The [Energy] Webs We Weave[1]

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Background

Energy customers, consumers, end users have multiple choices of fuel or technology options. *Or do we?*

We expect to move seamlessly from one form of energy to another for our daily and quality of life needs, to fuel our economies, provide our basic materials, and satisfy other values and priorities, like reducing greenhouse gases (GHG). *But can we?*

In fact, comprehending the full range of considerations inherent in making energy choices is far from easy. Each and every form of useful energy is delivered to end users through long and complex chains of supply-to-end-use activities. Every useful energy fuel and technology bears inherent risks. We may not, almost certainly do not, know what the inherent risks are for alternative fuels and technologies because these options have never constituted a large enough share of energy supply to attract significant scrutiny. (When that does happen, controversies can erupt – witness large hydroelectric power and biofuels for example.) When it comes to energy-environment "tradeoffs", i.e., the balance we think we need to achieve between our energy necessities and environmental protection and preservation, perception and reality on tradeoffs is particularly complex. Often the full supply-to-end-use chains are ignored. We worry a great deal about environmental "externalities" – environmental costs associated with producing and using different forms of energy that may not be fully captured in market price. We rarely, if ever, talk about "positive" externalities, benefits that are created and not measured. When it comes to the socioeconomic dimension – how energy projects affect host communities, impact local economies, and so on – "perception" and "reality" can merge quite rapidly and in chaotic ways.

In sum, we often talk about, and debate, energy choices as if many of them and the associated tradeoffs are a *fait accompli*, when nothing could be farther from the truth. The tradeoffs and considerations currently being played out are multi-dimensional and complex and dynamic. They are seldom dealt with in an open, clear manner and it is rare that even expert thinkers are fully educated on all of the tradeoffs, much less the general public (and voters).

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[1] Based on a concept paper and presentation provided by Michelle Michot Foss at Science & Technology in Society *forum*, Kyoto, Japan, October 2007.

Part of the problem is the sheer difficulty of gathering up enough information to evaluate the full range of considerations in order to understand tradeoffs and to grapple with "unknown unknowns" and unintended consequences that might occur. The number of dimensions for analysis is very large; the amount of data that would have to be collected and managed enormous. Existing and emerging tools for life-cycle assessment are useful but to implement the tools accurately the life-cycle supply-to-end-use chain should be identified correctly and all externalities – negative and positive – captured. Both the private (energy companies, large energy customers, financial institutions, and so on) and public (policy makers, news media, and public at large) domains need simpler tools to evaluate costs and benefits associated with multiple dimensions across the full energy supply-to-end-use chain.

"What if???"

Let's enter the U.S. energy "laboratory" which incorporates all known commercially available energy sources and technologies. Granted, the United States is very different than most every country – all countries and societies have fundamental cultural differences that impact energy choices deeply, an added complexity if the "unit of analysis" is global energy supply and use. The U.S. laboratory has an assortment of characteristics that drive patterns of energy consumption and inform the core debate about how energy is best provided and utilized. Perhaps most important are the following "rules of the game" (and note – while not everyone agrees our constitution, laws, and practices encompass the points made below).

- The U.S. imposes relatively few obstacles that constrain where and how the majority of people choose to live. Our habits of living and our metropolitan areas have evolved historically in ways that challenge energy grids. Our habits of living also reflect deeply held priorities for open spaces and vistas, constant re-gentrification and re-development, a high degree of labor and transportation mobility, a high degree of integrity in suburban and exurban areas, and a critical (and useful) component of individual choice and freedom which are essential if market-based approaches are to be used.
- The U.S. combines both federal and state jurisdictions for energy infrastructure development and oversight. Local governments (municipalities of all sizes) have substantial influence as well. Over time, numerous experiments have been conducted on both market-based and policy-driven energy investment and management. For our overall economy, we have, thus far, a consistent preference for market-based approaches. However, thus far none of our market-based experiments have fully utilized the dynamic of individual choice and freedom for energy access, pricing and reliability.
- In general, and again for our overall economy, we tend to prefer financial tools and mechanisms to manage risk and uncertainty in energy markets with evolving public oversight. Sharp disagreements permeate the political landscape at present, but even the most radical approaches to financial sector restructuring do not eliminate, or even deeply impact, the growing reliance on financial tools for risk management. The large population of market participants

and money – liquidity – in the U.S. energy markets also helps to support liquidity in the global energy marketplace.

- Developers can build to meet growth and changing patterns of energy use but face new challenges with regard to locating energy operations and infrastructure.
- At present, in the U.S. as elsewhere, there is vigorous discussion and experimentation regarding how best to use our generous fossil fuel endowments; maintain and expand – via international trade – our global energy connections; reinvigorate nuclear energy; and move forward with alternative energy fuels and technologies.

