
Fusion

Basic Economics

by Liona Fan-Chiang

“...because that goal will serve to organize and measure the best of our energies and skills.”

-John F. Kennedy at Rice University Sept. 12, 1962

Would a society, that could create stars of its own, despair at “natural disasters” such as earthquakes or resulting tsunamis? at lack of energy or water? Would that people tolerate short-term thinking, immoral pessimism, fascism, petty wars, or gambling finance as a replacement for industry? Would a society who had a sense of longevity beyond the death of this solar system bother with such short-term conflicts, or be so blind to the long-term suicidal effects of zero-growth policies?

It is precisely because this current population does not have that standard that many terrestrial problems seem insurmountable and currently threaten mass death.¹

Today, were we to suddenly seriously commit to fusion as a science driver for the whole economy, two most substantial yet immaterial things would immediately change, namely direction and intention, and in human economy, that means everything. We will all be astonished at what a nation, or group of nations, can do, when committed to a mission, as was the United States when it was committed to sending humans to another planetary body, 238,855 miles away, within a short 10 years.

Fusion is not a research project. It

is not a black pit of investment. It is not even just a new source of energy. Done right, putting controlled nuclear fusion—and a full blown fusion economy—on the near horizon, as an economic science driver, will serve both to pull us out of the current economic disaster and to create the potential to make any following steps forward.

Before getting a glimpse of what that new economy will look like, let’s begin with some basic economics, not currently taught in schools.



President John F. Kennedy, right, gets an explanation of the Saturn V launch system from Dr. Wernher von Braun, center, at Cape Canaveral in November 1963. NASA Deputy Administrator Robert Seamans is to the left of von Braun.

1. This includes the mounting war between the thermonuclear powers of the United States, Russia, and China.

Economics

As far as is currently known, fusion is what powers the Sun, and the Sun is what feeds life on Earth. Its rays power the commotions of the weather, of wind, of evaporation and transpiration. Its outpourings give us the auroras.

Thus, if we are to not be subject to the whims of a new ice age, be blind to extreme effects of something very cyclical about the sun, or be caught in its wake when it has spent its life, we must take on a stronger, more universal identity as a society, and plan accordingly.

As of now, relatively little is known about either plasma physics or the Sun. What is known is that the processes which compose the sun continue to push the limits of what we think we know. That challenge itself makes the study of it and related phenomena a worthy pursuit.

Fusion was induced in the first hydrogen bomb by exploding a nuclear fission bomb, itself the most powerful thing we had, around it. At that time, instigating fusion was akin to using a large boulder as a bottle opener. The challenge very quickly became to perform the more difficult task of controlling fusion, and to unlock the myriad potentials in that capability. This pursuit has led to the creation of temperatures over 100 times that of the Sun, hotter than any star known to man, and to power densities that can vaporize a cell without the next one noticing. It has led us to investigate the state of matter that

comprises 95% of the universe, and broken many mathematical models along the way.

These criteria make the pursuit of fusion the candidate for both an education about basic human economics, as well as the basis of a proposed crash economic driver program now.

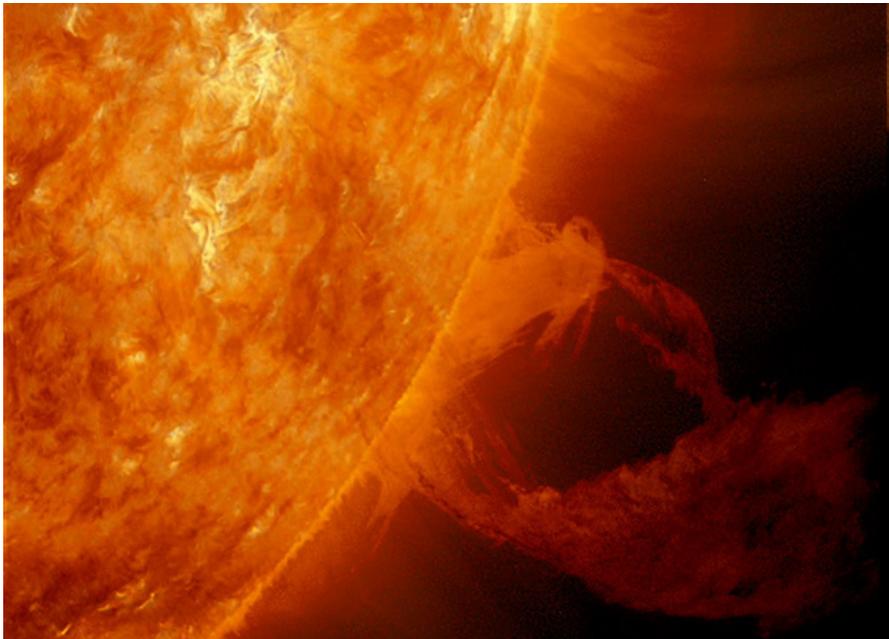
Economic Science

Economics as a science, promotes the study and practice of advancing mankind's relationship to the universe. Humans are not divorced from natural phenomena. On the contrary, humans are a very integral part of nature, and in fact, through scientific and artistic discovery, followed by broad application of those discoveries, play an active role in the development of that universe. When that intimate relationship is fostered, people flourish. When humans organize themselves in a way contrary to the laws of nature, civilizations disappear from history. Thus successful economic policy is one that seeks to foster that connection.

One of the natural laws of the universe is the continual increase in energy flux density. This law has been proven time and again on a cosmic scale and in the evolution of life on earth. It has become more apparent with the emergence of man, who can consciously adopt and enhance that basic principle of nature.

The natural progress of mankind, defined by the ability to increase our understanding and control over our universe, has expressed itself in the relationship of our standard of living to the degree to which we conquer higher density sources of fire, be it wood, coal, petroleum and natural gas, atomic or subatomic. When we have failed to continually make those transitions, by using current activity as a platform to develop the next, we have seen deadly consequences. The present shows us that stark reality.

Alternately, when the new limits are surpassed, and advances used to shape a new economy which can foster the activities required to push the next limits, then the condition of man is raised, and the seeds for the natural progress of evolution of human society are continually sown.



AIA 193 -2013/2/27 4:19:30Z, AIA 304 - 2013/02/07 4:19:31Z
A swirling mass of plasma churned above the Sun for almost two days before it finally erupted (Feb. 25-26, 2013). The image is a combination of two wavelengths of extreme ultraviolet light.

Evolve

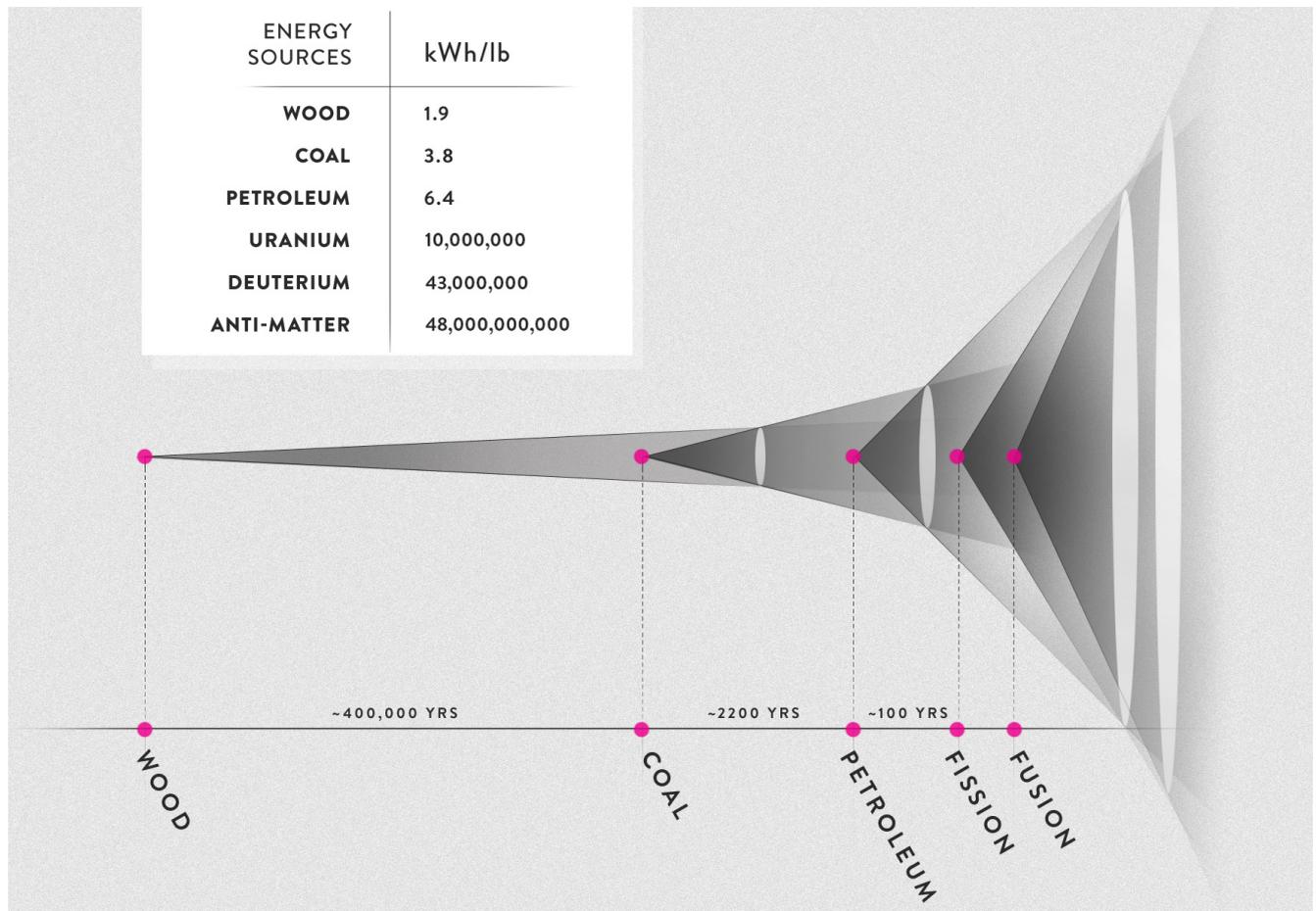
Take, for example, the next transition which must now be made: a transition into a fusion economy. A fusion economy is not just an economy based on fusion electricity. It will not simply be an enhanced version of the activities of today. Previous shifts, such as the petroleum and natural gas revolutions, which occurred in the 1800s, give clear examples. With the ability to use petroleum and natural gas, came not just the energy source to progress, but the understanding and control over chemistry in general, and therefore the chemical processes which have shaped our way of life. These applications themselves, in turn, defined the demand for more energy.

