium fission as recoverable energy, it is true that a small amount of the fission products produced will be sufficiently long lived to decay outside the reactor, ^{137}Cs, for instance, which has a half-life of 30.08 years[24] (the majority of the decay heat for mass number 137 is released *before* ^{137}Cs forms). I am not among those who consider isotopes like ^{137}Cs to be "waste," which needs to be buried or discarded, nor do I believe that the energy that they release after removal from the reactor need be useless. Quite to the contrary, with a little less irrational fear attached to them, they might solve some problems that are otherwise intractable, or far more difficult to address without the use of radiation.

For example: It has been shown[25] that a form of "synrock" designed for the immobilization of radiocesium isotopes, synthetic pollucite, by evaluating samples manufactured in the late 70's and early 80's, remains essentially structurally unchanged over periods of decades, despite incorporating the stable barium to which radiocesium decays and despite having been subject to continuous radiation exposure. (Natural pollucite is a cesium aluminosilicate found in some of the oldest rocks on earth.) This suggests that such pollucite might easily be used as a portable gamma source, and indeed it is, however, to a far too limited extent. Gamma radiation can be utilized, for instance, not only for sterilizing water, but also for the total destruction very dangerous polychlorinated biphenyls (PCB's)[26] – with only carbon dioxide and sodium chloride as the products – the destruction of powerfully carcinogenic nitrosoamines that are side products from the (necessary) disinfection of water,[27, 28] pharmaceuticals and their metabolites excreted or dumped into surface waters via sewage systems,[29] fuel additives in water,[30] and a host of other persistent organic pollutants (and especially in the case of air, persistent inorganic pollutants). Possibly even more interesting than radiocesium containing pollucite are titanium containing cesium synrock forms,[31] cesium titanosilicates, given the well-known ability of photochemically stimulated titanium oxides using visible, UV and X-ray radiation, to produce semiconductor "holes"[32] useful for catalyzing the destruction of a wide variety of very troublesome pollutants. This is recovered energy in the sense that the irradiation of water or air might serve to eliminate or reduce reliance on chlorination and/or the superior (to chlorination) practice of ozonolysis, both of which are energy intensive. This suggestion points to the fact that in a idealized nuclear powered world, energy might be used quite differently, with a vast number of similar efficiency and performance improvements.

With all this out of the way, let's go to the punchline, and figure out how much energy is available in the world's "depleted uranium:"

An electron volt (eV) is the amount of energy required to move a single electron through a potential of one volt, and it follows that the conversion factor from an electron volt to a Joule is simply the charge on an electron, 1.6022×10^{-19} Coulombs. Since a Watt is a Joule sec^{-1} it follows that the reciprocal of the total energy per fission divided by one second gives the number of fissions per second per Watt of power, which the table above gives as 3.14×10^{10}.

Those who have completed a high school chemistry class (or beyond) may recall that any number of atoms can be converted into a mass by use of the concept of a "mole," – defined by international agreement by an international organization known as IUPAC – as the exact number, Avogadro's number, of atoms in exactly 12.00000000… grams of the pure carbon-12 isotope. The best recent measurements of this number suggest that there are $6.02214129 \times 10^{23}$ atoms found in this circumstance. This number of atoms can thus be used to calculate the number of moles in any other pure substance, including pure ^{239}Pu. Thus one watt of energy is equivalent to fissioning 5.2108×10^{-14} moles of ^{239}Pu per second. Multiplying the number of moles of an isotope by its isotopic mass, 239.0521565 grams per mole for ^{239}Pu, one can find the mass of a number of moles; in this case, a watt of energy is produced by fissioning 1.2457×10^{-11} grams of ^{239}Pu, or 12.5 picograms, an amount which is so tiny as to be invisible even using an ordinary optical microscope.

We are now prepared to calculate what the one year "plutonium equivalent" amount of energy consumed by an "average" human being on this planet, understanding that the average reflects the poorest of the poor and the richest of the rich, since, as stated above, the continuous power demand of modern humans is roughly 2500 watts, as well as from the fact that a calendar year has 31,557,600 seconds in it. When we do this calculation we see that the "plutonium equivalent" of "average" human energy consumption, as compared to the 1.9 metric tons of "oil equivalent" is 0.98 grams per year "plutonium equivalent." Thus if one is average across the broad range of humanity, and one lives to become a centenarian, one would be, for the purpose of energy consumption, responsible for the utilization, for the purpose of meeting all one's energy needs, of less than a tenth of a kg of matter in a lifetime. By contrast, one might consume a kilogram of a dangerous fossil fuel in a few minutes of driving to a shopping mall.

The next question to address is how much plutonium must be fissioned over all. The answer to this question is that to address 100% of humanity's energy demand at current consumption levels, an average continuous power demand of 2500 watts, 6,800 tons would need to be fissioned each year. Thus at these levels the inventory of mined, refined and isolated "depleted uranium" would last roughly 220 years before any other energy source would be required anywhere at any time, and thus every energy mining operation on the planet could in theory be eliminated for this period of time. Under these conditions, the scourge of air pollution, responsible for more than 7 million deaths per year[33], would not exist, and many other intractable environmental problems that are currently ignored might be addressed.

