A Call for an International Crash Program

Creating the Fusion Economy

by *21st Century Science and Technology* Staff

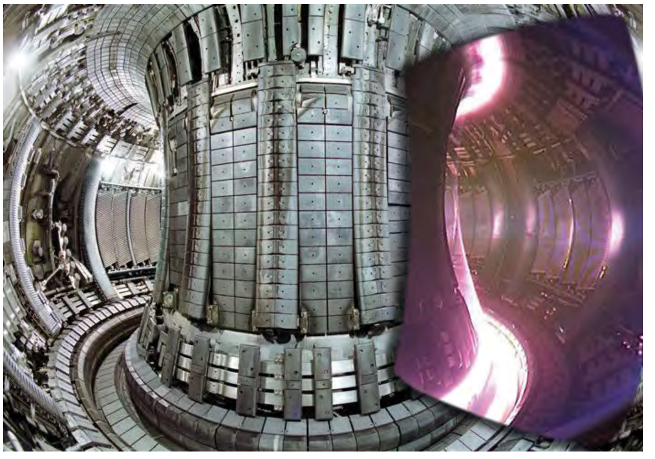
We have reached the point that not only is man's power to harness the processes of the Sun an emerging reality, it is in fact an existential necessity.

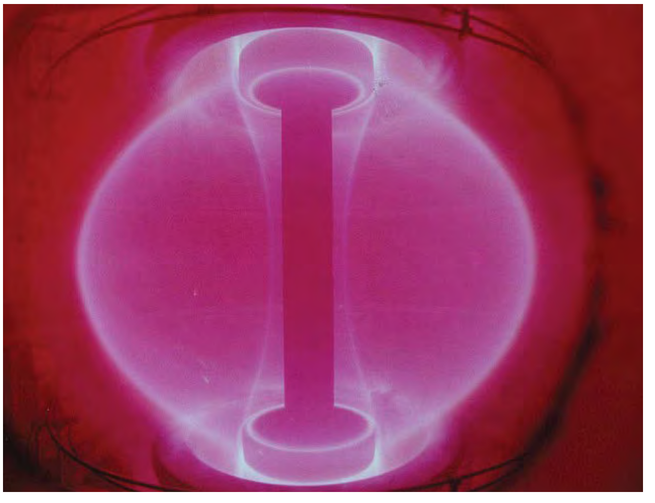
We must now direct our creative faculties and physical resources, in an international collaboration reaching from Eurasia to the Americas, towards achieving critical breakthroughs in the domain of thermonuclear processes. This is the already-delayed next step in the willful process of human evolution, illustrated by the previous successive transitions from a wood-based society, to a coal economy, then to petroleum and natural gas, followed by the higher potentials of nuclear fission power (see Appendix 1: Energy Flux Density).

By increasing what the American economist Lyndon LaRouche has defined as the *energy flux density* of the economy, we gain control over processes of higher energy throughput per unit of area, as expressed in a wide range of technologies, infrastructure projects, and production methods. With the fusion economy energy supplies become relatively limitless, since the fusion fuel contained in one liter of seawater provides as much energy as 300 liters of petroleum.

But this is more than limitless power. The fusion economy brings mankind into the domain of "high energy density physics,"[1] dealing with thermonuclear reactions and plasmas with energy densities on the order of 10^{11} joules per cm^3—a billion times the energy density of the battery in your smart phone—and the dynamic interrelationship between plasmas, lasers, fusion, and antimatter reactions. For example, ultra-high powered, petawatt, lasers are capable of producing extremely brief pulses of laser light 1,000 times as powerful as the energy coursing through the entire U.S. electrical grid (see Appendix 2: "The High Energy-Density Physics Platform").

This new platform brings a wide range of fusion-related technologies and experimental capabilities, from high-powered lasers, to particle accelerators, to high-temperature plasma generators, to directed energy explosions, all working in a dynamic relationship, complementing each other to transform mankind's entire economic system, eliminating any concerns over limited power or limited resources. Given the crises both in the United States and globally, this is an absolute necessity, and requires a global crash program, comparable to the Manhattan Project or the Apollo Program, but on an international scale.





Top: EFDA-JET; Bottom: U.K. Atomic Energy Authority:

Above, the Joint European Torus, below, superheated plasma.

1. For example, see "Frontiers in High Energy Density Physics," by the Committee on High Energy Density Plasma Physics, Plasma Science Committee, National Research Council, 2003. http://www.nap.edu/catalog.php?record_id=10544

What is Fusion?

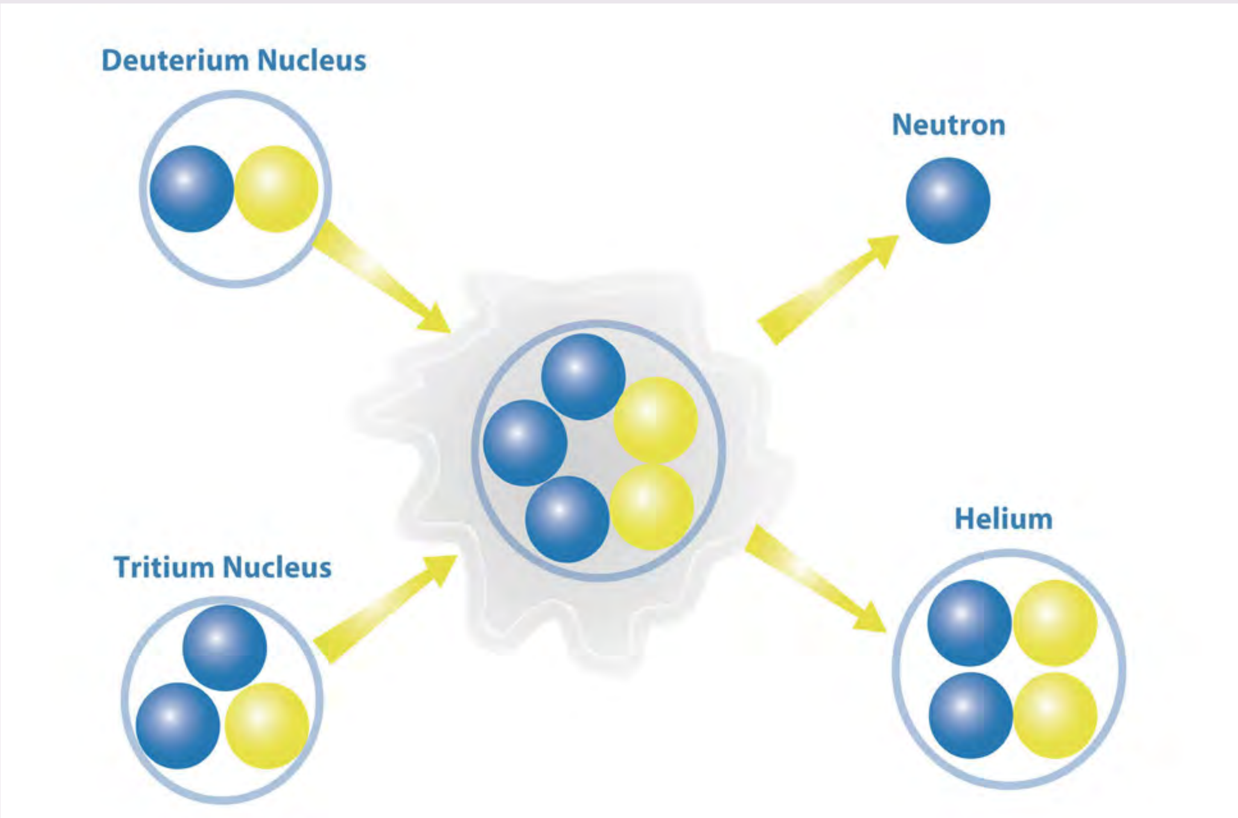
As opposed to fission, the breaking apart of the heavier elements (uranium, plutonium, thorium, etc.), thermonuclear fusion is the bringing together of the lightest elements (hydrogen or helium isotopes for example). When two isotopes of hydrogen are fused, the process produces helium and a free neutron (together weighing less than the sum of the two original hydrogen isotopes) plus the release of energy in accordance with Einstein's famous discovery that small amounts of mass can be converted into large amounts of energy (in proportion to the speed of light squared, $E = mc^2$).

