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The World Nuclear Renaissance Is in Progress! Will Colombia Join In?

*Prepared for VirtualPRO Conference on Biofuels, July 28, 2007
by Marjorie Mazel Hecht*

Atoms for Peace

If someone had told President Eisenhower and others in the Atoms for Peace program in 1953, that by the year 2007 we would still have 1.7 billion people living without electricity, and that world governments were scrambling to take land out of food production in order to grow biomass to use as fuel, they would have been incredulous. They would have thought we were absolutely crazy.

The optimistic view of the Atoms for Peace program in 1953, was that the world would use the new knowledge of fission to produce enough energy cheaply and safely to power development around the world, to light every household, to supply freshwater from seawater, and to educate new generations of youth who would make new discoveries to improve the state of the world. They envisioned 2000 nuclear plants by the year 2000, which would have been perfectly possible if their optimism had prevailed.

Now, we need 6,000 by 2050! This is the number of nuclear plants--6,000--that the world will need to meet the growth in energy demand by mid-century, with nuclear providing 30 percent of the electricity needed. We can do it, if there is the optimism and the political will to get the job done. What we need is the kind of vision that ordinary people had in the postwar period.

This was the spirit that rebuilt an almost totally devastated Europe, that inspired the independence movements in Asia and Africa, that captured the imagination of young people around the world and gave them hope. At the time, the world population looked to America, whose industrial capability had supplied the materiel that made it possible for the Allies to win the war against Hitler's fascist axis. This was the America of George Washington, Alexander Hamilton, Abraham Lincoln, and Franklin Delano Roosevelt, the America that represented freedom and progress--not the America of Cheney and Bush.

In 1958, at the second Geneva Conference for the Peaceful Uses of Atomic Energy, there was tremendous excitement. Every country present wanted to get in on the future--nuclear energy. A small research reactor built by General Atomics in the United States was reassembled on site at that meeting in Geneva, for people to explore. They could look at it in operation, through a protective water shield, to watch it produce radioisotopes for medical and industrial use. (This reactor was built in just two years after scientists came up with the idea for a small, safe teaching reactor.)

The working reactor on display in Geneva was afterwards shipped to the University of Lovanium in the Congo, in Leopoldville, to be used in training engineers, technicians, and scientists. Two countries, Italy and Vietnam, ordered research reactors on the spot, and many other nations subsequently ordered these Triga reactors. (Now, there are 65 of them in 24 countries, including 1 in Bogota since 1997.)

A year later, in 1959, another Triga research reactor was put into operation in India, at the World Agriculture Fair in New Delhi. President Eisenhower himself was there to push the button to start it. Three million Indians came to see the reactor in operation, producing isotopes for use in medicine and agriculture. This was the start of India's nuclear program, under the scientist Homi Bhabha, who planned a broad, 50-year nuclear development program for India.

At that time, in the fifties, the United States opened its universities and laboratories to the world, and developing-sector students came here to study nuclear science and engineering. Argonne National Laboratory, for example, trained 800 students. (Argonne is near Chicago, and was involved in building the first nuclear reactor or "pile" in the Manhattan Project during World War II.) This cadre of trained people then returned to their home countries, to become the nucleus of their scientific elite, and to establish nuclear programs.

In the last 50 years or so, which I have lived through and seen, the world has drastically changed. There was a deliberate campaign to stop this progress, to snuff out scientific optimism, led, not incidentally, by the same financial faction that funded Hitler and brought him to power. In the decade of the 1960s, when I attended college, the rock-drugs-sex counterculture was deliberately introduced to steal the minds of the 1968ers--a whole generation of youth who could have continued the spirit of Atoms for Peace and President Kennedy's Apollo Program to put man on the Moon.

I graduated in 1964, just before the big changes. Five and six years later, when my younger brothers were in college, it was a completely different culture, no more focussed on the idea of progress, of developing one's own knowledge and skills in order to improve conditions in the rest of the world. Probably many of you are too young even to have had the experience of living at a time when it was assumed that mankind could, and would, solve any problem--poverty, hunger, environment, disease.

Where We Are Today

And so, here we are today, not where the Atoms for Peace generation had planned, but diverted from the path of progress into globalization (another name for colonial control and exploitation) and more primitive technology. We have incredible advances in science and technology—and yet, still, incredible poverty, disease, and war. We have poverty in the United States, where the top 20 percent of the population had an income in 2005 that represented 51.4 percent of ALL national income; more than the combined income of the other 80 percent of U.S. households. And income in this 80 percent continues to shrink, even where families need two and three jobs, just to survive.

We cannot talk about the nuclear renaissance under way today, without situating the great hope for mankind's future that advanced technologies promise, within the grim political reality. We have the United States, the former industrial giant, in the grip of warmongers Dick Cheney and his puppet President, playing out the scenario of endless imperial wars to distract people from the looming financial collapse. We have to change this--fast, before there is yet another war.

21st Century Science & Technology magazine, of which I am the managing editor, is associated with the political movement of Lyndon LaRouche, the American statesman whom you have probably heard of, who is leading the fight to set up a new Bretton Woods financial system, and to establish community of nations led by Russia, China, India, and the United States, to reinstitute a policy of development--building our way out of the current depression.

LaRouche developed the plan for a World Land-Bridge, a maglev railroad system linking Eurasia from Eastern China to Rotterdam, with a northern route across Siberia, through a tunnel across the Bering Strait to Alaska and then throughout the Americas, from Canada down to the southern tip of Argentina. Other links would cover Asia, Africa, and Australia.

Along the Land-Bridge, across the barren lands of Eurasia which are rich in resources but totally undeveloped, for example, we would build new cities, agro-industrial centers powered by nuclear energy. These nuplexes of the future, would be centers of learning, for new industries, mineral extraction, and so on. These development plans are our answer to imperial wars and imperial directed terrorism.

(You can read more in detail about LaRouche, his science of physical economy, and the Land-Bridge at <http://www.larouchepub.com> or <http://www.larouhepac.com>)

The concept I want to stress here is vision: What is your vision of the next 25 years, the next 50 years, the next 100 years? What kind of a future do you want to leave for your children and grandchildren? Do you

want them to have a better life, better education, better health, better opportunities to develop than our present generation? Or, because of what we don't do, will the future generations degenerate to a Dark Age culture. This is really at the heart of why we have to go nuclear and then on to fusion. It is also the reason that it is foolish to pursue the so-called biofuels.

Today I will focus on the nuclear and energy questions, to cover the developments worldwide for building new nuclear plants, all kinds of plants--floating nuclear plants, high temperature gas cooled reactors, large conventional reactors, fast reactors that breed more fuel than they consume. I'll describe the new generation of nuclear plants with some of their applications, like making hydrogen for fuel, or desalinating seawater, and give you some idea of how to get those 6,000 plants built. I will talk about the next generation of development: the Isotope Economy, which involves thermonuclear fusion, and its possibilities for the generation of new resources, with the fusion torch.

I will also discuss biofuels, in the context of "energy flux density," which gives you a measure of energy generation and shows why nuclear is superior not only to biofuels, but to oil, gas, coal, wood, solar, wind, and so on.

Who Is Going Nuclear?

The nuclear renaissance is worldwide, but Asia is in the lead, having the most new nuclear plants under construction and planned. Here are some of the highlights, just to give you an idea of "nuclear on the move."

China. China now has 10 nuclear plants producing 8.6 gigawatts of power and intends to build two new nuclear plants a year, increasing to 40 gigawatts of nuclear power by 2020, and 120 to 160 gigawatts by 2030.

So far, China's largest plants have been imported, but it has an indigenous power plant program that will be able to build plants for domestic use and for export in the future. The estimate is that by 2017, China will have its first indigenously developed pressurized water reactor in operation, and by 2020 it will be able to rely on its own technology for new plants.

China's next large plant will be built in Shandong province on China's east coast, and will use Westinghouse technology.

There is also a large reactor site, Tianwan, that will eventually have four Russian VVER-1000 reactors in the east coast city of Lianyungang in Jiangsu province. This port is the Eastern end point of the Eurasian Land-Bridge, which will connect China, via Central Asia, to Rotterdam, the Netherlands.

The Tianwan project has one unit in operation, and another that just started operating on July 11. It is the largest joint project that China and Russia have ever undertaken, and has room for four more nuclear-generating units.

It is also of note that China has built a demonstration high-temperature pebble bed type reactor with a plan for more HTRs, has a fast reactor under construction, and has a pilot fuel reprocessing plant in operation. In addition, China has about 10 research reactors in operation, plus an advanced fusion energy program.

Taiwan. Taiwan has six nuclear reactors, with two in construction. Nuclear supplies 22 percent of its electricity.