The atomic age similarly promised a qualitative upshift. Complete control over the atom, and all the implications of that practice, has been the promise of almost an entire century. The ability to wield gamma rays, neutrons, beta particles, protons, and other nuclear processes

as well as the energy densities of fission and fusion has only been slowly becoming dominant. The ability to freely traverse the over 3000 known nuclei and utilize their unique properties is still on the horizon. Instead of a full blossoming of the atomic age over the past half century, a post-industrial, post-development culture was pushed into prominence, which gave credence to the idea that humans are by nature unnatural and thus should not have such high aims.²

Relative stagnation, in turn has given way to complaints that we are running out of resources, that we are destroying ourselves and our environment, that we live an unsustainable lifestyle and that there are just too many people. Instead of conquering those challenges, those same critics have then called for ways to cope with this

2. Hecht, "Science for Legislators: Is the Fear of Radiation Constitutional?" *21st Century Science and Technology*, Summer 2009.



The chart on the top right gives the relative power densities for various fuels. Fission and fusion fuels produce orders of magnitude more energy per mass than petroleum or coal. The center diagram gives the approximate times certain fuels were in use in human society. The intersection of the cones give when the new fuel source became dominant. Notice that the time between discoveries of new fuel sources shrinks exponentially. In reality, fission and fusion have been heavily attacked, and both fission and fusion do not follow this natural trend.

new found reality by arbitrarily designating a current or past state of development as ideal. This in turn has continued to feed the stagnation. In fact, it is precisely this insane demand to decrease human activity, or even to maintain it at any state, that has imposed these claimed limits, and threaten deadly consequences.

If progress toward the next platform, based on a new, denser sources of power, does not continue, any current resource, along with the potential that that resource provides, will eventually cease to exist, however slowly that end may be reached. Thus any argument for the continued exploitation of current resources, such as natural gas, as a replacement for the advance to nuclear fusion, is criminal.

As will be seen below, there is no such universal law of limited resources; in fact, if life is to be sustainable, there must be many more people than exist today, and at a higher standard of living. Resource limits are almost entirely self imposed.

A Fusion Economy

Here are just a few examples to illustrate the relationship of mankind to the universe in a fusion economy:

Controlled Fusion

The pursuit of controlled nuclear fusion energy, as opposed to the dramatic *uncontrolled* fusion energy of a thermonuclear bomb, has already led researchers to create temperatures hotter, densities greater, and light brighter than our sun. Plasma temperatures upwards of 100 million kelvin are generated and confined inside magnetic bottles such as the DIII-D Tokamak at General Atomic in San Diego, CA.³ Short bursts of plasmas at 2 billion kelvin have been generated at Sandia National Laboratory's Z Machine in Albuquerque, New Mexico. For comparison, the hottest temperatures on the Sun range from 1–27 million kelvin.

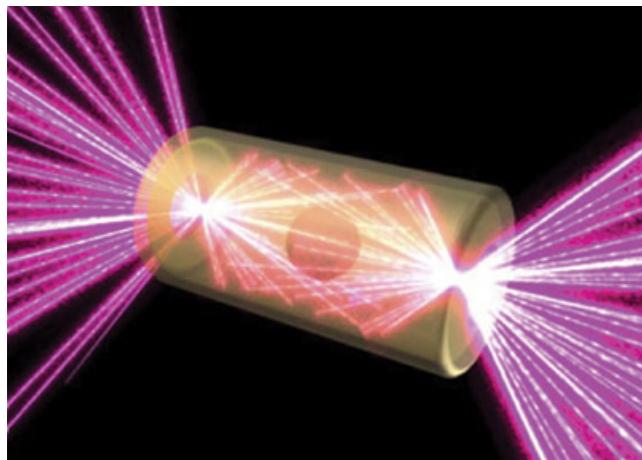
Intense investigation of plasmas, the state of matter theorized to be 95–99% of the universe, has led to many useful challenges. At fusion temperatures, and even far below, properties and evolutions of the plasma tend to shake the very foundations of physics. In contrast to the theory of ideal gases, even at far-below-fusion condi-

3. Fusion reactions are already induced routinely. However, the ability to induce enough fusion reactions to occur such that the energy from the fusion reactions sustain continued fusion reactions is a research priority. Ultimately, for energy production, fusion energy produced must exceed the total amount of energy used to initiate and sustain the reaction. The largest tokamak reactor, a donut shaped fusion reactor, ITER (International Thermonuclear Experimental Reactor) is now being built in France, and is designed to achieve break even.

Human nature demands that some amount of advance always occurs. Therefore, despite a stifling of fission power in the United States, and despite deep cuts to fusion funding throughout the last three decades, progress continues. However, the ability of discoveries to spread and be assimilated into the economy, in order to provide an economic and scientific base to feed more discoveries is a matter of policy.

In the past four decades, attrition has occurred, and potentials continue to be lost. A clear example is that, as fusion research continues to be held at bay, fusion scientists get older, retire or pass away, while a minimal replacement from the next generation follows.

To make up for these lost opportunities it is necessary to leapfrog by consciously propagating both a new view of man, one which sees man as a species that can wield stars, and by implimenting fusion-age discoveries throughout the economy to provide the necessary support for the next steps.



Schematic of laser confinement fusion at the National Ignition Facility, at Lawrence Livermore National Laboratory in Livermore, California. This facility uses 192 lasers which encircle a small (eraser sized) gold container. The lasers impinge on the inside of this gold container, causing the container to radiate soft x-rays. These x-rays in turn act to compress a very small pellet of frozen fusion fuel to very high densities, and finally, to fusion conditions.

tions, non-linear dynamics, evolution of singularities, coherence instead of randomness, and tendencies toward concentration rather than homogeneity dominate. Supercomputers have been advanced to deal with these complexities, but new states often cannot be forecast from simple evolutions of previous ones.

Laser inertial confinement, such as operating at the Na-

tional Ignition Facility at Lawrence Livermore National Laboratory, compresses its target to densities as much as 100 times the density of lead (around 1,000 g/cm³). Compare this to the center of the sun, which has a density of 150 g/cm³. At these densities, what state is it in? Time scales of action also shrink, as nanoseconds off in laser pulse timing can determine the difference between relative stability and instability.

Petawatt lasers, originally developed for fast ignition fusion,⁴ can produce light brighter than any star (10²¹ W/m² for the petawatt laser compared to 10²⁰ W/m² from gamma ray bursts from stars). These lasers produce this power density using ultra-short pulses, on the range of 150 femtoseconds, which bridge into the time scale of chemical reactions, allowing manipulation of atoms before chemical reactions can occur.

Finally, fusion energy, and the possibility of producing almost unlimited amounts of energy has continually gripped people's imaginations. Fusion presents the possibility of producing energy from seawater, or from lunar soil or even Jupiter's atmosphere.⁵ Energy resources can no longer be used as geopolitical chess pieces, and access to energy cannot be a limit to development.

Fusion Rockets

If we plan to efficiently act in the Solar System, we need fusion propelled rockets. Currently a trip to Mars, for example, takes several months.⁶ Besides human health concerns, commerce, communication and scientific collaboration are difficult on these kinds of time scales. Fusion propulsion, using a much more energy dense fuel than chemical propulsion, and thereby, enabling constant acceleration, will shorten that trip to a matter of weeks, and set the stage for civilization throughout the Solar System.

Most of the Solar System is still a wilderness to us. Missions sent out anywhere beyond geostationary orbit have been reconnaissance missions, forging through unknown territory, taking samples and cataloging along the way. Nation builders, such as the founding fathers of the

4. Fast ignition, uses lasers to compress the fuel, but then uses one or a few very high power petawatt lasers, for the last ignition shock.

5. Deuterium, a stable isotope of hydrogen, and a first generation fusion fuel, can be found in one of every 6,420 hydrogens in the oceans. ³He, an advanced fusion fuel, is deposited from the Sun, but is rare on Earth due to the protective geomagnetic field, but can be easily mined from the Moon, the atmosphere of Jupiter, and many other places.

6. Currently, space travel is mostly along various Hohman orbits, orbits which have a closest approach, perihelion, at the departure site (Earth) and a farthest distance, aphelion, at the destination. These pathways use the least amount of fuel, but take a very long time. Optimal departure times are also very narrow. Mars Science Laboratory, for example, launched November 26, 2011 and landed August 6, 2012, travelling for about 8.5 months.

Figure 1
Exhaust Velocities for Different Rocket Fuels

Chemical	3,000 meters/sec
Fission	50,000 meters/sec
Fusion	100,000,000 meters/sec

EIR

One of the major factors that determines how fast the spacecraft can go is the speed at which the propellant comes out as exhaust. Chemical rockets, like today's Space Shuttle, burn liquid hydrogen and liquid oxygen, and the vapor that comes out as the exhaust is traveling at 3,000 meters per second. Nuclear fission provides much faster-moving exhaust particles—50,000 meters per second—but the promise of fusion is that it will provide orders of magnitude increases in exhaust velocity—to 100 million meters per second.