These fusion reactants have energy densities millions of times greater than coal, oil, or natural gas, resulting in orders of magnitude less fuel required to generate comparable amounts of energy. For example, the same amount of electricity can be generated from either two million tonnes of coal (21,000 rail car loads), 1.3 million tonnes of oil (ten million barrels), 30 tonnes of uranium oxide (one rail car load), or one half tonne of the hydrogen isotope of deuterium (one pickup truck load).

Since ocean water contains deuterium, a fuel for fusion, the energy available with fusion is relatively limitless.

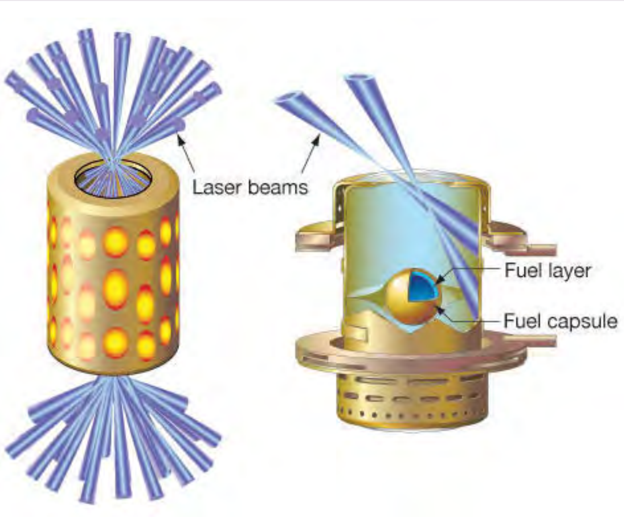
Fusion is the process that goes on in the Sun and the stars, as the light elements collide at high speeds and high densities. In both the Sun and the laboratory, ultra-high temperatures (50–200 million degrees) strip the negatively charged electrons from the nuclei, resulting in a highly charged state of matter called a plasma, in which any material can be manipulated at its atomic level. To fuse atoms in the laboratory requires not only ultra-high temperatures, but also a means of containing and controlling the reaction, sustaining it at a steady rate over a long period of time.

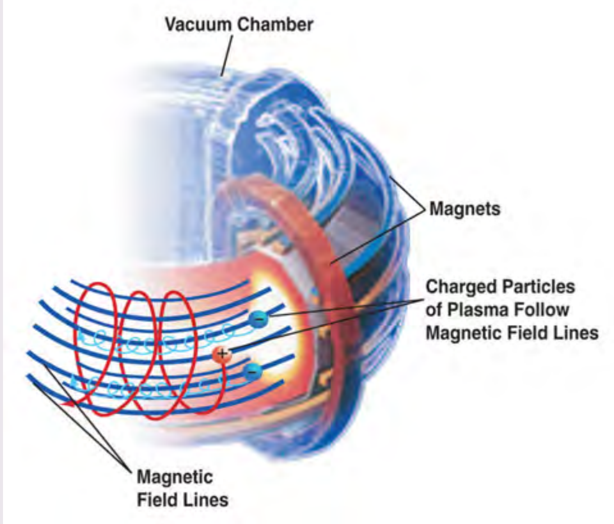
Since the 1950s, scientists have explored different ways of heating and confining hydrogen nuclei to fuse atoms of the heavier hydrogen isotopes, deuterium (^2H) and tri-



"The Surprising Benifits of Creating a Star," U.S. Department of Energy, 2001.

One type of fusion reaction: two isotopes of hydrogen, deuterium and tritium, combine to form a larger helium nucleus and a neutron, releasing energy in the process. Conditions of at least 100 million degrees under sufficient pressure are required to produce fusion.





Left: Lawrence Livermore National Laboratory; Right: "The Surprising Benefits of Creating a Star," U.S. Department of Energy, 2001

Left: This schematic of the National Ignition Facility shows its array of laser beams focussed on the tiny pellet of fusion fuel encapsulated in beryllium and carbide. The laser beams compress and heat the fuel pellet in a billionth of a second, so that the deuterium and tritium fuse before the pellet flies apart. The term "inertial" refers to the fact that the atoms must have enough inertia to resist flying apart before they combine. Right: This diagram of a fusion tokamak shows the magnets, the magnetic field lines, and the charged particles of plasma that follow the magnetic field lines, spiralling around the tokamak. The magnetic fields "contain" the plasma.

tium (^{3}H). Many proposals for devices and processes have been explored (tokamaks, stellarators, the ELMO bumpy torus, the z-pinch, to name a few). The two prevailing methods to control fusion are known as magnetic confinement and inertial confinement, both of which are embodied in the fusion research continuing today.

Progress in fusion research can be expressed in terms of increasing the "Lawson criterion," the product of plasma density, confinement time, and plasma temperature. The past several decades of research, despite chronic underfunding, have seen a 10,000-fold increase in this parameter. To make the breakthrough to commercial fusion requires a further increase of only about 10 times.

Full transformation will take some time, but certain fusion technologies can provide economic benefits in the relatively short term.

Already at the beginning of the fusion age, such visionaries as the co-founder of Lawrence Livermore National Laboratory and leading proponent of the Strategic Defense Initiative (SDI), Dr. Edward Teller, supported the utilization of the immense energy density made available with fusion reactions, in the form of Peaceful Nuclear Explosions (PNEs). It was demonstrated that this could revolutionize canal building, port construction, mining, aquifer creation, tunneling and other requirements of bulk earth moving. Today, PNE technology can be improved and applied for rapidly accelerating and cheapening the construction of vital projects, like NAWAPA XXI.

For materials processing and natural resources, the plasma torch, operating at temperatures below that required for fusion, can break down and separate many materials into their constituent elements and isotopes, meaning that chemical and nuclear "waste" can be processed into valuable resources. Such plasma torches can be a driver towards the higher densities of power achievable with a self-sustaining fusion reaction, at which point we could theoretically extract many times the current annual U.S. production of iron, copper, aluminum, and many other resources from virtually any cubic mile of dirt, and reprocess the valuable concentrations of materials in landfills.

Beyond separation and concentration of resources, a fusion economy allows for the creation of completely new materials with new properties, and even the transmutation of one element into another. For example, petawatt lasers have already demonstrated the ability to transform gold into platinum, and future transmutation potentials are much broader. Thus, the fusion economy demonstrates beyond a doubt that, for an advancing mankind, there are no limited resources, and no limits to growth.

While the broad-based implementation of some of these systems will require a generation or more of work, their future realization depends upon getting started now, and the first steps of a fusion economy are closer than you may think.

1. A Call for An International Manhattan Project

The slow progress in developing fusion power over the past four decades has been the result of political decisions, not scientific impossibilities. For example, in 1980 the U.S. Congress passed Congressman Michael McCormack's "Magnetic Fusion Energy Engineering Act," calling for a crash investment in fusion, and for the construction of a prototype magnetic confinement fusion reactor by the year 2000. However, the breakthroughs were never made because the program was simply never funded, as is indicated in the following graph of the annual fusion budget.

