Commercializing Low Energy Nuclear Reactions (LENRs): Cutting Energy's Gordian Knot

A Grand Challenge for Science and Energy

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Cost-effective, environmentally benign energy technologies are urgently needed. Vastly larger energy requirements of future societies must be satisfied at reasonable cost without destroying the entire planet in the process, whether by climate disasters or internecine wars over oil. Successful commercialization and deployment of "green" energy is imperative to attack an array of energy and climate change issues that confront our world today

The Gordian knot facing humanity is not that our world will ever run-out of energy per se in the foreseeable future. Between global coal reserves and electromagnetic energy in the form of photons streaming from the sun there is more than enough energy to be had for whatever purpose. Energy availability, in the broadest possible sense, is not the Gordian knot.

The Gordian knot is that worldwide consumers of energy need to have technologically usable, reasonably priced energy delivered to the right place at exactly the right time in forms that are environmentally benign and readily compatible with sustainable, long-term global economic growth.

LENRs could be an important part of a diversified portfolio of "green" carbon-free energy technologies. They have a unique combination of enormous energy density and cost advantages that cannot be matched by any other known nuclear or non-nuclear technology. If commercialized, these unparalleled attributes would enable LENRs to revolutionize portable power generation, radically changing the world as it exists today. This could in turn usher in a new era of cost-effective, LENR-based all-electric or steam-powered vehicles with unprecedented performance and range capabilities that might finally end the dominance of internal combustion engines in transportation.

Widespread global deployment of LENR technologies, together with synergistic large- and small-scale photovoltaic and wind-power systems, could create a less expensive, greener energy future for humanity. LENRs and the portfolio of carbon-free energy technologies have the potential to democratize access to affordable energy for every inhabitant of the planet.

Preface:

A unique array of factors has converged to create the world's recent energy price inflation and rapidly increasing demand for all forms of energy. Like it or not, the U.S. is now facing extraordinarily tumultuous economic times amidst heralding cries for energy independence.

Some suggest that we simply "drill, drill, drill" domestically for oil and gas; others promote their plans to expand development of alternative energy sources such as wind, solar, and biofuels. Unfortunately, cutting energy's "Gordian Knot" is not that simple. It is a complex global problem which deserves appropriate solutions that avoid mistakes of the past. Maintaining the status quo with business as usual is simply not a viable option for eventually achieving long-term security and prosperity for all nations.

In the 21st century, continued reliance on carbon-based sources of energy is not an answer --- it is a key part of the problem. The U.S. imports nearly 70% of its oil from foreign nations that have become increasingly embroiled in political, cultural, and/or military conflicts with us. Drilling for more domestic oil and gas, whether offshore or up in Alaska, may sound like a good idea, but it will take years to accomplish and is unlikely to be a long-term solution for our country's rising energy demand. We had better hope and pray that increasingly violent storms stay away from our shores and oil refineries.

Keep in mind that about 1.6 billion people struggle to live in impoverished rural areas of the world without any access to reliable electricity, clean water, or the Internet. Sadly, many of these same people face the horrors of famine, disease, and sometimes even genocide as they live in countries with unstable governments and military or civilian uprisings. A recent spate of huge capital investments and subsidies in corn-based ethanol did nothing to help these energy-poor people. Instead, it spurred ratcheting price inflation in basic food staples and even riots over food in some underdeveloped nations.

Was it wise to develop an alternative energy source based on an agricultural commodity so closely tied to the world's food supply? Although well-intentioned, US ethanol subsidies created a direct linkage between grain prices and the price of energy. It enabled energy price increases, for the first time, to rapidly propagate directly into the prices of feed grains and food grains. Does that type of alternative energy really make the world a safer or better place?

By contrast, wealthy industrialized societies have easy access to vast amounts of electricity because they generate and distribute it at low cost via regional grids. Even today's cell phones, mobile devices, Internet access, battery chargers, and electric cars ultimately connect back to grids. Casting aside any concern for impoverished, unstable areas of the world, can we just *assume* that we will all be able to stay connected electronically and access power from the electric grids on which we have become utterly dependent? We must hope and pray that any power outages from grids will be short-lived and not ever catastrophic.

The world is entering a new age of surging demand for energy. Viable long-term solutions for our present energy problems will require huge amounts of capital investment, careful planning, ingenuity, and breakthrough technological innovations. Failure to do so will only increase today's global conflicts and economic instabilities.

Our goal should be to ultimately revolutionize global access to energy by developing a diversified portfolio of "green" carbon-free energy technologies. We simply cannot continue to stumble along with ill-planned, incremental improvements and investments that do little or nothing to solve our long-term energy and environmental problems. There is perhaps no time in modern history when the need for "green" distributed power generation has been so great. The future of energy holds both great promise - and peril.

In this Grand Challenges white paper, we discuss the dynamic interaction between new technology development and economics; review the suitability and viability of a portfolio of carbon-free energy technologies, as well as their current technological limitations; and explain why there is no silver bullet, no single "magic" solution for today's energy crisis. Yet there is hope - new breakthroughs have occurred.

We then discuss the benefits of developing a revolutionary new energy technology based on Low Energy Nuclear Reactions ("LENRs") that is inherently safe, "green", carbon-free and ideally suited for a wide range of power generation applications. If successfully developed for portable and distributed power generation applications, this technology could provide improvements of many orders of magnitude over existing energy storage technologies such as chemical batteries. Importantly, it also has the potential to provide cost effective off-grid distributed power generation systems.

With unprecedented levels of energy density, longevity, and scalability, LENRs could ultimately be used to power a car or an airplane around the world without refueling. That would provide true "energy independence" and break oil's stranglehold on the US economy. LENRs have other important market applications that may substantially improve heavy oil recovery, nuclear fission power plant technology, and nuclear waste remediation.

Ongoing efforts to commercialize LENRs are quietly being pursued by small numbers of scientists in the U.S. and in foreign countries, including Russia, China, Japan, and Italy. More recently, there have been indications that India may renew its R&D efforts in this area. To date, funding has been very limited.

Beginning in 2005, Lattice Energy LLC made a series of major theoretical scientific breakthroughs which, for the first time, explain the physics underlying a large body of LENR experimental data which has been observed by scientists for over 100 years. Lattice believes that it has gained unique proprietary insights and the understanding required to overcome technological roadblocks in the path of commercialization.