Figure 2
Specific impulse for different Rocket Fuels

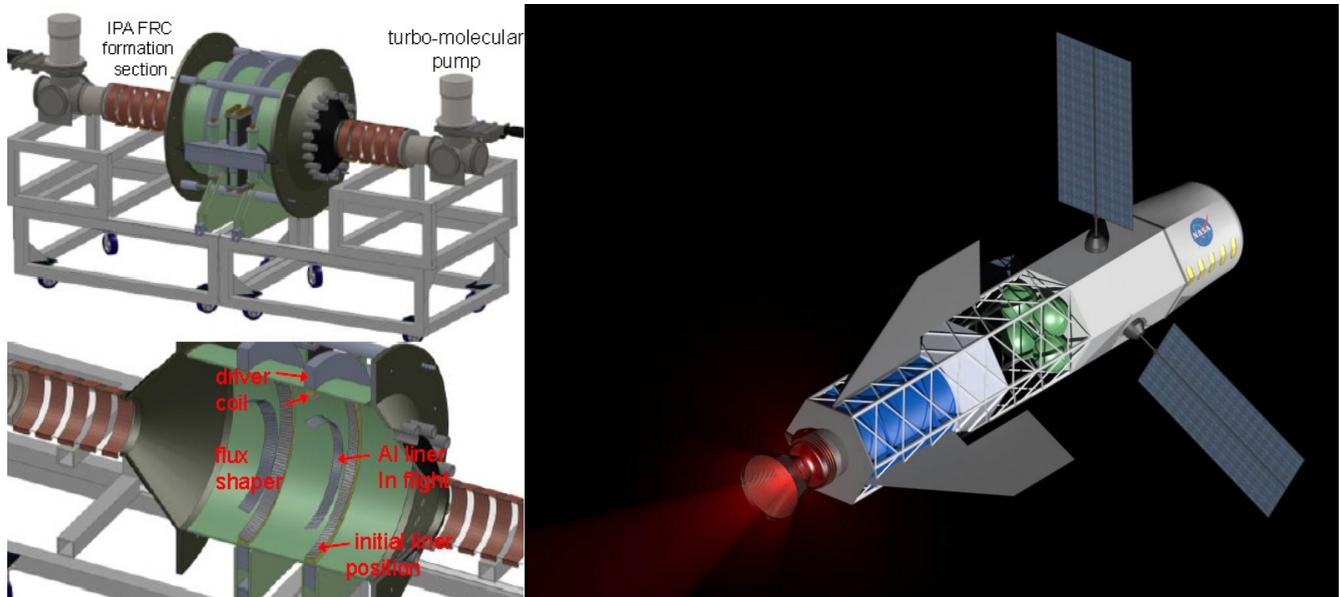
Chemical	450 seconds
Fission	1,000 seconds
Fusion	100,000 seconds

EIR

Another way of comparing different propulsion fuels is by measuring their specific impulse. This figure, measured in units of seconds, describes the efficiency of the fuel used—it is the impulse per unit weight of the rocket propellant. Here, again, fusion promises orders of magnitude improvements over both chemical and nuclear fission fuels.

United States, found it necessary to take a national census of population, resources, geography, etc. Were we to begin to think of the Earth as a part of the solar system, itself a part of the Milky Way galaxy, and of ourselves as stewards, we quickly find that our current capability is severely lacking.

Our environment is cosmic. All life on Earth depends upon a power source beyond Earth's ionosphere. Ice-houses, hothouses, Maunder and Dalton Minimums, and global mass extinctions have been periods of extreme changes which have shaken the delusion that Earth is iso-



University of Washington, MSNW

Here is a schematic of a NASA funded fusion rocket experiment at MSNW near University of Washington. The reactor (left) is to be used in a fusion driven rocket (FDR). It creates field reversed plasma toroids and accelerates them to high velocity. Metal liner rings, contracted by a pulsed magnetic field, both serves to first compress the plasmoid to fusion conditions, and then to absorb the neutrons, vaporize, expand and finally shoot out as propellant.

lated.⁷ Many other effects which are currently considered random or otherwise attributed to local causes,⁸ such as earthquakes, many health conditions, and extreme weather, have been suspected to be, at least in part, cosmically determined. Thus, even to have a competent understanding of Earth, a basic survey must be done of the

7. While this is huge subject in itself, it can be noted that cosmic influences influence the Earth's environment across all time scales. On the scale of tens to hundreds of millions of years, our current understanding of the motions of our Solar System through our galaxy are associated with cycles in biodiversity ("Do extragalactic cosmic rays induce cycles in fossil diversity?" Medvedev and Melott, 2007), cycles in geophysical activity ("An ~60-Million-Year Periodicity Is Common to Marine ⁸⁷Sr/⁸⁶Sr, Fossil Biodiversity, and Large-Scale Sedimentation: What Does the Periodicity Reflect?" Melott, Bambach, et al., *Journal of Geology*, 2012), and periods of global glaciation ("The spiral structure of the Milky Way, cosmic rays, and ice age epochs on Earth," Shaviv, *New Astronomy*, 2003). On shorter timescales of tens to hundreds of thousands of years, changes in the Earth's orbit and variations in cosmic radiation drive global climate fluctuations ("The Glacial Cycles and Cosmic Rays," Kirkby, Mangini, and Muller, 2004). On the scale of decades to hundreds of years changes in solar activity can alter regional and global climates on Earth ("Cosmic Rays and Climate," Kirkby, 2008). Even earthquake activity has been shown to be associated with decadal cycles of solar activity ("Possible Correlation between Solar Activity and Global Seismicity," Yumoto et al., 2011).

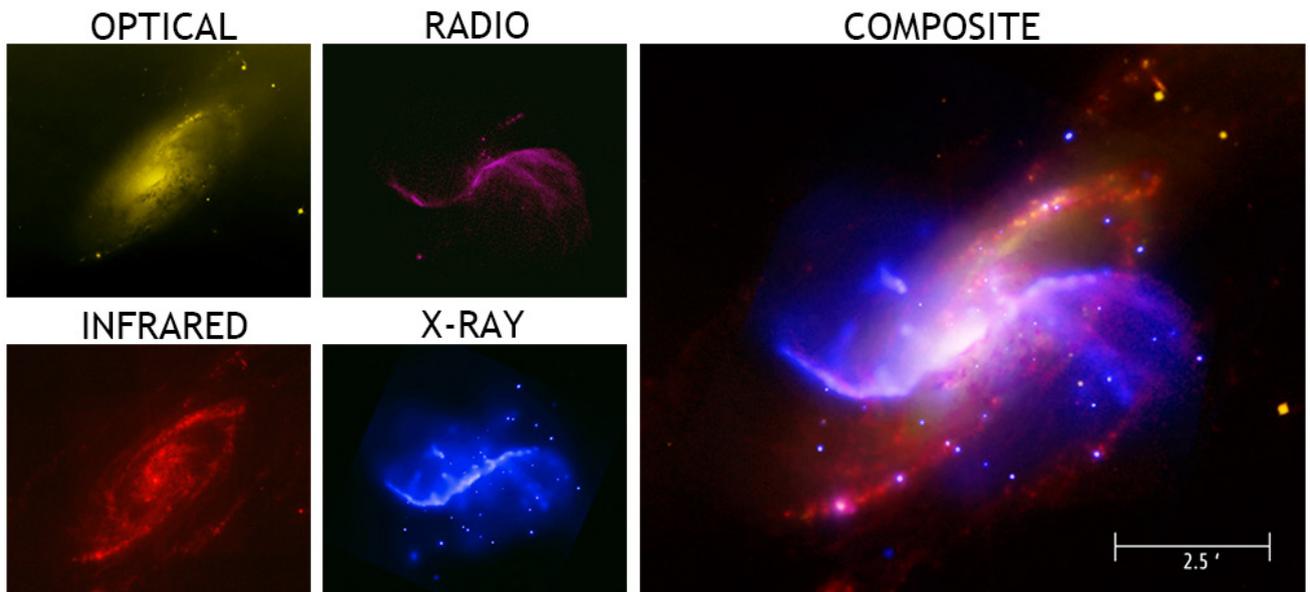
8. The fluctuations of the geomagnetic field was once thought to be purely caused by a combination of magnets moving within the Earth. When Carl Gauss introduced the idea of magnetic potential to the study, in 1832, he was able to create a three dimensional potential field map within which individual measurements had relevance. He also began a magnetic union to map the geomagnetic field, from which they discovered that there were, within the constant variations, small daily, monthly, and yearly variations.

immediate cosmic environment.

For example, begin with arrays of permanent stations or integrated receivers that give a 3D, and as close to real time as possible, map of cosmic rays, the entire electromagnetic spectrum, from gamma to radio waves, of the magnetic structure within the solar system, the solar influence across the solar system, and the interaction between these various phenomena. What aspects of their variation are a result of galactic influences? Continue to advance the full census of asteroids, including for mining purposes. Survey for resources such as ³He and water. Set up seismometers, or other equipment for this purpose, to detect quakes of other planets and moons.

Then there is the matter of infrastructure: transportation pathways, in-orbit assembly and launch stations, fuel stations, living quarters, educational bases, etc.—in short, civilization. Practicable pathways of travel will be redefined now that, with fusion propulsion, constant, or near constant acceleration, is possible. Just as, after the introduction of motor vehicles, "close" and "far" were redefined, the amount of cities one visited in a lifetime increased, and "soon" and "on-time" became more precise, fusion rockets will serve to redefine our concepts of time and space.

At a fundamental level, fusion and astrophysics are intimately connected fields of research, and fusion propulsion is no exception. First of all, a push toward fusion propulsion will greatly enhance fusion research in general, giving more breadth and flexibility to the fusion program. Fusion propulsion has very different require-

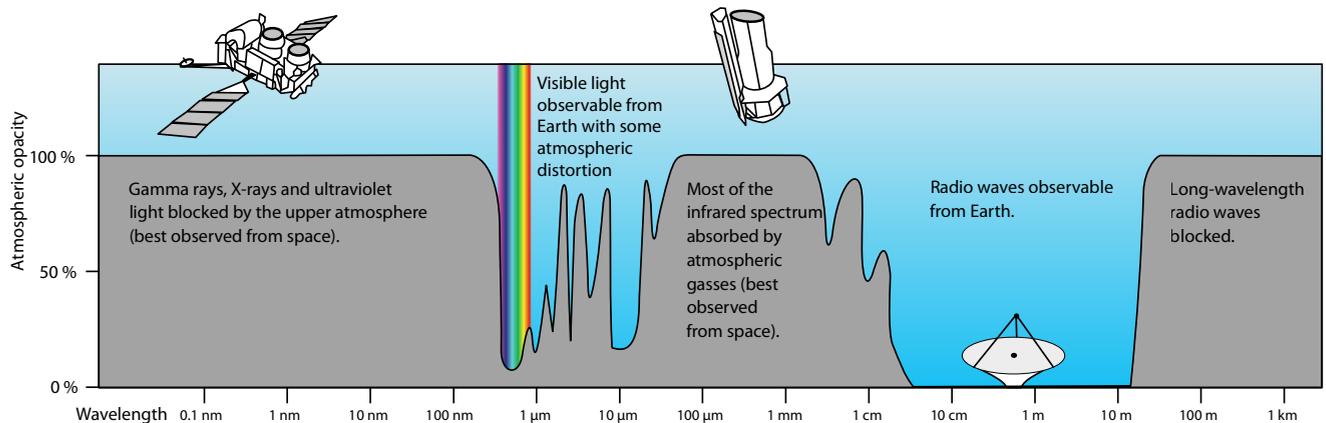


M106 (NGC 4258) spiral galaxy in the constellation Canes Venatici. In optical and infrared light, the galaxy appears to have only two arms. In x-ray and radio frequencies, it also appears to have only two arms, but they have a different pair. Not only do images such as these give a clearer idea of our neighbors, they also help us infer the composition of the local environment in which we are immersed. These images were taken by a combination of the Spitzer (infrared), Chandra (x-ray), European Space Agency's XMM-Newton (x-ray), and Hubble (optical) space telescopes, as well as the National Radio Astronomy Observatory's Very Long Baseline Array and the Very Large Array (radio) in New Mexico.

ments from energy production on Earth. Among other factors, propulsion demands compactness, dense and fast propellant, agility, and low mass. It does not necessarily require an electricity generation steam cycle. Its radioactivity requirements are very different. What is waste from fusion reactors on Earth becomes useful propellant in space. Since reactors must be small, many more reactors which operate on fundamentally different principles

can, and should, be explored simultaneously.