India. India also has ambitious nuclear plans. India now has 17 operating nuclear plants, 15 of them small and two of them medium size, producing 3.5 gigawatts of power, with plans to reach 40 gigawatts by 2020. India also has an abundant supply of thorium (the second largest supply in the world) , which, like uranium, can be used as fission fuel. And so its future plans center on developing a thorium fuel cycle.

India's nuclear program dates back to the Atoms for Peace days of the 1950s, when the nation decided on a three-stage nuclear program. The first stage used natural uranium in pressurized heavy water reactors; India now has 12 of these in operation. The second stage was to extract plutonium from the spent fuel of these reactors, to use as fuel for fast breeder reactors. These fast reactors would use a mixed oxide fuel to breed

uranium-233, which is fissile, in a “blanket” of thorium around the core of the fast reactors. Then, in the third stage, the fast breeders would use thorium-232 as fuel, producing uranium-233 for use in new reactors.

In addition to the three-stage plan, India also plans to build several large reactors to get to its goal of 40 gigawatts of nuclear by 2020. Russia is building two 1,000-megawatt VVER reactors in India, and there are plans for eight more units at the same site (Kudankulam).

India already has a small experimental fast breeder, and plans to build a larger, 500-megawatt prototype. It has in construction an advanced heavy water reactor, a hybrid design that will demonstrate the technology for thorium. India is also developing a small, sealed thorium breeder reactor (60 to 100 megawatts) that would need no refueling and no maintenance! This reactor is especially designed for rural areas.

One of the drivers for India's ambitious nuclear program is the need to desalinate seawater in order to meet the large and growing demand for freshwater. Nuclear energy is the most efficient way to power these desalination plants, and India has one nuclear desalination unit in operation, with more planned.

South Korea. South Korea has 20 nuclear reactors, supplying 40 percent of its electricity--26.6 gigawatts. Its program dates back to 1957, and there are plans to expand the number of reactors to supply 60 percent of its electricity by 2035. There are now eight reactors in construction or planned to meet this goal. Although the earlier reactors were “turnkey,” built by Western companies, South Korea has developed and is building a AN indigenously designed reactor. It also hosts the pilot project for DUPIC, an International Atomic Energy Agency program that chops up spent fuel and burns it as new fuel in reactors.

Japan. Japan has 55 reactors, supplying 30 percent of its electricity--47.5 gigawatts. As an island, Japan has almost no native sources of energy (oil, gas, or uranium), and so it has an ambitious program to gain self-sufficiency by completing the nuclear fuel cycle. This means recycling spent fuel and developing the fast breeder reactor to produce new fuel.

Japan plans to increase the percentage of nuclear to 37 percent by 2009, and 41 percent by 2014. There is one reactor under construction, another one almost in construction, and plans for 10 more reactors to come on line between 2012 and 2017.

Japan's reactors include two built by General Electric, 1,350 megawatts each as part of the Kashiwazaki nuclear complex that was hit with an earthquake July 16--and withstood the quake, while the area around it was devastated. Because it's in a high-earthquake zone, Japan builds its plants to withstand the highest level of quake that the area experiences. You probably noticed the headlines about this in the news, which talked about a “radioactive leak.” Actually the leak was radioactive at the level of one-billionth of the allowable level! And was just 300 or so gallons of water. This was hardly something to worry about when the whole area that was hit had no water or power and thousands of people were homeless. Yet, that is what the press headlines focussed on.

Russia. Russia has reorganized its nuclear program and plans to move forward rapidly to build new plants for domestic use and for export. The new, state-run agency that will handle the entire civilian nuclear enterprise is called AtomEnergProm, or AEP.

Now, 31 plants supply about 16 percent of its energy--21.7 gigawatts. The government intends to bring the nuclear percentage up to 23% by 2020 and 25% by 2030 (50 gigawatts), and at the same time to export nuclear plants and build turnkey plants for other countries. Three reactors are now under construction.

You are all familiar with Chernobyl, and the problems of the RBMK type of plants, which did not have containment buildings or the safety controls of plants in the West. But that has now changed, and Russia's new plant designs incorporate Western safety standards.

Russia plans to build fast reactors, mass-producible reactors, and, most exciting, floating nuclear plants, two of which are now in construction. The idea of a floating plant dates back to the 1960s and the Atoms for

Peace period, when floating plants on barges were envisioned as a way of bring electrical power to undeveloped coast areas around the world, to electrify them and begin industrial development.

The Russian design is for a 70-megawatt plant, which can supply a small city with power and desalination. Already, China, Indonesia, Malaysia, Algeria, Cape Verde, and Argentina have expressed interest. The plants would be designed to operate for 12 years, with on-site refueling every 3 to 4 years, and then return to the Russian shipyard for refurbishment. Russia plans to build seven more floating plants, which can be used to supply power in its remote areas for oil and gas exploration.

Also of note, Russia and the U.S. company General Atomics are collaborating on the engineering and construction of a fourth-generation modular high temperature gas cooled reactor that will burn weapons plutonium as fuel.

United States. Here in the United States, there has not been a new nuclear reactor commissioned since 1978. There are now proposals for 20 new reactors, most of them large advanced third-generation reactors. The construction and licensing procedure is ongoing, plus a lot of talk.

What killed the U.S. nuclear program, which had envisioned under Atoms for Peace, 2,000 nuclear plants by the year 2000 is an important story, which you can find (in English) in an article on the *21st Century Science & Technology* website, by Marsha Freeman (<http://www.21stcenturysciencetech.com/articles/spring01/nuclearpower.html>) Some of the same factors of course hold for Western Europe and South America: deliberate financial sabotage through high interest rates, and a well-funded environmentalist movement designed to stop the United States from being an industrial nation.

The United States now has 104 nuclear plants, which supply about 20 percent of U.S. electricity.

Western Europe. Briefly, the percentage of electricity production supplied by nuclear power varies; it's 80 percent in Lithuania, 78 percent in France, 33 percent in Germany. You can find a full list at the website of the World Nuclear Association.
<http://www.world-nuclear.org/info/inf01.html>

As for new reactors, Finland is constructing its fifth reactor, to come on line in 2011, and France is building a 1,600-megawatt plant, to come on line in 2012. Several other nations have new reactor plans.

South Africa. South Africa has two conventional nuclear plants in operation, supplying about 6 percent of its electricity. The country has an intensive nuclear development program, centered on the Pebble Bed Modular Reactor, a German design that South Africa is developing as a small, mass producible plant--165 megawatts--which is meltdown proof and very versatile. Its higher temperatures can be used for industrial processing, and it can be installed in up to eight units at a site, as needed, all using one control station.

South Africa plans to have a prototype built by 2011, and to build up to 30 reactors for domestic use and export. (They have an electricity demand that is growing much faster than the present capability to supply it.) Eventually, South Africa foresees export of 30 reactors per year. The PBMR is a fourth-generation nuclear reactor, which I will describe further below.

Also planned is another conventional reactor. By 2030, South Africa expects to have nuclear provide 30 percent of its electricity (27 gigawatts). Unlike the United States, the South African government ministries--Environment, Industry, etc. have given their full support to the PBMR as the country's future.

Ibero-America. Closer to home, both Argentina and Brazil are moving forward with nuclear energy, after a long period of no activity, largely the result of U.S. pressure on the bogus issue of "nonproliferation" and the oligarchy-funded green movement.

Argentina will complete Atucha 2 by 2010, and has plans to build a small Carem reactor. This indigenous Argentine design, developed in the 1980s, was recently installed in Australia as a 27-megawatt research reactor. It can be used for electricity production or for desalination.

The country's two nuclear reactors now supply about 8.6 percent of its electricity, and Argentina's Planning Minister announced that over the next 25 years, Argentina should have 5,000 megawatts of nuclear produced electricity.

In *Brazil*, the government recently made a decision to construct a third nuclear plant, Angra 3. Much of the equipment for the plant is already on site. Angra 1 and 2 produce 1,896 megawatts--about 4 percent of the electricity supply.

Mexico has two nuclear reactors at Laguna Verde, which supply about 5 percent of the nation's electricity--1.37 gigawatts. There is talk of building more nuclear power, and a decision was made two years ago to invest in increasing the power output of the two existing plants.

New nuclear nations. Most exciting on the nuclear front is the number of countries that are planning or discussing their first commercial nuclear plants--Vietnam, Thailand, Turkey, Bangladesh, Algeria, Egypt, Jordan, Malaysia, Indonesia, Saudi Arabia, Yemen, Angola, Myanmar, Ghana, and Namibia, among others. Tunisia has signed a nuclear cooperation agreement with France; Algeria has signed nuclear agreements with Russia and the United States; Morocco is studying the feasibility of a nuclear desalination plant, in cooperation with China; Bangladesh has a nuclear cooperation agreement with China; South Korea has signed a nuclear cooperation agreement with Vietnam--and these are just some of the developments in the works.