The U.S. government and private venture capital have largely ignored highly controversial LENRs, investing elsewhere. Previously, they argued that there was no theoretical understanding of LENRs, so it might not even be "real science," whatever that means. Now, they admit that a working theory exists, but say that LENRs have not been commercialized yet, so "call us when you have working prototypes, and then we might invest." This attitude will never cut energy's Gordian knot and address Grand Challenges.

Successful commercialization of LENR technology would be a game-changer for energy. However, that would threaten a myriad of vested interests: many businesses, the powerful oil industry, and other heavily entrenched areas of scientific research along with their richly paid lobbyists in Washington, D.C. For example, the U.S. Department of Energy has spent billions of dollars on "hot fusion" research that has continued for decades at national laboratories and universities. These well-funded, heavily lobbied "hot fusion" programs have yet to produce anything of commercial value; many scientists doubt that they ever will. Yet in spite of this incontestable fact, the U.S. DOE provided "hot fusion" researchers with $300 million in 2007. Does that make any sense? Lobbyists got paid, but what about the American people?

LENRs are a revolutionary new energy technology that could provide, safe, green, scalable distributed power systems that can be widely deployed throughout the world. This technology has the potential to help cut energy's Gordian knot, allowing the world to enter a "new age of energy" in the 21st century.

Along the way, and for whatever reasons, somewhere in recent years the United States seems to have drifted away from its unparalleled history of spurring world-changing scientific innovation and mass-market technology product commercialization with hopes of improving the future. Today, America's system for creating revolutionary scientific innovation lies broken. It must urgently be fixed if we are to have any hope at all of cutting energy's Gordian knot and ending today's global economic turmoil.

Quoting from Thomas Friedman's 2008 book, "*Hot, Flat, and Crowded*:"

> *"No single solution will defuse more of the Energy-Climate Era's problems at once than the invention of a source of abundant, clean, reliable, and cheap electrons. Give me abundant clean, reliable, and cheap electrons, and I will give you a world that can continue to grow without triggering unmanageable climate change ... I will eliminate any reason to drill in Mother Nature's environmental cathedrals … and I will enable millions of the earth's poor to get connected, to refrigerate their medicines, to educate their women, and to light up their nights."*

Concepts in this document:

Gordian knot - Is a metaphor for an intractable problem, solved by a bold stroke ("cutting the Gordian knot"). The legend it refers to is associated with Alexander the Great. In 333 BC, wintering at Gordium, Alexander attempted to untie the famous knot. When he could find no end to the knot, to unbind it, he sliced it in half with a powerful stroke of his sword, producing the required ends (the so-called "Alexandrian solution").

Carbon-based versus Carbon-free Primary Energy Sources – Carbon-based primary energy sources include: petroleum (oil), natural gas, coal, biomass (e.g., wood), and biofuels (e.g., ethanol). Carbon-free primary energy sources include: nuclear (e.g., fission, fusion, and LENRs), hydroelectric, geothermal (deep and shallow), solar (photovoltaic and heat), wind, and ocean-related energy recovery.

Energy Density – Is the amount of energy that is stored or generated in a given system or a region of space per unit of volume, or per unit of mass, depending on the context, although the latter is more formally "*specific energy,*" which is defined as the amount of energy stored or generated per unit of mass.

Chemical versus Nuclear Energies – The realm of chemical energies involves manipulation of outer atomic electrons; these energies are typically measured in electron-Volts (eVs). Much more powerful nuclear energies involve changes in the states of a nucleus inside an atom; they are measured in Mega electron-Volts (MeVs). Energies produced by nuclear processes are usually at least a *million times larger* than what can be produced by any type of chemical energy technology.

Energy Storage Devices versus Controlled Power Generation Systems - Electrochemical batteries and electrostatic capacitors are examples of devices that are used primarily for temporarily storing electrical energy that is actually generated elsewhere. By contrast, a power generation system is a controllable energy-producing device that requires some sort of chemical or nuclear "fuel" which is then "burned" to release chemical or nuclear energy that is then converted into electrical power (e.g., via an AC generator) or mechanical motion (e.g., steam engine).

Stationary, Mobile and Portable Power Generation – "Stationary" refers to power generation systems that are too heavy and/or bulky to be physically moved; they typically remain in a single fixed location for their useful operating lifetime, e.g. central station power plants. "Mobile" refers to a power generation system that is located on some sort of movable platform (e.g., such as an IC engine installed in a vehicle or a turboprop engine on an airplane). "Portable" refers to a power source (energy storage or generation) in a convenient form factor with a weight that can easily be carried by a person for long periods without undue fatigue. Energy density of power sources is especially critical for mobile and portable platforms.

Regional Electricity Grid – Is a large-scale, complex networked system that is financed and constructed for the generation, distribution, and sale of metered, low-cost electrical energy to very large numbers of different types of customers. Today, such grids typically comprise large central station power generation plants (mostly fired by coal, natural gas, or nuclear fission reactors) that are connected to end-user customers through an extensive web-like network of electrical tranmission lines (wires). In some areas, such as Texas, large-scale wind farm power generation is also being connected to regional grids; there are analogous plans for building large-scale photovoltaic solar power generation "farms."

Protons, Neutrons, Electrons, and Ions – Protons, neutrons, and electrons are elementary particles that altogether make an atom. Protons (having a +1 electric charge) and neutrons (neutral particle with no electric charge) comprise a central nucleus which is held tightly together by a very short-range, local nuclear force called the strong interaction. Electrons (having a -1 electric charge) are found in "clouds" at some distance away from the nucleus. In an electrically neutral (normal) atom, there are exactly as many electrons circling the nucleus as there are protons inside of it. An ion is an atom with one or more outer electrons missing; it has a net electric charge. Protons and electrons are stable elementary particles; they do not decay. A neutron is only stable when it is inside an atomic nucleus under the influence of the strong interaction. A neutron located outside of an atomic nucleus is unstable; it has a lifetime of ~13 minutes, decaying via a weak interaction into a proton, electron, and a neutrino. The number of protons in a nucleus determines its atomic number; each element in the Periodic Table has a different atomic number. A proton + a single electron form a neutral hydrogen atom; a proton + a neutron + a single electron form a neutral Deuterium atom ("heavy" hydrogen).