But is 2500 watts of average continuous power *enough* to sustain a human life *decently*?

In Switzerland, there is an organization that calls itself the "2000 Watt Society" which argues that the world's population should all strive to live on 2000 watts of average continuous power and declares, somewhat arbitrarily, that this goal should be reached by the year 2050, when presumably and conveniently, many of the people who have been making this argument will be dead, thus having avoided taking the responsibility they expect future generations will gladly embrace. (In 2011, we can calculate from the data in the free IEA report that the average continuous power demand of a Swiss citizen was roughly 4,300 Watts.) As we have seen above, 2000 Watts was the average continuous power of humanity in 1973, when the population of the planet was, again, 3.9 billion people, the percentage of whom who lived on less than $1.25 per day was much larger than it is now. By 2050, population projections of the US Census claim that the world population is expected to be 9.3 billion people. In a "2000 Watt" world – with each person entitled to a lawn mower's worth of average power – the planetary energy demand would be 587 exajoules, only 37 exajoules more than is currently used in our 2500 Watt world but nonetheless a prodigious amount of energy, since what we use *now* is prodigious.

Realistically though, how many people would we expect to have clean water in a "2000 Watt world?" Clean air? Medical care? Educational tools? Again, how many? A narrow elite? Everyone?

I personally believe that the world population will never reach 9.0 billion people, since it is becoming increasingly clear that the world cannot indefinitely support 7.0 billion people, never mind two billion more, without seriously degrading its carrying capacity, a process of degradation well underway now, no matter how many lies we tell ourselves in denial. Since his timing was wrong, and his mechanism was wrong, we have become rather glib and smug in assuming that Malthus was a blithering fool. But can we be sure he was? Call me a "doomsayer, an apocalyptic prophet," if you wish, but I believe that the world population will fall, sooner rather than later, most likely not in an orderly fashion, not as a result of managed attrition, not because of lower fertility rates, but rather in the catastrophic fashion described in Jared Diamond's insightful book on the environmental history of remote, isolated societies, "Collapse, How Societies Choose to Succeed or Fail."[34] And let's be clear: On a galactic scale this planet is, in fact, remote and isolated.

Nevertheless, I *hope* I am wrong about the mechanism by which population – the elephant in the environmental room – will fall, but the population *must* fall, one way or the other.

Repeatedly, I have argued in my writings and comments around the internet, by frequent appeal to the fine and widely read paper on the environmental and human effects of nuclear energy by the climate scientists Kharecha and Hansen,[35] that the ***fact*** that nuclear energy *saves* lives lies at the crux of the argument that the use of nuclear energy must be expanded as a moral imperative. At the same time as I am arguing for saving lives, I am arguing that the population must be reduced for decent human life to remain – or in too many cases to *become* – sustainable. It would seem that these ethical arguments are at cross purposes. However, with some exceptions, it is now understood by observation that those places where the fertility rate is at or below replacement level are most often the same places where people are secure in their homes, the places where they are well provided for, where they are educated and safe. Maybe, just maybe, the key to yet saving what might be saved of the planetary environment would be involved with honoring in practice, rather than broach, the 25th article of the Universal Declaration of Human Rights of 1948.[36]

From the data in the free IEA brochure, one can calculate that the average continuous per capita power consumption of a citizen of the US is 9,534 watts; the same figure for a citizen of China – a country about which many Americans complain because its carbon dioxide emissions, 825 watts. For the current world population, reportedly 7.16 billion, to consume like the average American consumes, world energy demand would be required to be 2,154 exajoules, as contrasted with approximately 550 exajoules actually consumed at present by the world population. Under such circumstances, the "exa-" prefix would no longer be adequate; we'd need to speak of "zetajoules."

That I have spent part of this work making it clear that I regard Amory Lovins to be an insufferable fool does not imply that I have no respect for the idea of energy efficiency; the questions of "Jevon's Paradox" aside, I still think that any true environmentalist should applaud efficient use of energy. The incontrovertible laws of thermodynamics show that the highest efficiency – the maximum "exergy" or work that can be extracted from an energy system – require the highest sustainable temperatures, and right now the best sustainable approach to producing such temperatures, in light of recent advances in materials science, is nuclear fission. Thus all of the ideal nuclear reactors I imagine in a sustainable future are high temperature systems with "combined cycle" features, where electricity might be a side product of other operations. A completely, or nearly completely nuclear powered, again, world would use energy quite differently than the world we actually live in, which as the introductory graphic shows, is largely a dangerous fossil fuel powered world. Perhaps, in this light, a decent world, the average citizen might live very well at 5,000 watts average continuous power per capita, in which case the mined, isolated uranium would still be good for more than a century, rather than two centuries at current levels of energy demand, with a requirement, of around 13,600 metric tons of plutonium requiring fission each year.