In Ibero-America, both Venezuela and Chile are in discussions about nuclear. A private group in Chile has had discussions with Areva about a new nuclear plant there.

The Energy Needs of the Future

Unless you foresee a return to a caveman society, the world will need more energy. How much more? Right now, 1.7 billion people in the world have no electricity. If we do nothing to change policies, the International Energy Agency says, there will still be 1.4 billion people without electricity in 2030.

(I think that is much too conservative a view. If we don't make policy changes now, the world population will shrink because of increased death rates from disease, poverty, and unmitigated natural disasters. The economic situation will devolve, including in the developing sector.)

The various international institutional estimates put the world energy requirements at a growth rate of 53 percent by 2050. The question then, is how most efficiently to meet this growth? We cannot immediately stop reliance on coal and oil, even though those resources should be reserved, as soon as possible, not for electricity production or transportation but for special industrial uses, such as petrochemicals. We have a certain amount of hydropower, and a certain amount of gas.

As for the so-called soft energies, there is no way, despite the fervent wishes of the greens, that solar, wind, etc. can provide baseload power for an industrial society. As I explain below, those forms of energy are intrinsically too diffuse to provide anything more than specialty applications. "Appropriate technologies," so called, for the developing sector are just another name for racism and keeping people in the dark. In Kenya, for example, a small medical clinic with a new solar panel--the supposedly appropriate technology for this part of the world--supplies enough electricity for the refrigerator or the medical equipment, not both at the same time.

The most efficient way to fill that energy gap, to get from where we are now to where we need to be to meet the projected demand, is to go nuclear.

James Muckerheide, the state nuclear engineer for Massachusetts, worked out a preliminary plan for how to build those 6,000 nuclear plants needed by 2050. (These would supply only 30 percent of the world's electricity needs in 2050, by the way--the equivalent in megawatts of supplying 100 percent of today's

electricity needs.) To come to the figure of 6,000 plants, Muckerheide looked at an estimated world population of 9 to 10 billion by 2050. He considered per capita energy usage today, and aimed for a substantial increase in such usage in the developing sector.

You can read Muckerheide's full article on the website of *21st Century* (<http://www.21stcenturysciencetech.com/Articles%202005/6000NuclearPlants.pdf>). In brief, he shows that nuclear power is competitive and cost-effective. He describes how you would organize the production of plants not on a plant-by-plant basis, but on a manufacturing-based strategy. As France did in the 1970s, you would choose a type of plant design and then build multiples of that design, mass producing the components. There would be such mass-production plans for a few types of plants, as I discuss below.

For example, across Eurasia, you would advance like the development of a cross-country railroad, from one key node to the next, developing the back-up industries needed to produce the reactor components, and building not just new plants from one node to the next, but building new factories to mass produce new nuclear plants for the next node.

The pessimistic critics of nuclear complain that we could never build enough plants to make a difference. I've read at least three such reports in the last month, including one by the Council on Foreign Relations. But all these reports are premised on the fact that it can't be done, before they even start to figure out how to do it! None has the idea of modular plants that could be mass-produced. None of them really cares about the consequences, in terms of human life, of **NOT** building 6,000 nuclear plants. (In fact, all of them presume that the world would be better off with fewer people.) And then there is the issue of nonproliferation, which, I contend, was invented in order to prevent most of the world from developing civilian nuclear energy.

The Oxford Research Group in England, for example, issued one of these pessimistic reports in early July, saying that the "it would be impossible to build even 48 new reactors per year, between now and 2075," the number it deemed necessary for "global warming" mitigation (a phony argument) The Oxford Group therefore concluded, why bother with nuclear, and advised that "nuclear power should be taken out of the energy mix."

The director-general of the World Nuclear Association, John Ritch, answered them very sharply. "If the OECD countries, plus China and India, were to build at France's 1980s start-up rate, the result would be five reactors per week, rather than one," he said. France built an average of 3.4 reactors per year from 1977 to 1993, achieving a nuclear share of electricity near 80 percent. "Whereas the [Oxford] authors dismiss as a pipedream the idea that the world's nations might somehow combine to build one reactor a week," Ritch said, "the future expansion of nuclear power will probably be even more rapid."

Another useful figure that Ritch has come up with is that about half the reactors operating today (218 out of 435) were put on line between 1980 and 1989--an average of one every 17 days. So why can't we do it again, after an initial period to gear up our production capabilities?

Ritch labelled the Oxford report as "a grab bag of fatuities that blends ignorance and ideology in equal measure," a description I think that fits the other such reports I have read.

Nuclear Power Plants and How They Work

To conclude this section, I will briefly describe how nuclear fission works, and some of the different types of plants that we will be building.

Fission is the splitting of the atomic nucleus of heavy elements, such as uranium, producing a quantity of heat (in the form of fast-moving particles) that is thousands of times greater than that obtained from burning an equivalent amount of coal, oil, or natural gas. When uranium fissions, each nucleus divides into two or more lighter elements. The fission is initiated when the uranium nucleus captures a neutral particle, called a neutron, which has been ejected by another atomic nucleus. The fission process is very fast; after a neutron is freed, it stays that way only for about 1/10,000th of a second. What makes fission so unique as a source of energy is the way it can multiply.

In fissioning, each uranium nucleus gives off two or more neutrons. This means that once the fission process is initiated, it can continue by itself, as the neutrons from each fissioned uranium nucleus trigger new fissions in nearby nuclei. This process is called a nuclear chain reaction.

In general, the heat from the fissioning is used to make steam that turns a turbine and creates electricity. A nuclear plant is like any other power plant in this respect. It is simply using a different fuel source--uranium--to create the heat.

Most conventional nuclear plants are light water reactors (LWRs), meaning that they are water cooled. Some of these are pressurized water reactors (PWRs) and others are boiling water reactors (BWRs).

There are 435 commercial nuclear reactors in the world in 30 countries. There are also 284 research reactors in 56 countries, plus another 220 reactors that power ships and submarines. The majority (284) of the commercial power reactors are PWRs; 94 are BWRs. The remaining reactors are mostly the Canadian-designed CANDU, which uses an unenriched uranium fuel, and a heavy water moderator.

The 6,000 plants we need to build will be a mixture of the next-generation conventional plants--General Electric's Advanced Boiling Water Reactor, for example--and new designs.

We need to build many kinds of nuclear plants: large ones for urban-industrial centers, medium and small reactors for developing nations and remote areas, breeder reactors to create new fuel, and fusion-fission hybrids to make the transition to a fusion economy.

The Fourth-Generation Reactors

The workhorse of the next-generation of nuclear reactors will be the modular high-temperature gas-cooled reactor, both the Pebble Bed Modular Reactor (PBMR) and the Gas-Turbine High Temperature Reactor (GT-MHR), because of their inherent safety and versatility. The PBMR, originally a German design (a small plant operated there from 1967-1989), is being built in South Africa, and a small plant now operates in China. The second, designed by the San Diego-based General Atomics, is being built in prototype in Russia, with the aim of burning excess plutonium from weapons.

The advantages of these reactors is that they are small enough to be modularly produced on an assembly line and shipped to the plant site for assembly, thus cutting the production costs. The nuclear site can be configured to start with one or two units and build up to six or eight, as needed, making use of a single control building. Thus a developing country, where the electricity grid is small, can start off with one unit, and build up as the country develops.

The GT-MHR is a 285-megawatt plant with passive and inherent safety features that make a meltdown impossible. Its tiny fuel particles are encased in ceramic spheres, which serve as "containment buildings" for the fission process. The overall design prevents the reactor from ever getting hot enough to melt the tiny ceramic spheres that surround the nuclear fuel. The fuel particles can withstand heat of 3,632 degrees F, and the reactor core temperature remains below 2,912 degrees F. The spheres are mixed with graphite and shaped into cylindrical fuel rods, which are then inserted into hexagonal fuel blocks that make up the reactor core.

The high temperature output of the reactor (1,560 degrees F), compared to the 600 degrees F limit of conventional water-cooled nuclear reactor, gives it greater generating efficiency and allows a wide range of industrial applications. It uses a direct-conversion gas turbine, with no steam cycle--a big improvement. The heat is carried by the helium gas, which is also the coolant. This simplifies the system and increases efficiency. The GT-MHR is 50 percent more efficient than conventional light-water nuclear reactors.