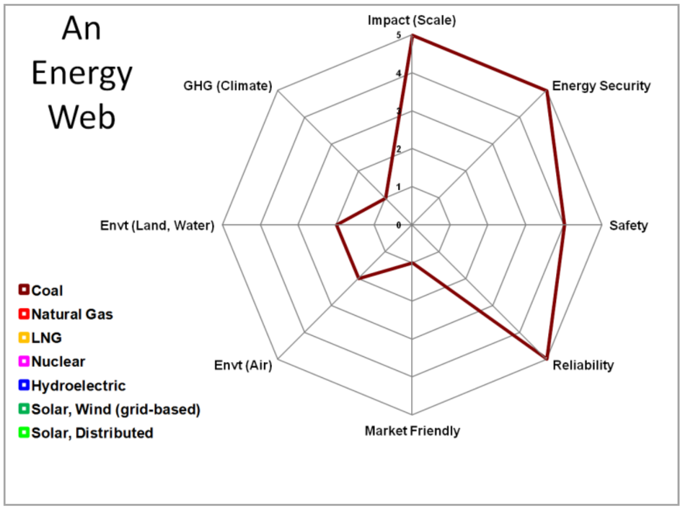
In our laboratory, we can distinguish key dimensions that allow us to experiment with possible tradeoffs.

- **Impact (scale):** "Impact" encompasses how well an energy fuel or technology lends itself to larger scale development. This includes availability of natural resources (coal, oil, natural gas, uranium and other energy fuels), energy density of different options and alternatives (how much "bang for the buck") and other qualities (how easy, or difficult, it might be to expand grids and networks). Impact affects affordability – the easier it is to "scale up" energy systems, the cheaper energy is on a unit basis (per British thermal unit, Btu, or per joule, or using other measures).
- **Market friendliness:** "Market friendliness" affects how well fuels, grids, and networks can be integrated into workably competitive regimes. The degree of competitiveness also drives affordability – the more competitive an energy sector, the more likely it is that new entrants can respond to higher price signals with new investment. Market friendliness implies mechanisms for managing price risk. Suppliers and end users are affected by the extent of price change, either higher or lower, and the speed or volatility at which prices change.
- **Energy security:** Security captures perceptions about the extent to which we can be "energy independent" or the degree of sensitivity of our national and regional economies to energy availability and affordability.
- **Safety:** Perceptions about safety influence public acceptance of different fuels and technologies and therefore relative ease (or difficulty in locating facilities). However, "safety" is an arena in which the perception-reality schism can be strongest. In general, we tend to worry a great deal about "low probability, high consequence" events while taking for granted, and doing very little to mitigate, more routine risks that, in total, can be just as debilitating. These attitudes affect regulatory reviews of projects, design of safety systems, and cost of regulatory enforcement and can make energy projects more expensive without improving public safety in meaningful ways.
- **Reliability:** *In nearly every respect, "reliability" is what we really pay for.* We need energy delivered when we need it. Users that require near 100 percent reliability rarely pay the full cost. In a market friendly environment, users that are flexible and intermittent pay accordingly. The energy equivalent of the "Saturday night stay" so common in airline ticket pricing is usually limited to large industrial end users that can switch fuels.

When environmental dimensions are considered, people are largely ill-informed about the extent of environmental improvements in society. Modern energy fuels and systems are cleaner (and more safe) than any in human history, and certainly cleaner and safer in richer countries than those that are poor. Our perceptions of risk (see above) can result in the pursuit of ever more rigorous (and costly) standards without commensurate benefits. "Energy poverty", which many worry about, can and should be considered in view of whether people have access to clean, safe, modern energy systems. Instead, many typically critique energy project development on the basis of "environmental justice". Fear that greenhouse gas (GHG) emissions associated with human activity may have some effect on climate complicate matters even more. Pronounced differences in attitude and positioning can exist when tradeoffs are made regarding urban air quality, land (especially public lands and coastal areas) and water use (including rivers and streams), and climate change. Certainly, environmental protections, host communities, and other facets of energy development need and deserve attention. But how can environmental and community values best be preserved while also meeting the priorities of economic development and national security? These tradeoffs are at the crux of the energy web dilemma. Thus, to the preceding list, we add the following.

