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ETHICAL ENERGY AND THE CLEAN ELECTRON

MICHAEL C. TRACHTENBERG* & GAL HOCHMAN**

I. BACKGROUND

A. The Role and Importance of Energy

Societies grow by amassing the work product of individuals by means of their own labor (with appropriate tools), by their labor augmented by that of other group members, by animal labor or by their work effort via exogenously powered machinery, and, presumably in the future, by the action of machinery largely alone. The historic and ongoing change in work product generator from human to machine as driven by technology, most importantly the industrial revolution and now the computer/information revolution. An obvious result is the change in importance from food energy to fuel energy. However, the competition for critical resources does not change. Energy is central to life and to the maintenance and growth of human society; while it is necessary, it is not sufficient. Access to and control of minerals and water (the near-univer-

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** Gal Hochman is an Associate Professor in Agricultural, Food, and Resource Economics. Dr. Hochman received his Ph.D. in Economics at Columbia University in 2004. While coming out of his Ph.D. he focused on international trade agreements and crony capitalism, the stay at UC Berkeley introduced him to energy and agricultural biotechnology. Dr. Hochman's current work focuses on the political economy of fuel policy, the economics of petroleum refineries, the economics of renewable energy, energy efficiency, as well as agriculture biotechnology. His research shows the importance of modeling OPEC as a cartel-of-nations and identifies key factors affecting fuel policy. Dr. Hochman's work also quantifies the importance of inventories in the 2007/08 food-commodity price spikes. His work on energy, trade, and the environment shows that allocation of rights among different entities along the supply chain has distributional impacts, which can become a stumbling block to a climate agreement. Dr. Hochman presented his work in numerous conferences, including AEA, AAEA, USAEE, IAEE, AERE, EAERE, ACS, among others, and is currently the chair of C-Fare: Energy Panel.

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sal solvent and reactant) are also of critical importance. Most importantly, a multitude of biological and chemical operators is needed to transform these resources into viable product.

B. Energy Sources and Transformation

Energy divides into two categories - food to support biological organisms and fuel to power non-biological apparatus. These two classes can interface, for example, in the manufacture of foods by use of fertilizers, derived from non-food fuels, to stimulate plant growth, the work product result of farming. The overwhelming fraction of energy derives from the sun by means of photons, gravitational forces, and geothermal energy. Figure 1 illustrates the capture of energy from primary sources and its use in generating a work product. Societal growth requires a constant increase in and renewal of the work product.

**Figure 1.** Relationship between energy, by source, and societal growth. Growth requires an ongoing stream of new energy supplies.¹

![Energy Sources, Uses, and Benefits Diagram](image)

Raw current energy is either used immediately and locally, transformed for distribution and immediate use, or stored for later use. The transformation is into energy carriers that fit the demand requirements. Energy storage occurs for on demand use at a differ-

¹ Dr. Michael Trachtenberg (created for use herein).
ent time or place from that of production. A well-defined transformative regimen is followed to achieve these ends. The principal options for stored energy are in the form of chemical bonds, e.g., fossil fuels, or potential energy (anti-gravity storage), e.g., naturally occurring lakes or man-made dams. These fuels are ultimately converted to photons (light), electrons (electricity), mechanical motion, or heat.

Plants are the primary transforming agent for food, which is then used directly, processed industrially, or provided to animals for bioprocessing, which in turn may then be used or processed industrially.

Joseph Tainter wrote, "Energy has always been the basis of cultural complexity and it always will be." Large quantities of energy are not only needed, but must appear to be very economical. For a society to grow, energy and its derivatives – food, fuel, and water –
must be, or at least appear to be, relatively cheap, abundant, reliable, and trustworthy. These requirements drive economic, technological, and ultimately, political decisions. This means that economic policies must be adjusted by means of political decisions to this end, i.e., by subsidies or tax policies, insurances, and research and development funds, and may need to be delivered in complex and obscure manners to transfer and diffuse burdens and costs.

II. The Fundamental Decision: The Dynamics of Energy Forms, Transformation, and Delivery

The 2010 world energy mix of primary energy, by fuel, consisted largely of fossil fuels (oil, coal, and gas) at 81.5%, renewables at 12.5%, and nuclear at 6%. In the developed world, to an overwhelming degree, these supplies were transformed and delivered from centralized, heavily industrialized sources coupled with widely dispersed distribution by the grid, rail, ship, pipelines, and tanker trucks. Logically the structure is a one-to-many pattern. These modes developed from the mid- to late nineteenth century through the late twentieth century and are now strongly ensconced.

Significant changes in energy production, delivery, and use are underway. These are termed “transition fuel” and “transition dynamic.” The transition fuel model is simple. It retains the existing infrastructure model of centralized generation and radial distribution replacing coal, and to some extent diesel, with natural gas, thus labeling natural gas as the transition fuel. The implication is that the new natural gas power plants that will be constructed to enable this transition will be abandoned in thirty years or less in favor of green energy, despite historic evidence to the contrary and indications that these modern plants will have a lifetime of at least sixty years.

Transition dynamic is a paradigmatic cultural change. The new paradigm has three elements. The first is a change from centralized, industrialized production to massively parallel generation, primarily of electricity and heat. The second is from a centralized radial distribution to a peer-to-peer format, largely in the form of electricity. The third is from brown and red to green fuels, i.e., from stored to current energy production and from hydrocarbon-rich fuels to hydrocarbon-free fuels.

This type of change is one that has played out many times previously, e.g., in railroads, intracity transport, oil and gas, shipping, automobile manufacture, and biological expansion, to identify only a few such examples. The initial flowering of many providers and formats is followed by consolidation and centralization.