The PBMR works essentially the same way. Tiny nuclear fuel particles are coated with layers of ceramics. But unlike the GT-MHR, the fuel particles are then embedded into fuel pebbles the size of tennis balls. Each of these balls contains about 15,000 fuel particles and about one-quarter ounce of uranium. The balls, 310,000 of them, circulate around the reactor. One advantage of this design is that the reactor can be continuously refueled, adding new fuel pebbles at the top, and removing spent fuel pebbles from the bottom of the reactor.

The unique fuel particles for both these reactors, about 0.75 millimeters (0.03 inch), were pioneered at General Atomics in the United States in the 1950s. They have several concentric layers of temperature-resistant materials--porous carbon, pyrolytic carbon, and silicon carbide, which "contain" the fission reaction of the uranium, even at very high temperatures. In fact, the fuel pebbles can withstand temperatures at which the metallic fuel rods in conventional light water reactors would fail.

Both of these reactors are located underground, with the auxiliary systems and control room above ground. The overall design of the reactor is meltdown proof. In addition to the usual control rods, which can slow down the fission process, there are two coolant systems, a primary system and a shutdown coolant system. If both of these were to fail, the reactor is designed to shut down on its own. There is a passive back-up system, whereby the heat from the reactor core is transferred by natural conduction to the reactor walls, which naturally convect the heat to an external sink. The concrete walls of the underground structure are lined with water-cooled panels to absorb the core heat from the vessel walls. Should these panels fail, the concrete of the structure alone is designed to absorb the heat.

In any type of loss-of-coolant accident, the reactor can withstand the heat without any operator intervention. Both of these reactor designs can be scaled up to 1,000-plus-megawatt reactors if there is a need.

Other Advanced Reactors

There are other advanced reactor types that will be part of the "6,000 by 2050." Fast neutron reactors, or breeders, will be necessary in order to create new nuclear fuel. The idea here is to make use of fast neutrons that will interact with a blanket of uranium-238 or thorium-232 around the reactor core, to create plutonium through fissioning. At the same time, the reactor will produce heat to make electricity. Eventually, depending on the reactor configuration, the fast reactor produces more fuel that it takes to run the reactor. This makes nuclear renewable!

In a conventional reactor, it should be noted, moderators like graphite are introduced to slow down the fast neutrons, because it is the slower neutrons that fission. Scientists early on, worked out exactly the speed required to cause fission in different types of fuel.

Japan has decided to make the fast reactor its standard in the future. In the United States, so far, the fast reactor is being conceived by the Bush-Cheney Administration in its GNEP (Global Nuclear Energy Partnership) as simply a way to burn up plutonium, not breed more fuel.

In the future, we will develop a very-high-temperature reactor, for use in industrial processing, and also a fusion-fission hybrid, which will pave the way for developing full fusion reactors. In the hybrid, neutrons from the fusion reaction interact with a blanket of fission fuel to create new fission fuel, which can be periodically removed from the blanket for use in nuclear reactors. These were reactor designs conceived and discussed 30 to 40 years ago, but then languished as we were pushed into the "post-industrial" hell.

Why Nuclear Is Superior

What is the proper way to measure man's progress? How do you evaluate a technology? Lyndon LaRouche developed the concept of potential relative population density, per capita and per square kilometer. If you look at the history of civilization, you see how man's inventions, man's creativity, his leaps in technological innovations, have allowed for the support of larger and larger human populations.

Human beings are the only form of life able to do this. Animals cannot creatively intervene in this way. There is a qualitative difference between man and beast.

Energy technologies have been especially important in the capability to support a larger population. It is only in recent centuries with the successive introduction of wood, coal, oil, and fission as energy sources that the world's population has taken off. (Of course, these resources were all "created" by man; coal was just a shiny rock, until its use was discovered and developed.) LaRouche's concept looks at this in terms of how each advance in technology enables a given population to be supported by a smaller amount of land. A grazing society, or a hunting and gathering society, for example, are limited by the area required to adequately feed the population enough to reproduce itself. In other words, the potential relative population density of a more primitive society is limited.

This advance can be measured in terms of the increase of energy-flux-density per square centimeter of the cross-section of the process involved--such as a boiler. Think of a laser, which focuses precisely on a target, compared with a hammer or knife. The laser can exquisitely shape an industrial form, or perform delicate surgery on human beings, compared with a hand-held knife. The laser's flux density and its efficiency are very high.

If we look at energy sources, the more concentrated the source, the more economical and efficient it is. In the chart of energy flux density, measured in megawatts per square meter, you can see that fission has a five-fold increase in energy flux density compared to fossil fuels, and that the various forms of solar energy are orders of magnitude inferior to the more advanced forms of energy. The more concentrated or dense the energy produced is, the more efficient and economical it is.

And so, although you can consider solar energy "free"--at least while the Sun is shining, and when you factor out the cost of installing solar collectors and maintaining them--it is a very dispersed form of energy. At the Earth's surface, its density is only ten thousandths of a megawatt. That means that to create as much electric power as one standard coal-burning plant, you need thousands of acres of solar collectors. At that rate, solar can never provide enough energy for an urban industrial society. At best it can have limited "niche" uses.

The use of coal, oil, and gas is an improvement in efficiency. You are not simply collecting the energy, but you are using the chemical process of combustion in an increased energy flux density to produce megawatts of energy. Fission, as you can see, has five to twenty times the energy flux density. In the future, as we develop working fusion reactors, or fission-fusion hybrids, we will have energy-flux densities trillions of times greater than at present. And we will have entirely new forms of energy, beyond heat, that are developed from the properties of advanced nuclear reactions.

Beyond that, although I can't be specific, I am sure mankind will invent even more efficient forms of energy, if we create the proper conditions now for future generations to develop.

Another way to visualize the efficiency of nuclear and fusion, is to look at comparisons of their fuel. As the energy density increases, the volume of fuel needed to do the same amount of work decreases. You can see that it takes .57 gram of fusion fuel, or 1.86 grams of uranium fuel to equal the energy in 30 barrels of oil at 42 gallons each, 6.15 tons of coal, or 23.5 tons of wood.

(These calculations were carried out in 1985 by Dr. Robert J. Moon, a physicist who worked with the Manhattan Project, creating the first nuclear reactor. Moon worked closely with LaRouche and with 21st Century. You can read more about him and his inventive work on the website of 21st Century.)

Think also about the savings involved in mining, transporting, and handling those large amounts of fuel. That's why, although the capital costs of building a nuclear plant may be higher than those of building a gas-burning plant or a coal plant, the continuing supply of fuel to an operating nuclear plant is comparatively small in cost.

Nuclear Is Renewable!

The beauty of the nuclear fuel cycle (and this is something we have posted in detail on our website http://www.21stcenturysciencetech.com/2006_articles/NuclearFuel.W05.pdf) is that nuclear is renewable. This is not just, as I mentioned earlier, that you can create more fuel in a breeder reactor than you put into it to run it, but also because you can recycle used nuclear fuel into new fuel. There is really no such thing as nuclear "waste."

To understand the "renewability" of nuclear fission fuel, we have to look at the complete fuel cycle. At the beginning of the nuclear age, it was assumed that nations would complete the fuel cycle--including the reprocessing of spent nuclear fuel from reactors, to get as near to 100 percent use of the uranium fuel as possible. Here I will very briefly review the seven steps of this cycle. Keep in mind that the brevity of description leaves out details of the complex chemical processes, which were initiated during the Manhattan Project and are still being improved on.

1. First, natural uranium is mined. There are enough sources of uranium worldwide for today's immediate needs, but once we begin an ambitious nuclear development program (to build 6,000 nuclear reactors in order to provide enough electricity to bring the entire world population up to a decent living standard), we would have to accelerate the development of fast breeder nuclear reactors, which produce more fuel than they consume in operation.

2. Next, the uranium is processed and milled into uranium oxide (U₃O₈), called yellowcake, which is the raw material for fission fuel. Yellowcake became infamous in the political fabrication that Saddam Hussein's Iraq was trying to import yellowcake from Niger, in order to use it for bomb-making.

It is basically natural uranium ore, which is crushed and processed by leaching (with acid or carbonate) to dissolve the uranium, which can then be extracted and concentrated to 75 percent uranium, in combination with ammonium or sodium-magnesium.

3. The concentrated uranium is then converted into uranium hexafluoride (UF₆), which is heated into a gas form suitable for enrichment.

4. Natural uranium has one primary isotope, U-238, which is not fissionable, and a much smaller amount of U-235, which fissions. Because most uranium (99.276 percent) is U-238, the uranium fuel must go through a process of enrichment, to increase the ratio of fissionable U-235 to the non-fissionable U-238, from about 0.7 percent to 3 to 4 percent. (Weapons uranium is enriched to about 93 percent U-235.)