- **Environment (air):** Concerns about urban air quality are differentiated from concerns about climate, even though some overlap exists. Public health is the key concept for this dimension and traditional emissions (sulfur dioxide or SO_2, nitrogen oxides or NO_x, particulates, mercury, and other substances) are the main focus.
- **Environment (land, water):** Perceptions about urban air quality and climate tend to differ from land and water values. Many environmental groups are rooted in protection of public lands and waterways, especially wild running rivers and streams and crucial coastal wetlands. Land use intensity can constitute a major dimension for private lands as well, including proximity of energy projects and infrastructure to communities. Water use for energy development and production is growing as an element of concern and in importance as a dimension for tradeoffs.
- **GHG emissions and climate:** GHG is an extremely complicated dimension with regard to perceived risks and uncertainties, especially with regard to present and future costs and benefits of mitigation. Lack of clarity about both costs and benefits, and how to evaluate these, as well as complexity of climate systems is daunting. A host of gases are in the GHG mix, including carbon dioxide (CO_2), methane (CH_4), hydrofluorcarbons (HFCs) and many others.

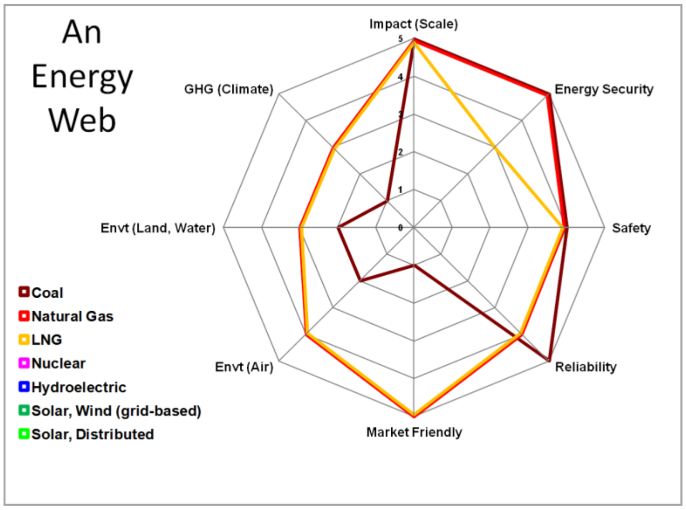
Now ***what if***, in our laboratory, we focused on electric power systems? Electricity is, literally, the stuff of life. Access to electric power has improved living standards enormously. We know that availability of electricity is linked to level of education, quality of public health, and many other aspects of society that we consider non-negotiable for human development. ***What if*** we could rank or score each dimension for an array of different energy choices? ***What if*** we set scoring from zero (0) to five (5), the higher the better, with a score of three (3) as "neutral"? What would a possible outcome or scenario look like? Remember, these are only possible outcomes. There are many possible outcomes, or scenarios, depending upon assumptions and inputs.



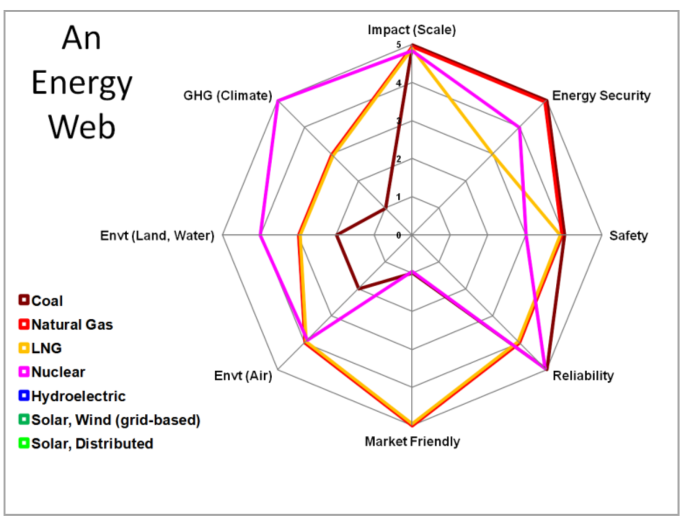
Coal could be ranked highly for impact, energy security, and reliability since modern coal combustion power generation plants constitute the backbone of our electric power system in the U.S. and in many other countries. Public perceptions of mine safety might affect that score. Coal might score lower for market friendliness; the cost and regulatory hurdles involved in building coal plants make these investments difficult in open, competitive markets. They are most typically built with some form of regulated cost recovery, allocated across all customers in a market area (what we call "cost of service ratemaking" in the U.S.). Coal is most challenged on the environmental dimensions of air, land/water and GHG. Modern coal generation units can be retrofitted to manage typical emissions for urban air quality, but it can still be costly. The U.S. has a market for SO_2 that has proved to be reasonably successful in spurring abatement.