Thus far I have not discussed the favorite fuel of many nuclear energy aficionados, thorium. I have nothing against thorium; it's a fine nuclear fuel, probably not infinitely available as uranium is owing to uranium's higher solubility[37] in seawater, but available from crustal rocks for millennia to come. I disagree with anyone who argues that thorium is the ***only*** *acceptable* nuclear fuel, but yes, it's a fine fuel with the potential to increase the fuel efficiency of the existing thermal spectrum nuclear infrastructure.

Let me say this about thorium: In the Ridgewood section of Queens, New York there is a "superfund site" described in *The New Yorker* as "The Most Radioactive Place in New York City.[38]" The media, with its fondness for anti-nuke hysteria has tried to imply that the thorium dumped into the sewer system there by the Wolff Alport Chemical Company, which operated on the site beginning in the early 1900's through the 1950's was a dedicated thorium production site that existed to serve the nuclear energy and nuclear war industries. Actually, the site, for most of its historical operations, was a site for the refining on lanthanides (aka "rare earths") – the same lanthanides now used to make wind turbines and electric cars – most ores of which are, in fact, mildly radioactive owing to the presence of thorium in them. The Wolff Alport people only *stopped* dumping the thorium into the sewer system when a nuclear market appeared for it. In various places around the world, including the United States, there are lanthanide mine tailings containing significant amounts of partially refined thorium. These mined resources might extend the potential of already recovered nuclear fuel materials for another few centuries, although a complete inventory of such materials seems to be not readily available.

And when, after some centuries, the *already* mined and refined, or partially refined (in the case of thorium) supplies are exhausted what then? I referred earlier to a post of mine elsewhere where I examined in detail the sixty year history of research on approaches for obtaining uranium from the massive reserves in the sea; it is known to be feasible to so obtain uranium at any point where the price rises high enough to justify it, even though price increases in uranium have little effect on nuclear energy prices because of the extreme energy/mass density uranium transformed into plutonium enjoys.

However, there are other uranium sources from natural geological formations, and it might make sense to remove this uranium – killing two birds with one stone – from places where it may impact human health. For instance the Marcellus shale, particularly that in New York State, which is being pulverized in the very short sighted attempt to offer transitory supplies dangerous natural gas for one selfish generation to burn at the expense of all future generations, occurs in a natural uranium formation, something we can recognize by the large amounts of radioactive radon gas found in the produced gas[39]. Indeed, the brines used in hydraulic fracturing, can have concentrations of radium (which decays to radon and has a half-life of 1610 years) that exceed 10,000 pCi/liter (370 Beq/Liter or 370,000 Beq/m^3) according to a news item in one scientific journal[40], an amount of radioactive material that exceeds, by 4 to 5 orders of magnitude, the amount of radioactivity in seawater associated with the leaking of cesium isotopes outside the Fukushima reactors[41]. (Water of this type from fracking operations, called "flow back water," is often brought to the surface and dumped in landfills.[42] In the Marcellus shale formation, the amount of flow back water created in 2014 is roughly 5 billion liters.[43]) Unless the uranium, the parent element of the radon, from this formation is removed, the radon gas will continue to leach ***forever*** from the shattered shale into the ground water and air that all future citizens of the area will drink and breathe for as long as the humanity exists. The uranium might be removed, after the gas is gone, by injecting supercritical carbon dioxide[44] (with an appropriate uranium complexing solute) into the formations, and "washing" (leaching) the uranium out, and fissioning it.

Similarly, groundwater used for, among other things, drinking water can sometimes leach uranium. There is, for example, a region in Germany near Munich where the groundwater has significantly higher concentrations of uranium than the maximum allowance by German regulatory authorities, more than 10 μg/L.[45]

Thus we might reasonable – using well understood solid phase uranium extraction resins – collect additional resin from waters or residues contaminated with uranium because of horrific environmental practices such as "fracking" or because of the necessity of mining ground water *naturally* "contaminated."

Before closing with some commentary on ethics – and, as stated, I do believe that energy and ethics are very much involved with one another - let me discuss some related technical issues, as I am largely a technical guy:

A facile challenge to my arguments above would note that very few commercial breeder reactors have been built, and with some exceptions, most have been balky economic failures. There are several reasons for this – and they are complex – some technical and others clearly cultural, involved with the fear, ignorance, and selective attention of the world's cacophonous, if jejune, anti-nuke community, and others involved with the unsustainable, if increasingly universal, disposable culture. Thus in recent years only two major examples of fast breeder reactors have been built, a Russian version and an Indian version. Russia ran the most successful commercial breeder ever built, the BN-600 for about 3 decades – and has just finished a BN-800 a model that China is considering purchasing to construct a small fleet of breeders. India will shortly bring the indigenously developed Kalapakkam fast 500 MW breeder on line and plans building more such reactors.