This brings us to a second connection between fusion and astrophysics. In a survey of fusion reactors for fusion propulsion, prepared for the United States Air Force in 1989, the compact torus and variants of inertial confinement were selected as primary subjects of study for further development of fusion propulsion. Compact tori, rings of relatively self-confined plasmas, depend on a



Earth's atmosphere blocks out many frequencies of the electromagnetic spectrum, including harmful ultraviolet light and x-rays. Since the Earth is cloaked with this atmosphere, space telescopes must be sent out in order to see the rest of the universe, including our Sun, in these frequencies. We currently depend upon a very small number of satellites. Radio waves, which have a large wavelength, require very large arrays, which are difficult to deploy into space. A radio observatory, viewing the universe in frequencies never before seen, and likely revealing phenomena never before hypothesized, can be built on the side of the Moon which faces away from Earth, shielded from Earth's radio signals.

non-equilibrium condition evolving into higher energy densities and finally into fusion conditions. Various compact torus designs were among the proposals to work *with* the plasma, rather than against it, letting the plasma teach us physics. Today, the few existing reactors that are explicitly based on self bounded plasmas, are mostly underfunded. Since reactors that rely on self-bounding do not require giant heavy external magnets, they are good candidates for propulsion. Perhaps a drive towards compactness will force a breakthrough in physical theory which will begin to shine new light on large scale astronomical phenomena which themselves often appear extremely ordered, self-evolving and coherent.

These are necessary breakthroughs. According to what is known about the Sun currently, it will become a very uncomfortable neighbor in about 1 billion years, and possibly much before, at which point, we will want to have already developed matter-antimatter propulsion and perhaps even bring along a star of our own.

Transmutation

Radioactivity, fission and fusion have been investigated intensely; yet if compared to the extent to which we control chemical combinations, we are far from having full control over atomic processes. For example, our ability to not just create new combinations of elements (such as in chemical reactions) but to create one element out of another,—the process of transmutation—is still very limited. Part of this has been due to the limited extent to which we can create abundant amounts of high energy particles and our ability to create more energy dense coherent beams of both light and particles. Continual advances in particle accelerators have pushed the limits, though the particles they produce have been in small quantities. To what extent can we wield subatomic particles, gamma rays, and x-rays, the atoms' own arsenal, to sculpt an atom which expresses unique characteristics?

For example, fusion reactions of deuterium and tritium, the most popular and easiest reaction today, produce one extremely energetic, 14 MeV, neutron per reaction. Currently, neutrons are largely provided by fission reactors which produce 2-3 neutrons, whose mean energies are 2 MeV, per fission reaction.⁹ Fusion neutrons, much

9. One big disadvantage, however, is that though mean energies of fission neutrons are about 2 MeV, that energy ranges from 0-14 MeV,

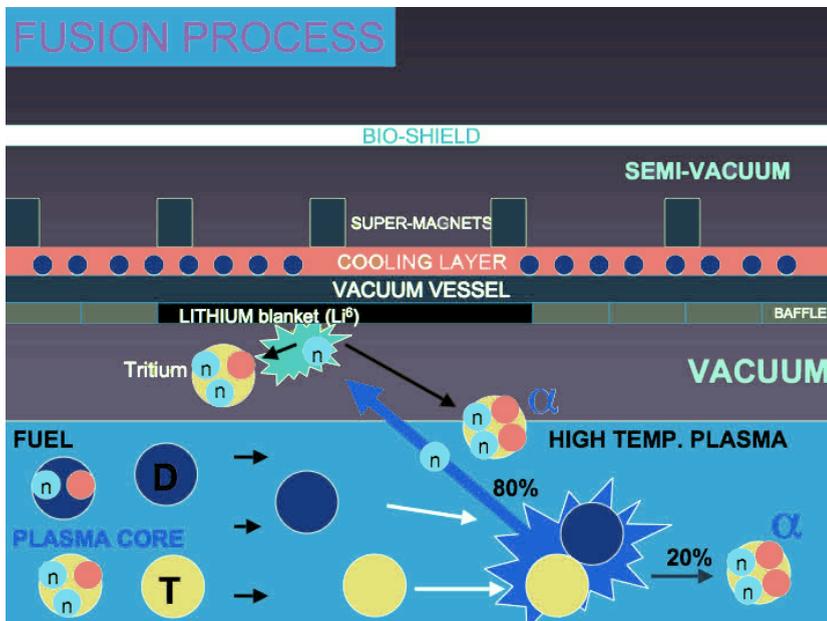


Diagram of the wall of a magnetically confined fusion reaction. This deuterium-tritium reaction produces a very high energy neutron and a helium nucleus. The helium will stay in the magnetically confined area, however the neutron will escape the plasma and strike the wall. In this reaction, some amount of these neutrons must be used to produce new tritium from the lithium blanket to feed sustained fusion. Blankets can be made to breed other elements or more neutrons.

more energetic, can fission even previously non-fissile heavy nuclei and can be used to intentionally bombard other materials, tailored to multiply the neutron output.

Neutrons can be used to do things nothing else can, and are therefore valuable commodities. Since they are neutral, they are very good at penetrating straight into the nucleus and transforming it. Instead of using these precious energetic neutrons to boil water for steam, or to unintentionally degrade material,¹⁰ these can be used to transmute many materials, changing one element into another, for a variety of applications.

One potential use of these neutrons is to breed fission fuel. By essentially placing a small fusion reactor inside a fission reactor, fission fuel can be bred from spent nuclear fuel or ore, while providing just enough fission power to maintain the assembly. Typically, fission reactors produce just enough neutrons to keep the chain reaction going,

making them unreliable for some applications, such as imaging.

10. Currently neutrons from fission reactions are used to heat up water into steam. The steam is then directed through a turbine to generate electricity. In this case, there is no distinction between using heat from burning coal or using neutrons, except that much less fuel is used, which is not an unimportant distinction. More important uses of neutrons, especially high-powered fusion neutrons, will be in those applications which no amount of coal could accomplish.

thus leaving very few extra to breed fuel from not yet fissile isotopes.¹¹ By selecting a proper blanket material¹² for the fusion part of the reactor, fusion neutrons can be used to breed more neutrons, thus multiplying them. These then can in turn be used to breed tritium for fusion as well as fission fuel such as ²³⁹Pu, ²³⁵U or ²³³U. This hybrid fission-fusion reactor was conceptualized in the 1950s, promoted by Hans Bethe in the 1970s and many designs exist today.¹³

Neutrons are already currently used for breeding radioisotopes for medical diagnosis, medical treatment and sanitation, as well as for food irradiation and sewage treatment. With more accessible compact neutron sources available, shorter lived radioisotopes, readily produced at the treatment site, can finally be utilized.¹⁴

Fast neutrons, protons, electrons, heavier ions, etc., produced from a combination of currently existing particle accelerators, more advanced upcoming ones, fusion reactors, and particle acceleration from the use of petawatt lasers, can transmute a wide array of nuclei for radiative as well as other purposes. Lasers, plasma separation or electrochemical separation can then be used to isolate desired isotopes. Isopure materials, materials made of only one isotope, have not been investigated very thoroughly, though what little has been done holds great promise for increasing our control over matter. For example, isotopically pure diamonds, either carbon-12 or carbon-13 have been shown to be stronger and have higher thermal conductivity than diamonds made of a mix of the two isotopes. The semiconductor industry has been investigating isopure silicon to allow for operation at higher power without overheating. Isotopically selected materials open up a new degree of freedom, and will have a tremendous impact on both industry and on

11. For example, uranium-233, a fissile isotope of uranium, can be bred from thorium-232, which is naturally abundant. When irradiated by neutrons, thorium-232 absorbs a neutron, becoming thorium-233, then decays to protactinium-233, and then finally to uranium-233.

12. The wall of the fusion reactor must be lined with material that accomplish a number of tasks. For a sustained fusion deuterium-tritium reaction, these blanket materials must have lithium so that neutrons bombarding the walls can breed tritium to continue to feed the fusion reaction. Blankets must also sufficiently shield components. In addition, a fusion-fission hybrid could use a beryllium, lead and/or fissionable isotopes as blanket material to breed more neutrons which then reach fission fuel. For more see DOE, "Research Needs for Fission-Fusion Hybrid Systems," Report of the Research Needs Workshop (ReNeW), Gaithersburg, Maryland, Sept 30 – Oct 2, 2009.

13. H. Bethe, The Fusion Hybrid, *Physics Today*, May 1979. For a list of resources covering history and current research on fusion-fission hybrids, see www.ralphmoir.com/fusion-fission.

14. Currently, radioisotopes either have to be generated in large, expensive particle accelerators, making it difficult for smaller hospitals to obtain, or must be shipped from a producer site, making short-lived isotopes impractical. Some small fusion reactors are already being used as neutron sources.

the study of life, which is highly isotopically selective.¹⁵ More importantly, it will force us to expand and refine what we currently think we know about the properties of matter.¹⁶

Overall, we should aim for nothing less than the ability to freely traverse the over 3,000 isotopes, and be able to exploit all of their unique properties, be they radioactive, structural, magnetic, conductive, superconductive, or other properties yet unexplored.

Directed Energy

We continue to move away from bulk heating toward tuned, coherent and concentrated forms of energy.

From burning wood to coal to nuclear, from using infrared light to gamma ray radiation, from pure radiative to coherent energy, and from continuous laser beams to pulses of quintillionths of a second, we have continued to concentrate and refine energy, quantitatively and qualitatively, and have thereby accessed completely new domains of physics and biology.

Infrared light, radiating from hot objects, allowed access to the structural properties of matter. Ultraviolet light opened up the molecular domain, allowing us to catalyze chemical reactions. X-rays, generated by electrons, gave us access to the atomic, bringing light to crystal structure. Gamma rays, native to the nucleus, gave access to the nucleus.