Neutrino - An invisible, ghostly type of photon (light) that carries energy but barely interacts with ordinary matter; an energetic neutrino can pass through a billion miles of lead with very little chance of being absorbed. Among other places, neutrinos are produced in enormous quantities by certain nuclear reactions in the sun; billions pass through our bodies every day without effect.

Beta decays and transmutations - In beta decay a neutral neutron (no net electric charge) located inside of an unstable atomic nucleus spontaneously decays into a positively charged proton (which remains inside the nucleus), an energetic negatively charged electron (that escapes the nucleus entirely, being emitted from the atom as a so-called "beta particle"), and a neutrino photon (which flies off into space). Since the nucleus of the atom that underwent decay suddenly contains one more "new" proton, its atomic number increases by +1 which means that the atom is now a different element. This transformation of one element into another different element or isotope is called a transmutation. These reactions can release energies of up to tens of MeVs.

Weak Interaction versus Strong Interaction Processes - Weak interaction processes typically end-up producing stable elements, releasing comparatively benign beta particles and neutrinos via beta decay transmutations along the way. By contrast, nuclear fission and fusion processes involving the "strong interaction" typically produce dangerous energetic neutrons, "hard radiation" (X- and gamma-rays), and long-lived radioactive isotopes.

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Economic backdrop of the current global energy dilemma: a primer

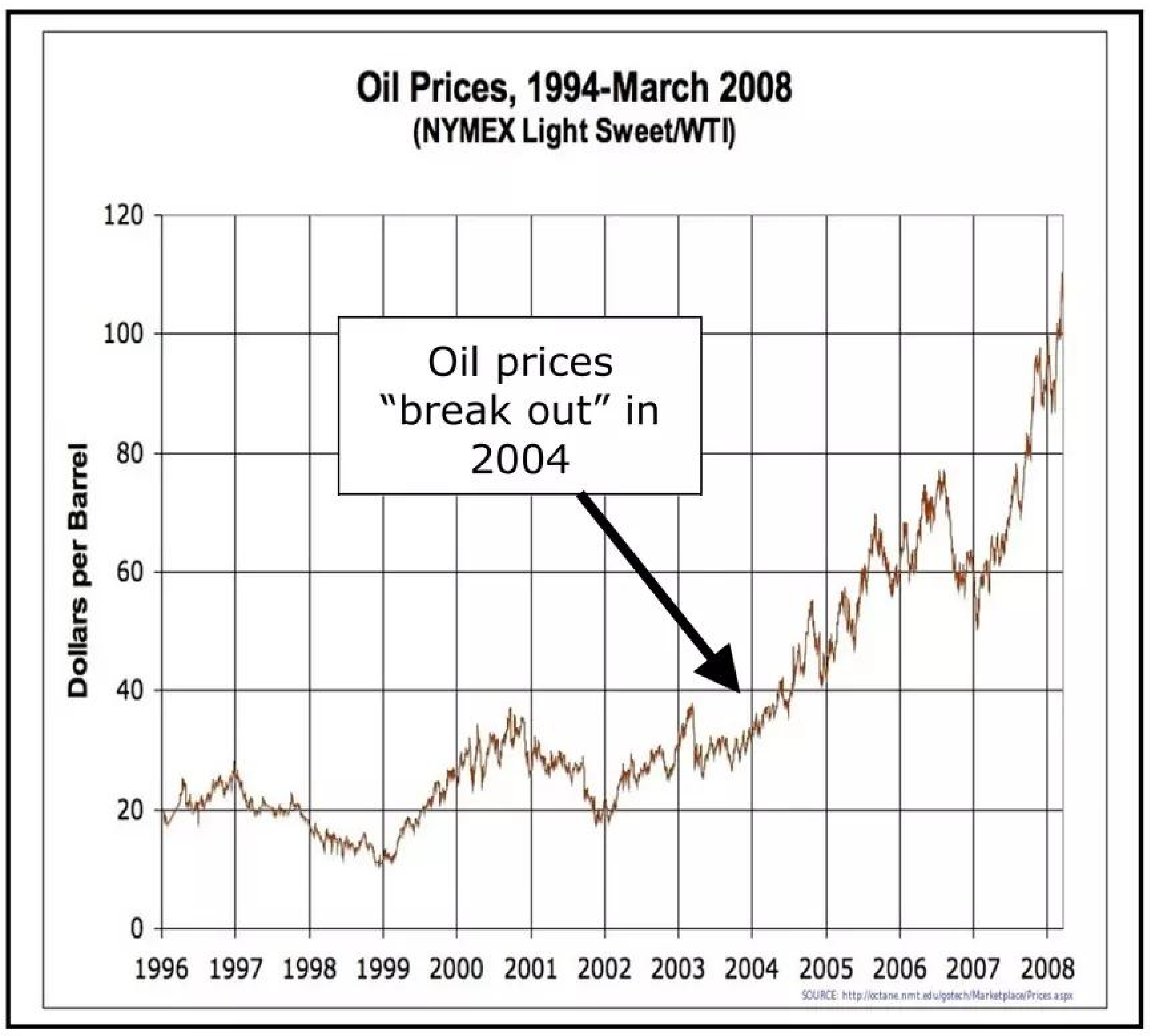
Price appears to be skyrocketing with no end in sight: present day energy's Gordian knot -

Energy today is an extremely well-arbitraged US$ 5 trillion worldwide market that is inextricably linked to economic growth and the price of goods and services in every country on earth.

Crude oil prices recently exceeded US$140/barrel, simultaneously ratcheting the prices of gasoline and substitutable sources of energy such as coal and natural gas. Since hitting that peak, oil prices have temporarily declined back to lower levels. In addition, drastic increases in embedded energy costs are gradually working their way into the market price of many different types of goods and services throughout the world, including the price of food. Not surprisingly, price and availability of various energy sources have become intense economic, political, and military issues in most countries around the world, including the United States. Where will it end?