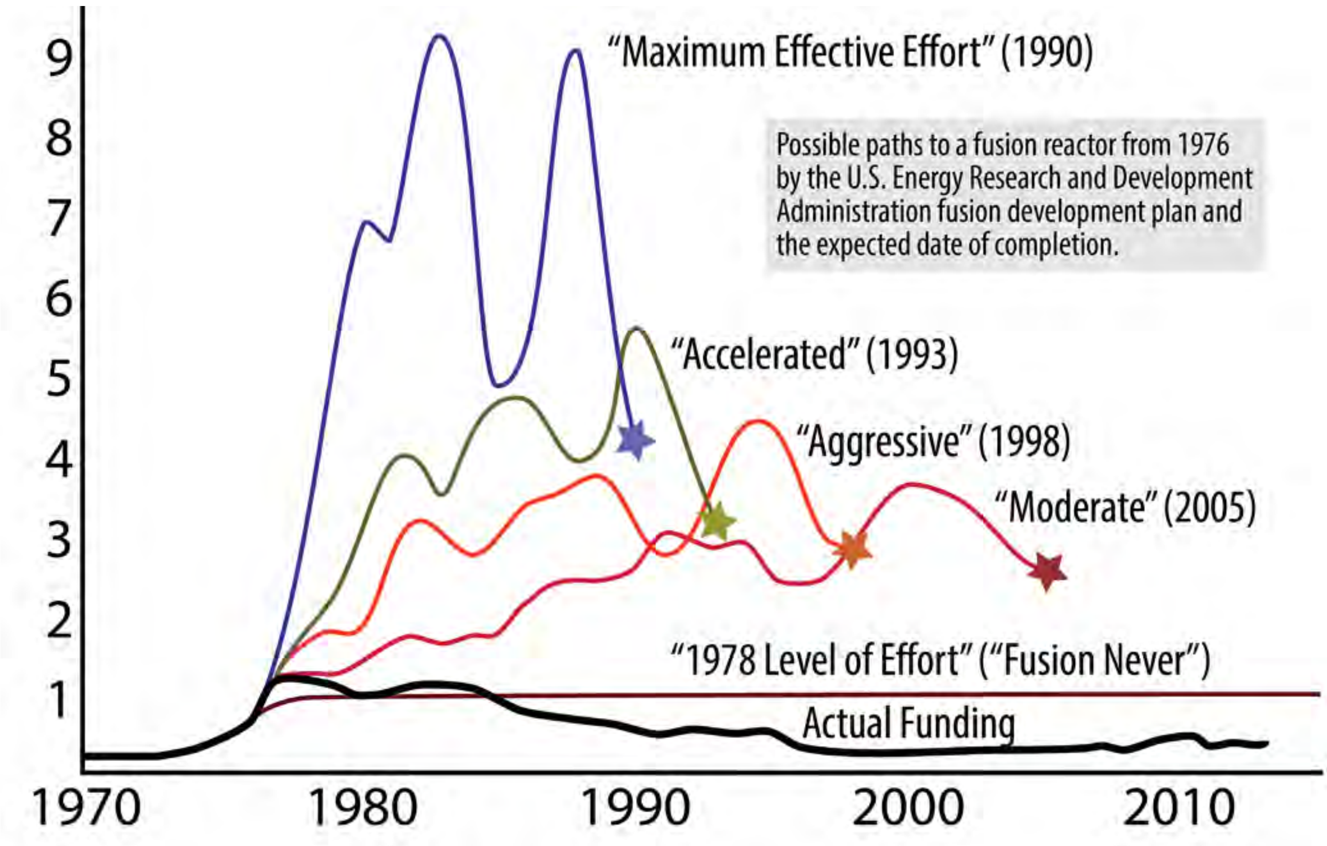
Thus, the challenge today is as much political as scientific. The *decision* must be made to develop the fusion economy; with this commitment, and with full funding and support of key governments, an international crash effort can make this a reality.

Fusion scientists from around the world (and especially the remaining veterans of the fusion efforts going back to the 1960s) must be pulled together to properly plan a serious crash program. The purpose of such a scientific gathering is clear: move the accountants out of the room, get the bureaucracy out of the way, and let the scientists hammer out what must be done from a scientific standpoint. No options should be off the table, including the revival of alternative fusion reactor designs which were shelved for political or budgetary reasons.

With the scientific, technical, and engineering considerations placed clearly on the table, a crash program can begin, pulling together the fusion and high technology resources of the United States, Russia, China, Japan, South Korea, the nations of Europe, and other countries, along with support from existing bodies such as the International Atomic Energy Agency (IAEA).

While this new crash program is being developed and implemented, an array of existing fusion programs can be fully supported and accelerated, including the large international project, the International Thermonuclear Experimental Reactor (ITER), which has been delayed because of lack of funding and poor coordination.

In the United States, greatly increased funding must be supplied to domestic fusion programs, reversing the



Credit: graphic design by Geoffrey M. Olynyk, incorporating 1976 projections from the U.S. Energy Research and Development Administration, "Fusion power by magnetic confinement: Program Plan," by S. O. Dean.

Four possible funding paths to create a magnetic confinement fusion reactor from 1976, measured in billions of dollars (adjusted to 2012 values). Actual funding falls below all projections, even a steady funding from 1978 levels (which was known to be too little to ever make the breakthroughs needed).

Obama administration's slashing of the fusion budget. This includes saving the Alcator C-Mod research facility at MIT (the largest U.S. training facility for students studying fusion) and funding the expansion of the fusion research going on at the nation's various national labs, universities, and industries.

Other nations can do the same, as with the advanced work going on in China with their Experimental Advanced Superconducting Tokamak (EAST), in South Korea with the Superconducting Tokamak Reactor (K-STAR), and the joint Russian-Italian IGNITOR project, among others.

These are only a few examples of ongoing work. A full survey of currently existing programs and past proposals must be done from the standpoint of an open-ended international crash program effort. This will lead to a selection of new demonstration and experimental systems to be constructed. (See Table 1 below.)

While effectively unlimited electricity is critical to the future, it is not the only benefit of a fusion economy. The international crash program will also focus on the applications of the great energy densities and unique physical properties of the fusion process, as applied to materials processing, industry, and manufacturing, for example. Put simply, a fusion economy completely revolutionizes man's relationship to the periodic table of elements, and what are considered "natural resources."

2. Fusion Technology for Production and Industry

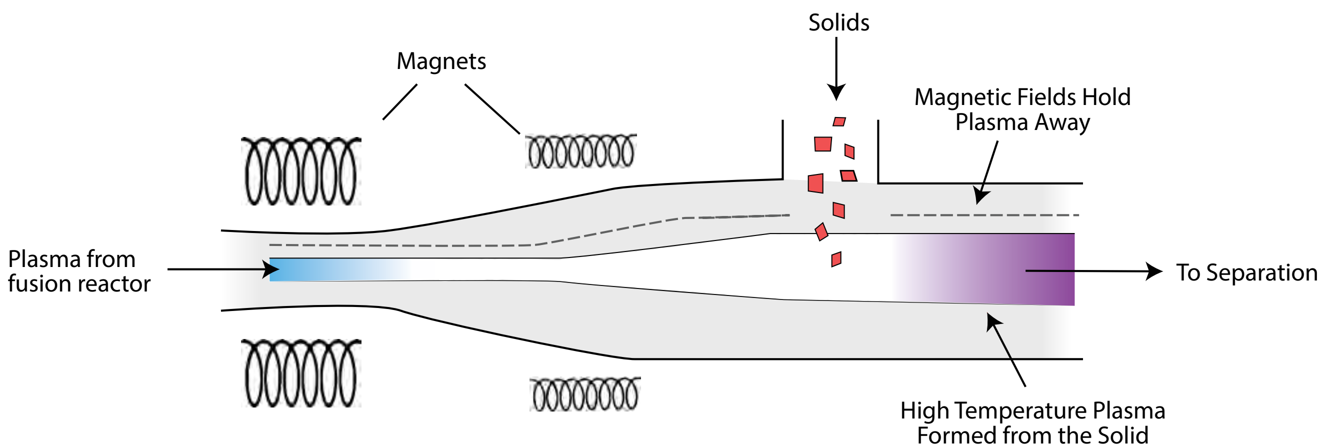
With fusion, we will be able to create plasmas at temperatures of tens and hundreds of millions of degrees. At these temperatures, any known substance can be easily broken down into its constituent elements. However, even low-temperature plasmas (tens of thousands of degrees) are already in use in certain industries today, and their use must be expanded. For example, so-called "arc plasmas" are used in welding and in specialty steel making, and a plasma separation process has been used to isolate desired isotopes for medical and other purposes. While these lower-temperature plasmas do not exhibit the full potential of what we will be able to achieve with a fusion reactor, they show the promise of what is to come when man has full access to controlled thermonuclear processes as the basis of his economic platform.