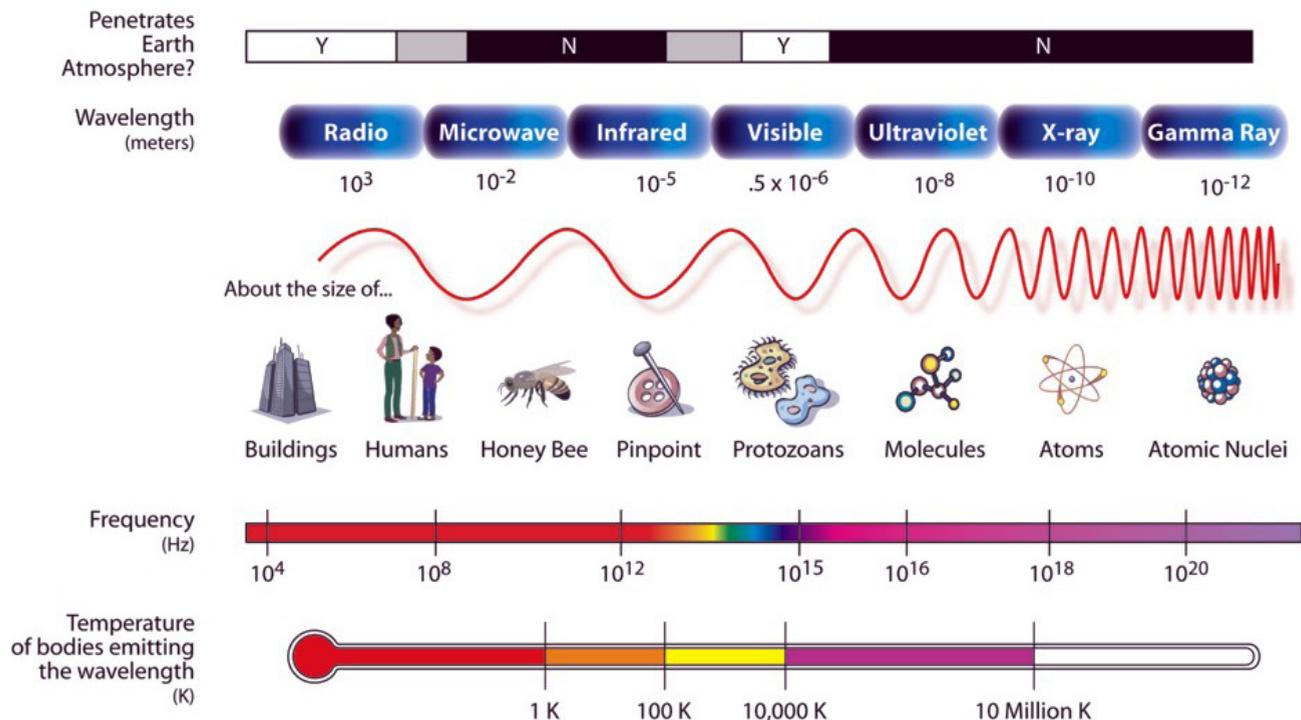
Lasers took light and rendered it into a coherent and tuned form, while focusing it on a small area, thereby increasing power and precision. For example, this enabled infrared light, which before could only heat, to cut and machine quickly and precisely. Bulk radiation of any light became archaic and absurd in some cases, such as in surface treatment. Prior to the ability to apply high heats in a focused way, surfaces could only be treated by placing the entire piece inside of a furnace, heating parts or layers unnecessarily and requiring a large furnace.

In 1983, on the heels of President Reagan's announcement of the Strategic Defense Initiative, *Executive Intelligence Review* released a report titled "The Economic Impact of Relativistic Beam Technology," which reviewed several technologies which were within a 30 year reach. In it, they forecasted, that with this directed energy revolution, over 10 years "total industrial output will be approximately quadrupled," with the largest bottleneck being energy production.¹⁷ Due to political sabotage, this

15. M. Roulliard, "Isotopes and Life: Considerations for. Space Colonization," *21st Century Sci. Tech.*, Summer 2010.

16. Tennenbaum, "The Isotope Economy," *21st Century Sci. Tech.*, Fall-Winter 2006.

17. The Economic Impact of Relativistic Beam Technology, *Executive Intelligence Review Special Report*, June 1983.



The electromagnetic spectrum and a comparison of wavelengths to sizes of objects. Wavelengths must be on the same scale to probe the structure of the object. Thus crystal structure had to wait for x-rays to be imaged.

revolution did not occur, and much of what was outlined has either very slowly come on line over the past 30 years, or not at all. For example, laser machining, used since 1965 still has not completely replaced metal on metal machining despite its versatility, speed and precision.¹⁸ Much of this has to do with lack of raw energy production.

One application which shows the power of collimated, coherent and tuned light¹⁹ is laser isotope separation. Highly precise lasers, tuned to specific frequencies, have been used to separate isotopes. For example, the Atomic Vapor Laser Isotope Separation (AVLIS) technology developed at Lawrence Livermore National Laboratory in the 1970s was able to exploit the fact that the two most abundant isotopes of uranium, uranium-235 and uranium-238, have a very small difference in ionizing energy, as can be seen in their absorption lines (a wavelength of 502.73 nm for ²³⁸U and 502.74 nm for ²³⁵U). By subjecting the sample to only one of these two frequencies, that absorbed by ²³⁵U, only the ²³⁵U will be photoionized.

18. Though in limited use, high power lasers are now used to machine parts. Since they are made to act fast, cuts can be made without heating the material around the cut. These lasers are also very versatile, cutting, welding, and drilling with the same laser. These lasers can drill holes smaller than any bit that can be made, while providing a soft finish, eliminating the finishing steps of deburring.

19. Laser light is unique in that all the light is going in the same direction, in phase, or resonating, and can be made to have a narrow frequency band.

Once ionized, the ²³⁵U can be drawn away with an electric field.²⁰

Soon after the creation of the laser, came the idea of locking various frequencies together such that they interfere to create a string of very short, large pulses of light.²¹ Today, that, with some amplification, has led to pulses that are on the order of quadrillionths of a second long delivering a quadrillion watts each. This is on the order of 2,000 times the power of the United States energy grid.²² These time scales are faster than chemical reactions, while these powers make an entirely new domain—atomic and subatomic—malleable.

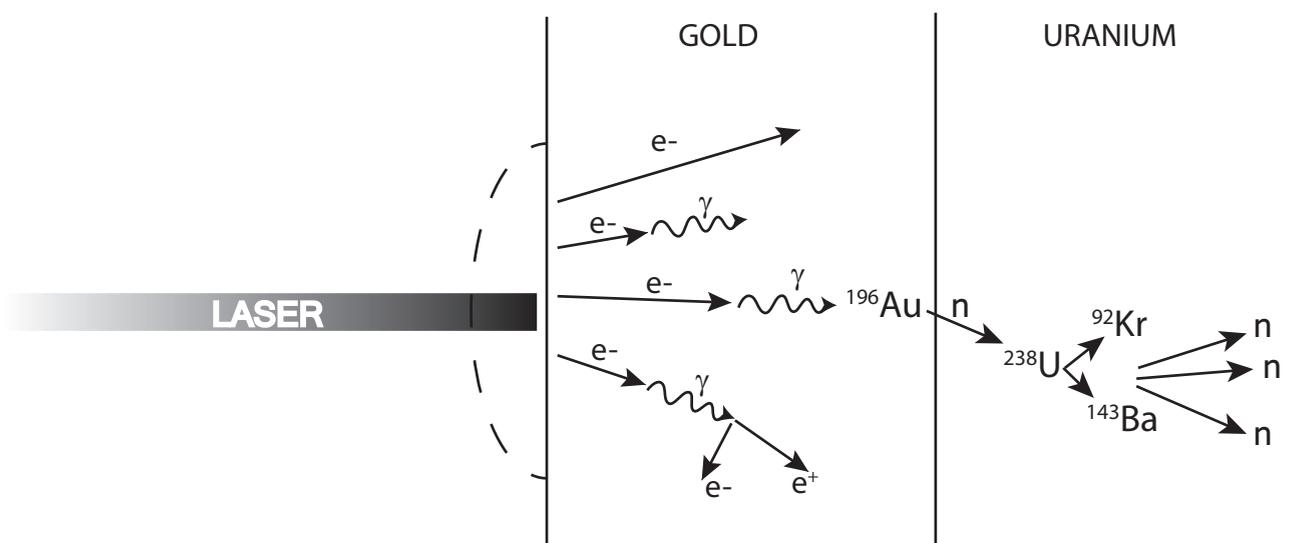
For example, petawatt lasers (quadrillion watts), originally developed for inertial fusion, have been used for high-precision cutting, welding, drilling and machining. Acting at less or equal to the shortest period of the highest frequency of lattice vibrations,²³ with powers orders

20. AVLIS was shut down when the U.S. Energy Policy Act “privatized” uranium enrichment, subjecting an emerging technology to short-term “shareholder values” standards. The government sold AVLIS to a private company, USEC, which then decided the technology was too risky. It had shown itself to be competitive with gaseous diffusion and centrifuge technologies even before optimization.

21. This process is called mode locking. A visualization can be found at Principles of Mode-Locking <http://youtu.be/efxFduO2Y18>

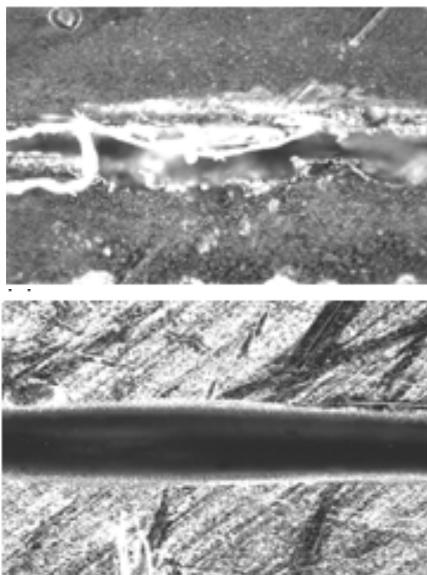
22. If this laser could deliver that amount of power continuously for one second, it would be equivalent to leaving a light bulb on for the age of the universe.

23. Conventional lasers, with longer pulses, deposit heat, i.e. lattice



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 (γ) in the target, which in turn can knock neutrons out of the gold nuclei (^{196}Au). Those neutrons cause uranium nuclei to fission. Some gamma-rays are converted into matter-antimatter electron-positron pairs ($e^- e^+$).

In stainless steel, (left) a conventional infrared laser (wavelength of 1,053 nanometers) operating at a pulse duration of more than one nanosecond, produced a jagged cut and much slag, but Livermore's new cutter, with a pulse duration of 350 femtoseconds and the same wavelength, produced a clean cut with no slag.