The latter reactor is designed to produce plutonium as a key to unlock the potential of India's huge reserves of thorium. India is a world leader in the use of heavy water reactors which, when charged with ^{233}U produced from thorium, can function quite well as breeders even under thermal conditions; in fact, fueled with ^{233}U, ***all*** of India's 18 heavy water reactors[46] now operating, as well as the four due to come on line in the next two years, will be operating as *breeder* reactors. Breeding with thorium is slower than breeding with plutonium but breeding is still breeding. A nice paper[47] discusses the many options open to the innovative Indian nuclear power program, utilizing various schemes to utilize plutonium, uranium (both enriched and depleted) and thorium to power its reactors under breeder conditions.

(It is a matter of some irony that Lovins' 1976 "Road Less Traveled" discourse mentions India only once, and not with any sympathy for, or acknowledgement of, the even worse living conditions that existed in that country then than those we observe now, but only to remark, with absurd confidence:

> "Nuclear expansion is all but halted by grass-roots opposition in Japan and the Netherlands; has been severely impeded in West Germany, France, Switzerland, Italy and Austria; has been slowed and may soon be stopped in Sweden; has been rejected in Norway and (so far) Australia and New Zealand, as well as in two Canadian Provinces; faces an uncertain prospect in Denmark and many American states; has been widely questioned in Britain, Canada and the U.S.S.R."; and has been opposed in Spain, Brazil, ***India***, Thailand and elsewhere."[48]

Tarot card readers, I would guess, could have produced more accurate predictions for ten bucks on a boardwalk in a vacation beach town, probably at considerably less cost than the trillions of dollars that have been squandered in failed attempts to make many of the ideas Lovins advanced in that otherwise silly fantasy of 1976 into practical policies. What is worse than the squandered trillions is the tragedy of the cost of missed opportunities.

In 2011, we were using 1,216% as much nuclear energy as we used in 1973, but it was hardly enough.

Despite what urban myths you may have heard, advanced by people who take Lovins seriously, *experimental* results, which always trump theory, show that nuclear energy and not so called "renewable energy" was over a period of 4 decades, the fastest growing form of climate change gas free primary energy. Without catcalls from people who know nothing at all about nuclear energy but hate it anyway, it might have done even better.)

To return to what critics of my ideas might easily point out, it is true that neither current plutonium inventories, including both reactor grade material from used nuclear fuel and weapons grade material available from practical nuclear weapons disarmament are nowhere near the 6,800 tons I indicated would be needed to be consumed each year to provide for the “2500 Watt world” in which we now live, never mind a “5000 Watt world” requiring 13,600 tons.

The United States has been, for more than four decades, the world’s largest producer of nuclear energy. According to figures from the Nuclear Energy Institute, the NEI, the inventory of commercial used nuclear fuel in the United States was 71,780 metric tons[49], accumulated over a period of half a century. Most of the mass of this fuel, roughly as much as 95%, is simply unreacted uranium, about 1% is plutonium formed from uranium during operations, with the balance consisting with both radioactive and non-radioactive fission products. This suggests that the United States could obtain about 700 MT of plutonium from its used nuclear fuel. Possibly, if we came to our senses and found a politically viable way to dismantle our stupid and useless nuclear weapons, we might obtain an additional 200 MT; let’s say for argument sake that we might have (by the time we come to our senses and reprocess used nuclear fuels) 1,000 MT here.

Below is a table, labeled “Table 7.3” as it was in the original reference, a comprehensive monograph on fast breeder reactors published in 1980,[50] showing the proposed fuel loadings of types of breeder reactors that were designed nearly half a century ago, in the late 1960’s, reactors that would never be built today – they’re way too primitive – but are nonetheless illustrative in the sense that they show the required fuel to load a large breeder reactor. Crudely, from this data, this suggests that available US plutonium inventories are only sufficient to fuel for a single cycle, between 250 and 300 fast breeder reactors, reactors that could be built as fast as is possible, perhaps in a fashion similar to that by which Henry Kaiser built “Liberty Ships” during the second flare up of the “Great War,” sometimes called “World War II.” After these reactors were built however, the rate at which reactors could be built would be essentially constrained by the rate at which plutonium excesses from breeding accumulated and became accessible.