Coal units require considerable water resources and coal mining raises concerns about land use and associated impacts, water use, dust, and other impacts (mined land reclamation has advanced to a point where many reclaimed lands provide ecosystem benefits beyond what the original state provided, but at a cost). In our laboratory we can only consider, for practical reasons, modern combustion coal plants (we can include "advanced combustion" plants in our analysis of tradeoffs in order to reduce traditional emissions, with a higher investment cost). Interest remains high in options to capture and sequester CO_2 ("carbon capture and sequestration" or CCS, with some form of underground burial most often the option) to satisfy the GHG climate dimension. This is a most expensive undertaking. Prevailing opinions are that public sector support and rate base regulation are needed to accommodate major "coal+CCS" projects (assuming technical feasibility and that attendant other challenges can be met, such as access to subsurface storage and ways to manage potential liability exposure associated with CO_2 storage). The result is a market/government tradeoff that is burdened by our past experience with energy policy. A critical question is whether "cap and trade" schemes can yield sufficient value from carbon credits to offset costs, encourage CCS investments, and still support affordable delivered electricity prices. Texas (a competitive market regime with nodal design under implementation) and Illinois (traditional cost of service ratemaking) competed for the federally supported FutureGen coal+CCS project. After selecting one of the Illinois sites, the U.S.

Department of Energy and its private sector partners suspended the FutureGen program and reorganized its approach because of escalating costs.[2]



Natural gas (and liquefied natural gas, or **LNG**, used for international marine transportation and trade as well as for domestic storage of natural gas supplies) score highly for impact. Gas generation units tend to be used mainly for generation during peak periods of electricity demand, a current target of attention. LNG scores slightly lower for security, as imported energy, and neutral on safety (LNG is particularly affected by public perceptions in this regard). Natural gas/LNG are reliable and valued for market friendliness, given the relatively low cost of gas-fired generation and competitive intensity in the natural gas segment overall. NO_x emissions, methane (the main natural gas molecule used for both power generation and home delivery) as a GHG contributor, and land/water use for domestic natural gas supply development can affect how gas generators are viewed on other environmental values.



What about **nuclear**? Attitudes on nuclear energy are particularly complex following damage to Japan's Fukushima nuclear complex caused by the earthquake and tsunami. Disposal of high level nuclear waste (the future cost of which is as uncertain as costs of GHG mitigation) is a matter of public policy. By law the federal government must provide a central waste disposal solution, something the U.S. Congress has, thus far, failed to accomplish. Yet most Americans and many communities remain interested in and willing to host nuclear generation facilities. Nuclear plants achieve large economies of scale and thus score highly on impact. Nuclear facilities have run reliably for base load in spite of concerns about safety (perceptions are

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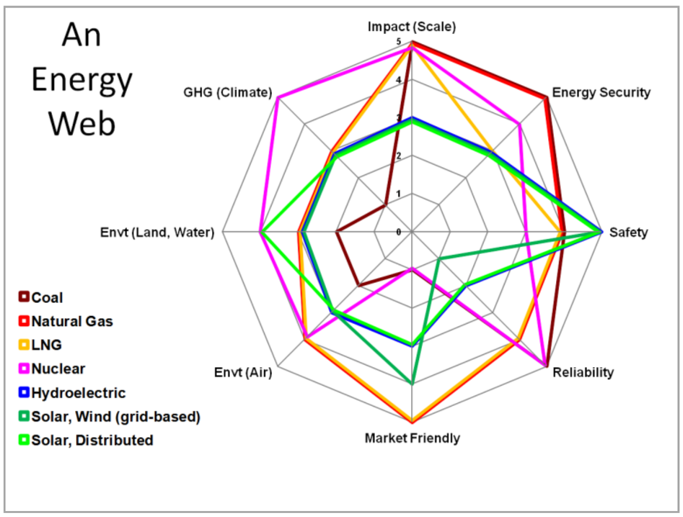
[2] The Bureau of Economic Geology at UT-Austin led the State of Texas proposal in the FutureGen clean coal competition and hosts the Gulf Coast Carbon Center for CCS research and development. See www.beg.utexas.edu. The final cost estimate for FutureGen reached $2.3 billion dollars. The power generation capacity target had been reduced to 250 MW (megawatt), resulting in a cost of $9.2 million per MW. See http://www.futuregenalliance.org/ for an update on "FutureGen 2.0".

tending positive) and most U.S. units are operating well past their projected time horizons. New nuclear units, like new coal units, can dispatch power into competitive regimes but locating new units and amortizing new investments in fully competitive market regimes has not been tested. Costs for new nuclear units have soared, a trend even before Fukushima. Nuclear satisfies many national security and environmental dimensions. Assuming suitable waste disposal strategies (re-processing would vastly reduce the amount of high level waste) nuclear is a highly valued alternative for other environmental priorities.

How do coal, natural gas/LNG and nuclear stack up against other options? Here is where the tradeoffs perhaps are most interesting.