LLNL

of magnitude times conventional lasers (more than a quadrillion watts vs. 10-100 watts), the petawatt laser delivers enough power to vaporize the target while transferring little to no heat to the surrounding material, thus producing "cold" ablation. This leads to extremely high precision cutting and machining, with very low transfer of either heat, shock waves or other effects that could

vibrations, thus melting or boiling the material. With ultra-short femto-second scale pulses, a type of cold ablation occurs, where laser energy is absorbed without transferring heat to surrounding material. See C. Stevens, "Petawatt Laser Creates Machine-Tool Revolution," *Executive Intelligence Review*, Vol 25, No. 40, 1998, p28-33.

deform the material,²⁴ and has resulted in production which is faster and requires less steps and less variety of machinery, while still leading to a higher quality product.

In the laboratory, these lasers are even more powerful. As described by the Livermore Laboratory,

The intense beam of Livermore's Petawatt laser was powerful enough to break up atoms by causing reactions in their nuclei. Accelerated by the laser, electrons traveling at nearly the speed of light collided with nuclei in a gold foil target, producing gamma rays that knocked out some of the neutrons from other gold nuclei and caused the gold to decay into elements such as platinum. Gamma rays also zoomed in on a layer of uranium sitting behind the gold and split uranium nuclei into lighter elements. Before the Petawatt, all of these effects had been solely in the domain of particle accelerators or nuclear reactors.²⁵

One might think that these levels of power must require an enormous amount of energy. In actuality, these

24. Cf. S. Dean, "Applications of Plasma and Fusion Research," *Journal of Fusion Energy*, Vol 14, No 2, 1995, C. Stevens, "Petawatt Laser Creates Machine Tool Revolution," *Executive Intelligence Review*, Vol 25, No 40, 1998.

25. <https://www.llnl.gov/str/MPerry.html>

lasers use the same amount of energy your 60 watt light bulb uses in 3 seconds. The difference is that the energy is delivered over quadrillionths of a second! By applying this energy in such a condensed way, unique domains of activity become accessible, which could not have been, had that amount of energy come from a light bulb.

These are just a few examples of what has and can be done, and should give a hint as to what has yet to be conquered. What processes will exawatt lasers (1,000 times more powerful than petawatt lasers) be able to access?

Lasers now only cover a limited part of the spectrum. For example, gamma rays, first discovered emitting from atomic nuclei, have been handled by creating, storing and transporting radioisotopes for a variety of biological treatments and industrial purposes. They are effective in sterilizing foodstuffs, spices, drinking water, and sewage. A gamma ray laser would be a lased form of nuclear energy, which could involve coordinated resonant decay of trillions of excited nuclei at the same time.²⁶

26. J. Tennenbaum, "Technologies to Take Man into Space: A 100-year perspective," from FEF Special Report, *The Strategic Defense Initiative: Its scientific, economic, and strategic dimensions*. Proceedings of the conference sponsored by the Fusion Energy Foundation and the Schiller Institute, April 22-23, 1986, Tokyo, Japan.

Fusion Torch

Precisely because no material can handle the ultra-high heats of fusion and related processes, a fusion torch can be used to recycle just about anything by breaking apart all chemical bonds.

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 times the tin, and 6 times the zinc.

RESOURCES IN AVERAGE CUBIC MILE OF DIRT

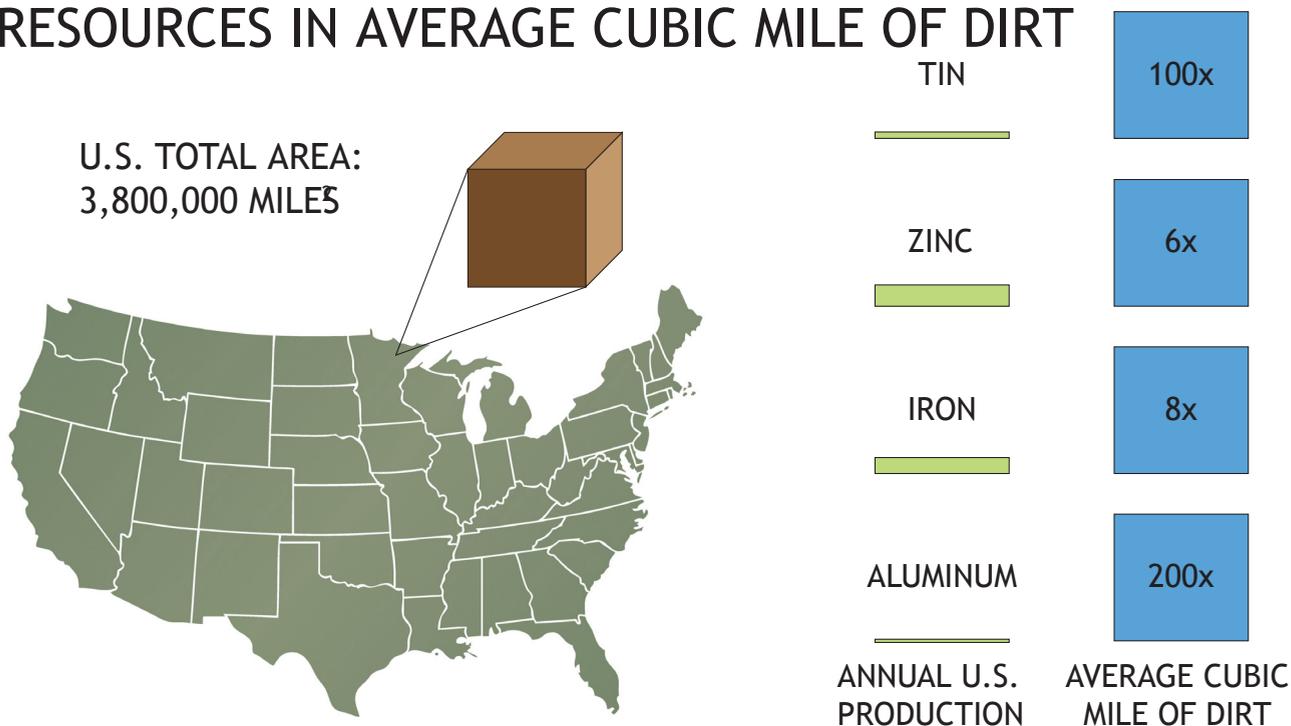
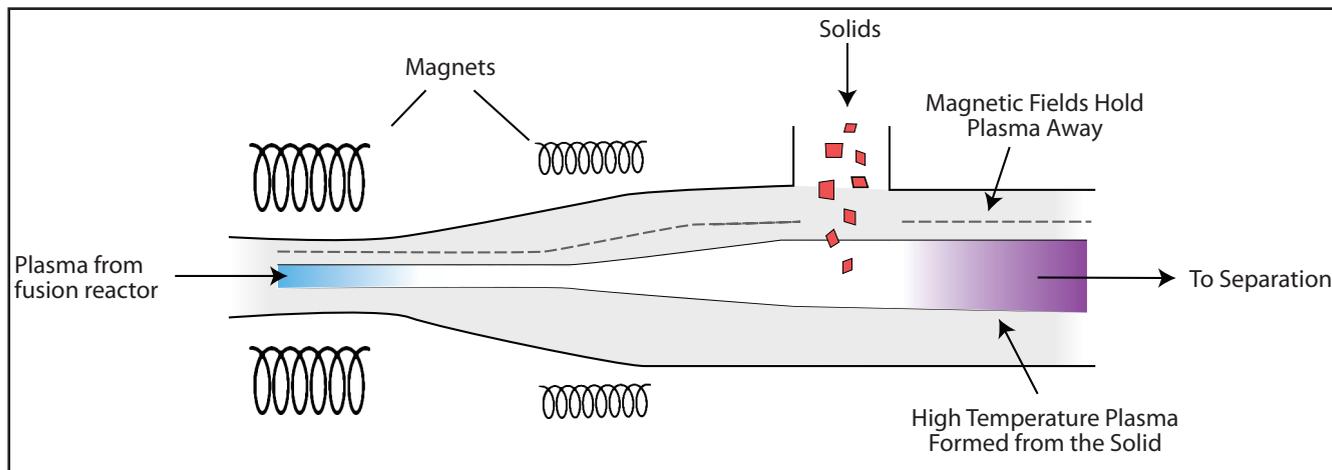


Diagram showing the amount of tin, zinc, iron and aluminum in a average cubic mile of dirt relative to current annual production in the United States.



Schematic of fusion torch processing of solid aste.

effectively mine and process with current technologies.²⁷

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 concentration mineral deposits (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. 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 pro-

cesses ranging from industry, to fusion reactors, to space travel. Very high purity steel, resistant to neutron degradation, made for higher performance fusion or fission reactors can also be produced on a large scale.

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

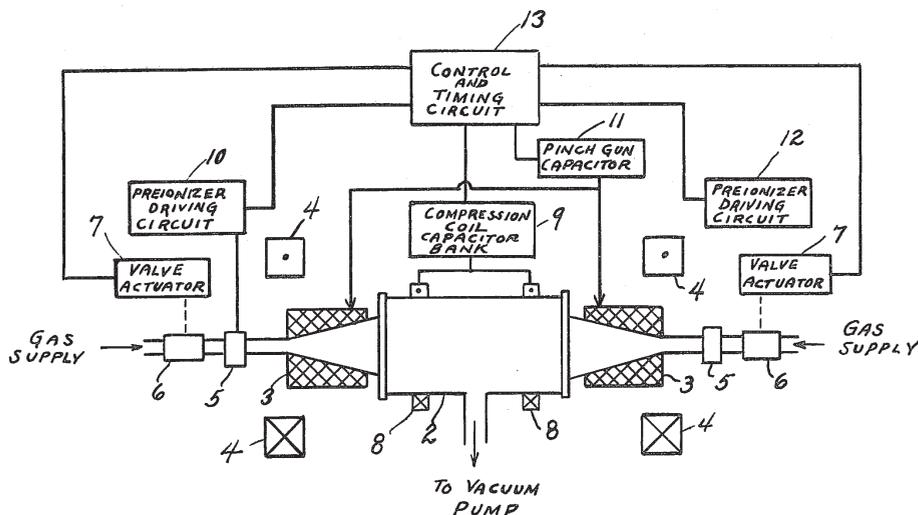
Singularities

High energy density physics, under which most of the subjects we have discussed so far fall, deals with subjects which are highly non-linear, non-equilibrium, and dynamic. Plasmas, for example, show a tendency to self-organize and take on sudden global changes. They have even been described as having behavior usually attributed to living process. Already, at far-below-fusion conditions, non-linear coupling, coherence instead of randomness, and evolution toward increasing concentration rather than homogeneity dominate.