TABLE 7-3 Fuel Cycle Results as a Function of Fuel Pin Diameter for Homogeneous and Heterogeneous Designs (Adapted from Reference 9)

Common Parameters:		
	Fuel	UO_2-PuO_2
	Electrical rating	1200 MWe
	Thermal rating	3300 MWth
	Residence times	
	core and internal blankets	2 *y*
	radial blanket	5 *y*
	Fuel cycle interval	1 *y*
	Capacity factor	0.7

Configuration	Homogeneous						Heterogeneous					
Fuel pin diameter, mm	6.35		7.62		8.38		6.35		7.62		8.38	
	BOEC	EOEC	BOEC	EOEC	BOEC	EOEC	BOEC	EOEC	BOEC	EOEC	BOEC	EOEC
Fissile inventory (kg)												
core	3319	3023	4019	3878	4551	4504	4292	3791	6233	5751	6908	6500
internal blanket							255	710	278	797	258	743
radial blanket	436	637	391	574	350	516	410	596	456	670	453	667
axial blanket	114	325	120	349	121	353	65	190	77	226	81	238
Total	3869	3985	4530	4801	5022	5373	5022	5287	7044	7444	7700	8148
Discharge burnup (MWd/kg)												
core average	82		56		46		77		52		43	
core peak	116		80		66		109		78		70	
Fraction power (%)												
core	93	89	94	91	94	93	83	74	87	81	88	84
internal blanket							10	18	7	13	6	10
radial blanket	4	6	3	4	3	3	5	6	4	4	4	4
axial blanket	3	5	3	5	3	4	2	2	2	2	2	2
Fuel cycle reactivity (absolute)	−0.058		−0.023		−0.009		−0.019		−0.023		−0.020	
Breeding ratio	1.11		1.26		1.33		1.24		1.35		1.39	
Doubling time, CSDT (*y*)	43.5		19.3		16.5		22.3		20.7		20.2	

This is some hand waving on my part, but I believe that there are no unmanageable impediments for nuclear power plants to reach 60% thermal efficiency, although this may not involve direct “exergy” per se, but might also include producing from nuclear energy chemical products including the replacement of materials now produced from petrochemical sources, and portable high density fluid fuels, such as jet and diesel fuels. In this case, in order to produce a *sustainable* and *decent “5,000 watt world”* with a population of 7 billion we would need something like 6,000 nuclear 3000 MW(th) reactors operating at

60% thermal efficiency. There clearly isn't, right now, even enough plutonium on the planet, regrettably, to run this number of reactors for a single year.

Of course, every breeder reactor is built and fueled will accelerate the rate at which plutonium (or in the thorium cycle case, ^{233}U) accumulates, and the "doubling time" – the time required for a reactor to produce enough fuel to fuel not only itself but also another reactor just like itself – will not refer simply to a single reactor (as in table "7-3" above) but to the entire *system* of reactors. In this case, plutonium (or ^{233}U) will accumulate much like compound interest accumulates in a bank, with the main difference being that "withdrawal" for use would accelerate, rather than slow down, accumulation of "interest."[51]

This said, it may not even be necessary to have large reserves of plutonium from used nuclear fuel to utilize depleted uranium as a source of energy. Earlier I alluded to the Terrapower reactor, design details of which have been published[52] recently, (acknowledging this time the contribution of Seikomoto, Teller and others to the original conception). This is a "breed and burn" type of reactor, in which transmutation of the fertile fuel (^{238}U or ^{232}Th) into fissile fuel (^{239}Pu or ^{233}U) is carried out within the reactor over very long periods without shutting down. In the Terrapower case, the reactor is said to be designed to run for 60 years without ever refueling, and without ever having the fuel reprocessed, simply converting "depleted uranium" into energy *in situ*. After 60 years, future generations would be able to dismantle the reactor, recover the fission products and put them to use to face the vast set of problems they will surely face because of this generation's irresponsibility, and "reload" with the residual plutonium and the inventory of "depleted uranium" that remains for them to use.

Let me say that from my less than fully informed perspective, the Terrapower reactor, which is sodium cooled and is chock full of cladded solid phase fuel and seems to face, in spades, all of the historical challenges associated with high burn up fuels (as well as with sodium coolants), with respect to fuel swelling and xenon, krypton and helium gas release; they intend to vent the fuel rods. Most likely, though, I raise these concerns out of ignorance, since they claim they have proprietary technology for the preparation of metallic fuels with excellent "smear density" properties to address swelling. (Venting in oxide fuels can be very problematic from a swelling prospective, owing to the formation of low density sodium plutonates and uranates[53]) One hopes, therefore, that they will succeed.

Metallic fuels, in general, are superior to other types of fuels when it comes to providing breeding neutrons, as is shown in the following table reproduced in a recent publication[54] referring to a "reference" uranium/plutonium fuel cycle[55] as discussed 3 decades ago.

Table 1. Comparison of Breeding Ratio Components between Oxide, Carbide, and Metal Fueled SFRs for Pu/U Cycle

	Oxide	Carbide	Metal
η of Fissile Isotopes	2.283	2.353	2.450
Fertile Fission Bonus, ε	0.356	0.429	0.509
η-1+ε	1.639	1.782	1.959
Neutron Loss	0.308	0.279	0.332
Absorption Loss	0.231	0.199	0.218
Structure	0.158	0.131	0.127
Coolant	0.010	0.009	0.008
Fission Products	0.055	0.058	0.058
O, C, or Zr	0.008	0.001	0.025
Leakage Loss	0.046	0.051	0.082
Pu-241 Decay Loss	0.031	0.029	0.032
Net Neutrons for Breeding	1.331	1.503	1.627

Probably owing to the age of the document, nitride fuels, which have many interesting properties that in my view have not been fully explored, are not discussed.   It seems safe to assume however that the generation of breeding neutrons would be similar to that obtained for carbide and nitride fuels.