The technology of enrichment was developed during the World War II Manhattan Project, when the object was to create highly enriched uranium (HEU) to be used in the atomic bomb. Civilian power reactors use mostly low-enriched uranium (LEU). (The exception is Canada, which developed the CANDU reactor which uses unenriched, natural uranium.)

The gaseous diffusion method of enrichment, which is still used by the United States, was developed under the Manhattan Project. Uranium hexafluoride gas is pumped through a vast series of porous membranes--thousands of miles of them. The molecules of the lighter isotope (U-235) pass through the membrane walls slightly faster than do the heavier isotope (U-238). When extracted, the gas has an increased content of U-235, which is fed into the next membrane-sieve, and the process is repeated until the desired enrichment is reached. Because the molecular speeds of the two uranium isotopes differ by only about 0.4 percent, each diffusion operation must be repeated 1,200 times.

The Manhattan Project devised this method of gaseous diffusion with incredible speed and secrecy. It was not finished in time to produce all the uranium for the uranium bomb dropped on Japan, but it produced most of the enriched uranium for the civilian and military programs in subsequent years. Although a successful method, it required a tremendous amount of energy and a huge physical structure to house the "cascades" of separate membranes. Four power plants were built in Oak Ridge, Tenn., to power the process, producing as much electric power as the consumption of the entire Soviet Union in 1939! Almost all the power consumed in the diffusion process is used to circulate and compress the uranium gas.

At the time the gaseous diffusion plant was being built, scientists had not yet figured out how to make a membrane to be used in the process--but they did it in time to make it work!

The centrifuge system, used in Europe and Japan, is 10 times as energy efficient. The strong centrifugal field of a rotating cylinder sends the heavier isotope in uranium hexafluoride to the outside of the cylinder, where it can be drawn off, while the U-235 diffuses to the inside of the cylinder. Because of the limitations of size of the centrifuge, many thousands of identical centrifuges, connected in a series called a cascade, are necessary to produce the required amounts of enriched uranium.

A centrifuge plant requires only about 4 percent of the power needed for a gaseous diffusion plant, and less water is needed for cooling.

Other methods of enrichment are possible—electromagnetic separation, laser isotope separation, and biological methods. The laser isotope separation method existed in a pilot plant at the Lawrence Livermore National Laboratory in California, but under the "privatization" of the Reagan Administration, this technology was sold to a private company, which then decided, based on a foolish short-term way of calculating, that it

wasn't "cost-effective" to develop the advanced technology. This company then shut down the working pilot plant.

5. Once the enriched uranium is separated from the depleted uranium, it is converted from UF₆ into uranium dioxide and fabricated into uniform pellets. The pellets are loaded into long tubes made out of a zirconium alloy, which captures very few neutrons. This cladding prevents the release of fission products and also transfers the heat produced by the nuclear fission process in the fuel. The fuel is then transported to the reactor site.

Different types of reactors require different designs of fuel rods and fuel bundles. In a light water reactor, the fuel rods are inserted into the reactor to produce fission. The fuel for the next-generation high-temperature gas-cooled reactors is different, as discussed above.

6. Fuel rods are used for about four and a half years before replacement, and usually a reactor replaces about a third of its fuel at one time. The fuel is considered spent when the concentration of fissile uranium-235 becomes less than 1 percent. When removed from the reactor, the spent fuel is put into cooling pools, which shield it as its short-lived nuclides decay. Within a year, the total radioactivity level is only about 12 percent of what it was when the fuel rod came out of the reactor.

At present, unlike other nations, the United States does not reprocess spent fuel, and so the spent fuel rods sit in cooling pools at the reactor. After the spent fuel has cooled, it is stored in dry casks, waiting--for "burial" or reprocessing.

But the spent fuel is not "waste"! It contains between 90 and 95 percent of usable uranium, that can be separated out and recycled into new fuel, and it also contains a smaller amount--about 1 percent--of plutonium, a fuel for breeder reactors.

7. Now for the remarkable *renewability* of nuclear fuel. The spent fuel from a single 1,000-megawatt nuclear plant, operated over 40 years, is equal to the energy in 130 million barrels of oil, or 37 million tons of coal. Why bury it? Extract it and process it into new fuel. Short-sighted policy makers decided in the 1970s, for no good reasons, that it was preferable to prevent the full use of this potential by burying the spent fuel in a once-through cycle.

The reprocessing method that was successfully used in the United States at the Savannah River facility in South Carolina for military purposes is just as efficient for civilian spent fuel. Spent fuel rods are processed to remove the highly radioactive fission products, and separate out (partition) the fissionable U-235 and plutonium.

This plutonium could be directly used as fuel for breeder reactors, which was the intention of the completed fuel cycle. It can also be used to make mixed-oxide fuel, or MOX, which some of today's reactors are being converted to burn as fuel. (Thirty-five reactors in Europe now use MOX fuel.)

The reprocessing facilities at Savannah River were called "canyons" because they were tall, narrow buildings. The spent nuclear fuel was handled remotely by technicians who were behind protective walls. This was large-scale industrial processing, which was entirely successful, safe, and safeguarded.

Once the uranium was separated out, it was sent to another building at Savannah River to be fabricated for weapons use. The remaining amount of highly radioactive fission products--a tiny fraction of the spent fuel--was set aside for vitrification and storage. Today, the technologies exist, or could be developed, to extract valuable medical and other isotopes from this 3 percent of high-level waste. Virtually all of the spent fuel could be made usable.

U.S. civilian spent fuel could be reprocessed in a similar fashion using the Savannah River model--or by new technologies still to be developed. Right now, Britain, France, Russia, and India reprocess civilian spent fuel, using the Purex method (which stands for Plutonium Uranium Extraction), and Japan has a commercial reprocessing plant now in a start-up phase. Other nuclear nations send their spent fuel to Britain or France for reprocessing, or they store it. China reprocesses military spent fuel.

Reprocessing makes the anti-population faction very nervous, because it implies that nuclear power will continue to develop as a source of electricity, and with a cheap and clean source of power, there are no limits to growth. Malthusians and other alarmists rant about the "dangers of proliferation," but if you poke them, what they are really concerned about is the potential for nuclear energy to expand, and population and industrial development to grow.

The overt arguments against reprocessing are mostly scare tactics: Permitting U.S. reprocessing will make it easier, they say, for "bad guys" to build bombs--or dirty bombs. This is the gist of the objection, although it may be posed at length in more academic (and tedious) language.

But this argument is one based on fear--fear that an advanced technology can never be managed properly, and fear that we will never have a world where there aren't "bad guys" who want to bomb us. It is the opposite of the Atoms for Peace philosophy.

In fact, if one is truly worried about diversion of plutonium, why not burn it to produce electricity, instead of letting it accumulate in storage? And as Savannah River manager William P. Bebbington, a veteran of the Manhattan Project wrote in a famous 1976 article on reprocessing, "Perhaps our best hope is that someday plutonium will be more valuable for power-reactor fuel than for weapons, and that the nations will then beat their bombs into fuel rods."

A second objection is that reprocessing is not "economical" it is cheaper to have a "once through cycle" and discard the spent fuel. But the cost/benefit basis on which such economics are calculated is a sham. What is the cost of *not* reprocessing--in terms of lives lost and society not advancing? And what about the cost of the storage of spent fuel--not to mention the still unused U.S. storage facility at Yucca Mountain, Nevada, which has become a costly political and emotional football.

The "proliferation" argument was key in 1976 in stopping U.S. reprocessing. Fear was fed by the idea that reprocessing would make more plutonium available, which could be diverted by "rogue" nations or groups to make clandestine nuclear weapons. President Ford, the incumbent, carried out a secret study, and issued a nuclear policy statement on Oct. 28, 1976, just five days before the election, which advocated an end to reprocessing.

Jimmy Carter, who won that election, then carried out the policy to stop U.S. reprocessing; and the next President, Ronald Reagan, sealed the lid on the fuel-cycle coffin with the idea of "privatizing" both reprocessing and breeder reactors.

The full story of how reprocessing was stopped still has to be told. But the ending of the story is clear: The United States shot itself in the foot--twice: (1) The United States stopped an important technology, which it had pioneered, and (2) the U.S. anti-reprocessing policy did *absolutely nothing* in the rest of the world to stop other countries from developing the full nuclear fuel cycle, or desiring to.