Renewable energy technologies (hydroelectric; solar and wind that are grid-based or connected to power grids; solar that is distributed throughout a market) can satisfy security and safety values but are not high impact options for the foreseeable future. Indeed, the unknown unknowns associated with some large scale renewable energy systems are……unknown.

Hydroelectric resources are viewed by some to be important enough for GHG mitigation to justify building new dams and reservoirs in spite of other environmental trade-offs. For some time, the U.S. has been decommissioning, or reviewing hydro facilities for decommissioning, rather than certifying new facilities. Free-running river systems are deeply valued in many locations. Yet, hydroelectric facilities can provide a solution to persnickety problem - energy storage – via pumped storage *if* economics and energy balance concerns can be met. Creative coupling of large scale wind and hydro also offers tantalizing possibilities.

Wind and solar projects that are connected to electric power grids present a host of challenges associated with managing intermittency and frequency. For distributed (off grid) solar to be introduced in ways that many think possible, grid access still is essential both to back up local solar systems as well as to provide market friendly re-distribution of local solar energy to the grid. Grid-based wind is valued in many locations (not least Texas) but requires "socialization" of costs of new transmission lines and usually a mandate, which even market friendly renewable portfolio standards entail. Grid-based solar and wind involve large surface land access commitments and thus the same kinds of environmental impacts that fossil fuel operations do – especially roads and large networks of roads that impact local ecosystems. The need for back up generation to both balance intermittent wind and solar systems and ensure reliability means GHG production (unless energy storage solutions can be found, which presents other dilemmas).

Large scale renewable systems entail the same, if not more, requirements as conventional energy systems: an effective industrial (manufacturing base); access to raw materials (including, for renewable systems, strategic minerals that the U.S. does not have in abundance); water (for example, concentrated solar power systems use 4-5 times as much water per kWh than gas-fired plants for wet cooling). In short, large scale renewable energy needs all of the same GHG intensive inputs that a modern economy, overall, requires.

A resulting scenario from our "laboratory" places natural gas as the top ranked solution, an outcome some will like, and others won't. Scores are provided in the table below. (You can view the "energy web" by using a Powerpoint show posted with this concept paper at http://www.beg.utexas.edu/energyecon/thinkcorner/).

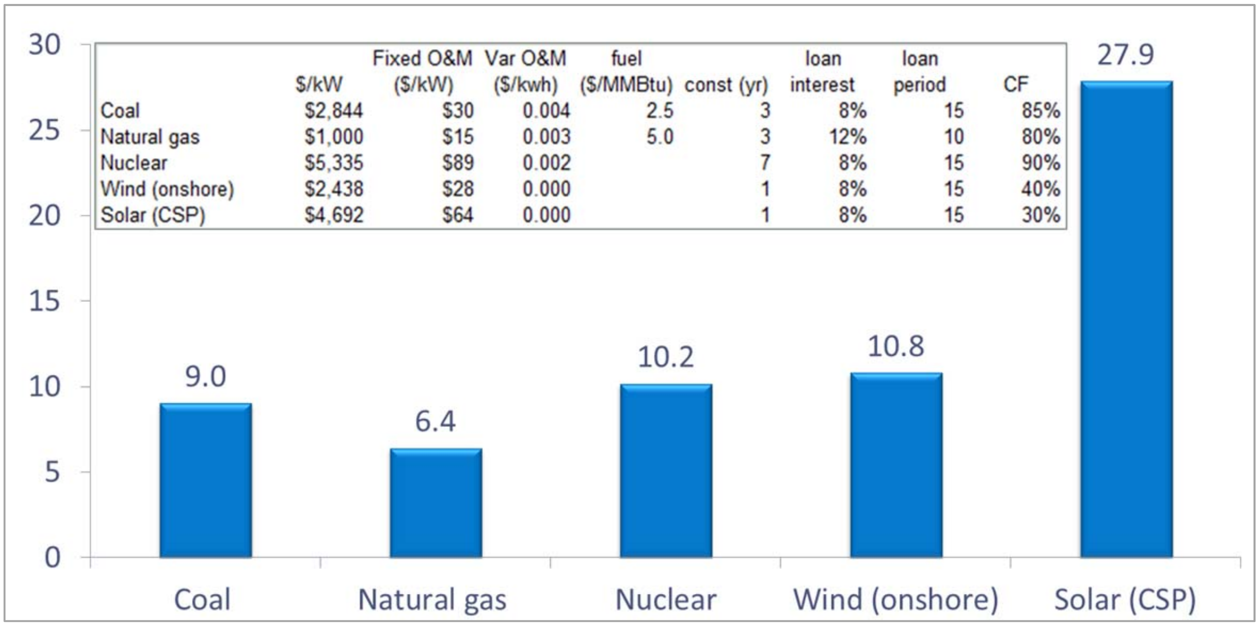
	Impact (Scale)	Energy Security	Safety	Reliability	Market Friendly	Envt (Air)	Envt (Land, Water)	GHG (Climate)	Tot.
Coal	5	5	4	5	1	2	2	1	**25**
Natural Gas	5	5	4	4	5	4	3	3	**33**
LNG	5	3	4	4	5	4	3	3	**31**
Nuclear	5	4	3	5	1	4	4	5	**31**
Hydro-electric	3	3	5	2	3	3	3	3	**25**
Solar, Wind (grid-based)	3	3	5	1	4	3	3	3	**25**
Solar (off grid)	3	3	5	2	3	3	4	3	**26**