All of this relates to ***solid*** fuels, but many people argue, with considerable justification, for fluid phase reactors, of which the famous Liquid Fluoride Thorium Reactor, the LFTR, which has been widely promoted by the admirable and remarkable enthusiasm of Kirk Sorensen, President and Chief Technologist of FLIBE energy,[56] is one example.   The FLIBE technology is based on the Molten Salt Reactor Experiment (MSRE), a reactor that operated in the late 60's at Oak Ridge National Laboratory.

In my view, the chief advantage of fluid phased reactors – and as a chemist who is quite fond of actinide, lanthanide and other fission product chemistry - is their capacity for in continuous in line reprocessing of nuclear fuels via chemical, electrochemical or even physical separation, for instance, distillation. (Arguably the venting of Terrapower fuels, depending on operating temperatures, would result in some physical separation, via volatilization, not only of gases, but of other volatile fission products, notably iodine and cesium, thus minimizing the risk of a large scale failure releasing accumulated fission products such as occurred at Fukushima.)

What is seldom discussed is the unique opportunity represented by another of plutonium's rather unusual properties, its low melting point.   A "connected" phase diagram of the actinide elements[57] shows this unusual plutonium property quite graphically, also showing that a neptunium-plutonium eutectic exists with an even lower melting point than pure plutonium metal:

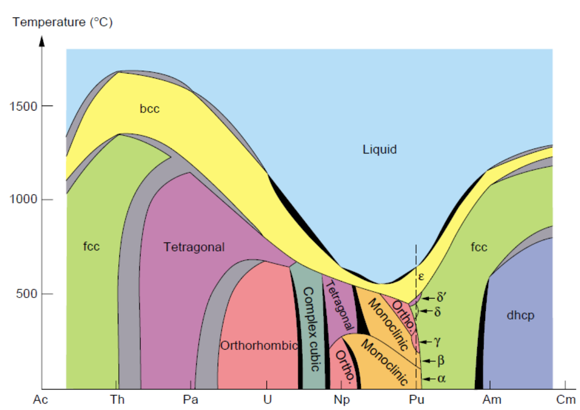


Figure 10. Connected Binary-Phase Diagram of the Actinides
The binary-phase diagrams (temperature vs composition) for adjacent actinide elements are connected across the entire series to demonstrate the transition from typical metallic behavior at thorium to the enormous complexity at plutonium and back to typical metallic behavior past americium. Two-phase regions are in black; uncertain regions are in gray.

Alloys of plutonium and neptunium are attractive nuclear fuels because they further reduce the already low (but often over emphasized, *ad absurdum*) risk of weapons diversion of reactor grade plutonium, by causing the buildup of the heat generating ^{238}Pu isotope that essentially renders plutonium useless[58] for use in weapons, this while consuming neptunium, which in many ways is the most problematic of all actinides produced in nuclear reactors, at least in the silly case where actinides are *buried* as "waste." (I note that no similar technology exists for making *oil* useless for use in weapons, which is probably why wars using oil based weapons of mass destruction are continuously observed and nuclear wars are not.)

For reference, here is the isolated phase diagram of neptunium/plutonium metal alloys is available[59] and is reproduced here:

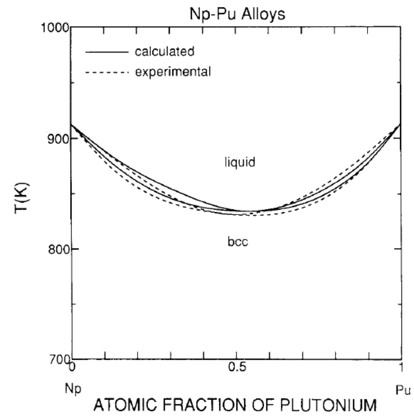


Fig. 2. Liquid–b.c.c. equilibrium in the Np–Pu system.

In general, the low melting point of plutonium is considered problematic in most modern fast reactor metallic fuels,[60] since liquid plutonium metal is considered quite corrosive to cladding, but historically a 1 MW research reactor – far less famous perhaps than the MSRE – was run for a few years in the early 1960's in which *liquid* plutonium fuel, in this case an iron eutectic that actually melts a lower temperature than pure plutonium, was utilized. This was the LAMPRE experiment, (Los Alamos Molten Plutonium Reactor Experiment)[61].