Continuing to broaden our use of plasma technologies today will serve to (1) improve our knowledge of plasmas in general, (2) aid in the development of technologies to handle them and put them to work, (3) train a new generation of scientists and industrial workers in the use of plasmas and fusion-related technologies, and (4) produce specialty materials which could overcome materials challenges arising in fusion research, such that the advances in productivity made today will contribute to accelerating the realization of fusion.

2.1 The Fusion Torch

The "fusion torch" design, first proposed in 1969 by Bernard Eastlund and William Gough of the U.S. Atomic Energy Commission, uses an ultra-high temperature fusion plasma, diverted from a fusion reactor core, to reduce virtually any feedstock (low-grade ore, fission by-products, seawater, garbage from landfills, etc.) to its constituent elements. Once the feedstock has been injected into the plasma, the elements become dissociated into electrons and ions, and the desired elements (or isotopes) can be separated from one another by atomic number or atomic mass, creating pure, newly synthesized mineral "deposits" from virtually any substance.

To make the point, an average cubic mile of dirt contains approximately 200 times the amount of annual U.S. aluminum production, 8 times the iron production, 100



Schematic of Fusion Torch Processing of Solid Waste

Table 1: Selected Fusion Experimental Designs

		Country	Reactor	Status	Features
Magnetic Confinement	Tokamak	International (being built in France)	ITER	Construction phase, first plasma expected in 2020	Utilizes superconducting magnets
		France	Tore Supra	Operational since 1988	Longest plasma duration for a tokamak (6.5 sec)
		Russia and Italy	IGNITOR	Under construction in Troitzk, Russia, expected to be completed in 2014, first plasma by 2016	Designed to demonstrate feasibility of ignition
		South Korea	K-STAR	Operational since 2008	Utilizes superconducting magnets
		United States (PPPL)	NSTX	Operational since 1999	
		United States (MIT)	Alcator C-Mod	To be shut down in October 2013 due to budget cuts, operational from 1991-2013	Reactor with the highest plasma pressure in the world
		China	EAST	Operational since 2006	Utilizes superconducting magnets
		Europe	JET	Operational since 1983	
		Japan	JT-60SA	Under construction, to be completed in 2016	Utilizes superconducting magnets
	Stellarator	United States (PPPL)	NCSX	Canceled in 2008. Constructed, but never assembled for budgetary reasons.	
		Germany (MPG)	Wendelstein 7-X	To be completed in 2015	
		Japan	LHD	Operational since 1998	Largest superconducting stellarator in the world
	Reversed Field Pinch	United States (University of Wisconsin)	MST	Operational	
	Tandem Mirror	United States (LLNL)	MFTF	Built in 1986 and promptly shut down due to budget cuts. No experiments were ever performed.	
	Dense Plasma Focus	International (AAAPT)	UNU/ICTP PFF Network	Operational, 12 systems in 9 countries	
	Magnetized Target	Canada (General Fusion)	General Fusion Reactor	Prototype expected by 2015, reactor by 2020	Combines features of magnetic and inertial confinement techniques

		Country	Reactor	Status	Features
Inertial Confinement	Laser	United States (LLNL)	NIF	Operational since 2003	
		Japan (Osaka University)	GEKKO XII	Operational since 1983, currently being upgraded by the addition of a second laser.	Upgraded apparatus will be part of an experiment for "fast ignition"
		Russia (VNIIEF)	ISKRA-5 and ISKRA-6	ISKRA-5 operation since 1989. ISKRA-6, proposed for construction, would be a NIF-class laser	
		France (CEA)	LJM	Prototype operational since 2003, full operation expected in 2014	
		European Union	HiPER	In design stages, construction expected to begin in 2014	
	Non-Laser	United States (SNL)	Z Machine	Operational since 1996	Largest X-ray generator in the world, has achieved temperatures of >2 billion degrees (theoretically high enough for fusion of heavier elements)
		United States (LANL)	Project PACER	Under research until 1975 under Project Plowshare	Utilizes fusion bombs exploded in a cavity

times the tin, and 6 times the zinc, though most of it is not in a concentrated form, making it impossible to effectively mine and process with current technologies.[2] Even with the fusion torch we will likely not need to mine random plots of dirt, but this indicates how extensive the available resources are when we move to more energy-dense processing techniques. Lower-grade ores and lower concentrations (which are currently useless to us) will suddenly become readily available resources. *Dirt* becomes *ore*. Scrap materials which already contain concentrated elements, can also be efficiently reprocessed as new, vital raw materials. Urban landfills, containing disorganized forms of most all the elements we already use, become one of the most potentially valuable concentrations of materials waiting to be processed. According to Eastlund and Gough, with the wide availability of commercial fusion, the fusion torch will become an efficient method of generating whatever bulk raw materials are necessary to meet humanity's industrial and other needs.

Even before mastering a self-sustaining fusion reaction, a high temperature plasma torch can be created with today's technology. By the 1980s the company TRW had patented and was promoting the commercial construction of a plasma torch design fully capable of processing spent nuclear fission fuel, and retrieving valuable isotopes.[3] Already then, what some still today call "nuclear waste" or "chemical waste" had become a potential resource, with the application of the available processing technologies.

Beyond accessing existing resources, the ability to select and harvest very specific ratios of isotopes and elements in substantial quantities creates the potential for a revolution in the qualities and properties of materials. For example, specialty steel can be isotopically tuned, improving the capabilities for handling high energy processes ranging from industry, to fusion reactors, to space travel.

Claims of crises caused by "limited resources" fly out the window with the fusion torch and a fusion economy.

2.2 Chemicals Processing

Another use for the fusion torch design will be the transformation of the energy from the plasma into a radiation field for processing industrial materials and chemicals.

By injecting selected "seed" materials into the fusion torch, the emission frequency and intensity of the radiation can be finely modulated by the amount and type

2. See "The Fusion Torch: Creating New Raw Materials for the 21st Century," *21st Century Science & Technology*, Fall-Winter 2006.

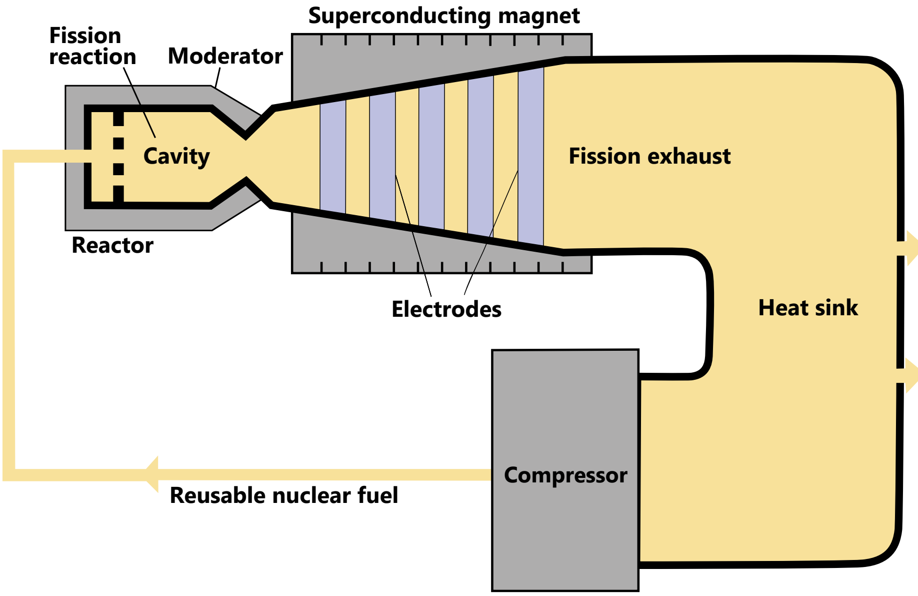
3. See "Plasma Separation Process for Generic Isotope Separation," by Steven N. Suchard, from the *1983 Waste Management Symposia*, and "The Status of the Isotope Separation by PSP," by Yuri A. Muromkin, February, 2013, *Journal of Energy and Power Engineering*.

of materials chosen. With a fusion plasma, as opposed to lower-temperature plasmas, it is possible to maximize the energy within specified, narrow bands of the spectrum.[4] This radiation can then be transmitted through a "window" material to a fluid or other body. Because the frequency of the radiation can be tuned to the material being processed, the existing limitation placed on bulk processing by the limits of surface heat transfer is greatly overcome. For example, ultraviolet radiation could be generated to sterilize industrial process water and drinking water.[5]

The neutrons from the fusion reaction can be used for direct or indirect heating of process materials to temperatures ranging from 1,000ºC to more than 3,000ºC.[6] They can also be used themselves, or converted via a blanket material into high-energy gamma rays, for catalyzing chemical reactions, thus directly converting the fusion energy into chemical energy. This could greatly increase the efficiency of the production of industrial chemicals requiring high heats or high activation energies, such as hydrogen, ozone, carbon monoxide, and formic acid. This increased power over materials and chemicals processing opens up a scale of production never before possible.