"So what?"

Cost is not an inconsequential factor in making decisions on tradeoffs. Many argue that costs for some energy systems, like renewables, or costs associated with GHG mitigation, like CCS for coal (or even natural gas generation), need to be incorporated into the market price for fossil fuels. For instance, the thinking goes, a carbon credit would make coal much more expensive, and thus encourage development of GHG free (at least during power generation) renewables. But to be fair, the full cost of renewables also would need to be reflected in market price. This presents a conundrum, because transmission for renewables (the best wind and solar locations almost always are remote from customer locations), balancing, ensuring reliability, and so on, along with the "unknown unknown" consequences are expensive. Normally, customers are not aware of all of these other costs, because governments provide various subsidies to encourage renewable energy projects.[3] Our own rough calculations excluding all subsidies put natural gas at the

[3] Energy subsidies are hotly debated. For a U.S. government view on energy subsidies, visit http://www.eia.gov/analysis/requests/subsidy/. Many critics argue that fossil fuel subsidies

cheap end of electric power choices (prices that yield 12 percent return on the investment).



	$/kW	Fixed O&M ($/kW)	Var O&M ($/kwh)	fuel ($/MMBtu)	const (yr)	loan interest	loan period	CF
Coal	$2,844	$30	0.004	2.5	3	8%	15	85%
Natural gas	$1,000	$15	0.003	5.0	3	12%	10	80%
Nuclear	$5,335	$89	0.002		7	8%	15	90%
Wind (onshore)	$2,438	$28	0.000		1	8%	15	40%
Solar (CSP)	$4,692	$64	0.000		1	8%	15	30%

Capital and O&M costs are based on U.S. EIA's Nov 2010 report:
http://www.eia.gov/oiaf/beck_plantcosts/index.html

When it comes to the particular problem of GHG mitigation, how would coal with CCS or, for that matter, CCS with any fossil fuel, be developed in the U.S.? Short of policy mandates or very strong market incentives, most thinking centers on CCS associated with enhanced oil recovery (EOR; possibly including enhanced natural gas recovery or coal seam gas exploitation). This would allow us to extract remaining value from our mature, but still substantial, hydrocarbon base. A host of issues and hurdles must be resolved, ranging from commercial and market structures (not least of which is establishing and determining willingness to pay for captured CO_2) to locating and permitting new CO_2 transportation infrastructure, locating and accessing appropriate EOR "sinks" and completing the CCS value chain so that energy remains affordable and accessible for economic development. CEE has investigated many of the economic considerations of CCS, separately and in concert with our BEG projects, and publications on our research are forthcoming.

A distinct conundrum underlying the energy web tradeoffs, and embedded in the "impact" dimension, is energy density, as alluded to previously. Fossil fuels are