An appreciation of the cost/benefit and risk/reward aspects of this paradigm change requires a full accounting of all energy related costs. Multiple life cycle analyses would include those for energy and for economics where all subsidies and externalities are taken into account, e.g., an ELCA (energy life cycle analysis), an LCOE (levelized cost of an EROI (energy return on investment), as well as an economic return on investment. These have to be integrated by type and over time on a rolling basis because of the lifetime of large industrial equipment.

These options would be considered in a matrix that defines opportunities, constraints, and boundary conditions through multiple lenses: technology, i.e., capability; economics, i.e., asset risk and reward; politics, i.e., class and value; and society, the immediate and fluid zeitgeist. However, the presentations are a rhetorical mix and match of arguments derived from each of these domains towards a pre-determined outcome. Below we will try to provide an agnostic understanding of principal issues involved in enacting the transition dynamic.
III. THE ENERGY MAP: ENERGY FORMS

Figure 3. A fuel map showing categories, types, & products of concern.  

Figure 3 is an energy map that illustrates the concepts advanced in this article. These energy categories are competing technically, economically, and politically. So too is the issue of new installs versus extension and improvement of the installed base.

Conceptually, energy forms are divisible into three categories that we term red, brown, and green. Red refers to fissile energy derived from nuclear decay where the heat associated with decay is used to transform water to steam that drives a turbine to yield electricity. Brown refers to hydrocarbon based fuels, both fossil and current production, where combustion (oxidation) of the carbon-hydrogen bond yields carbon dioxide (CO₂), water vapor (H₂O), and heat, the last of which is used to convert water to steam that

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8. Dr. Michael Trachtenberg (created for use herein).
drives a turbine and generates electricity.\(^9\) Green refers to a wealth of technologies whose mechanical or electrochemical force can yield electrons (electricity) directly. Examples include wind, solar, wave, and geothermal. Green energy can also be used to produce hydrogen as an energy carrier. For many green energy forms, secondary storage is needed to manage the rate and timing of delivery to conform to human needs and demand. Secondary storage examples include damming water, air pressure, flywheels, batteries, and hydrogen.

A. Red Energy

Red energy, which was the dream of the post-World War II atomic efforts,\(^10\) faces a number of difficulties in further implementation. One is the detailed certification process that results in an eight to ten year build cycle despite efforts to reduce the time and cost. Disposing of the once-through spent fuel is politically mired. Regeneration would be needed for large-scale implementation, as there is an insufficient quantity of primary fissile material available to satisfy growing electricity needs, particularly if nations in need of electricity were to install nuclear power. Moreover, regeneration presents significant concerns of nuclear proliferation. Cost competition by natural gas is a construction impediment. Fear of "China Syndrome" events, as exemplified by Chernobyl and Fukushima Daiichi, loom large in the collective consciousness.

Finally, there are the concerns of the International Atomic Energy Agency (IAEA), as the IAEA states that it can account for only 99% of the fissile materials currently in play (including in heavily westernized, democratic countries). If generation of electricity by atomic energy were to become widespread, this would mean that 590kT of fissile materials could not be accounted for. In a heavily populated metropolitan area, New York for example, a 1kT suitcase-sized weapon could kill 40,000 people.\(^11\) Today, there are 422 cities worldwide with populations of more than one million people.

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9. Fuel cells oxidize without combustion and use electron transfer for direct production of electricity eliminating the thermal expansion-steam step. Depending on the fuel cell, CO\(_2\) can still be produced.


In sum, the red energy option is problematic as a future energy source, in spite of newer, more secure, and smaller designs.\textsuperscript{12} In terms of research and development subsidies, nuclear fission has been the largest recipient for a very long time. For example, in International Atomic Energy (IEA) countries in 2005, nuclear fission received 33\% of all fuel related monies: $3,168,000 of a total of $9,586,000. In earlier years the fraction was far greater – up to 63.5\% worldwide and 45\% in the United States in 1975.\textsuperscript{13}

B. Brown Energy

Brown energy sources are those that, at present, extract energy by combustion releasing heat.\textsuperscript{14} This is achieved via external combustion (fire) or internal combustion engines. Natural gas fuel cells can produce electricity by capturing the electrons released during oxidation to yield CO\textsubscript{2} and H\textsubscript{2}O without the accompanying pollutants common to air or oxygen combustion. Currently, their presence in the market is nominal, but they may represent a future opportunity if the CO\textsubscript{2} problem can be managed.

Brown fuels divide into those created long ago (fossil) and those created today (current). Fossil fuels include coal in all of its ranks (from peat to anthracite), crude oil and all of its refined products, raw natural gas from wells and subsequent to hydraulic fracturing and its extracted products, the most evident being methane, and the newly harvested natural gas clathrates (frozen ice mixes of seawater, often carbon dioxide and methane available on the seabed). Current brown energy includes wood, dung, and current biofuels.

No matter the source, combustion of these materials results in the release of some or all of the following pollutant products:\textsuperscript{15} carbon dioxide (CO\textsubscript{2}), nitrogen oxides (NO\textsubscript{x}) (from the nitrogen in the air), sulfur oxides (SO\textsubscript{x}) (from the sulfur in the coal), aerosols, particulates, ash, mercury, arsenic (the metals being in the coal), and various volatiles. Some fuels, such as methane, are cleaner than others, e.g., coal, in terms of emitting fewer pollutants. While there is considerable difference in the specific pattern of pollutants between one fuel and another, every brown fuel releases materials –


\textsuperscript{14} Combustion is oxidation of hydrocarbons to CO\textsubscript{2} and water.

\textsuperscript{15} See Figure 3.
many of which are greenhouse gases (GHGs), meaning they trap heat warming the planet and provide acid gases that acidify the ocean. Regulatory agencies impose limits to the release of some of these components at present. CO₂ is not currently regulated in the United States, though the Environmental Protection Agency (EPA) promises regulations by 2016. Similarly, there are no regulations concerning unburned (leaked) methane which, as noted, is about thirty-four times more potent a GHG than CO₂ (the exact value depends on the presumed lifetime). Regulations have been proposed, but not enacted.