Further complicating an already volatile supply/demand balance, some research suggests that there could be causal linkage between global warming and CO_2 emissions from fossil fuels. To the extent that this is provably true or perceived to be true, it will constrain the market's ability to freely shift global energy demand from oil and oil-products toward consumption of substitutable sources of carbon-based energy such as natural gas and comparatively abundant global coal reserves.

A chart of oil prices since 1994 and breakdowns of energy use by source (2001, 2005) and are as follows:



% of Total Annual Energy Consumption		
Source	**US**	**World**
Oil	40.6	36.8
Coal	22.9	25.2
Gas	22.6	26.0
Nuclear	8.1	7.5
Hydro	2.7	2.4
Biomass	2.7	NA
Geotherm	0.4	0.4
Solar (all)	0.1	0.6
Wind	0.2	<0.1
Ocean rel.	~0.0	~0.0
Year:	**2005**	**2001**
Data:	**EIA**	**IEA**

Note: source for US data is the "Monthly Energy Review" of the Energy Information Administration (EIA) of the US Dept. of Energy; world data is taken from annual reports of the International Energy Association (IEA).

The fundamental change in oil prices that occurred in 2004 (as evidenced in the chart above) is very well explained on page 39 of Thomas Friedman's latest book, "*Hot, Flat, and Crowded*", where he says,

> *"The pivotal year that told us we were in a new era in terms of global energy supply and demand was 2004, says Larry Goldstein, an oil expert at the Energy Policy Research Foundation. 'What happened in 2004 was the world's first demand-led energy shock.' Here's what he means: In 1973, 1980, and 1990, we saw sudden oil price spikes because of wars or revolution in the Middle East, which sharply limited the supply of oil. What happened in 2004 said Goldstein, was a price shock that was simply the product of long-term trends that pushed*

> *demand well ahead of supply, spurred in large part by a sudden leap in demand by China…Two things happened that year. All the shock absorbers, all that spare crude, product, and refining capacity, disappeared, and demand for energy took a great leap forward, due to China's growth. At the start of 2004, the International Energy Agency [IEA] predicted that global demand for crude oil would grow by 1.5 million barrels a day that year, said Goldstein. 'Instead, it grew by three million barrels a day, and [demand in] China alone grew by over one million barrels a day,' he said. And because all three of the traditional shock absorbers were gone, that extra demand could not be cushioned."*

Dramatic increases in crude oil prices since 2004 are an unmistakable signal from energy markets that oil supplies and increasing demand are on a collision course; they in disequilibrium. Price charts don't lie.

Beneficial economic functions of price signals: especially price increases –

The short- and long-term economic function of such price increases in freely traded energy markets is to:

- Reduce demand; price of energy rises to whatever is necessary to lower consumption,
- Encourage economic substitution; where practically and technologically possible, and
- Stimulate capital investment; to increase energy supplies and develop new technologies._

Reduce the demand for energy from consumers -

Price *increases* ration consumer demand and allocate inventories of goods and services amongst competing consumers. Theoretically, in freely traded markets the price of a good or service in short supply will rise to whatever level is required to insure that "pipeline" supply chains and carryover inventories are nonzero. Conversely, price *decreases* in goods and services *stimulate* consumer demand and help clear excess inventories in both the short- and the long-term. Such up and down price fluctuations are a perfectly normal, *necessary* feature of the short- and long-term supply/demand rhythms of modern economic life. *They are not to be confused with decadal secular increases or decreases in the level of prices caused by externally superimposed macroeconomic forces associated with inflationary eras (in which national governments typically "print money" in excess of is what is required to support real economic growth) or deflationary economic regimes associated with extreme market panics, severe recessions, and/or multi-year depressions.*

Demand for oil in the US is finally being impacted by gasoline prices that exceeded $4.50 per gallon in 2008. Car owners are driving fewer miles and/or using/purchasing more fuel-efficient vehicles. Some are switching from Cadillac Escalades, GM Hummers, and 400 hp Ford Mustang GTs to the Ford Focus, Toyota Prius, and Chevrolet Neons. Some people living in large cities are simply leaving their cars in the garage and using public transportation instead of driving themselves. Prices of airline fares go way up; passenger miles flown go down. High energy prices are thus in the process of changing consumer behavior which in turn reduces short- and long-term oil demand all over the world. At some point, the demand for oil will drop far enough to temporarily stabilize price. If demand reduction overshoots on the downside, which is often the case, the price of oil could drop significantly from its near-term peak; and so forth. This dynamic back-and-forth seesaw between the twin forces of supply and demand creates the jagged "saw tooth" pattern commonly seen in charts of stocks and commodity prices. In real-world markets, states of true price equilibrium and extreme stability are transitory at best; disequilibrium is the rule, not the exception.

Encourage economic substitution by consumers between competing sources of energy -

Economic substitution is the replacement of one type of good or service with another with which it is fungible. Typically, such behavior is driven by a desire to minimize costs and/or maximize availability. It is often triggered by some sort of restrictions on availability and/or substantial increases or decreases in the price of a good or service. Over the short-run, economic substitution primarily involves utilization of readily available, cost-effective fungible alternatives. For example, consumers faced with high prices may:

substitute hamburger for steak; off-brand clothes for designer clothes; or heat their homes with word-burning stoves rather than buy more expensive fuel oil or propane from a local distributor. Similarly, businesses faced with rising costs may in the case of: restaurants – substitute processed chicken for hand-cut chicken breasts; electrical contracting – where permitted by code, replace more expensive steel conduit with ROMAX cable; grid-connected 500 MW power plants – advanced multi-fuel-capable facilities allow them to shift from burning high-priced natural gas to less expensive local supplies of coal or biomass; etc.

Over the long run, in free markets with minimal government interference, the process of economic substitution is further facilitated by the availability of greatly improved and/or *entirely new* types of goods and services created by the investment of capital and application of technology to perceived profit-making business opportunities. This interactive capitalistic process is what the famous economist Joseph Schumpeter referred to as “creative destruction.” It is a dynamic process that replaced horse-drawn buggies and wagons with automobiles and trucks; telegraphs with telephones; landlines with portable wireless cellphones; passenger pigeons and hot-air balloons with airplanes and missiles; and stamped letters via the USPS with overnight FedEx and e-mail.