Though the process of self-organization of plasmas is not very well understood, fusion reactors depend on plasma's capability to do just that. Every magnetic fusion reactor takes advantage of plasma's inherent ability to induce its own magnetic and electric fields. Even more, reactors depend upon states of the plasma in which fields are produced within the plasma that help to confine it. These states are much more effective than any external confinement that can be built, at least so far. Tokamak reactors, for example, depend on a state of the plasma called the high-confinement mode, or simply H-mode. Akin to tuning piano strings,²⁸ as more heat power is added to the plasma, discontinuous states of resonance

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

28. When two strings of a musical instrument are tuned to frequencies very near to each other, the instrument begins to experience a form of turbulence, as the two very similar frequencies interact, called "beats." These beats increase their frequency and intensity until the strings come into perfect harmony with each other at which point the beats stop altogether.



Schematic of Dr. Dan Wells' TRISOPS VIII machine which produces two counter-rotating plasma rings from the two ends, which collide at the center. Image from "Method and Apparatus for Generation of Thermonuclear Power" Patent US 4342720 A 1982.

Daniel Wells in 1986: "I am of the school that looks for naturally occurring geometries in the plasma to do the job of confinement."

can be easily recognized. In this case, the plasma enters a highly turbulent state after which it enters a resonant, quiet state, which is more stable than before having entering the turbulent period. In this new state, confinement time nearly doubles. Global variables such as temperature, particle density, and plasma radiation change. All parameters establishing the local pressure gradient increase.

Another example is a class of reactors, which include the reverse field pinch, spheromak, and field reverse configuration, which depend almost solely upon plasma's self confining features and thus do not use, or minimally use, external confinement.

After a presentation of his TRISOPS fusion reactor concept to a Fusion Energy Foundation conference in 1985, Dr. Daniel Wells, provoked by a suggestion by Lyndon LaRouche to take his theory into the astronomical domain, developed his idea of force-free²⁹ tori evolution for the development of the solar system.³⁰ His idea of force-free vortices was not new to him. Winston Bostick, a teacher of Wells, had worked on a concept for fusion, called a plasma focus, which did not look for a particular configuration of the plasma, but rather nurtured the plasma's tendency to twist and concentrate, thereby de-

veloping into progressively denser and more complex structures.^{31,32} Filaments, one of the first concentrated structures to be formed, are normally avoided in steady state reactors such as the tokamak, because they become the source of dense escape of plasma from confinement, and thus a source of disaster for the reactor, which can get over heated by the plasma. Therefore much research

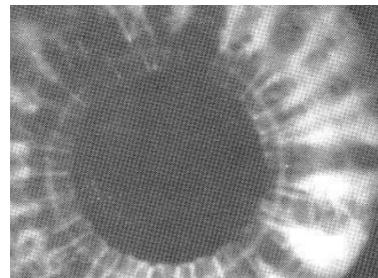


Photo of plasma filaments taken by Dr. Bostick.

is done to make sure these never or hardly occur. The plasma focus, instead intentionally induces a continual progression of increasingly concentrated states of the plasma. In this way, the plasma is able to achieve over a billion kelvin.

Since most of the universe is in a plasma state, work along these lines, has and will continue to show us that in fact these tendencies to self-organize into more organized states may be a more fundamental property of the universe than we realize, and that linear progressions and homogeneous distributions are in fact anomalies.³³

29. Dr. Robert Moon stipulated that, just as planets consider Keplerian orbits force free pathways, which take the least amount of effort to move on, force free pathways should exist for other phenomena, including fusion. In this way, he said, all fusion was really cold fusion. This was, and still is, controversial, and is at odds with collision based fusion theory.

30. Cf. D. Wells, "How the Solar System Was Formed," *21st Century Science and Technology*, July-Aug 1988, pp.18-28.

31. Cf. W. Bostick, The Pinch Effect Revisited, *International Journal of Fusion Energy*, Vol 1, no. 1, 1977

32. This design is currently being worked on at Lawrenceville Plasma Physics Laboratory with very promising results. lawrenceville-plasmaphysics.com

33. For more, see S. Bardwell, "Elementary Plasma Physics from an Advanced Standpoint," *Fusion*, Nov. 1978. p.18-42.

Fusion Energy

In order to support this growing economy, while eliminating third world conditions, and increasing the energy flux density of operations across the board, a baseline supply of energy must follow closely.

Currently the United States uses approximately 10kW per capita,³⁴ while countries like Zimbabwe, though having a similar population density, use 412W per capita. As a rough approximation, were 7 billion people to use 10kW per capita, an increase from 16TW to 70TW would be required. If all of this were electricity, this would be the equivalent of building 162,000 1 GW fission power plants.

This is still a low approximation. Even now, at 10kW per capita, energy is lacking. For example, were we to decide to desalinate water to relieve the parched western half of the United States, there is no extra energy to spare. New power plants would have to built.

An even larger margin of deficit comes from industry. The United States, and many other formerly industrial nations, no longer have an industrial economy. Residential and commercial use of energy per capita has continued to rise at a slow but steady linear rate. However, the

34. This includes all primary power use, and not only electricity. U.S. electricity use is about 1.4kW per capita.

industrial sector, which uses the lion's share of energy, has steadily declined from using near 48% of energy, to using now 31% of total energy.³⁵ Though some of that decrease in energy use might be attributed to increase in efficiency of machines, no one will claim that that increase in efficiency can account for the steep decline even over just the past 10 years. Our industrial products come from overseas. That means the energy we actually consume per capita is much higher, but that much of that energy is being leached from elsewhere.

As mentioned previously, *Executive Intelligence Review* estimated that were we to have taken the directed energy revolution into industry, productivity would have increased four-fold in ten years, and electricity requirements would increase six-fold.³⁶ Were the the other areas which reflect a fusion economy, such as space development and full control over atomic processes, to be integrated, both values—production and electricity requirements—would be much higher.

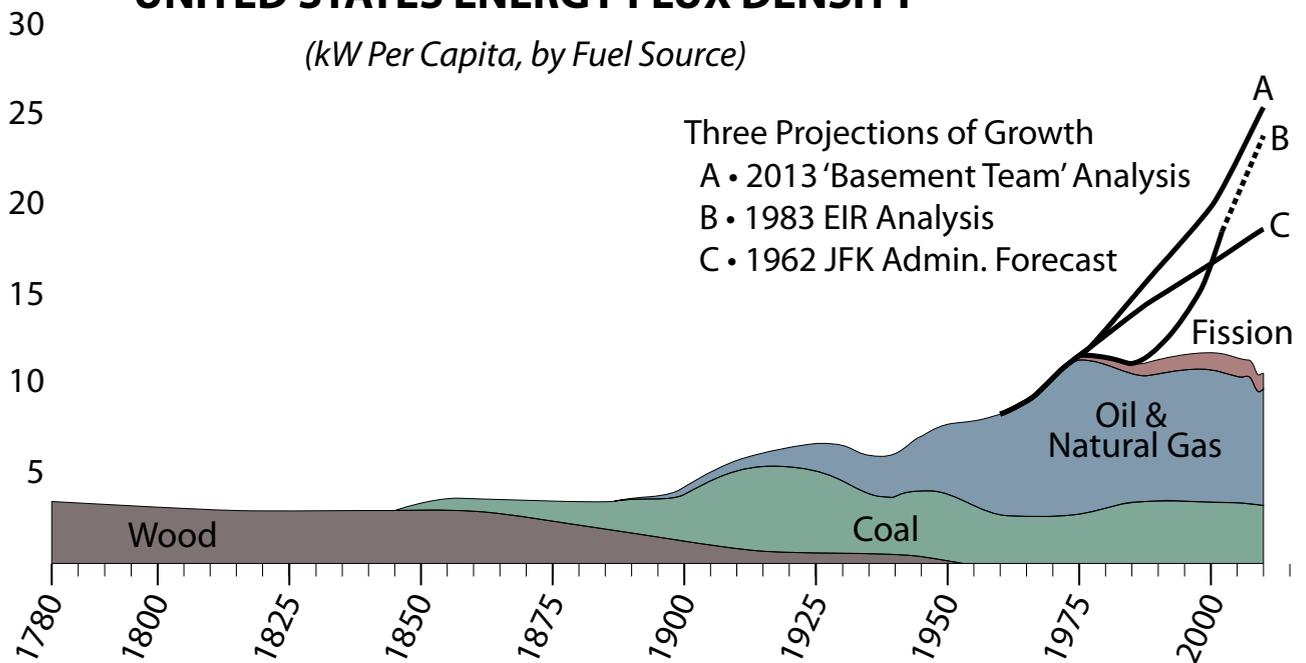
Rather than fighting over fossil fuel supplies and

35. According to the rate of growth during John F. Kennedy's time, he projected that by the turn of the century, per capita energy consumption would be 20kW.

36. Remember also that part of the directed energy revolution is moving away from using the heat from burning fossil fuels, and toward using electricity to drive much more concentrated and tuned forms of energy.

UNITED STATES ENERGY FLUX DENSITY

(kW Per Capita, by Fuel Source)



Per capita power consumption for the United States from 1780 to 2010. Trajectories A, B and C show three different projections of growth, which all make clear a 40-year growth gap. Notice that the required growth of fission was never allowed to come to be. Closing this gap now requires a crash program for the development of fusion.

Reactants	Products	%
${}^2_1\text{D} + {}^3_1\text{T}$	${}^4_2\text{He}$ (3.5 MeV) + n^0 (14.1 MeV)	
${}^2_1\text{D} + {}^2_1\text{D}$	${}^3_1\text{T}$ (1.01 MeV) + p^+ (3.02 MeV)	50
	${}^3_2\text{He}$ (0.82 MeV) + n^0 (2.45 MeV)	50
${}^2_1\text{D} + {}^3_2\text{He}$	${}^4_2\text{He}$ (3.6 MeV) + p^+ (14.7 MeV)	
${}^3_2\text{He} + {}^3_2\text{He}$	${}^4_2\text{He} + 2 p^+$ (12.9 MeV distributed)	
$p^+ + {}^{11}_5\text{B}$	$3 {}^4_2\text{He}$ (8.7 MeV distributed)	

A selection of fusion reactions. When products consist of more than two particles, energy is distributed variably amongst them. The right column gives a probability of resulting in one or the other set of products when given the same reactants.

whether they will last one hundred or two hundred years, we must take the next steps now. Nature requires that we use current resources and capability, at an increasing rate, to advance into the next platform of activity. It will be making that breakthrough that finally frees us from the dependence on fossil fuels for energy.