Commenting on President Carter's 1977 policy to shut down reprocessing and the Clinch River Breeder Reactor, Bernard Goldschmidt, a preeminent French nuclear scientist, who had studied with Marie Curie, wrote: "By this extraordinary and unique act of self-mutilation, an already declining American industry was to become paralyzed in two key sectors of future development, fuel reprocessing and breeder reactors, precisely the sectors in which the United States was already between 5 and 10 years behind the Soviet Union and Western Europe, in particular, France...."

Interestingly, the Republican Ford Administration's policy in 1976, which advocated killing U.S. reprocessing for the same fallacious reasons that Democratic President Carter later elaborated, was written under the direction of Ford's chief of staff--Dick Cheney. And one of the key reports supporting Carter's ban on reprocessing was written by the mentor of the leading neo-cons in the Bush Administration, Albert Wohlstetter, then a consultant to the Department of Defense.

Once the political decision is taken to begin an ambitious nuclear construction program, reprocessing--both Purex and new technologies--will follow.

Biofuels: A Dead End

Biofuels are not a new concept. In the 1970s, LaRouche's publications were already warning that the concept was dangerous and would destroy agriculture and the labor force in Brazil. As we warned then, the only way biofuels from sugar cane could be considered "profitable," and I use that word in its most limited sense, was to employ slave labor to cut the sugar cane. Indeed, this is exactly what is happening today. In June, Brazilian anti-slavery police freed 1,108 such slaves from a sugar cane plantation in the state of Para.

To me, using food crops, or any crops that take away from necessary food production is crazy. It is self-cannibalization, like eating your arm or leg, when you are starving. It is a continuation of the colonial looting system, where cartels drained nations of their raw materials and enslaved their population, preventing development.

This point is perhaps most important. Here, I will quote from my husband Laurence's analysis of the ethanol question, which you can read on the websites of *21st Century* and LaRouche.

"In evaluating so-called biofuels, it is necessary to distinguish between energy and *power*. The useful *power* contained in a kernel of corn is not to be measured by the number of kilocalories or BTU's of heat that can be generated by burning either the whole kernel, or its less-energetic ethanol derivate. Thus, we come to a ... paradox: In terms of raw heat energy, there is several million times more available energy in a gram of slightly enriched uranium than in a kernel of corn. yet the corn kernel contains more *power*, because it represents a far higher degree of organization of matter. Its *power* to support human or animal metabolism is not only greater, but immeasurably so. (Just imagine eating one or the other, and the point may be grasped immediately.)"

The projection is, that by 2008, half of the U.S. corn crop could be siphoned off into ethanol. Right now, one-third of the U.S. corn crop is going to ethanol. To take any percentage of U.S. farm acreage away from food crops to grow corn for ethanol means that prices will skyrocket and people will starve. The only beneficiaries are the cartels, like Archer Daniels Midland and Cargill, which are making record profits.

In Mexico, where corn prices went up by 60 percent in December 2006, there was a tortilla crisis; the government was forced to cap the price of corn. In Italy, there is now a looming pasta crisis, as durum wheat acreage has been converted to corn for biofuels, and the price of pasta is already up 10 to 20 percent. The price spike affects the entire food chain, as prices soar for livestock feed for cattle, chickens, and pigs.

The United Nations World Food Program director Josette Sheeran told the July 16 Financial Times that food cost increases "mean we are now able to reach far less people" with a total amount of food aid which, at \$600 million annually, hasn't changed since 2000. She said that WFP purchasing costs for all types of food have risen 50 percent in five years. Because of the maize and cereal price increases, she said, "We face the tightest agriculture markets in decades, and, in some cases, the tightest ever on record." Global wheat stocks are at their lowest levels in 25 years, while at the same time, the world's population has grown by 60 percent, according to the U.S. Department of Agriculture.

In the May/June issue of Foreign Affairs magazine, two U.S. agricultural economists conservatively estimated that if "the prices of staple foods increased because of demand for biofuels ... the number of food-insecure people in the world would rise by over 16 million for every percentage increase in the real prices of staple foods. That means that 1.2 billion people could be chronically hungry by 2025."

The idea that ethanol can break even in terms of energy balance is a gigantic scientific hoax. My husband's in-depth research on the matter showed that when all the inputs are taken into account it takes considerably more energy to produce a gallon of ethanol that can be derived from it. Dr. David Pimentel of Cornell University's College of Agriculture and Life Science, in the most recent study, showed that there is a negative net energy balance of 29 percent for corn ethanol.

The claims of U.S. Department of Agriculture and Department of Energy economists that new developments have changed this balance turn out to be a sham. To improve the economics on paper, they have taken a "coproduct energy credit" for the by-products of ethanol production that can be used in the preparation of animal feed. USDA leading economist Hosein Shapouri gives an energy "credit" of 26.6 percent of the total energy they had calculated for the entire ethanol production. His argument is that if such preparation had not used these by-products, it would have taken a certain amount of energy to produce them, hence ethanol gets an energy credit.

A further "coproduct energy credit" is given for the corn production and transport process. Shapouri argues that since ethanol is derived from the starchy part of the corn, and corn consists of only 66 percent starch by weight, only 66 percent of the energy cost of corn production and corn transport should be assigned to ethanol production. By this method, the total energy consumed in ethanol production miraculously shrinks, and there is a 67 percent net energy value.

I urge you to read the extensive documentation that my associates have compiled on biofuels, and to bear in mind the distinction between energy and power--the power in a kernel of corn in relation to human life.

As for the basic problem of how to replace the use of gasoline, the non-cannibalistic solution is to use the higher heat of nuclear energy to produce hydrogen for fuel, and more immediately to generate nuclear electricity to power hybrid/plug-in electric vehicles.

The Isotope Economy

In the Periodic Table of the Elements, there are tiny discrepancies in the elements that have nearly identical chemical behavior but very different physical properties. These isotopes have been known since the discovery of fission, where, as discussed above, a tiny fraction of natural uranium--0.7 percent--is the fissionable isotope U-235, while the rest is the unfissionable U-238. Over the past 60 years, we have developed many specialized uses for isotopes, particularly the use of radioactive isotopes in medicine. Radioisotopes are commonly used for diagnostic testing, and less so (which is a shame) for treatment of tumors and cancerous tissue. But this is just scratching the surface of what we know, and what we can do.

In the present century, developing our knowledge and use of the 3,000 or so known isotopes, will take us to new levels of understanding and control of physical processes here and in the rest of the universe. I am sure that we will be able to "retire" some of the laws of physics. This revolution in human science is described in a lengthy article by Jonathan Tennenbaum available on the website of *21st Century* (http://www.21stcenturysciencetech.com/2006_articles/Isotope_Economy.pdf).

What I will discuss here is one specific part of the Isotope Economy: the development of thermonuclear fusion and the fusion torch. The fusion torch captures the essence of the Isotope Economy, for its high temperatures will enable us to get rid of waste--all kinds of waste--by reducing it to its constituent elements, and to create new mineral resources by "mining" ordinary dirt and rocks. No more dangerous coal mines, or other underground mines. And no more mountains of garbage. Who could rationally object to these advances in human civilization?

Thermonuclear Fusion

In fission, the breaking apart of the heaviest elements (like uranium) a tremendous amount of heat energy is released. As a fuel, uranium is 3 million times more energy dense than coal, and 2.2 million times more energy dense than oil. But fusion of hydrogen isotopes is orders of magnitude more energy dense, and more challenging to harness as a power source.

When two atoms of the lightest element, hydrogen, are fused, the process produces helium (the second-lightest element) and "free" energy in the form of heat. For every two nuclei of hydrogen as fuel, there is one helium nucleus (called an alpha particle) produced and a specific amount of energy, which comes from the difference in mass between the input hydrogen and the output helium.

Fusion is the process that goes on in the Sun and the stars, as the light elements collide at high speeds and high densities. The problem is how to replicate the process here on Earth. To fuse atoms in the laboratory requires very high, Sun-like temperatures--tens of millions of degrees Celsius--and a means of containing and controlling the reaction, sustaining it at a steady rate over a long period of time.

In both the Sun and the laboratory, ultra-high temperatures strip the negatively charged electrons from the nuclei, resulting in a highly charged gas, called a plasma. Plasma, called the fourth state of matter, is a more familiar word now, because of television screen technology. Plasma screens have two thin layers of glass, with the gases argon, neon, and xenon trapped inside; the atoms of the gas are excited to the plasma state by electric pulses, emitting color.

Since the 1950s, scientists have explored different ways of heating and confining hydrogen nuclei to fuse atoms of the heavier hydrogen isotopes of deuterium (H-2) and tritium (H-3). The ordinary hydrogen nucleus (H) has one proton, deuterium has one proton plus one neutron in its nucleus, and tritium has one proton plus two neutrons. Deuterium is found naturally in seawater, but tritium is rare, and has to be created by the decay of lithium.