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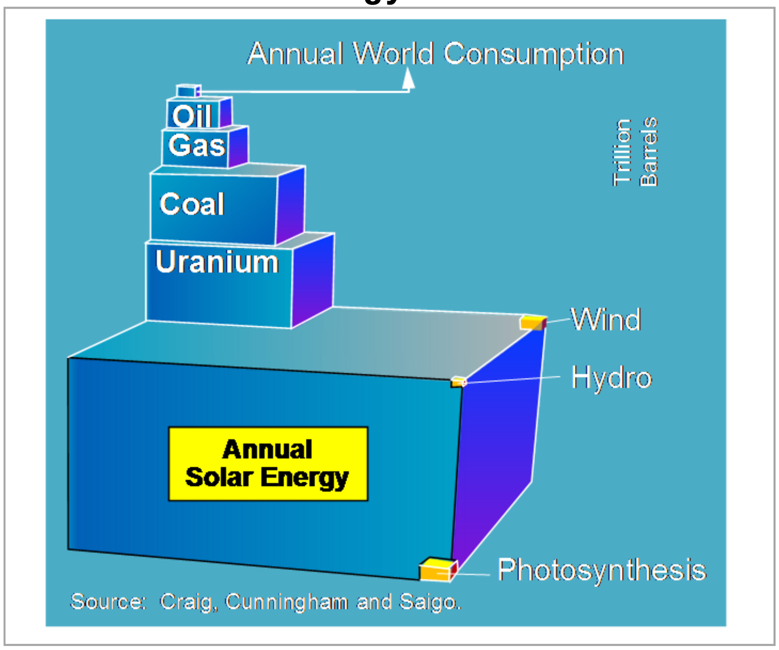
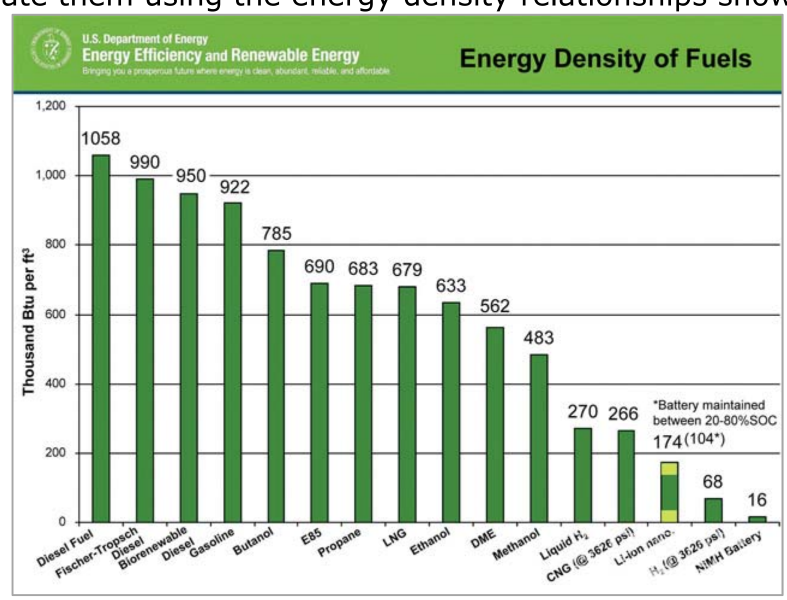
are larger and should be phased out. The U.S. government has been subsidizing renewable and other alternative energy projects for decades; we still only obtain about two percent of our total energy from these sources. This means that the public cost of subsidies remains expensive relative to fossil fuels. Some subsidies, such as credits for oil and gas drilling and depletion allowances, are simply forms of depreciation that all industries are provided through the U.S. tax code. Like the U.S. economy overall, energy would benefit from simpler, more transparent tax reform. Consumers (voters) would benefit if public support for renewable and alternative energy, including biofuels and including state and local subsidies, was less opaque and information more accessible.

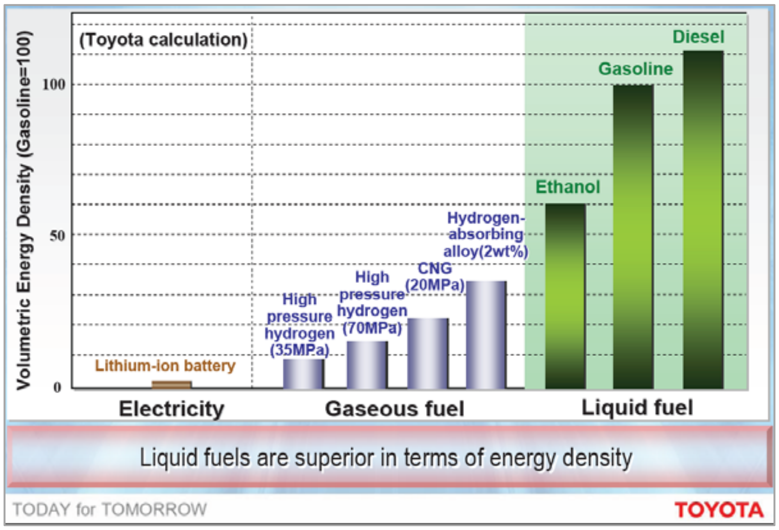
highly valued because they are packed with energy content that is difficult to replace through other sources (nuclear fuels being an important exception). In addition, fossil fuels provide essential molecules that we use for critical materials – the building blocks of everyday life, from consumer products to healthcare to industrial plastics, fabrics, fibers, and other key inputs. We still need these molecules, making the value attained from fossil fuels even more difficult to substitute. Finally, while the earth is bathed in energy every day, capturing highly dispersed and uneven solar, wind, and tidal energy sources requires considerable infrastructure.

Total Energy Resources



The energy density challenge is even better highlighted when transportation fuels and systems are considered. If our lab experiment had focused on these tradeoffs, we would evaluate them using the energy density relationships shown below.