With the use of high-temperature plasmas the quality and quantity of available resources is completely transformed. As was said in 1969 by Eastlund and Gough, "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."

Nuclear Cavity Reactor with MHD Conversion



From "Magnetohydrodynamics: Doubling Energy Efficiency by Direct Conversion," by Marsha Freeman, *Fusion*, April 1980

An externally moderated or cavity reactor would use the exhaust from the nuclear fission process in a closed cycle as the working fluid for MHD direct conversion. In this simple 1968 design, heat from the MHD generator's exit plasma could be could still be used to run a steam turbine. The design provides for the reuse of the nuclear fuel.

3. Magnetohydrodynamics (MHD) For Direct Conversion

For the generation of electricity from fusion power we will have to revive and advance the science of magnetohydrodynamics (MHD), a technology which can be used with virtually any source of energy to generate electricity directly from a high-temperature plasma. As a "direct conversion" process it eliminates the need for large steam turbines, and has the potential to *double* the amount of electric power generated from every unit of fuel used.

While in the 1980s some of the basic technologies were under development in the United States with coal powered systems, in the USSR with natural gas based systems, and in Japan using petroleum, the ultimate goal is the application to fusion power generation, with a possible role for utilization in fission power systems along the way.

The basic principle in MHD conversion is to pass a high-temperature plasma through a magnetic field. The magnetic field creates an electrical current in the plasma, which is drawn off by electrodes along the length of the channel through which the plasma flows. There are essentially no moving parts, since the plasma is itself moving through the magnetic field.

In a standard power plant (coal or nuclear), only 30% to 40% of the energy released by the fuel gets converted into electricity through the heating of steam used to

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4. "The Fusion Torch: Closing the Cycle from Use to Reuse," Eastlund and Gough, 1969.

5. The absorption depth of ultraviolet radiation in water is about 1 meter. With the fusion plasma torch, energy fluxes of ultraviolet radiation on the scale of megawatts per m^2 can be generated and transferred to the water with very little loss, thus permitting a scale of bulk processing not possible before.

6. "A Survey of Applications of Fusion Power Technology for the Chemical and Material Processing Industries," Steinberg, Beller and Powell, *Energy Sources*, 1978.

then spin a turbine, while the rest of the energy is lost as "waste heat" (this is the efficiency of the power plant).

In basic MHD systems the direct conversion can nearly double the electricity generated without changing the amount of fuel, with the 50% efficiencies of simple MHD systems. Adding a steam turbine (to take advantage of the remaining heat) can increase the efficiency to 60%.

These are more than theoretical concepts: in the late 1970s, researchers at Argonne National Laboratory succeeded in achieving a 60% efficiency with a nuclear fission-powered MHD system, and the experimenters were confident they could reach a level of 80% with future developments.[7]

However, despite these exciting studies and results, serious MHD direct conversion research basically ended in the 1980s (along with many other areas of promising research).

MHD must be revived for the generation of power with fusion (with the possible application for more efficient fission systems as well). Using advanced fusion fuels, such as deuterium and helium-3, in a magnetically confined system, the charged particles of the fusion product can be continuously run through a magnetic field to directly generate electricity at efficiencies of 70%.[8]

4. Plowshare and Engineering with Nuclear Explosions

An important and relatively short-term application of thermonuclear power is the use of peaceful nuclear explosions (PNEs) for construction, the general precedent for which has already been well established by the 1960s–70s U.S. Plowshare Program, which took its name from the book of Isaiah: "And he shall judge among the nations, and shall rebuke many people: and they shall beat their swords into plowshares, and their spears into pruning hooks: nation shall not lift up sword against nation, neither shall they learn war any more."[9]

Although detailed plans for their application in the construction of the NAWAPA project are not known to the authors of this report, in 1968, Ralph Parsons (the head of the company which originally designed NAWAPA) did raise the general possibility of using nuclear explosives for its construction in a letter to a leading proponent of the project at the time, Senator Frank Moss.[10]

Today such considerations must again be put up front, to fast-track the construction of NAWAPA XXI and similar projects.

To bring some of the abundant northern waters down into the water-starved regions of the continent (from the Mississippi River to the Pacific Coast, and from the Canadian Prairies to Northern Mexico), NAWAPA XXI requires that an immense amount of earth be moved, totalling around 725 billion cubic feet (about 5 cubic miles), including 39 tunnels (totalling 1,200 miles) and 5,400 miles of canals. PNEs could be used for the construction of these new tunnels and canals, for widening or deepening existing rivers and reservoirs involved in the system, and even for the construction of new deep-water ports if needed.

Peaceful nuclear and thermonuclear explosions can be used to sculpt terrains on scales difficult or impossible with conventional methods, dramatically decreasing both the construction time, and the physical costs, based on the higher energy density unique to nuclear and thermonuclear reactions.

For example, according to the 1960s Atomic Energy Commission's informational videos on Plowshare, a 10-kiloton nuclear explosive could, at the time, be as small as a cylinder three feet long and fifteen inches in diameter. To release an equivalent amount of energy from conventional explosives would require 10,000 tons of TNT (hence the "10 kiloton" measure of the yield of the nuclear explosive), which would form a cylinder 200 feet long and 36 feet in diameter—that is equivalent to comparing the size of about 36 semi trucks to the size of your chair.

Over two decades, Project Plowshare completed 27 test nuclear explosions, and proposed using the technique for projects ranging from creating an artificial harbor at Cape Thompson, Alaska, to creating a new, sea-level Panama Canal, where studies showed that the excavation costs could be reduced by up to an order of magnitude with the usage of PNEs.[11] This reflected the general optimism around the "Atoms for Peace" outlook outlined by the Eisenhower Administration and promoted by Kennedy.[12]

7. See "Magnetohydrodynamics: Doubling Energy Efficiency by Direct Conversion," by Marsha Freeman, April, 1980, *Fusion*.

8. See "Direct Energy Conversion in Fusion Reactors," by Ralph W. Moir, *Energy Technology Handbook*, McGraw Hill, 1977, pp. 5150 to 5154.

9. Isaiah 2:4.

10. In a May 10, 1968 letter to Senator Frank Moss discussing NAWAPA, Ralph Parsons said, "In the past five years great advances have taken place in tunneling, for example, in earth moving, and in transmission of electric power. One construction factor which could very drastically change both the design and economic basis is the prospect of using nuclear explosives to create deep artificial aquifers for both storage and transfer underground." This was five years after the original NAWAPA design was proposed by Parsons' company.

11. "Major Activities In The Atomic Energy Programs," U.S. Atomic Energy Commission, 1965.

12. President Kennedy appointed Leland Haworth to the Atomic Energy Commission in 1961. An avid proponent of Project Plowshare, Haworth studied the proposal for a harbor in Alaska, Project Chariot in July of 1961. In March 1962 President Kennedy requested the AEC, to "take a new and hard look at the role of nuclear power in our

Kra Canal: PNE Case Study

In 1983 and 1984, the Fusion Energy Foundation (FEF) and *Executive Intelligence Review*, together with the Thai Ministry of Communication, held two conferences on the Kra Canal Project. The FEF updated an earlier feasibility study and further developed the project's economic and industrial benefits.

The 1984 conference included a presentation by *EIR*/FEF researchers on the use of PNEs, as the fastest, most efficient and most cost-effective method of construction. It was during this same period that Lyndon LaRouche and the FEF were involved in another program calling for the peaceful use of nuclear technology: the Strategic Defense Initiative.