The two basic methods to control fusion are known as magnetic confinement and inertial confinement.

Magnetic confinement. In this method, magnetic fields are used to “hold” the fusion plasma in place. The most common magnetic reactor device is called a tokamak, from the Russian words for toroidal (donut-shaped) chamber. The fusion plasma is contained using a strong magnetic field created by the combination of toroidal and poloidal magnetic fields (the first refers to the long way round the torus, and the other, the short way). The resulting magnetic field forces the fusion particles to take spiral paths around the field lines. This prevents them from hitting the walls of the reactor vessel, which would cool the plasma and inhibit the reaction.

Just as in fission, where the speed and density of fissioning atoms, and the most favorable isotopes had to be carefully determined and engineered, to create the optimal conditions for a chain reaction, so in fusion, researchers had to figure out the most favorable hydrogen density and other conditions to produce fusion. Here is where the fun came in, designing different apparatuses to test hypotheses about sustaining and controlling a fusion plasma.

There are many tokamak research reactors around the world, including some small ones in the United States, and there was a succession of increasingly larger tokamaks at the Princeton Plasma Physics Laboratory, which I was lucky enough to see in person in the 1980s. This increasing capability would have continued, if not for the budget cuts described below. Each successive reactor achieved higher temperatures and longer confinement times. Each reactor also made progress in solving the technical difficulties, such as heating, turbulence, and radiation.

The largest current device is an internationally sponsored tokamak, ITER (pronounced “eater”), to be built in Cadarache, France, with the aim of producing breakeven fusion power; that is, outputting more power than that required to create the fusion on a steady basis. The sponsors are the European Union, Japan, the Russian Federation, Korea, China, India, and the United States. The ITER's goal is to produce 500 megawatts of fusion power sustained for up to 500 seconds. ITER's predecessor, JET, the Joint European Torus, produced only 16 megawatts for less than a second.

ITER will produce net power as heat, but the heat will not be used to generate any electricity. Ned R. Sauthoff, project manager for the U.S. participation in ITER, estimates that ITER will be operating by 2016, and that commercial plants will follow by 2050. A commercial power plant would generate about 3,000 to 4,000 megawatts of thermal power.

Inertial confinement. In inertial confinement, also known as laser fusion, lasers or electron beams are focussed on a small pellet of fusion fuel, igniting it in a tiny controlled fusion explosion. In contrast, in the hydrogen bomb, fission is used to ignite fusion fuel in an *uncontrolled* fusion reaction. The term “inertial” refers to the fact that the atoms in the target have to use their own inertia not to fly apart before they can fuse.

The basic idea is to rapidly heat the surface of the target so that it is surrounded by a hot plasma. Then as the hot surface material “blows off” like a rocket, the fuel is compressed. The target fuel core becomes extremely dense, and then ignites when it reaches 100 million degrees Celsius. As it “burns,” it produces many times more energy than the input beam energy.

The United States has a large laser fusion facility at the Lawrence Livermore National Laboratory, the NIF or National Ignition Facility. Other inertial confinement laser programs are the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics), the Nike at the Naval Research Laboratory, and the Trident at Los Alamos National Laboratory. There is also a Particle Beam Fusion Accelerator and the Saturn pulsed-power facility at Sandia National Laboratories.

All the inertial confinement programs provide support for the National Nuclear Security Administration of the Department of Energy and other defense programs related to nuclear weapons, as well as civilian energy and basic scientific goals. The weapons aspect makes them a target for anti-nuclear groups, who want to shut down the weapons program and anything else that has to do with nuclear, including fusion energy. The NIF also has university and industry collaboration.

NIF is the largest laser in the world, the size of a football stadium, and very powerful. The laser system equals 1,000 times the entire U.S. electric-generating power. Each pulse is very short, just a few billionths of a second, directed at a tiny target, 1 millimeter—the size of a BB-gun pellet. The experiments involve directing this powerful beam for just a fraction of a second at the target, and then studying the results.

What Happened to Fusion

The last 25 years of fusion research in the United States is a sad story; the fusion program became a victim of such severe budget cuts, that no engineering progress could be achieved, just research in scientific problem-solving. Yet, in 1980, fusion research had been progressing so well, with a wide variety of fusion devices, that both houses of Congress passed the Magnetic Fusion Energy Engineering Act of 1980, which mandated, in the spirit of the Apollo Program, that the United States accelerate the current magnetic fusion program (1) to put on line an engineering device by the year 1990, and (2) to put on line a demonstration reactor by the turn of the century.

The Act, Public Law 96-386, was signed into law on Oct. 7, 1980, by President Carter. The Act's purpose was: "To provide for an accelerated program of research and development of magnetic fusion energy technologies leading to the construction and successful operation of a magnetic fusion demonstration plant in the United States before the end of the twentieth century to be carried out by the Department of Energy."

The Act specified how this was to be done, and the required funding: a doubling of the 1980 magnetic fusion budget in the next seven years, starting with a 25 percent funding increase in the fiscal years 1982 and 1983.

The Fusion Energy Foundation, launched by Lyndon LaRouche, Jr., in November 1974, was in the middle of the fight for fusion, and the Foundation's magazine, *Fusion*, the predecessor of *21st Century*, which had a circulation of nearly 200,000, made "fusion" a household word in the years before the successful passage of the Fusion Act. It provided the public with an understanding of the science of fusion and of the experimental progress with different species of fusion devices.

But, the funds specified in the Fusion Act were never allocated under the Reagan Administration. The Act remained on the books, but the Department of Energy relegated fusion to be a "science research" program only, not the engineering program specified in the legislation. Like the Apollo program, fusion drew the wrath of those who said it would cost too much--with no regard for the boon to future generations of perfecting a high-temperature power source whose fuel was obtained from seawater, and which had no waste products. These critics--including, since 1989, many "cold fusion" researchers, whose research is also not funded--then complained that fusion research had gotten X amount of money for years, without producing commercial fusion, so why bother putting more money into a "sinkhole."

The overall problem is a profound ignorance of how a physical economy works, and, for a healthy economy, what percentage of public funds should be invested in the scientific research to be a "driver" for the rest of the economy. Without such science drivers, the economy runs into a dead end. As the United States sank further into "services" instead of production, and chiseled and "privatized" the research programs of its national laboratories, universities, and other institutions, the nation largely lost the ability to discover new scientific principles, and educate new generations of students who could move the country forward.

Without a reversal of these anti-science, anti-prosperity policies, the United States will collapse into Third World status, having to import technologies perfected elsewhere. We need a crash program to regain what we lost, and ensure that we implement the thrust of the 1980 Magnetic Fusion Energy Engineering Act in the next 25 years.

Where we stand today in fusion, is having a handful of U.S. research reactors, all inching along in national laboratories, universities, and at one private company (General Atomics), with a small core of experienced fusion scientists and a small number of younger students.

Creating a fusion reactor for a fusion economy is an example of a great project, planning for 50 years ahead, when most of the initial participants will no longer be alive. But what better inspiration for the younger generations, to work on perfecting a virtually unlimited energy source--instead of dung power.

The Fusion Torch

In May 1969, two researchers with the U.S. Atomic Energy Commission, Bernard J. Eastlund and William C. Gough, published a booklet, "The Fusion Torch: Closing the Cycle from Use to Reuse," which described two uses for the ultra-high temperature plasmas that were expected to be achieved with commercial fusion reactors. The first was a fusion torch that would use the high-temperature plasma "to reduce *any* material to its basic elements for separation." The second was "the use of the fusion torch to transform the energy in the ultra-high temperature plasma into a radiation field, to permit process heating to be done *in the body* of a fluid." For example, heavy elements would be added to the plasma so that it emits X-rays or other radiation in large quantities to do work without the limits of a surface that would absorb some of the energy.

Their idea, conceived in 1968, captured the imagination of many, including the major press, which reported on the fusion torch with headlines like "Space-Age Science Would Atomize Pollutant Wastes" (*Washington Post*, Nov. 26, 1969) and "Drowning in Waste? Vaporize It by Fusion!" (*New York Times*, March 15, 1970).

In the first application, the fusion reactor-produced plasma energy flux would be used for shock vaporization (the propagation of shock waves) and ionization of a solid, such as garbage or rock. Then, separation techniques would be used to "segregate the ionic species according to either atomic number or atomic mass." Eastlund and Gough noted that there were several possible separation techniques, including electromagnetic, quenching of the plasma flow, selective recombination, or charge exchange.