Stimulate capital investment: increase energy supplies; develop new energy technologies -

The supply-side angle of capital investment in energy is well known: for example, vastly increased revenues/profits from currently high crude oil prices are providing oil companies and governments with additional capital that is being utilized to intensify exploration and drilling activities all over the world. New technologies are applied to existing oil/gas wells to increase recovery, and so forth. These supply-side effects typically occur in the short- to medium term; that is, over periods under a decade or so.

A much longer-term economic process, in which high prices stimulate capital investment in developing entirely new and better technologies that can replace old ones, is not discussed as often. That is because new technology development, from a published scientific advance to the establishment of significant commercial markets, commonly takes 3 - 10 years. In many cases, the complex, multi-stage process of high-tech commercialization can require 10 – 20 years or more.

For example, the first demonstration of a working laser in a laboratory took place in 1960; the first mass-market consumer technologies using lasers in a central role (e.g., CD players) did not enter the commercial marketplace until the late 1970s; it took ~20 years. Deployment of powerful military weapons lasers is finally starting; that's ~50 years. Even 60 years of R&D and market development is not uncommon. Being a long, drawn-out R, D & E process, it is often little heralded by the media.

Importantly, a prolonged period of effectively high prices can ultimately stimulate economic substitution through capital investment and return-driven technological change. In free-market economies high prices create financial opportunities to develop new types of products that can be cheaper, better, faster than those they are intended to replace. In countries with free, market-driven economies, this creative economic role is usually undertaken by a financial services industry that includes a combination of investment banking firms, venture capitalists, and/or individual investors.

For example, from the mid 1970s until the present, California's Silicon Valley venture capital firms were instrumental in financing the development of a broad range of technologies. Their successful commercialization efforts were responsible for the world-changing personal computer and Internet revolutions. Altogether, it took roughly 30 years to get from the pre-PC era to where we are today.

Starting with Apple, Inc. (1977), Radio Shack (1980), and IBM Corporation (1981), personal computers (PCs) based on low-cost Intel/Motorola microprocessors, commodity DRAM memory and hard disks, and related microcomputer software, created a worldwide revolution. PCs beat mainframes and minicomputers on price/performance by dramatically reducing the price of computation. This created huge new markets for PCs as well as establishing a low-cost global software base and related computational backbone that enabled the rise of the Internet. Indeed, Google probably would not exist in the absence of low cost commodity PCs coupled to affordable application software and standardized communications protocols. Since 1977, the world PC market alone has grown from almost nothing to US$ ~125 billion in annual sales. Internet-related economic transactions comprising sales of goods and services are now substantially larger than that value.

The PC era collapsed the inflation-adjusted price of computation and democratized access to computers for at least a billion people worldwide. The rise of the Internet democratized low-cost worldwide access to all forms of information, ideas, goods, services and human knowledge; it is gradually knitting the entire world together into a vast, complex skein of diverse, electronically interconnected humanity.

Similar to the early days of semiconductors, microprocessors, and PCs, a rare confluence of macroeconomic, geopolitical, and technological forces are creating a unique formative environment that will spawn an unprecedented array of business opportunities within the energy sector. Today, energy prices that have been persistently high since 2004 are beginning to focus vast global entrepreneurial forces that will accelerate the development of a wide range of new energy technologies.

Government intervention in complex economic processes: the good, the bad, and the ugly -

Quietly guided by 1700s economist Adam Smith's so-called "invisible hand," free-market pricing, unfettered competition, highly organized financial services industries, and return-driven capital allocation are well known to be highly effective mechanisms for creating long-term economic and technological growth. They enabled the United States' to grow from a thinly populated, trackless wilderness to a global superpower with 300 million inhabitants in less than 250 years. Even ancient China, saddled with a (now nominally) Communist political dictatorship since 1949, has embraced mostly free-market economics to create phenomenal rates of national growth over the past decade or two. Mostly unaided, these "blind" economic forces have managed to transform the world.

Given the enormous importance of adequate, reasonably-priced energy resources in modern economic life, energy is one of the most heavily politicized basic commodities. This is because the price and availability of energy affects the end-user cost of almost all goods and services sold to consumers, who actually get to vote in many countries. In conjunction with intrinsic national energy resources (or a lack thereof), it also heavily impacts the conduct of national security policies, which are typically formulated and executed by military and/or politico-economic power elites.

Unfortunately, energy's crucial role in modern life leads to various types of intervention by national governments. They engage in it by virtue of being politicized governing bodies, democratic or otherwise. Driven by specific socioeconomic and/or technological agendas (e.g., the nebulous goal of "energy independence"), governments intervene when they are: (a.) playing to issues that are popular with their citizenry or; (b.) impatient to "improve" or accelerate otherwise "automatic" operation of the "invisible hand" in achieving economic and/or technological progress. In doing so, they are deliberately tampering with very complex, multiyear macroeconomic processes in which the final outcomes of energy and technology policies are not necessarily predictable with certainty.

Governments have many powerful state-only "tools" at their disposal for intervening in economic affairs. These include: various types of government subsidies; direct taxation and/or import tariffs; tax and investment credit incentives to encourage private sector capital investment in targeted areas of economic activities and/or R&D; focused government-supported R&D, and so forth.

When one examines the historical record of government intervention in energy and technology across many countries, results range all the way from tremendous successes to total fiascos … and everything in between. It is an exceedingly complex mixture of varied outcomes.

For example, longstanding high government taxes on oil-based transportation fuels in continental Europe (resulting in gasoline pump prices that are nearly triple those in the US) are generally credited with creating a much more fuel-efficient transportation system and fewer driven miles per capita, reducing oil demand in the European Union from what it might have been otherwise. Today, many would call that good energy policies result. By contrast, countries with policies of national *subsidies* on transportation fuels that *limit* effective oil price increases to consumers (e.g., China, India, Mexico, Indonesia, Malaysia, South Korea, etc.) have recently experienced little or no decrease in the demand for energy from their transportation sectors, in spite of dramatically escalating oil prices. Over and above the enormous expense to taxpayers in such countries, many today would call that a bad energy policy result in that it interferes with normal demand reduction mechanisms and exacerbates an already tight worldwide energy supply/demand balance.