Milo Nordyke of Lawrence Livermore National Laboratory in the U.S. and Harry Ekizian of TAMS engineering firm, both of which groups were involved in the 1973 feasibility study for the canal, presented the physical parameters for building the 30 mile long canal using both nuclear and conventional methods, with the nuclear methods roughly halving both the cost and the construction time.

Mr. Samak Sundaravej, then Minister of Communications and later Prime Minister, addressed the 1984 conference, stating, "The question is can we do it, how and which way?... If we use TNT, it will take 10 years, but if we use atomic energy for peace, it will shorten the excavation time by 5 years."

A spokesman from Lawrence Livermore suggested that a major nuclear isotope separation plant could be constructed as part of the Kra Canal complex of industrial centers constructed at both ends of the canal.

A later Japanese plan also advocated for the use of nuclear technology in the construction of the canal in a 1985 report. This plan would have used over twenty nuclear devices each roughly 30 kilotons—fulfilling the quote from Isaiah, by turning the former weapons of war into a tool for the betterment of all mankind.[1]

1. See "Kra Canal: Gateway to Asia's Development," in *Fusion*, July–August, 1984, and "International Conference Puts Kra Canal Back on the Agenda in Thailand," in *Fusion Asia*, January, 1985.

While the official U.S. program ended in the 1970s, the concept has continued to be discussed and considered. For example, another well-known case for the use of PNEs is a project which currently has renewed momentum: the construction of the Kra Canal across Thailand, providing an alternative to the congested straits of Malacca. While also designed for construction with conventional methods, this project attracted the interest of scientists at Lawrence Livermore National Labs for the application of PNEs (See box, Kra Canal: PNE Case Study). In fact, to dispel unjustified fears of radiation release, Lawrence Livermore scientist Dr. Edward Teller promised that he would move his entire family to Thailand after the construction of the Kra Canal, if they built it with PNEs.

While the original Plowshare tests were dealing with the very early stages of nuclear and thermonuclear technology, the tests allowed them to figure out how to contain the radiation release from the explosions, and by the end of the program the scientists involved were confident that the most dangerous safety hazards posed by PNEs would be the same as in any conventional explosion—the groundshock, air blast, dust cloud, etc.—and not the radiation.

If a PNE program is restarted today, the development of newer technologies can guarantee the radiation issue will pose no problem whatsoever.

This includes the prospect of "non-nuclear triggers" for thermonuclear explosions. Currently fusion explosions require a fission reaction to trigger the fusion, meaning the fission products are involved in the explosion (although they can be contained).[13] However, other methods can trigger fusion reactions as well, including inertial

economy," and Haworth led the writing of the report "Civilian Nuclear Power–A Report to the President–1962". In 1963, President Kennedy asked Haworth to direct the National Science Foundation.

13. Unlike fusion, which creates a very limited number of products, almost none of which are directly radioactive, fission creates nearly all the isotopes of the periodic table.

confinement (as with lasers for example) or even small amounts of antimatter.

Fulfilling the Thermonuclear Age

The fusion economy is not just a new way of acquiring power to be applied to the existing economy.

The entire history of the development of humanity has been characterized by the creation of *new economic systems*, with *new resource bases*, and *new technological capabilities*—a series of qualitative changes driven by increasing levels of controlled energy flux density. This is one of the purest expressions of the unique creative powers that separate mankind from any mere animal species.

The greatest economic revolutions have been driven by transitions to qualitatively higher levels of power sources. Fusion is now the imperative for mankind. By starting now, over the course of the next two generations the power and resource requirements of a growing world population can be met, and mankind can be set upon a new path, one actually befitting our true, creative nature.

Appendix 1: Energy Flux Density

The first evidence of a distinction between mankind and the apes comes with first appearance of ancient fire pits, used to control the power of fire for the betterment of the conditions of life of those wielding that new power.

From that time onward, mankind could no longer be characterized biologically or by biological evolution—the evolution of the creative mental powers unique to the human mind became the determining factor. Biology took a backseat to the increased power of thought wielded by the human species.

This is the secret—and science—of economic growth, and is expressed in the control over successively higher forms of fire. This started with transitions to more energy-dense forms of chemical combustion, from wood burning (and charcoal), to coal (and coke), to petroleum and natural gas. The developments around the end of the 19th century showed mankind an immense potential beyond chemical reactions: the fundamental equivalence of matter and energy, as expressed in the domains of fission, fusion, and matter-antimatter reactions, each with qualitatively higher energy densities.

Control over higher energy densities drives the increase in what Lyndon LaRouche has identified as the energy flux density of the economy, as can be measured by the rate of energy use per person and per unit area of the economy as a whole. As is illustrated in the accompanying articles ("A Call for An International Crash Program: Creating the Fusion Economy" and "Nuclear Agro-Industrial Complexes for NAWAPA XXI"), this increasing power drives qualitative changes throughout the entire society—creating fundamentally new technologies, new resources bases, new levels of living standards, and, actually, new economies.

Table I: The Energy Density of Fuels

FUEL SOURCE	ENERGY DENSITY (J/g)
Combustion of Wood	1.8×10^4
Combustion of Coal (Bituminous)	2.7×10^4
Combustion of Petroleum (Diesel)	4.6×10^4
Combustion of H_2/O_2	1.3×10^4 (full mass considered)
Combustion of H_2/O_2	1.2×10^5 (only H_2 mass considered)
Typical Nuclear Fuel	3.7×10^9
Direct Fission Energy of U-235	8.2×10^{10}
Deuterium-Tritium Fusion	3.2×10^{11}
Annihilation of Antimatter	9.0×10^{13}

Fuel energy densities. The change from wood to matter-antimatter reactions is so great that progress must be counted in orders of magnitude, and the greatest single leap is seen in the transition from chemical to nuclear processes.

For example, start with the simple rate of biological energy usage for the human body, about 100 watts (as sustained by eating a standard 2,000 calorie diet). Assuming a hypothetical pre-fire civilization in which everything is done by human muscle, the power employed to sustain the "economy"—the power of labor—is only 100 watts per capita.

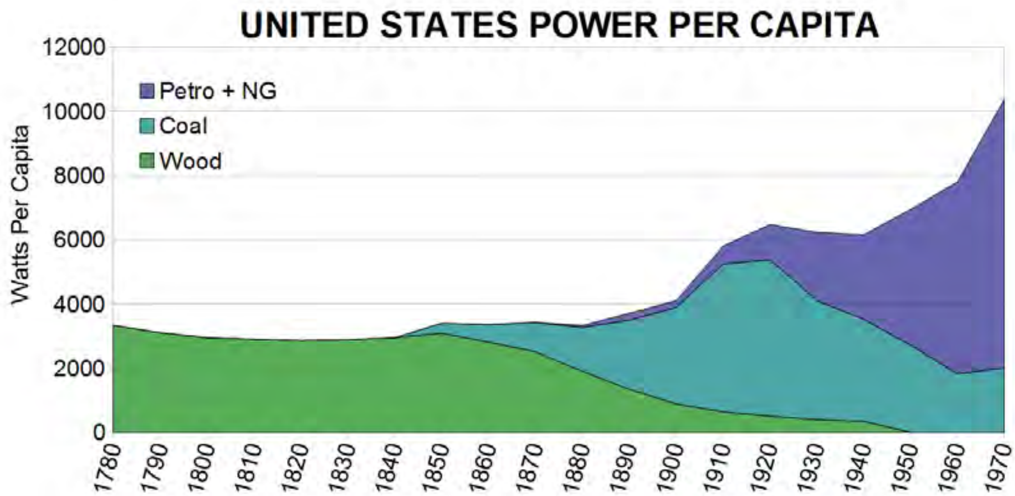
Compare this with the growing per capita power usage throughout the history of the United States. At the time of the nation's founding, the wood-based economy provided around 3,000 watts per capita, a thirty-fold increase over the muscle power of a fireless society. Then the widespread use of coal throughout the economy increased the power per capita to over 5,000 watts by the 1920s, and the implementation of petroleum and natural gas brought this to over 10,000 watts by 1970—100 times the per capita power of our hypothetical fireless society.