In the second application, trace amounts of chosen elements would be injected into the fusion torch plasma, allowing the control of the frequency and intensity of the radiation emitted. For example, the plasma could be made to output radiation in the ultraviolet range. Because ultraviolet radiation can be absorbed in water to a depth of about 1 meter, the ultraviolet radiation could then be absorbed into the working fluid, to sterilize or desalinate water in bulk, process sewage, or be directly converted to electricity (through fuel cells). This method eliminates the problem of having to transfer heat from a *surface* to the body of the fluid, which limits the process heating.

Making the Plasma Work

Eastlund and Gough present detailed ideas and mathematical equations in their 1969 paper concerning the atomic composition of the plasma, its flow velocity, and energy losses. Region II in the torch diagram is designed as the area where any neutrons produced by the fusion source (Region I), especially with the deuterium-tritium cycle of fusion, are isolated by trapping them in a lithium blanket. The resulting working plasma in Region III, like the plasma throughout the fusion torch, would have its density, temperature, and flow velocity controlled by methods that were already researched in 1969.

In their 1971 paper, Eastlund and Gough present a schematic for fusion torch recycling of solid waste, which they say would fit "quite naturally into the overall scheme" of then-planned solid waste treatment facilities. The solid wastes would be shredded, dried, and sorted, and then various combinations would be injected into the fusion torch plasma to be vaporized, dissociated, and ionized. The end products could then be separated out into specific elements for collection and recovery. The energy used to produce the plasma could also be recovered, in large part, because the system operates at such a high temperature.

The ionization of the solids occurs as the plasma energy is absorbed into the surface layer of the solid, producing a shock wave that vaporizes and ionizes it. This is possible only with an ultra-high temperature plasma, where the energy flux is greater than the shock speed in a solid and the energy needed to vaporize per unit volume. The resulting plasma that leaves Region III of the fusion torch would then be separated into constituent elements at lower temperatures.

Eastlund and Gough discuss several methods of separating the ionized solids into constituent elements, all of which could be handled in one recovery plant. Electromagnetic separation tops the list. In their 1969 paper, they note that the primary interest is in separating just a few elements with large mass differences. For example, reducing iron oxide ore ($\text{FeO}@i2$) would require separation of iron (mass 56) from oxygen (mass 16). They note at the time that there had been advancement in plasma physics and beam handling, so that electromagnetic separation was more attractive as a technology.

Another separation technology noted, which Eastlund and Gough thought would have low capital cost and no energy, is quenching, rapidly cooling the plasma flow, by injecting a cooler gas, flowing the plasma over a cold surface, or expanding the plasma flow. This would work with ore reduction, especially high grade ore with impurities; recovery of elements from eutectics (low melting point combinations), alloys, and low-grade metal scrap; and the elimination of plastic and paper waste products. This method of recycling could be used, Eastlund and Gough said, with "modified plasma technology" already available in 1969.

Selective recombination is another separation technique, where the temperature and density of the plasma would maintain conditions that would allow some of the elements in the plasma to recombine on the walls of the torch chamber, while others were "piped away." This method is based on the ionization characteristics of the species involved.

A fourth technique suggested in the 1969 paper is charge exchange. In this method, a beam of a gas would be sprayed at the flowing plasma stream from the fusion torch, and an atom or molecule in the injected gas would replace a selected ion in the plasma. The desired combination would be collected on the wall of the torch chamber, while the rest of the material would be magnetically piped away.

The method of separation would also depend on the state into which the solid was transformed by the fusion torch. Eastlund and Gough list four different stages: (1) conversion of the solid into a gaseous state, (2) the complete dissociation of the molecules, (3) raising the temperature of the gas to the point that some of the elements are ionized, and (4) raising the temperature of the gas to the point that all the elements are ionized.

The ability to transform the waste solids into the above states selectively, makes it possible to use a combination of methods to most inexpensively reduce solid waste into its constituent elements. For example, the major heavier elements in solid refuse (aluminum, copper, magnesium, tin, iron, lead, etc.) could be ionized at a temperature of 10,000 K, and separated out, while the lighter elements (carbon, oxygen, and hydrogen) could remain as neutral gases and handled chemically. Eastlund and Gough calculate that this partial ionization process would save 35,000 kW/h of energy.

Of course there are problems to solve in developing fusion and the ultra-high temperature plasma torch. Plasmas are tricky to handle, a lot of energy is involved, new materials need to be developed. But these are the kinds of problems and challenges that can be solved--if one wants to solve them.

Where Do We Stand Today?

Gough and Eastlund conclude their 1969 report:

"Ultra-high temperature plasmas are available *now*, although at a cost in energy. Little thought has gone into their potential use for industrial applications, nor has much imaginative thought gone into taking full advantage of the unique properties of fusion plasmas that will be available in future controlled thermonuclear energy sources.

While not attempting to minimize the large amount of research both on fusion itself and on fusion torch physics, it is entertaining to speculate on the vision this concept provides of the future—large cities, operated electrically by clean, safe fusion reactors that eliminate the city's waste products and generate the city's raw materials.

"The vision is there; its attainment does not appear to be blocked by nature. Its achievement will depend on the will and the desire of men to see that it is brought about."

Today, nearly 40 years later, where do we stand? We don't have fusion yet, or the fusion torch. As Eastlund told the Fusion Energy Foundation back in 1975, the kind of research needed for developing the fusion torch was not going on. "What's required," he said, "is a commitment by a responsible funding agency to put some solid underpinning to the physics, chemistry, and technology of fusion torch applications."

The commitment to do this is still not there in the United States. But some of the technologies explored by Eastlund and Gough have been incorporated into lower temperature plasma torches that are now used in industry. Universities, the national laboratories, and many private companies have explored plasma processing, and make use of plasma torches. The plasmas are heated by microwaves or by passing a gas through an electric arc between two electrodes in a plasma generator.

The Russians and others have used a low-temperature plasma torch process to produce steel from scrap metal. The East Germans and Soviets developed the process in the late 1960s, and commercialized it in the 1970s. At the time, their direct current argon plasma torch method reduced the cost of steel production by \$400 per ton, compared to conventional high-temperature electric arc furnaces. Also, it cut the noise level from 140 decibels to only 40 decibels. The argon plasma torch produced temperatures of 15,000 degrees C, compared to maximum temperatures of 3,600 degrees C for conventional furnaces using electricity for energy.

The Japanese have developed the Plasma Type Incinerated Ash Fusion System, with a demonstration plant in Chiba City to recycle incinerator ash and reduce solid waste.

Today, Ben Eastlund holds three patents for plasma processing techniques that could perform the tasks outlined in his 1969 article. Specifically, Eastlund has more recently proposed that his Fusion Torch/Large Volume Plasma Processor, or LVPP, be applied to the recycling of nuclear spent fuel from civilian nuclear plants and tank wastes left over from the Department of Energy weapons program. The LVPP would use an ultra-high temperature plasma to extract the radioactive components from bulk waste products using a "dry" process, as opposed to conventional technologies that use acids or molten metals, and a prototype could be in operation in two years. On his website (<http://www.Eastlundscience.com>), Eastlund writes:

"The Large Volume Plasma Processor can be used to separate the elements contained in the waste on an element-by-element basis. The non-radioactive elements can be released into the environment after ensuring there are no radioactive elements contained therein. The radioactive components would be recovered in a form suitable for conversion to industrial uses, severely reducing the volume of material slated for geological storage. Furthermore, because the 10,000,000 degree temperature of the LVPP can ionize any material, the uncharacterized nature of the material in the tanks does not present a problem.

"The LVPP could significantly reduce the financial risk of proceeding with cleanup of the Hanford tanks. The 'wet chemistry' approach requires the construction of large facilities that need to be financed up-front. Years will pass before their operation can be assured as a success.... The LVPP, a relatively small system, immediately begins separating radioactive materials. The material is injected as a slurry, ionizes in 300 millionths of a second, and is separated in less than 25 milliseconds. Separated material can be removed as often as needed, continuously for many elements, to assure that there is never a dangerous inventory in the system. When the tanks have been cleaned, the LVPP can then be easily removed from the site. In fact, the tanks themselves might be processed by the LVPP."

The fusion torch, in the form of the LVPP or in other forms, has the promise of supplying the world with new resources and getting rid of our garbage and waste with no pollution. As Dr. Eastlund suggests just above, the fusion torch can even turn the radioactive waste containers into usable materials!

What are we waiting for? Any true environmentalist who cares about the world should happily jump on the fusion torch bandwagon for 21st Century technologies, instead of crawling into the doom, gloom, and cold of the Stone Age.

We need to return to a culture of optimism and to take up the Atoms for Peace banner, training the next generation of engineers, technicians, and scientists who will build those 6,000 nuclear plants, develop fusion energy, make use of the fusion torch, and bring about the Isotope Economy.

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