I wouldn't regard this reactor as "off the shelf" in the way the LFTR is sometimes represented. In many ways it was primitive. Compared to modern times, materials science was relatively poorly developed and the only material that was known then to have sufficient resistance to corrosion by liquid plutonium was the metal tantalum, a constituent of the tragic ore "Coltan" that has resulted in modern tragedy[62] for those, including children, who mine it under near slavery conditions to make "super capacitors" on which cell phone technology and other devices (including computers) depend. On moral grounds, I would never approve of a reactor dependent upon tantalum mining. But, again, materials science has advanced tremendously in the last half a century, so that one might easily imagine a reactor utilizing refractory ceramics, perhaps nanostructured composites, to contain the plutonium, for example, and coolants other than the molten sodium, which would allow it to operate at much higher temperatures than the LAMPRE operated. Noting that some of the most refractory ceramics known happen to be actinide ceramics,[63] most famously thorium oxide, but also including many high temperature uranium compounds, very interesting possibilities for future reactor types suggest themselves. (The melting point of uranium nitride has recently been measured, using laser heating, as being 3125 +/- 30K.[64])

As I play around with these ideas privately, it occurs to me that reactors are possible that include features of "breed and burn" reactors, molten fuel reactors, and very high temperature reactors in one reactor type. Indeed the interesting physical and chemical properties of plutonium metal[65] suggest passive control features as well as remarkable spontaneous *in situ* fission product separations that to my knowledge have not been extensively explored but might be in some conceivable future.

A conceivable future however, is not necessarily a likely future, and I do not expect that all of the knowledge we have acquired about nuclear energy in more than half a century of practice *will* be employed to save what might have been saved were things otherwise. Too many absurd and selective elements of fear and ignorance directed against nuclear energy have been allowed to prevail culturally for that to happen. I could go on almost endlessly on the topic of possible reactor designs that might serve humanity well, but it would amount to little more than spitting at a hurricane. Thus, having referred, in the Coltan evocation above, to the moral dimension of technology, let us now turn to the subject of the ethics of nuclear opponents, of whom Amory Lovins is only an egregious and prominent example.

There are those who can fly around in private jets to "Live Earth" concerts like those held in 2007 for the ephemeral, disingenuous, transient and absurd genuflection towards the idea of "fighting" climate change (as opposed, one imagines, to partying through it) – such people burn orders of magnitude more than their 1.9 ton share of oil "equivalents" per year. On the other hand there are those whose income have never, not once, afforded them access to any dangerous fossil fuel "resource" at all, who live burning sticks harvested from the edges of dying forests, or else on the combustion of bits of gathered garbage, or perhaps a few pieces of coal in a desperate effort to stay alive.

For me, with my peculiar attention, the image that sticks in my mind of the 2007 "Live Earth" debacle, is that of some hirsute Rock and Roller enjoying his Warholian 15 minutes, prancing around in front of tens of thousands of watts of sound equipment with his guitar wearing an insipid "No Nukes" tee shirt, thus sharing his obliviousness with those who are not illiterate by choice but rather by their lack of opportunity – those pulling sticks and pieces of cardboard out of the mud to cook their food for example - but nonetheless illiterate all the same, each in their own way moving with us all to our shared destruction.

If there is a God – something I personally doubt – may that God forgive that hairy rocker.

The real question is not about the inane affectations of bourgeois rock and rollers but rather about the whole of humanity and this is why nuclear energy, the ***only*** energy form powerful enough, concentrated enough, to provide safely for all of extant humanity the inherent standards set in the Universal Declaration of Human Rights, represents an essential *ethical* issue beyond the ken of insipid sloganeering.

Why should *every* human being, beyond conditions of birth, matter? Couldn't some of us – the privileged few, imaging ourselves born into special rights - just hole up with our bourgeois solar power/wind power/electric car dreams and forget them?

The great theological thinker Elaine Pagels, a more worthy MacArthur fellow perhaps than Lovins, has suggested[66] that the real triumph of Christian theology was to insert into the world moral culture the axiom that individual human beings have equality in value, and thus in the right to justice, be it secular or divine. This is hardly obvious in a world that has contained, as aforementioned, both Fermi and Lovins, or for that matter, Yo-Yo Ma and tone deaf third graders. Indeed, the way we live our lives even today suggests we really don't believe in that axiom, any more than Thomas Jefferson, he of the "self-evident truths," believed himself the equivalent of his sometime "lover," (or victim) the barely pubescent slave Sally Hemmings. Still, for me at least, this moral axiom nevertheless has power, I accept it as a basic tenet of human decency, even if it is more honored in breech than practice.

Almost exactly a century ago as I write, a tremendous shock, from which the world has never really completely recovered, commenced - the "Great" war – an event by which we understood, almost too late, that the power of knowledge, of technology, our machineries of wealth, run irresponsibly, indeed childishly, had a vast potential to kill as well as save. As the "Great" war died out, and rose in fits, spits and starts here and there again and again, launched once more into full flame, right through the twentieth century and into the twenty-first, we grew to fear our technologies as we fear ourselves, some technologies more than others, not always rationally, and not always with a clear and sober balance between what we *must do* to live, and what we *must not do* to prevent ourselves from dying out as a species. In making these choices, too often we have fed on the intoxicating ambrosia of fear and ignorance, coupled with wishful thinking, self-delusion and denial.