One argument made in favor of current biofuels in preference to fossil fuels is that plants consume CO₂ during the growth process. While this is true during the day, the issue is the quantitative values. Wood, for example, has a fifty-year recovery period as a new tree grows to capture the amount of CO₂ released during combustion (not to mention release of other pollutants). Although plants consume CO₂, harvesting of the energy feedstock and the use of the plant’s starch and sugar to produce ethanol consumes energy. De-watering is one example of an energy operating expense that needs to be accounted for. Many other examples exist. Thus, regulatory tools for all fuels (red, brown, or green) need to provide a level comparison. A “well-to-wheels” assessment is needed. Accepting LCA as a major regulatory tool to calculate GHGs, the challenge is to use economic analysis to evaluate the various indirect effects such as indirect land use changes.¹⁶

1. Brown Energy Pollutants and Responses

Apart from combustion derived pollution, brown fuels (fossil fuels in particular) present three other problems. The first is the immediate environmental damage by activities such as mountain topping and the creation of waste and tailings ponds. The second is leaks and spills, these being more common in oil and gas, but coalmines are a major methane leak source. (So too are fields, particularly rice paddies.) In view of the excitement about hydraulic fracturing to produce shale natural gas, the issue of gas leakage becomes very meaningful. This is due to the strong multiplier of methane versus CO₂ as a GHG, about thirty-four times (or more depending on the timeline selected). Further, leakage along the cement shell of the drill core increases with age as the cement de-

¹⁶. See David Zilberman et al., The Impact of Biofuels on Commodity Food Prices: Assessment of Findings, 95 AM. J. AG. ECON. 275 (2012) (summarizing research on relationship between food and fuel markets).
grades. A third issue deals with the energy and pollution cost of acquisition, a problem particularly evident in the Alberta tar sands. Here, as in many other situations, the economic metric is out of register with the energy and environmental degradation metrics.

The current paradigm response to brown fuels explained in this article is presented in terms of the ready availability, high energy density, incorporation into the energy fabric over the last 175 years, and support of an ever growing population. This understanding is framed in terms of current human demand versus the GHG and pollutant damage, both current and future. In this understanding, some of the questions that emerge are of two types – enabling and strategic each directed towards the goal of minimizing adverse impacts on humans, other animals and the overall environment. The enabling issues are technical and economic, i.e., can we do it? The strategic issues are political, i.e., should we do it?

In view of the breadth and complexity of the subject we will limit ourselves to a few issues: Can coal be cleaned? Is carbon capture a viable and wise approach? Is natural gas a viable substitute energy form? Are biofuels a reasonable alternative?

2. Clean Coal

Coal can be used under one of three regimens to produce electricity: (1) pre-combustion where hydrogen is extracted and carbon stored, (2) oxy-combustion where coal is burned in relatively pure oxygen instead of air which eliminates the NOx otherwise formed, the other pollutants remain, and (3) post-combustion where some of the many combustion products are filtered, reacted, or extracted. SOx, NOx, and particulates are regulated to some extent under parts of the Clean Air Act and its amendments. The EPA is revising these standards to include mercury, reduce particulate size and concentration, and introduce CO2 capture above certain values such that the new regulations will have a strong impact on coal plants and some older, inefficient natural gas plants, but not on newer natural gas combustion electricity generators. At present, the vast majority of power plants are of the coal-fired, post-combustion type.

Technologies exist to achieve capture of each of these pollutants. However, CO2 capture is not energy or cost efficient. The

18. Clean coal, e.g., Department of Energy Future Gen, now Gasification Systems Program.
combination of these regulations, their inherent cost increase, the
greater efficiency of natural gas fired plants, and the recent low cost
of natural gas is driving power producers away from coal and to-
wards natural gas. Ultimately, when regulations are extended to
natural gas CO₂ emissions, the cost will be much higher because the
feed CO₂ concentration is about three-and-one-half times lower.
This decrease in CO₂ concentration makes capture that much more
difficult, though certain other pollutants are also absent, e.g., SOx,
particulates, and ash. These regulations are enabling natural gas.

3. CO₂ Capture from Coal Combustion: Costs and Benefits

Many technical, economic, political, and social questions arise
with regard to “carbon capture.”¹⁹ Carbon Capture and Use or
Storage (CCUS, the current embodiment of CCS), as applied to
post-combustion streams, means the separation and enrichment of
CO₂ from a mixed (flue) gas stream, followed by its compression
and pipelining to a selected geologic storage site or its conversion
(use) to some other beneficial form.

Many issues involved require elucidation: how much CO₂ will
be captured? How much will it cost directly and indirectly? How
long will it take to implement? How does this timeline compare
with that of coal availability lifetime? How is the CO₂ captured, dis-
oposed of, and stored?

In the first step, CO₂ capture (separation and purification)
technology is complex and does not exist in isolation. SOx and
NOx levels have to be lowered significantly from current regulated
values not to interfere with the carbon capture process. The capital
equipment will cost hundreds of millions of dollars for each plant;
the exact amount depending on the emission profile, the methods
selected, and the volume of the emission stream. The additional
cost for installation of cleanup equipment on a pulverized coal
plant is almost 83% coupled with a 30% decrease in performance
and an operating cost of forty to sixty dollars per ton of CO₂ cap-
tured. The process has two elements – (1) extracting and enrich-
ing the CO₂ from the flue gas stream and (2) then compressing it to

¹⁹. See HELEEN DE CONINCK ET AL., ENERGY RES. CTR. OF THE NETHERLANDS,
ACCEPTABILITY OF CO₂ STORAGE: A REVIEW OF LEGAL, REGULATORY, ECONOMIC AND
.ecn.nl/docs/library/report/2006/c06026.pdf (analyzing non-technical aspects of
carbon capture and storage).
about fifteen megapascals (MPa) (~2200psi) for pipeline transport.20

The IEA calculates that by 2050, the effective reduction in CO₂ emission by CCS would be, only, nineteen percent.21

The second step is development of a pipeline system equivalent in scale to that put in place over the last thirty-five to fifty years to transport natural gas, to now transport this high-pressure supercritical CO₂ (SCCO2) – less than fifty-two thousand kilometers (~32.6 thousand miles) with a twenty-five year installation period.