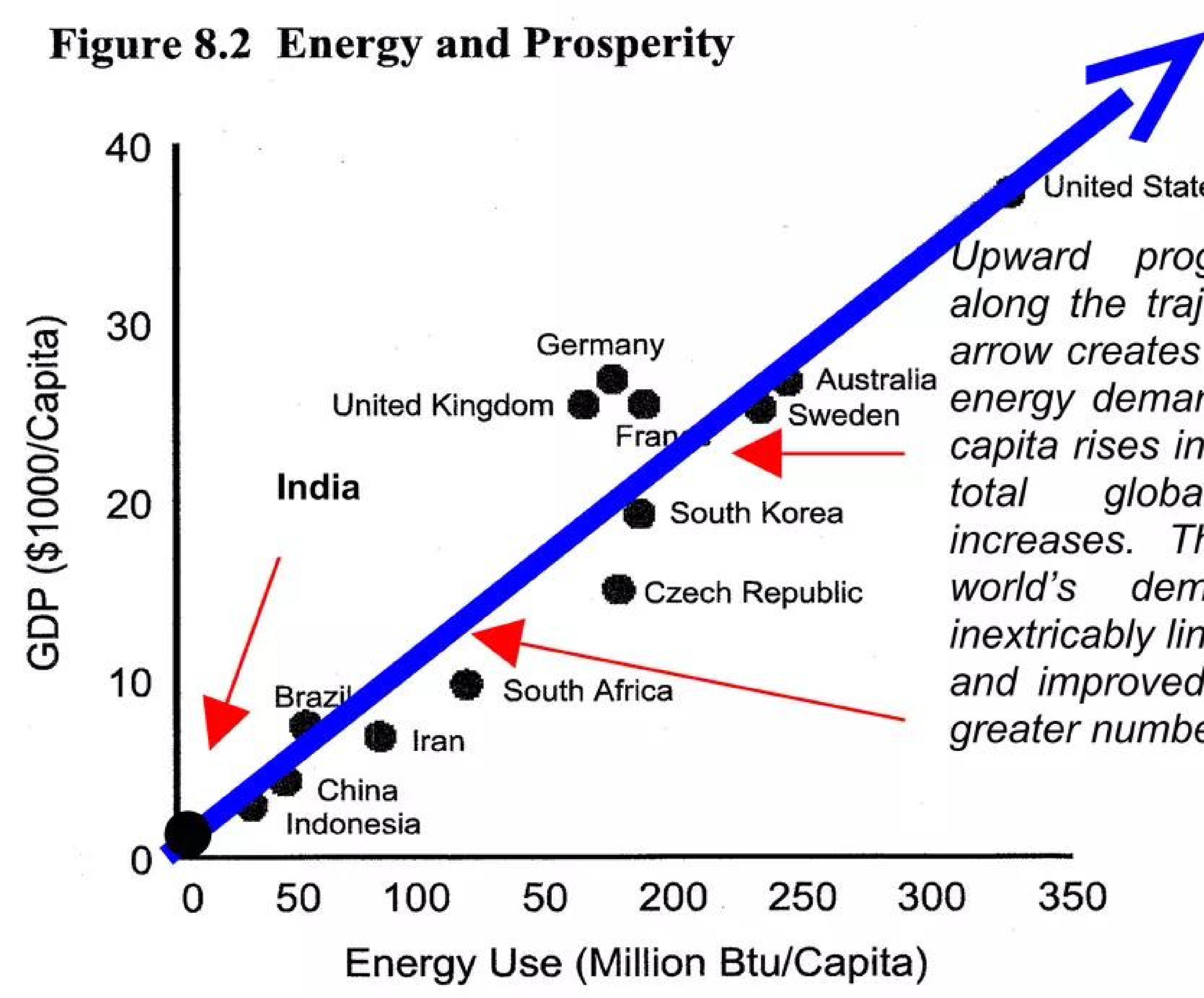
Ethanol from corn subsidies in the US is a perfect example of well-intentioned policy gone terribly wrong. They were initially enacted to encourage partial substitution of domestic ethanol for foreign oil in gasoline and help-out (then) financially beleaguered Midwest farmers. Sounded good at the time. The unanticipated result was the creation, for the first time, of a direct, readily arbitraged linkage between the price of feedgrains (which affect food prices) and the price of energy. Now, increases in energy prices can be very rapidly injected into the price of foodstuffs – an ugly result.

Price of energy and relationship to economic growth in the present era

Global energy use – overall demand for energy is currently very strong and appears likely to increase substantially in the future – one of the root causes of energy's Gordian knot

Note: in 2008 India (not shown in Huber-Mills' chart) had an estimated GDP ($1000/Capita) of 1.327 and Energy Use (Million Btu/Capita) of 12.6, placing it squarely near the origin of the bold arrow in the lowermost corner of the left quadrant.

Also note that India and China now account for 40% of the world population.



Upward progression of countries along the trajectory of the bold blue arrow creates increases in total world energy demand. The faster GDP per capita rises in all countries, the faster total global energy demand increases. Thus, expansion in the world's demand for energy is inextricably linked to economic growth and improved standards of living for greater numbers of people.

Source: CIA, *World Factbook*; BP p.l.c.

Roughly, this chart implies that if India and China are to reach the same energy use per capita as Western Europe by the year 2048, their combined demand for energy must increase by ~14% per year <u>for the next 40 years</u>. If energy's Gordian knot is not somehow cut, such demand increases will be unsustainable.

Strong upward trends in oil prices suggest that global demand for energy in all forms continues to increase faster than increases in total oil supplies. In great part, this phenomenon is being driven by comparatively recent high rates of economic growth and improved standards of living in populous countries of the former so-called "Third World", e.g. China and India.

The driving force underlying recent persistent upward pressures on global energy prices is clearly revealed in the above chart (adapted from *The Bottomless Well* by Huber and Mills 2005). Assuming that the underlying data sources in this chart are accurate (most would agree that the CIA and British

Petroleum are reasonably trustworthy sources), it shows that increased per capita economic activity (as measured by GDP), in conjunction with improved standards of living for a given country's citizens, directly increases global demand for energy – *that could be a big problem going forward.*

Importantly, if people living in countries currently located in the lower left quadrant of this chart are ever to attain and enjoy anywhere close to the standard of living that is now prevalent in Europe (let alone the United States), there will be correspondingly large increases in global demand for energy.