With each succession, the previous fuel base declines as a power source (allowing it to be used for things other than combustion, as wood is used for construction, and petroleum should be used for plastics and related non-combustible products of the petrochemical industry).

Following the post-World War II developments, nuclear fission power was fully capable of sustaining this growth rate into the 21st century. In a conservative estimate based upon previous growth rates and the potentials of nuclear power, this should have brought the U.S. economy to a level in the range of 20,000 watts per capita by some time before the year 2000.[14]

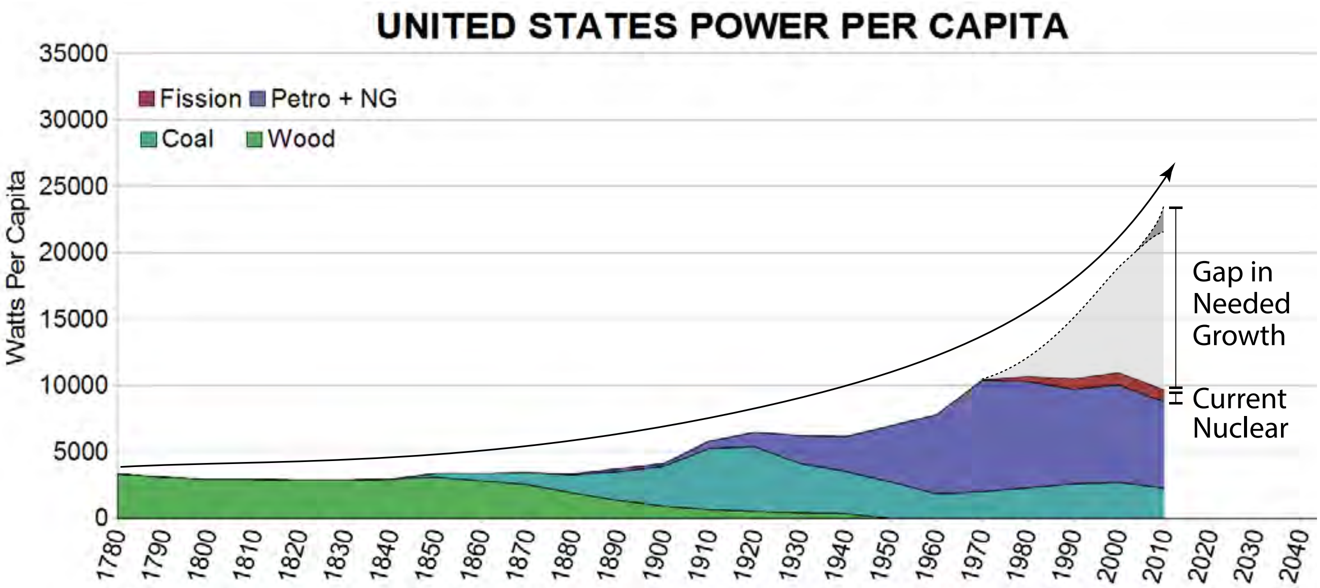
By then, assuming the nation had maintained a pro-growth orientation, as fission power was becoming the dominant power source, the beginnings of applied fusion power should have begun to emerge. With ocean water becoming an effectively limitless fuel source for fusion reactors, the U.S. economy would have been on a path to

14. If a serious economic policy had governed the nation following World War II (as was intended by Franklin Roosevelt, but reversed by the presidency of Harry Truman), a higher level could have been reached faster.



Per capita power consumption for the United States from 1780 to 1970. "Other" power sources, such as hydropower, or so-called renewables, have been left out because of their minimal impact on the total per capita values.

Based on data from the U.S. Energy Information Administration's "2011 Annual Energy Review."



Per capita power consumption for the United States from 1780 to 2010. The general growth trend is indicated by the long arrow on top, with the gray wedge representing what needed to happen with a fission economy and the beginning of a fusion economy. The lower arrow on the right shows the direction of the immediate path which must be started today to overcome the 40-year growth gap. This requires a crash program for the development of fusion.

an energy flux density of around 40,000 watts per capita, and beyond, in the first generation of the 21st century, four times the current value of 10,000 watts. Again, this would not simply be more power for the same economy, but a fundamentally new economy.

However, this natural growth process was halted with the takeover of the anti-progress environmentalist movement, a shift, then, which sent the economy on the direct path into the attritional collapse being experienced, now—a collapse process accelerated by imposing policies which lowered the energy flux density of the economy.[15]

15. This was not some happenstance change, but resulted from the top-down strategic intention of the Anglo-Dutch Empire, whose leaders have been explicitly and openly operating on a policy intention of reducing the world population to less than one billion people. For example, see "Behind London's War Drive: A Policy To Kill Billions," by Nancy Spannaus, *EIR*, November 18, 2011.

As is clear in the second graph shown, nuclear fission power was never allowed to realize its full potential, and the energy flux density of the economy stagnated and began to collapse.

While the actual implementation of nuclear fission is seen in the red sliver, the role it needed to play is indicated in the gray wedge above, a projected value which keeps with the natural growth rates of a progressing human economy, and includes the beginnings of a fusion economy as well.

The 40-year gap between the needed growth rate and the present levels expresses the source of the current economic breakdown, and demonstrates the immediate need for a crash program to develop and implement the next stage, the fusion economy, to overcome decades of lost time by creating a new economy at a higher level than ever before.

Appendix 2: Our Future in and of the Stars: The High Energy-Density Physics Platform—Plasmas, Lasers, Antimatter, and Fusion

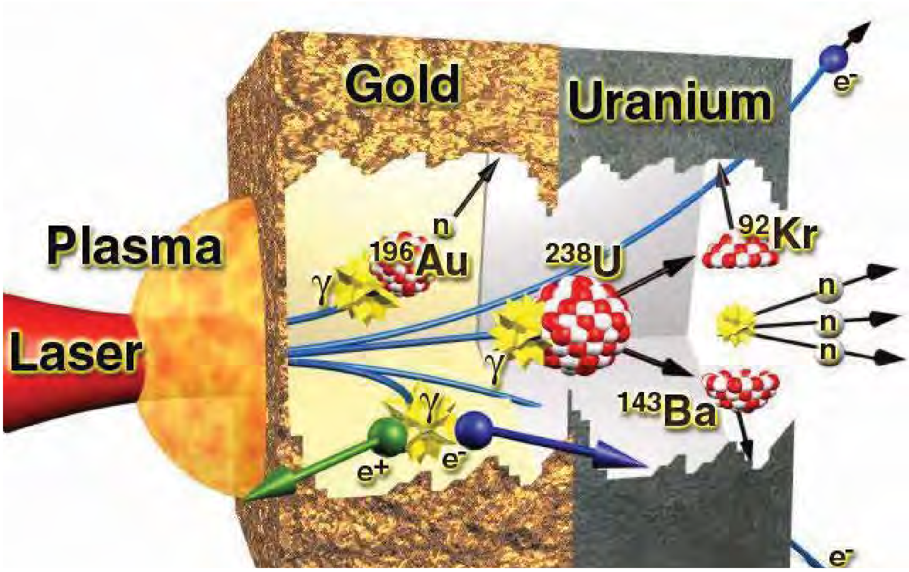
The next platform in the evolution of our human economy is the control of atomic processes like those found in our Sun, as this is to be applied to energy production, materials creation, and earthmoving, among other things. But this is not just for use here on Earth: the development of this power will be applied to conquering the entire domain of our Sun's influence, the Solar System, and will ultimately put us in range of our closest neighboring stars.

To achieve this will require the full exploitation of the dynamic relationships which currently exist between the fields of plasma, laser, antimatter, and fusion research, i.e., high-energy-density physics, where much of the work is already vectoring towards the next generation of space propulsion techniques. Only fusion propulsion can generate the 1-gravity equivalent acceleration, which is ideal for the human body, in that it both produces an Earth-like gravity environment, which mitigates some of the deleterious effects of microgravity, and reduces travel time, thus limiting exposure to harmful cosmic radiation. For example, at 1-G acceleration a trip to Mars could take as little as one week, achieving velocities of one-tenth the speed of light.