The third step is geological storage of the SCCO2. Geological sites can be abandoned salt domes, abandoned or active oil or gas wells, or deep saline reservoirs. Salt domes are empty, making addition of SCCO2 non-problematic. For oil and gas wells, the production of new hydrocarbons is considered beneficial and in line with existing applications. Saline reservoirs differ because they are already filled with water that must be displaced. Oil and gas now displaced leave a void volume for the SCCO2. This huge volume of water must now go somewhere and do so without trespassing on or damaging someone else’s property or economic interests. Next, the SCCO2 has to remain in place for ten thousand years without significant, or at least controlled migration and without leaking back to the atmosphere. Current concretes used to complete wells have been demonstrated for about fifty years. Lastly, there is the issue of long-term responsibility as the stored SCCO2 is supposed to remain “bottled up” for eons. Companies are negotiating to limit their liability to a decade with the state assuming responsibility thereafter – a dramatic example of privatizing profits and socializing costs.22 Not only has no company existed for the requisite period of responsibility, but also neither has any government. While posting a bond would be beneficial, the reality is that, like nuclear wastes, we humans have never faced a problem of this kind before.

Yet another issue is the transactional costs, as the contentiousness of this solution promises to be of the same order as the storage of nuclear waste. It needs to be included in the LCA at full and worst case cost.

20. Supercriticality occurs at lower pressure – 7.39MPa, 304.25K – but pipeline companies demand supply to the network that satisfies their operational needs.


22. For further discussion, see infra Part IV: Subsidies and Externalities.
One final issue is that of social acceptance of CO₂ storage. Although scientific studies indicate that there is sufficient capacity to store CO₂, social acceptance studies worldwide indicate a mixed bag based on lack of information and distrust for industry.²³ Public opinion may change, but it will do so slowly.

4. Carbon Capture vs. Coal Lifetime

How does the time to implementation compare with the reserve life of coal? According to the BP Statistical Review of World Energy 2011, the world contains about seventy-seven years of coal at current consumption rates. Academic predictions tend to be shorter by about one-third while coal industry predictions longer. If we assume that carbon capture will not begin in earnest until 2025, that leaves sixty years of coal and likely fifty years to implement the capture process to a large measure in the developed and rapidly developing countries. Allowing that newly installed coal plants may be more amenable to carbon capture structurally and in terms of available land, under positive assumptions, perhaps 25% of the coal-based carbon could be captured by 2075. The base emissions contribute about one-third of all CO₂ released; thus, world CO₂ emissions could decline by 8% assuming, quite incorrectly, no growth in transportation-related CO₂ by direct tailpipe emissions or indirect grid-based emissions. As noted, the overall benefit would be about a 19% decrease in CO₂ emissions.

5. Conclusions Regarding CCS from Coal Combustion

In our view this is an unwise activity. We reach this conclusion for the following reasons: (1) CCS will be technically difficult, economically costly, and socially disadvantageous, (2) capture preserves coal-fired heating when alternatives, such as natural gas or green energy, could displace coal making it obsolete without the CCS effort and do so all the more quickly as subsidies disappear and externalities internalize, (3) coal reserves will expire by the time the CCS is completed, and (4) technologies may be in the offing to remove the CO₂ at a far lower cost without the current energy penalty and without the need for pipeline or storage.

6. Natural Gas

Natural gas is a complex mixture of gases; the most common of which is methane that is extracted, cleaned, and pipelined under the name “natural gas.” Methane is released from multiple sources that divide into at least four categories, though substantial variation exists in the reported distribution and even in the categorization. The U.S. EIA reports the division as agriculture (31%), waste (29%), industrial process (1%), and energy sources (40%). Other sources attribute as much as 7.7% to insects. All of these emissions are subject to human activity, whether in the short run or the long. Four sources that have received much recent attention, in part because of their sudden increase, include: traditional gas wells where a bubble of gas is trapped in a geologic formation and can be tapped by simple drilling; shale gas where the natural gas trapped between layers of flat sediments is extracted by means of hydraulic fracturing; deep sea methane clathrates, a frozen slush of methane, seawater and sometimes CO₂ that can be recovered from the sea floor; and surface releases as from melting tundra and also coalmine mouths.

Hydraulic fracturing, or “fracking,” is recently under intense development. It uses horizontal drilling, a technology developed by the oil exploration industry wherein the drill is rotated underground from the vertical to the horizontal, with the opportunity to create radial bores much like a tree root. Shale being laid down in flat laminae is readily separated when water (with proprietary fluids) and sand are injected under high pressure. The sand keeps the cleats open and allows the gas to flow along the free path.

7. Natural Gas Transition Fuel

Natural gas is represented as the transition fuel between coal and green renewables. The potential replacement of coal, or even oil, by natural gas rests on the following arguments:

(1) Availability: Consequent to fracking, gas is now readily available and will be so far into the future.
(2) Price: Because of its availability, it is cheap.
(3) Compatibility: It is produced, distributed, and used by demonstrated and widely applicable technologies.
(4) It can be used to provide as much electricity as needed under all circumstances, 365/24/7. On combustion it releases about half the CO₂ as does coal, and no SOx (as the sulfur was removed during refining), or particulates or heavy metals.
(5) Natural gas can replace oil products for many of the same reasons even if its CO₂ output is not quite as beneficial. Emphasis is on long haul trucking as diesel combustion still yields considerable levels of SOₓ. There is also some interest in the use of natural gas for passenger and light truck vehicles (Class I).