The orders-of-magnitude greater energy required must be provided for by new, more energy dense power sources. This can be done with a combination of fusion energy through direct conversion, fission energy (which can also use direct conversion), and synthetic fuels, such as hydrogen and hydrogen enriched hydrocarbons, produced therefrom.

Currently, regardless of energy source, whether coal, petroleum, or fission, most electricity is generated by heating up water to convert to steam, which is then funneled through a turbine to generate electricity. This cycle is at best around 30-40% efficient, meaning 60-70% of energy is lost as waste heat. Inert gas cycles, such as the helium cycle used in fourth generation gas cooled nuclear reactors can bring this up to 50%.

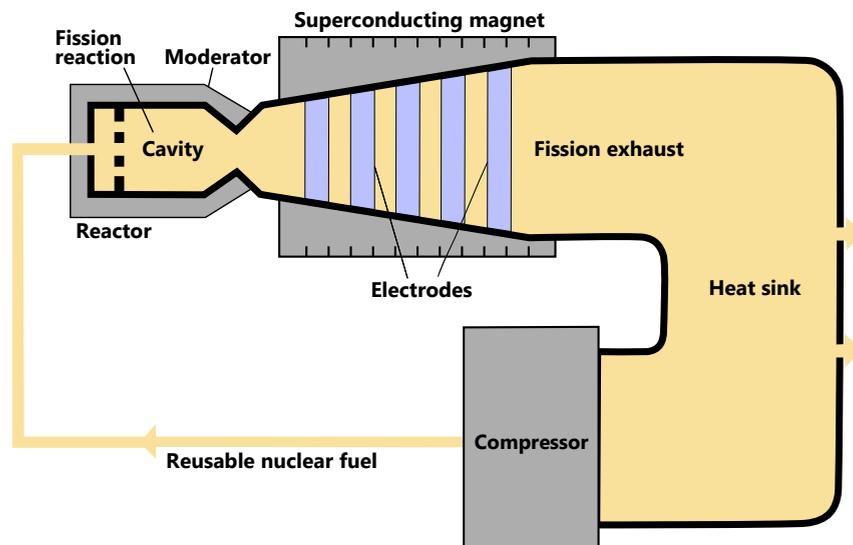
Instead of converting heat radiation, whether from burning fossil fuels or from inundating water with neutrons from fission or fusion reactions, the ionized products of combusted fossil fuel or from fission or fusion reactions, can be used to generate electricity directly.

Fusion is particularly conducive to direct conversion, and several designs exist for converting both the motion of the charged particles, and the x-rays and microwaves they radiate, directly into electricity.

For example, a magnetohydrodynamic (MHD) electric power generator, uses a strong magnetic field to separate out the positive and negatively charged particles in a fast flowing plasma. This magnetic field acts to move the fast and hot energetic ions perpendicular to the field, thereby generating moving charges, or electrical current. This design can be adapted for low temperature plasma emitted from the burning of coal, or fusion plasmas.³⁷ Whichever design turns out to be the most effective, conversion of fusion plasma energy directly to electricity, avoiding the steam cycle altogether, must be a natural part of the fusion economy.

A crucial aspect of direct conversion for fusion, however, is the use of what are considered advanced fuels. Since direct conversion makes use of energy of charged particles, reactions of deuterium and helium-3 ($\text{D}-{}^3\text{He}$), ${}^3\text{He}-{}^3\text{He}$, or proton and boron-11 ($p-{}^{11}\text{B}$) are preferable. Whereas deuterium and tritium react to produce a low energy helium-4 ion and a high energy

37. See M. Freeman, Magnetohydrodynamics: Doubling Energy Efficiency by Direct Conversion, *Fusion*, April 1980, pp.25-48. and en.wikipedia.org/wiki/Direct_energy_conversion



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

Nuclear Cavity Reactor with MHD Conversion. 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.

neutron,³⁸ which does not respond to a magnetic field, those just listed ($D-^3\text{He}$, $^3\text{He}-^3\text{He}$, $p-^{11}\text{B}$) produce little or no neutrons and instead emit high energy charged particles. The most powerful of those listed is the $D-^3\text{He}$ re-

38. Currently the easiest fusion reaction is between deuterium and tritium, two isotopes of hydrogen. However, most of the energy of this reaction is in a 14.1 MeV neutron, great for transmutation, not so good for direct conversion to electricity.

A Fusion Economy as an Economic Science Driver

Controlled nuclear fusion has been at our fingertips for decades. The International Tokamak Experimental Reactor (ITER), the largest tokamak now being built was conceived in 1985. A generation later, many of the original trailblazers of fusion are deceased or have retired, while youth with engineering degrees would prefer to calculate for Wall Street than be underpaid fusion scientists wondering if there will be funding to continue next year.

Due to extreme economic, political and social conditions, we are on a short deadline to decide the fate of fusion and our future, which depends upon it.

In a very real sense we cannot just pick up where we left off by reviving or rebuilding old designs and adequately funding the currently (or very recently) operational programs. That would be a start. The effect on the economy, and on human capital, of not driving toward fusion over the past few decades has been too extreme. That culture and industrial capacity which fostered that community who brought about those designs is not what we have now, especially in the U.S. and Russia, where much of that work originated.

In order to train a new generation, increase the productive capability globally, and achieve a platform of activity from which we can competently go to the next step, whether that be anti-matter based or something not yet hypothesized, we must: a) be much more conscious about creating a new economy than ever before, and b) let that prescience guide and value all

action, which gives one very energetic, 14.7MeV, proton per reaction.

Even before fusion becomes reliable enough to supply the electricity grid, fusion energy can be stored applied in other ways. Fusion-fission hybrid reactors can essentially store fusion energy in fission fuel, and can supply a rapid proliferation of fourth generation nuclear power plants. Fusion energy can also be stored and transported, chemically, in synthetic fuels.

other activities. An economic science driver will facilitate both.



1955 postage stamp. Eisenhower's *Atoms for Peace* program was a national program to immediately develop nuclear technology for the maximum benefit of mankind.



Soviet stamp from 1987 showing a tokamak fusion reactor.

For the upcoming young generation, a fusion science driver program today will serve as a lesson in basic economics, which is contrary to the money economy they have grown up with. Two values replace money as measures for rate of progress, **energy flux density**, the ability to use energy in a more concentrated way, and the closely connected **power of labor**, the ability for the same, or less, amount of labor to accomplish more, both qualitatively and quantitatively.

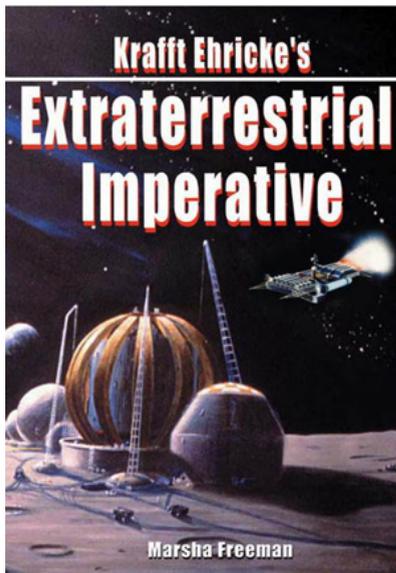
Take the case of the Apollo program, one of the last two attempted economic science drivers. Though the space age had started much earlier, with Sputnik and various other satellites and space laboratories, Apollo was able to use the space race to create the next platform of activity. The demand for a capability for which no textbook or profession existed, to support humans far away from womb of the Earth, and to build machines no machine tool had to precision to craft forced an integration and upgrade across various fields of industry and science. Most important were those advances close to the point of production, for example in machine tools, the machines that make all other machines. This included the burgeoning fields of stress analysis and materials science, giving heat resistant coatings and stronger alloys for drill bits. In combination with computerized control, these allowed

bits to be smaller, and faster, while providing the precision required. Since machine tools make all other machines, including new machine tools, advancements quickly propagated throughout the entire economy.

A combination of satellite imaging of pests, soil content, and weather, with combines which had more powerful engines and implements, which were bigger and yet light and still less likely to break, greatly increased each farmer's output. Many new fields were created, and those that existed experienced increases in both quantity and quality of product per laborer with the same amount or less work than before.

The Apollo program was also highly integrated into universities and private industry. At its peak it employed 400,000 people and was supported by over 200,000 industrial firms and universities. This integration and, most importantly, the optimism about humans and our future which the program created, served to shape basic education, culture, and business.

Based on this pace of activity, Krafft Ehricke, space visionary and engineer, had made a year-to-year plan for space development, which included a manned landing on Mars in 1984.



Krafft Ehricke, German American space pioneer, considered the development of space by mankind an imperative.



Paul Rivenberg and Mary Pat McNally, MIT Plasma Science and Fusion Center

Students in the control room of the Alcator C-mod fusion reactor at MIT

This did not happen. The Apollo program started losing funding before the first landing on the Moon. Sex, drugs, rock and roll, and the Vietnam War took its place. The result can be seen in later years of NASA's *Spinoff* magazine. As a reflection of the cultural shift in society, advertised spinoffs shifted from producer goods to consumer goods—from medical and farm equipment to polarized

sun-glasses and swimsuits.

A crash program for today would be successful only if intent on continued development is unwavering. Law-makers must be able to see the physical value of any investment today based on that investment's role in creating a incommensurable increase in capability for tomorrow. In some ways, this can be taught in the process of the initial stages of that crash program.

In addition, as the case of Apollo demonstrates, economies are not composed of technologies. Nor do economies progress one technology at a time. It is true that discoveries and technologies are ultimately made by individuals, though always in a social environment, but the ability to manifest those discoveries, such that they assimilate and propagate into the economy, thereby serving to create the conditions for further discoveries, is contingent on the economic policies, which encompass education, the arts, industry, etc.

Instead, a crash program must seek to build a new platform of activity, a power or capability, upon which a completely new set of activities can be supported, and upon which a capability to make further advances, to build the next platform, is accessible. Therefore, done right, an economic science driver today will not be the end. All that has been broadly placed under the umbrella of a "fusion economy" above, is only a next step, and only the currently foreseeable aspects of it. An economic science driver does not seek to define an ultimate state or level to achieve. There are milestones to be set. However, a successful science driver will merely serve as a catalyst, providing the impetus for a new pace of progress.