The data shown in figure 8.2 above clearly implies that, barring a prolonged period of worldwide economic recession or depression, global demand for energy will continue to be strong and increasing for the foreseeable future. It is an unavoidable result of continued economic growth as measured by GDP. Importantly, if supplies of existing carbon-based energy sources are not dramatically increased and new types of energy technologies are not further developed and commercialized, the overall price of energy will inevitably rise to levels vastly higher than today's.

Present enormous dominance of carbon-based sources of energy

The data in the chart below show that carbon-based energy sources (oil, coal, natural gas, biomass, and biofuels) now provide roughly 88% of the world's current energy needs; nuclear (fission) currently supplies about 7.5%. The balance of "green" carbon-free sources (hydroelectric, geothermal, all solar, wind, and ocean-related energy recovery) now supplies only ~4.5% of total global energy demand.

Since (1) energy markets are relatively freely traded, (2) alternative sources of energy are very rapidly price-arbitraged against each other by market participants, and (3) many fossil fuels can be technologically substituted for each other with only modest economic disruption, spectacular increases in the oil price since ~ 2004 are an unmistakable economic signal that total world demand for oil has been increasing faster than supplies. That much is an obvious fact.

Actually, the comparatively recent surge in energy prices has only a little to do with terrorist activity and politico-military instabilities in the Middle East. In fact, it mostly results from relatively unrestricted trade in energy sources between countries; heavily arbitraged global energy markets; significantly increased rates of economic growth in many parts of the world; as well as overall improvement in living standards and increased per capita disposable income in many countries.

India and China are especially important consumers of energy because they comprise nearly 40% of the world's population. They now also have the financial resources to buy whatever energy they need on the open market, in direct competition with older industrialized energy-importing nations such as the European Union, Japan, and the US. This has intensified competition for energy supplies and has been a major factor in the acceleration of energy price inflation that has occurred during the past several years.

The overwhelming dominance of carbon-based energy sources as a % of current global energy consumption has simple underlying economic reasons: even with recent price increases, oil, coal, natural gas, and other carbon-based fuels are among the least expensive, most readily available, most economically and technologically fungible energy sources that exist on the planet today. This dominance and continued price competitiveness is the second root cause of energy's Gordian knot.

As previously shown on Page 1, this version of that chart shows a different breakdown of current global energy use by source:

% of Total Annual Energy Consumption				
Alternative Primary Energy Sources			**US**	**World**
Carbon: The "Old World" of energy – mostly since the 1800s	Carbon-based Primary Energy Sources	Oil	40.6	36.8
		Coal	22.9	25.2
		Gas	22.6	26.0
	Carbon-Based Renewables	Biomass	2.5	NA
		Biofuels (ethanol)	0.2 est.	NA
	All Carbon-based	**Subtotal**	**88.8**	**88.0**
Nuclear: The "New World" of nuclear carbon-free energy (ca. 1942) - "greener" vis a vis carbon-based sources – but currently has some environmental and nuclear proliferation issues	**Nuclear Electric Power**	**Fission**	**8.1**	**7.5**
"Green" carbon-free: The "New World" of carbon-free energy – hydroelectric power has been around since the 1800s; the remainder have been around in one form or another at various times thereafter	"Green," clean, renewable, and environmentally sustainable	Hydro	2.7	2.4
		Geotherm	0.4	0.4
		Solar (all)	0.1	0.6
		Wind	0.2	<0.1
		Ocean rel.	~0.0	~0.0
	All carbon-free	**Subtotal**	**3.4**	**<3.5**
Note: source for US data is the "Monthly Energy Review" of the Energy Information Administration (EIA) of the US Dept. of Energy; world data is taken from annual reports of the International Energy Association (IEA).		**Year:**	**2005**	**2001**
		Data:	**EIA**	**IEA**

Problem: alternative sources of energy are not freely substitutable

In a perfect economic and technological world, all available energy sources could be easily substituted for each other. "Blind" economic forces could then "automatically" allocate energy supplies via complex market mechanisms that integrate a myriad of causal factors that move supply, demand, and spatial-geographic availability of a given energy source inexorably toward a state of spatial and temporal price equilibrium. In such an ideal world, the energy-equivalent prices of different alternative energy sources (expressed, say, in US$ per million British thermal unit or Btu) would be roughly the same because of price arbitrage activities by market participants.

Unfortunately, this theoretical ideal almost never occurs in the world that we live in. Price equilibrium is an ever elusive, unattainable market goal --- disequilibrium is the rule, not the exception. In addition, it turns out that there are varying degrees of short- and medium-term economic and technological constraints on consumers' ability to optimize their economic costs by substituting one energy source for another. This places practical limits on markets' near-term ability to shift end-user demand to geographically available energy sources that are in greater supply. This means, as is clearly illustrated in the data below, there can be major disparities in the energy-equivalent prices of different, competing energy sources; this is another side of the Gordian knot.

Energy sources commonly utilized in the US were recently priced as follows; please note especially that the fuel price is expressed on a common, energy equivalent basis, i.e. US$/million btu:

Alternative Energy Sources	US$ fuel price per million Btu	Multiple of price of coal
Reg. unleaded gasoline (gallon) - recent peak price	$39.43	4.9x
Electricity (grid-delivered @ $0.102/kWh)	$29.95	3.7x
Kerosene (gallon)	$27.31	3.4x
Propane gas (gallon)	$25.23	3.1x
No. 2 fuel oil, home heating (gallon)	$22.42	2.8x
Corn kernels (dried and simply burned - ton)	$15.15	1.9x
Natural gas (Therm)	$12.40	1.5x
Wood (cord)	$9.09	1.1x
Coal (anthracite - ton)	$8.03	1.0

As one can see in the illustrative data above, coal and wood are among the least expensive sources of energy --- they also happen to be among the dirtiest from an air pollution standpoint. The US has relatively abundant indigenous supplies of coal, natural gas, and wood. Much of our oil and its products must be imported and transported (which costs more $) from distant regions of the world. Thus, it is not surprising that gasoline can be priced at $39.43 while coal is just $8.03 on an energy-equivalent basis.