The principal argument to counter these benefits deals with natural gas leakage, a subject discussed below.

Currently, the United States is the world leader in the requisite fracking technology and also has extensive shale deposits. As a consequence, the volume of natural gas available has increased, the price has decreased, and, as described above, the increased costs imposed upon coal-based electricity have also gone up; thus, installation of new natural gas-fired electric plants is on the rise. Another benefit is that the CO₂ output per Megawatt (MW) is about half for natural gas versus coal, a great advantage.

However, some small fraction of natural gas wells leak. This is due to poor completion of the cement work, to shifting of the earth cracking the cement sleeve, or to degradation of the cement sleeve over time. The ongoing replacement of wildcatters with established oil and gas companies means that their better skills and improved technologies will reduce leakage. Most important, however, is ongoing monitoring of the wells during and after their installation. There are now 482,822 producing natural gas wells in the United States, not counting the number of completed or abandoned wells. Z Magazine summarizes sources reporting about two and a half million abandoned wells in the United States and tens of millions internationally.

This observation is critical to any argument in favor of natural gas as on a CO₂ pollution basis, to the extent that natural gas leakage can be controlled to below 3.6% it is suitable as a coal replacement. If it can be reduced to less than 1.5%, natural gas becomes a reasonable replacement for transport fuels.


FIGURE 4. Electricity from renewable sources in some developed nations. Table on left is re-represented as a radar graph on the right.\textsuperscript{27}

<table>
<thead>
<tr>
<th>Country</th>
<th>Non-Renewable</th>
<th>Renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Israel</td>
<td>1%</td>
<td>99%</td>
</tr>
<tr>
<td>France</td>
<td>12%</td>
<td>88%</td>
</tr>
<tr>
<td>United States</td>
<td>13%</td>
<td>87%</td>
</tr>
<tr>
<td>Germany</td>
<td>21%</td>
<td>79%</td>
</tr>
<tr>
<td>Spain</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>Denmark</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Portugal</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>Sweden</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>Canada</td>
<td>63%</td>
<td>37%</td>
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<tr>
<td>Norway</td>
<td>97%</td>
<td>3%</td>
</tr>
<tr>
<td>Iceland</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

In contrast, the EPA has released a report that revises emissions downward.\textsuperscript{28} The reality is that in the absence of a detailed, time consuming, and expensive evaluation, the information available on the number of leaking wells or the amount of natural gas that is leaking is grossly inadequate.

8. Biofuels

Biofuels exist in myriad forms, each with its own unique carbon budget. We will focus on three: ethanol from sugar cane, ethanol from corn, and biodiesel from algae.

Brazil has been eminently successful in its sugar cane to ethanol project. The net carbon cost is about 40\% to 60\% that of fossil fuels.\textsuperscript{29} Efforts in Brazil have shown that sugar-ethanol is efficient and can be used to fuel more than 50\% of their domestic car fleet,


and that its GHG emissions are similar to that emitted when combusting natural gas. Further, using sugarcane co-product – bagasse – to produce electricity results in even better outcomes.

The United States, in 2005, and later in 2007 under President George W. Bush, enacted the U.S. Energy and Security Act to mandate the use of ethanol, including first-generation corn-ethanol. That program has come under significant criticism due the low efficiency conversion of corn to ethanol and to the overall energy costs of this approach. The net energy ratio of corn-ethanol ranges from 1.29 to 2.23.³⁰

Algae, green or blue-green, have been the hope for current biofuel production since the launch of the Aquatic Species Program in 1978. Substantial efforts have gone into genetic engineering, process engineering, and product utilization in order to attempt to make a profit from a commodity product. One key idea has been to offset the inadequate price for biodiesel by selling other higher value chemicals. Unfortunately, the vast differences in market size for fuels versus specialty chemicals, pharmaceuticals, or other ancillary products have vitiated this argument. Several companies, e.g., Sapphire Energy, are trying to incorporate best practices from a variety of industries to maximize yield of cells and product and minimize costs. Large-scale algae, sufficient to eliminate United States crude oil imports, would require a land area comparable to that currently used for wheat and will include significant capital investment to establish the ponds, the harvesting, and processing structure. In addition, the water operating expense will be substantial and challenging per a change in precipitation patterns.

Biofuels have the potential to contribute to the energy mix, and to provide local solutions in some regions but not others. However, current generation biofuels are not carbon neutral and first-generation, corn-based biofuels contribute to food commodity inflation.

9. Summary

With regard to brown energy, primarily fossil fuels taken as a whole, CCS is best understood as “closing the barn door after the

horse has bolted." It is expensive, long in coming, completed after fossil fuels have been severely decreased, if not exhausted, and it leaves the taxpayers with an unending liability and responsibility. Biofuels, while preferable to fossil fuels, are competing with natural gas as the would-be transition fuel. They provide modest gain and are also sorely taxed by the availability and cost of natural gas.

Overall these are problem areas that are best avoided than be subject to piecemeal and ever ongoing successive efforts to re-cork the bottle. As Montaigne pondered in 1580, is the game worth the candle? That we have been using fossil fuels over the last two hundred and fifty years is no reason to continue. The issue of importance is how to change and how to do so rapidly.

C. Green Energy

Green energy, in general the production of electricity without production of GHGs or other pollutants, can be divided into two groups: the 365/24/7 sources and the intermittent sources. It is understood that any intermittent source can be made 365/24/7 with storage and any green energy source can be made "100% reliable" should that be needed from peak supply by another green energy source, or by natural gas sources via combustion, or fuel cells, or electricity from distant sites over the grid.

365/24/7 sources include geothermal, hydroelectric, space solar, high altitude wind, osmotic reactions, hydrogen, and fusion energy. Intermittent sources include low altitude wind, solar, and wave/tide sources (Fig. 3). Any of these can be used to generate heat or electricity.