In addition to the space travel benefits of thermonuclear processes, the fields of high energy-density physics are furthering our understanding of processes occurring in stars and other cosmic phenomena, such as supernovas, widening our scope of understanding about the universe. This is opening up a renewed and necessary collaboration between astronomical, quantum, laser, and plasma physicists, where insights in one field quickly feed into the investigations of another. The physics of the lab and the physics of the stars are becoming more coherent.

Petawatt lasers, which operate on the order of 10^{15} watts of power, equal to 1,000 times the power of the entire U.S. electrical grid—a feat achieved by compressing mere hundreds of joules of energy (enough to light a 100-watt bulb for a few seconds) into pulses of trillionths of a second duration (femtoseconds)—are opening up vast new potentials for humanity. These lasers have thus far been directed towards the production of such things as: deuterium-deuterium fusion neutrons, the transmutation of gold into platinum, and the creation of anti-electrons (positrons), among other effects.

One such device is being operated by a group at the University of Michigan, where researchers have created what is being called the first table-top antimatter gun. The group has been aiming a petawatt laser at hydrogen gas, which in turn fires a stream of high-energy electrons at a thin metal foil, thereby producing quadrillions of antimatter particles (positrons). They have yet to develop



Lawrence Livermore National Laboratory

Interaction of the petawatt laser pulse with the gold and uranium target material. The laser forms a plasma plume at the target surface, in which electrons (e-) are produced with very high energies. Some of these electrons make gamma-rays (g) in the target, which in turn can knock neutrons out of the gold nuclei. Those neutrons cause uranium nuclei to fission. Some gamma-rays are converted into matter-antimatter electron-positron pairs (green e+).

the ability to trap and hold the antimatter, but that will be the next step they aim for.[1]

The other petawatt laser currently operating in the U.S. is at the University of Texas, where researchers have directed their efforts towards using the high-powered pulse for the creation of fusion reactions by blasting a plasma of hydrogen. Thus far they have been successful in generating neutrons from the fusion of deuterium-deuterium, and hope to increase the yield by adding a collapsing magnetic field around the plasma, further increasing the density.[2] This is a technique similar to that being developed by a group led by John Slough at the University of Washington. Slough proposes using a collapsing magnetic field around a plasma to rapidly contract a metal casing upon fusion fuel, triggering fusion, and then being ejected along with the fusion products for space propulsion.[3]

Continuing with the theme of antimatter's role in this new high energy-density paradigm, and the dynamic that exists between these different paths of pursuit, antimatter has the potential to be used as a trigger for fusion reactions. One application being explored is the antimatter triggered fusion propulsion system for rockets. To this end, a study was recently put out by a joint group from Pennsylvania State University and NASA Johnson Space Center which demonstrates the feasibility of two different models for antimatter-catalyzed propulsion, based on existing production rates of antimatter and methods for its application, as this would be applied for deep space exploration.[4]

Various proposals are being floated for antimatter triggered fusion propulsion systems, but they will all necessitate significantly more physical and intellectual investment to achieve the breakthroughs required.

The designs for rockets run all the way from antimatter triggered fusion propulsion, up to pure antimatter fuel propulsion. As things currently stand, the main road-block to making these systems a feasible reality are the limits in antimatter production and containment of the fuel, along with some engineering challenges. All of these are really a matter of proper rates of investment, as opposed to theoretical challenges. In addition, laser cooling techniques may be the key to efficiently generating Bose-Einstein condensates of anti-hydrogen, which are orders of magnitude more dense than simple anti-hydrogen gas or liquid. These condensates would make antimatter storage a real possibility for deep space flight, since (charged) anti-protons cannot themselves be packed densely, and (neutral) anti-hydrogen is difficult to contain otherwise. The proposed system would achieve velocities of just over half the speed of light and get within the range of our nearest star beyond the Sun in about 18 years.[5]

Another option for the use of antimatter triggered explosions is their use as shaped charges for large scale earth-moving and tunnel boring purposes, along with other applications as proposed in operation Plowshare,

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1. Center for Ultrafast Optical Science, Michigan Engineering, http://www.engin.umich.edu/research/cuos/ResearchGroups/HFS/Experimentalfacilities/HERCULESPetawattLaser.html; Bob Yrka, "Physicists Create Table Top Anti-matter Gun," June 25, 2013, http://phys.org/news/2013-06-physicists-tabletop-antimatter-gun.html.

2. The Texas Petawatt Laser, The Center for High Energy Density Science, http://texaspetawatt.ph.utexas.edu/overview.php.

3. See: John Slough, "Developing Fusion Rockets to Go to Mars," *21st Century Science & Technology*, Fall-Winter, 2012-2013.

4. Schmidt, G. R., et al., "Anti-matter Production For Near Term Propulsion Applications," http://www.engr.psu.edu/antimatter/papers/nasa_anti.pdf.

5. Turyshev, Slava G., et al., "Controlled Anti-hydrogen Propulsion For Nasa's Future In Very Deep Space," October 21, 2004, http://arxiv.org/pdf/astro-ph/0410511v1.pdf.

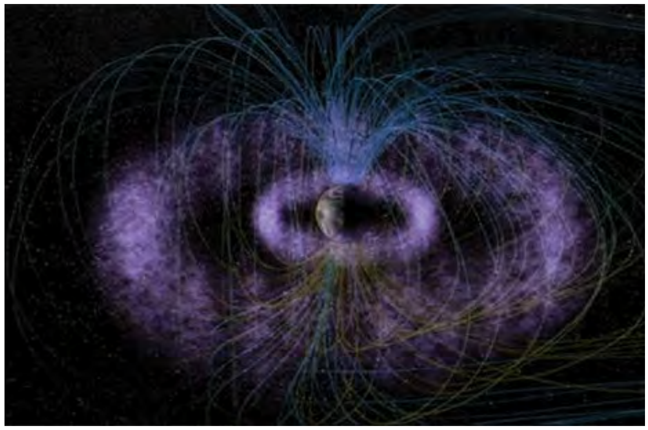
for example. Anti-matter fusion explosions do not produce the radioactive fall-out associated with the PNEs of earlier designs.[6]

Regarding plasmas, the fourth state of matter, around which much of this new scientific paradigm revolves, in addition to those being developed in the tokamak fusion reactors and plasma torches discussed above, there is the potential for the controlled use of plasmas in fusion propulsion systems and petawatt lasers. One design for a propulsion system being developed by a group at the University of Alabama in Huntsville, utilizes the plasma pinch approach to create the densities for fusion reactions. The plasmas themselves are generated by electric pulses equivalent to 20% of world power output, which then go through a process of magnetic self-compression (the pinch), towards densities of action capable of igniting fusion reactions.[7]

The importance of the plasma state cannot be overemphasized, as it is a key aspect of all these interacting lines of development, for it seems to always accompany processes moving towards fusion. More to the point, the majority of observable phenomena in the universe seem to exist as some form of plasma, and as such, are better understood in terms of electromagnetic fluid dynamics, with its various non-linear qualities. This means changing our emphasis away from simple mechanics and thermodynamics, and towards the kind of non-linear evolutionary dynamics found in living processes, for example. This means broadening the scope of what we mean by astrobiology. This can already be seen clearly in the immediate Earth domain where lightning (a plasma) has been found to generate antimatter, and NASA has just discovered that the Van Allen (plasma) Belts that surround the globe, bear a functional resemblance to particle accelerators. Both processes are the product of life's effects and its interaction with cosmic processes.

6. Gsponer, André, et al., "Anti-matter Induced Fusion and Thermo-Nuclear Explosions," February 2, 2008, http://arxiv.org/pdf/physics/0507125.pdf.

7. "UAHuntsville student seeking 'Holy Grail' of rocket propulsion system", http://www.uah.edu/news/research/3855-alpharetta-graduate-seeking-holy-grail-of-rocket-propulsion-system#.UiYc3TYkJ8E.



NASA

The Van Allen Belts. NASA studies have shown a particle accelerator effect acting within the belts.