Against this backdrop, the outset of visceral terror of the ongoing "Great War," during which human lives were macerated, burned, boiled, punctured, dissolved alive, namelessly, facelessly, becoming no more than shreds of rotting meat, some poets among the shock of shells asked themselves, "What is a human being? Is there anything to such a thing as the human being that might be as to make human beings worth saving *from themselves*?"

Writing in 1918, *Die Dichter* - the poet - Herman Hesse, in his transcendent prologue to *Demian*[67], wrote this:

> *Was das ist, ein wirklicher lebender Mensch, das weiß man heute allerdings weniger als jemals, und man schießt denn auch die Menschen, deren jeder ein kostbarer, einmaliger Versuch der Natur ist, zu Mengen tot. Wären wir nicht noch mehr als einmalige Menschen, könnte man jeden von uns wirklich mit einer Flintenkugel ganz und gar aus der Welt schaffen, so hätte es keinen Sinn mehr, Geschichten zu erzählen.*
>
> What that is, a real living person, one actually knows today less than ever, for we shoot lots of people – each of them a valuable, unique experiment of nature – to death. Were we nothing more than individual persons, were it really possible to take one completely out of the world with a rifle bullet, it would not make sense to tell (human) stories anymore.

I would suppose, with the growing contempt around the world for the poor, who more or less represent a *majority* human beings now living, many of whom *still* are born and die in short brutal lives of unspeakable horror and, too often, equally unspeakable violence – people whose stories are not told, or if they *are* told, are widely ignored - we still "know less than ever" what a human being is. It seems certain that there are billions of human whose whole lives we value at less than the cost of a fashion or gossip magazine, much less than the cost of a ticket to a football game. Could we not provide for these people at least enough for a modicum of decency so as to see in their unique realities the awe inherent in the universe? How? Shouldn't we do so? Again, why?

For me, the answer to the last question, "Why?" is contained in the text following the lines above in Hesse's same prologue to Demian[68]:

> *Jeder Mensch aber ist nicht nur er selber, er ist auch der einmalige, ganz besondere, in jedem Fall wichtige und merkwürdige Punkt, wo die Erscheinungen der Welt sich kreuzen, nur*

> *einmal so und nie wieder. Darum ist jedes Menschen Geschichte wichtig, ewig, göttlich, darum ist jeder Mensch, solange er irgend lebt und den Willen der Natur erfüllt, wunderbar und jeder Aufmerksamkeit würdig. In jedem ist der Geist Gestalt geworden, in jedem leidet die Kreatur, in jedem wird ein Erlöser gekreuzigt.*

I have my own translation of these lines; with their beautiful evocation (and rearrangement) of Christian moral Trinitarian theology. Whatever my failings as a translator, the translation is one by which I have tried to live, so much as has been possible, my *moral* life, such as it is.

(All of the translations I have seen seem to strip away the poetry, and cannot capture the beauty of the original. As such, knowing how limited and weak my German is, and not wanting to trample upon the sacred, such as there are sacred things, I will leave it for those who know the language well enough to read it themselves to do so.)

> *…der...wichtige und merkwürdige Punkt, wo die Erscheinungen der Welt sich kreuzen, nur einmal so und nie wieder…*

With our vision extending now literally across the universe, perhaps we are less profane, more sacred then we know.

This diatribe is way too long already, so let me close it and close it with this:

The physics and chemistry of plutonium are too beautiful, too weirdly mutable, too wonderful to fall short of the ineffable: Plutonium, the frenetic dancing element, the dervish element, with its raging picometer seas of its profligate electrons, its kaleidoscopic dance of color as each atom wriggles through oxidation states irrespective of its neighbors, its armory of collapsing and heaving phases, its helium breath, its unbound krypton and xenon and radon breath, its heat, its light, its way of becoming and then of coming apart, flinging particles in and out of itself, becoming what it never was in ways both regular and wholly free of order, its bolts of energy, its property of self-destruction whenever it finds too much of itself.

Were we mystics, if we really looked at plutonium, really strove to know as much as we could about it, we should see plutonium as though it were a chimeric god, at once terrible and nurturing, at once as profane and sacred, at once loving and fearsome, a giver of power and a means to weakness, giving both a danger and a safe harbor alike; like all our gods, such as they are, reflections of ourselves, measures of ourselves, as women, as men.

Were we mystics, we might decide that so compelling is the element plutonium, so like and unlike the world, that its existence *had* to be put here for us to use. Were we mystics, we might see plutonium as perhaps the ancients saw fire itself, fire being a gift so awesome that the gods punished Prometheus for eternity for giving it to humanity, for in so doing, Prometheus thus gave mere human beings powers beyond the gods, ideally powers to do the good and great things that the gods and perhaps humans, when fueled like gods, may do.

Even as I have little use for mysticism myself, I would that it were so.

Notes and References.

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