In the United States today, green renewable energy delivers 11.21% of all electricity – 460.33TWh. Onshore wind accounts for 119.75TWh (26% of renewable energy) and geothermal 16.7TWh (3.6%), respectively. The relative fraction of electricity derived from renewable sources in the developed world ranges from 1% to 100% and keeps increasing.

The issue of green energy sources for electricity has profound, indeed existential, implications for the energy industry. For electricity generators, it means a move from centralized, heavily industrialized power plants to widely distribute, much smaller generators. It also means massive devaluation of existing plants and facilities,

31. MICHEL DE MONTAIGNE, Of Presumption (1580), in ESSAYS OF MONTAIGNE (William C. Hazlitt, ed., 1877) ("The game is not worth the candle.").
32. See Figure 4.
particularly with regard to coal and older, less efficient units. In all, green energy is a "transition dynamic."

Above, we discussed natural gas and biofuels as transition fuels. However, the real competition is between these brown transition fuels and the distributed green transition dynamic largely in the form of solar and wind. The transition dynamic provides some anxiety for construction of natural gas power plants for as ever more green energy comes online, the need for natural gas electricity will be imperiled, meaning that the return on investment (ROI) may be smaller than investors might hope for and the lifetime will be curtailed.

It also means a complete and real break between power generation and transmission as the grid becomes the backup carrier for widely distributed energy sources. More importantly, the grid will move from being a few-to-many configuration (power plants to customers) to a many-to-many, peer-to-peer structure whose income stream has more statistical uncertainties.

For the oil and gas industry, it means, in part, a shift from transportation to fixed-site generation (including natural gas power plants) and a decline in mobile use of oil derived products. The use of batteries as an energy storage device and the move to fully electric vehicles will also have profound effects on the engine and parts industries. The income and jobs implications are obvious.

These changes are as serious as the effect of kerosene on whale oil or of electricity on kerosene for lamps. Figure 5 illustrates the changes in primary fuel use in the United States since 1775. Each of these changes came with substantial reorganization of jobs, industries, and municipal structure. The same will occur again.

The preferred strategy then is to embrace the transition dynamic and implement green technologies rapidly. Natural gas then would be a bridge limited by the degree of leakage and with the intent of minimizing the number of new installations to limit extended lifetime use. To this end, green energy sources should be targeted to the most egregious coal-fired emitters with the goal of closing these plants without the effort of imposing CCS.

One statement at the forefront of green energy discussions is, where is the money that will be needed for the transition? A second is the "philosophical" position that government should not "choose winners and losers." In part, this is a statement about technological development preferences, in part, it is related to the selection of specific strategies and even specific fuels, and in part, to the funding of specific companies.
Government is a catchall phrase applicable to multiple levels and a diversity of departments, each acting somewhat autonomously. "Government" actually plays all three roles, as a seer, as an investor, and as a customer. It is the best early stage investor available and takes the greatest risks. All investors, short-term or long-term, are obligated to try to select winners. Federal investment has a hit rate about five times better than the average venture capitalist. Government has long-term and strategic responsibilities and must interact with other governments in ways that will come at the expense of given industries.

**Figure 5.** The prevalence of energy by time illustrates the dynamic character of these markets. 
Source: U.S. Energy Information Administration

| History of energy consumption in the United States (1776-2012) |
|---|---|---|
| Age of Wood | Age of Coal | Age of Oil |
| 45 | 40 | 35 |
| Age of Wood | Age of Coal | Age of Oil |
| 40 | 35 | 30 |
| Age of Wood | Age of Coal | Age of Oil |
| 35 | 30 | 25 |
| Age of Wood | Age of Coal | Age of Oil |
| 30 | 25 | 20 |
| Age of Wood | Age of Coal | Age of Oil |
| 25 | 20 | 15 |
| Age of Wood | Age of Coal | Age of Oil |
| 20 | 15 | 10 |
| Age of Wood | Age of Coal | Age of Oil |
| 15 | 10 | 5 |
| Age of Wood | Age of Coal | Age of Oil |
| 10 | 5 | 0 |

**IV. Subsidies and Externalities: The Source of the Funds**

A government commonly gives subsidies to jumpstart new technologies, for local trade protection and for jobs creation and conservation, though this last idea is somewhat quaint in this age of globalization. As the technology matures it has a bad habit of becoming dependent on and demanding of its subsidies giving it a distinct advantage over any new challenge. Typically, there is no sunset to subsidies. Limits in measurement or in understanding current or future impacts are often the start of externalities in the form of pollutant emissions. Deleterious environmental processes

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are often then dismissed as being critical to the use of the technology or in trade for jobs, taxes, or local development. Once the adverse effects become clear, imposing new standards is difficult technically, economically, and politically.

The magnitude and types of subsidies and the effects of the externalities is important to understand, as this is critical to addressing the concern about funds availability to subsidize the introduction of green energy. Table 1 provides a list of the dollar value of subsidies and externalities relevant to fossil fuels worldwide and in the United States. Worldwide, the combination of subsidies and externalities is more than 5.4% of world GDP or 4.4 trillion dollars while in the United States the fraction of GDP is only about 2.5% or 490 billion dollars. This is a sizable amount of money that could be directed towards improving electric grids, making them smart, and introducing a wealth of green energies. To appreciate the magnitude here, the World Bank has estimated that the cost of a "moderate pandemic" could be 3% of world GDP or, in a serious outbreak, 5%, or 1.8 to 3 trillion dollars.35

**Table 1. Fossil fuel subsidies and externalities, worldwide and US.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Worldwide</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T/y</td>
<td>% GDP</td>
</tr>
<tr>
<td>Subsidies</td>
<td>0.5-1.91</td>
<td>0.6-2.29</td>
</tr>
<tr>
<td>Externalities</td>
<td>2.63</td>
<td>3.13</td>
</tr>
<tr>
<td>Total</td>
<td>4.4</td>
<td>5.41</td>
</tr>
</tbody>
</table>


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Table 2 provides insights into subsidies for energy sources. It shows that in the United States renewables have enjoyed subsidy support of more than half of the total.