For example, although they typically burned high-quality black anthracite coal, in an emergency old-time steam locomotives could readily run on almost anything that would burn in their boilers --- e.g., low-grade brown coal, cordwood, creosote-soaked railroad ties, whatever. Modern locomotives and trucks based on diesel engines are currently designed to strictly burn some sort of liquid diesel or diesel-like fuel --- coal or wood are simply not short-term, substitutable alternatives. The situation is identical for the global fleet of passenger automobiles, most of which are now designed to run on gasoline, albeit laced with some % of ethanol in some countries. *Thanks to internal combustion engines, oil demand can be very inelastic over certain time frames.*

Widespread use of internal combustion engines is another major constraining factor –

The fact is that internal combustion (IC) engines, which have been optimized in transportation applications for more than 125 years, are by far the least expensive way to convert the energy contained in oil-based fuels into motive power. Today, transportation fuels for IC engines are primarily based on products derived from crude oil, e.g., gasoline (automobiles), diesel (trucks and heavy equipment), and Jet A (aircraft). This has occurred historically because oil-based fuels have a much higher volumetric energy density than coal or wood, which permits a much greater range for a given volume and weight of onboard fuel. Coal-powered aircraft would simply not be feasible. Compared to coal or wood, energy-dense liquid fuels are more compact, easier to dispense, and less expensive to handle and transport in bulk through present day fuel distribution systems.

Summation: final remarks

Energy's Gordian knot -

In the realm of energy, simply maintaining the status quo and doing business as usual are no longer viable options for humanity. In some worst-case climate change scenarios, the future of all higher life on this planet could be at risk. The stakes are simply too high not to take any action to avert potentially unimaginable catastrophes. The future of energy holds great promise and peril. Failure is not an option.

Cost-effective, environmentally benign energy technologies are urgently needed. Vastly larger energy requirements of future societies must be satisfied at reasonable cost without destroying the entire planet in the process, whether by climate disasters or internecine wars over oil. Successful commercialization and deployment of "green" energy is imperative to attack an array of energy and climate change issues that confront our world today.

The Gordian knot facing humanity is not that our world will ever run-out of energy per se in the foreseeable future. Between global coal reserves and electromagnetic energy in the form of photons streaming from the sun there is more than enough energy to be had for whatever purpose. Energy availability, in the broadest possible sense, is not the Gordian knot.

The Gordian knot is that worldwide consumers of energy need to have technologically usable kinds of reasonably priced energy delivered to the right place at exactly the right time in forms that are environmentally benign and readily compatible with sustainable, long-term global economic growth.

LENRs: cutting energy's Gordian knot -

LENRs could be an important part of a diversified portfolio of "green" carbon-free energy technologies. They have a unique combination of enormous energy density and cost advantages that cannot be matched by any other known nuclear or non-nuclear technology. If commercialized, these unparalleled attributes would enable LENRs to revolutionize portable power generation, radically changing the world as it exists today. This could in turn usher in a new era of cost-effective, LENR-based all-electric or steam-powered vehicles with unprecedented performance and range capabilities that might finally end the dominance of internal combustion engines in transportation.

Being extraordinarily scalable, affordable LENR-based power generation systems could be designed with total power outputs ranging from microwatts to Megawatts, suitable for off-grid or on-grid applications.

If Lattice Energy LLC and its strategic partners can successfully commercialize LENRs as a clean, low cost, carbon-free energy source for power generation applications, it could specifically help cut energy's Gordian knot by:

- Replacing chemical batteries in many applications: this would solve the twin Achilles' heels of electricity and portable electronics, enable cost-effective all-electric and/or steam-powered cars, and revolutionize personal access to large amounts of portable energy;

- Gradually replacing the internal combustion engine over time: this would enable the entire world to finally achieve "energy independence" from petroleum;

- Developing systems that can serve as an integral part of a broadly deployed collection of small-scale, *grid-independent* LENR-based, photovoltaic, and wind-based distributed power generation technologies: they could end energy poverty for 1.6 billion rural residents presently living without any electricity and bring them into the 21st century of ubiquitous human access to reliable electricity, clean drinking water from deep wells or desalinization plants, and connectivity to the Internet;

- Providing cost-effective *grid-connected* smaller-scale power generation capacity that, in conjunction with deployment of "smart grid" technologies, further increases grid demand responsiveness, stability, and reliability: this would also reduce the need for building even more large-scale fission and coal-fired/natural gas power generation plants to meet consumers' future demand for electricity.

Widespread global deployment of cost-effective LENR technologies, in parallel with broad deployment of synergistic large- and small-scale photovoltaic and wind-power systems, could create an energy-rich, "greener" energy future for humanity. Importantly, LENRs and the portfolio of carbon-free energy technologies have the potential to democratize access to affordable energy for every inhabitant of this planet.

The future of energy: the time has come to decide … and to take bold action -

So there it is. Not to decide is to decide. Sooner or later, we must all place our bets on the future.

While very painful in the short-run, massive escalation in the price of oil creates the seeds of its own destruction; in one sense, sky-high prices may be a blessing in disguise. Why? Because a protracted period of sharply elevated oil prices will unleash a torrent of human ingenuity and creativity that will cut energy's Gordian knot, eventually providing humanity with a "green," energy-rich future for its children.

Roughly 2,200 years ago, the famous Greek scientist Archimedes said, "Give me a lever and a place to stand and I can move the world."

Today, the widely read *New York Times* columnist Thomas Friedman says, "Give me abundant clean, reliable, and cheap electrons, and I will …"

> *"No single solution will defuse more of the Energy-Climate Era's problems at once than the invention of a source of abundant, clean, reliable, and cheap electrons. Give me abundant clean, reliable, and cheap electrons, and I will give you a world that can continue to grow without triggering unmanageable climate change. Give me abundant clean, reliable, and cheap electrons, and I will give you water in the desert from a deep generator-powered well. Give me abundant clean, reliable, and cheap electrons, and I will put every petrodictator out of business. Give me abundant clean, reliable, and cheap electrons, and I will end deforestation from communities desperate for fuel and I will eliminate any reason to drill in Mother Nature's environmental cathedrals. Give me abundant clean, reliable, and cheap electrons, and I will enable millions of the earth's poor to get connected, to refrigerate their medicines, to educate their women, and to light up their nights."*

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