Table 3 examines the research and development support by fuel type over the last 30 years. Over that period the lion’s share of research and development funding has gone to nuclear fission. In 2005 the fractions devoted to conservation, fossil fuels, and renewable combined were about equal and comparable to that for nuclear fission – 3195 versus 3168.

The conclusion from these data is that the funds that are needed for a rapid and dramatic switch from brown to green energy are available and their use would have no impact on the overall economy in the sort-term and significant benefit in the long-term.

**Table 2. Fuel-based subsidies for electricity production, 2010.**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>37</td>
<td>486</td>
<td>575</td>
<td>91</td>
<td>0</td>
<td>1,189</td>
<td>10.0%</td>
<td>44.9%</td>
</tr>
<tr>
<td>Natural Gas / Petroleum Liquids</td>
<td>1</td>
<td>583</td>
<td>15</td>
<td>56</td>
<td>0</td>
<td>654</td>
<td>5.5%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
<td>908</td>
<td>1,169</td>
<td>157</td>
<td>265</td>
<td>2,499</td>
<td>21.0%</td>
<td>19.6%</td>
</tr>
<tr>
<td>Renewables</td>
<td>4,178</td>
<td>1,347</td>
<td>632</td>
<td>135</td>
<td>260</td>
<td>6,560</td>
<td>55.3%</td>
<td>10.3%</td>
</tr>
<tr>
<td>Biomass</td>
<td>6</td>
<td>54</td>
<td>55</td>
<td>0</td>
<td>0</td>
<td>114</td>
<td>1%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>115</td>
<td>1</td>
<td>72</td>
<td>0</td>
<td>12</td>
<td>200</td>
<td>1.7%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Hydropower</td>
<td>17</td>
<td>17</td>
<td>51</td>
<td>130</td>
<td>0</td>
<td>215</td>
<td>1.8%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Solar</td>
<td>409</td>
<td>99</td>
<td>287</td>
<td>0</td>
<td>173</td>
<td>968</td>
<td>8.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Wind</td>
<td>3,556</td>
<td>1,178</td>
<td>166</td>
<td>1</td>
<td>85</td>
<td>4,986</td>
<td>42.0%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Unallocated Renewables</td>
<td>75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>75</td>
<td>0.6%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Transmission &amp; Distribution</td>
<td>461</td>
<td>58</td>
<td>222</td>
<td>211</td>
<td>20</td>
<td>971</td>
<td>8.2%</td>
<td>NA</td>
</tr>
<tr>
<td>Total</td>
<td><strong>4,677</strong></td>
<td><strong>3,382</strong></td>
<td><strong>2,613</strong></td>
<td><strong>648</strong></td>
<td><strong>555</strong></td>
<td><strong>11,873</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

| Unexpected               | 44             | 1,123       | 645 | 147                      | -              | 1,957 | 16.5%                       | 71.3%                           |
| Unexpected               | 0              | 908         | 1,169| 157                     | 265            | 2,499 | 21.0%                       | 19.6%                           |
| Unexpected               | 4,172          | 1,295       | 576 | 131                      | 270            | 6,444 | 54.5%                       | 8.9%                            |

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37. Dr. Michael Trachtenberg (created for use herein and deriving underlying data from Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010, supra note 34, tbls. ES4, ES5).
TABLE 3. Expenditure by IEA countries on energy R&D.38

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Conservation</td>
<td>333</td>
<td>955</td>
<td>725</td>
<td>510</td>
<td>1240</td>
<td>1497</td>
<td>1075</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>587</td>
<td>2564</td>
<td>1510</td>
<td>1793</td>
<td>1050</td>
<td>612</td>
<td>1007</td>
</tr>
<tr>
<td>Renewables</td>
<td>208</td>
<td>1914</td>
<td>843</td>
<td>563</td>
<td>809</td>
<td>773</td>
<td>1113</td>
</tr>
<tr>
<td>Nuclear Fusion</td>
<td>4808</td>
<td>6794</td>
<td>6575</td>
<td>4199</td>
<td>3616</td>
<td>3406</td>
<td>3168</td>
</tr>
<tr>
<td>Nuclear Fusion</td>
<td>597</td>
<td>1221</td>
<td>1470</td>
<td>1055</td>
<td>1120</td>
<td>893</td>
<td>715</td>
</tr>
<tr>
<td>Other</td>
<td>893</td>
<td>1160</td>
<td>787</td>
<td>916</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Energy R &amp; D</td>
<td>7563</td>
<td>15034</td>
<td>12186</td>
<td>9483</td>
<td>9070</td>
<td>9586</td>
<td></td>
</tr>
<tr>
<td>Total: Japan</td>
<td>1508</td>
<td>3438</td>
<td>3793</td>
<td>3452</td>
<td>3672</td>
<td>3721</td>
<td>3905</td>
</tr>
<tr>
<td>Total: w/o Japan</td>
<td>6055</td>
<td>11596</td>
<td>8448</td>
<td>5942</td>
<td>5811</td>
<td>5349</td>
<td>5681</td>
</tr>
</tbody>
</table>

V. GREEN ENERGY, GREENHOUSE GASES, GLOBAL WARMING, AND GLOBAL CLIMATE CHANGE

Today, when the planet has exceeded the "threshold" of four hundred parts per million (ppm) CO₂, and the CO₂ in the atmosphere will affect climate for the next thousand years, halfway measures are grossly insufficient.

We humans are at a crossroads and must decide the future not only on the basis of technology or economics or psychology or even the integral of these, but on the vision we see for the future, and we must decide to get there with all deliberate haste. The crossroads has two conflicting entry points and four candidate exit paths. The first entry is the presence in the atmosphere of greater than four hundred ppm CO₂ as well as enough CO₂ in the atmosphere to affect weather patterns for the next thousand years. This demands remediation, protection, and accommodation to deal with the sequelae of processes already initiated. The second is the moral imperative to provide power to the millions of persons throughout the world whose standard of living could be greatly improved by this effort, in addition to the very significant profits to be turned by this activity.

As to the paths forward:

1) The first is business as usual (BAU), meaning more fossil fuel power coupled with more subsidies and more inefficiency.

(2) The second, BAU-clean, meaning the effort to introduce CCS to mitigate some of the worst abuses and major externalities of the current methods.

(3) The third, the transition, meaning substituting other, perhaps less injurious, brown fuels (GHG and pollutant emitting hydrocarbon-based fuels coupled with some reduction in inefficiencies (Transition = BAU-lite)).

(4) The fourth is the transition dynamic path, the green fuels low inefficiency path, i.e., non-GHG or pollutant emitting energy sources such as wind and solar, etc. (re-envisioning). This article argues in favor of the re-envisioning Transition Dynamic approach and against Transition Fuel and BAU-clean.

The World Bank is taking the long view in warning against the election of short-term solutions that will have long-term consequences when they speak to the issue of getting locked into unsustainable energy paths:

Avoid getting locked into unsustainable paths [in order] to generate immediate, local benefits.  

They shed light on the reality of human behavior, i.e., that once established, a given solution attempts to be self-propagating for a variety of emotional, political, and economic reasons, and thus like an unwelcome houseguest, overstays its welcome. The unsolved issue is how to readily sunset technologies (and their large capital installations) that are no longer efficient or as efficient (in the large sense) or beneficial as new entries to the market space. The reason for this is that unlike biological organisms that are always a work in progress, businessmen and engineers seek permanency in their capital goods and known processes. Rate of turnover is a function of economics; cost versus funds availability, feature desirability, and the number of independent (albeit influenced) purchase authorities. It is also a function of regulations. In this sense, the electron has no added features or benefits to distinguish it when derived from one primary fuel source or another.

Short-term solutions are generally justified on one or more rationales that divide into anxiety reduction, via known approaches, and anxiety increase, via new approaches. Some of the more com-

mon “positive” rationales are: jobs are needed here and now, the technology is known and available, the raw energy source is known and available. The “negative” characterizations are the alternate technology is unproven, uncertain, or incompatible with the remaining infrastructure, more expensive (in the short-term), and disruptive. There are both psychological and economic reasons for these orientations.

In view of these arguments, is the transition dynamic reasonable and feasible?

Jacobson and colleagues recently published a plan to convert New York State’s energy infrastructure to electricity based on green renewable energy sources. Their data are summarized in Table 4. Dramatic gains are visible in energy supply, job creation, public health, and health care costs.

Germany, a country with only as many solar days as Seattle, now derives twenty-three percent of its electricity from solar, threatening coal-fired power plants. How has this occurred? The key to success of Germany’s solar installation is enactment of a feed-in tariff. This tariff forced utilities to buy solar electricity at retail rates, thereby creating a green subsidy and guaranteeing an investment return for a prolonged period. With this guarantee, investors devised clever schemes to promote installation. This change did not occur overnight but over a twenty-five year period. Given the current sophistication of green energy technologies, a comparable change could occur in ten years.

40. See Mark Z. Jacobson et al., Examining the Feasibility of Converting New York State’s All-Purpose Energy Infrastructure to One Using Wind, Water, and Sunlight, 57 ENERGY POL’Y 585 (2013).

The benefits they report are:

- **End-use power demand**: Demand reduction by ~37% coupled with stabilized energy prices (as fuel costs would be zero).
- **Jobs**: Within state energy production would create more jobs than would be lost.
- **Air pollution**: Mortality would decrease by ~4000 (1200-7600) deaths/yr. Mortality costs would decline by $33 (10-76) billion/yr (3% of NYSGDP)
- **Emissions**: NYS decrease alone would reduce 2050 U.S climate costs by ~$3.2 billion/yr.
- **Repayment**: ~17 years for the 271 GW installed power needed, before accounting for electricity sales.

**VI. Conclusions**

Energy – food and fuel (minerals and water) – is critical to the growth and maintenance of societies; the larger and more complicated the society, the more important is the ever increasing, reliable, cheap supply. Fuel energy is divided into red, brown, and green sources.

Green energy, heat used locally, and electricity for local and distributed use, the transition dynamic, is the preferred approach. Introduced broadly and rapidly, it would obviate the need for any CCS effort and would reduce the transition fuel alternative.

Red fuel, nuclear fission, presents high costs, long approval timelines, careful oversight, pollution dangers, spent fuel disposal issues, high anxiety, and terrorist risks that increase dramatically with broader use. Per our assessment, it is unlikely that red energy

42. Dr. Michael Trachtenberg (created for use herein and deriving underlying data from Jacobson et al., supra note 40).
has a meaningful or increasing role in the future; rather as old plants age, they will be retired.

Brown fuels, those that release GHG and other pollutants, have been in use since the beginning of civilization, but have been particularly developed and refined over the last two hundred and fifty years. They are divisible into two categories – fossil and current. Because of their availability, apparent low cost, extensive experience base, and energy density, they provide near-term advantages, but these come with near-term and long-term costs that greatly exceed their gains.

The ethical electron derives from sources that burden the environment least.

The most effective, straightforward, and rapid way to achieve the transition dynamic is to impose a carbon tax, use some of the funds for a green subsidy, and install a feed-forward tariff in favor of green generated energy. The benefits illustrated by Jacobson et al. will more than pay for the change by reducing subsidies and externalities.43

43. See Jacobson et al., supra note 40 and accompanying text.