Energy density enables capture and release of larger amounts of energy from smaller volumes, enhancing economies of scale for high impact. Uranium and other nuclear energy resources provide even more powerful energy density benefits.

The same lithium-ion battery technology (Li-ion) that forms the core of hybrid and electric vehicle designs also constitutes the core technology for battery designs that some think could balance renewable and alternative electricity and "smart grid" electric power systems. Other solutions may be used for energy storage and balancing, and many are under discussion like compressed air for wind, flywheels for grids, and so on. All have challenges. Fundamentally, it is this dilemma – the lower amount of energy yield per unit of investment – that makes scaling up renewable and alternative energy systems so hard. Technology, especially advanced materials, might help make this problem more manageable in the future. *For this reason, concentrating public investment into materials science research makes more sense than underwriting renewable and alternative projects that deploy known technologies.*

Last, how do our tradeoffs in the U.S. compare with those in other nations and regions? In many respects they are very similar and everywhere very dynamic. Differences occur mainly with respect to context, especially in how tradeoffs are prioritized and in willingness to rely on market rather than government regimes. Natural resource endowments and international trade access to generation fuels vary widely. Public acceptance of critical energy infrastructure is an emerging issue in many countries and world regions and we observe many instances of low acceptance even for renewable energy projects. Not every country has access to adequate media for carbon sequestration and nuclear entails distinct national technical skill sets and policy and regulatory management.

"How to…"

We have suggested a way of thinking about complex, multidimensional tradeoffs using the energy web approach. Truly implementing the energy web approach will require much more than presented here. We need to develop robust scoring formulas, determine the best way to collect and manage data (and to approximate where data are not available). Our approach requires the following.

1- A complete list of objectives, building blocks for different scenarios.
2- A complete list of dimensions and perhaps additional layers, although a "reductionist" view is important
3- A complete list of energy options for different scenarios
4- A formula to link weights of objectives to different dimensions
5- Test cases to yield scenarios and demonstrate the usefulness of the tool

CEE is in the process of adapting the energy web as an internet based game and tool. We are interested in YOUR scores. In this way, our laboratory can expand to include the depth of societal values that influence decision making.

Energy Security as a Special Consideration[4]

Ultimately, we are most interested in the convergence of options that are most adaptable and flexible to sustain large, modern economies, and the frameworks – public and private – most conducive to enabling these options to flourish. Fundamentally, improving energy security is about ensuring availability of reliable energy services to the economy. As such, diversification has been at the heart of strategies followed by countries around the world. In particular, experiences of countries with little domestic resources, such as Japan, France, South Korea and Singapore, that have yet been able to sustain economic growth, provide a set of strategies that have proved successful in most circumstances. Most common are the following:

- increasing the number of fuels and technologies that are in the energy mix;
- increasing the number of suppliers for each fuel (especially if imported);
- increasing energy efficiency and conservation; and
- developing storage capacity for different fuels (e.g., strategic reserves).

However, achieving the desired level of diversification across all of these dimensions faces many challenges. As with any risk mitigation approach, premiums should be commensurate with the size and likelihood of the anticipated risk. Buying oil or natural gas reserves or investing in upstream projects through national companies in producing countries, engaging in long-term supply agreements, or building multiple pipelines may help with supply security but not necessarily diversification unless multiple producers are pursued. These strategies can also cost more in the long-run if, for example, the market price falls or fields turn out to be less productive or more costly.

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[4] This section is taken from the *Energy Security Quarterly*, Issue 1 produced by Dr. Gürcan Gülen and others at CEE for the USAID South Asia Regional Initiative for Energy with input from Tetra Tech's international development advisory group. http://www.sari-energy.org/Energy_Security_Quarterlies/ESQ1_January_08.pdf

Similarly, building strategic reserves, for instance, for petroleum, can be expensive in terms of both the capital cost of building storage facilities and the cost of fuels purchased to fill them. Somewhat paradoxically, the urge to fill petroleum reserves gets stronger as fuel prices rise in anticipation of further increases; significant sums can be spent filling storage with expensive fuel (as International Energy Agency, IEA, member countries did in the 1970s and 1980s, and many such as the U.S. and China do today). Supporting new fuels or technologies may require substantial investment in production capacity or subsidies for the fuel or both. If there are already subsidies for products like electricity, liquid petroleum gases (LPG, most commonly propane), kerosene, or diesel, the alternatives will have an even more difficult time penetrating the market. Subsidies also discourage conservation and investment in more efficient buildings or equipment.

Therefore, it is useful to identify and compare key dimensions of energy security as they apply to various fuels. In order for any fuel to be a realistic part of a diversified fuel portfolio, sufficient resources should be available; producers should be able to have the technology, capital, and access to produce the resource; and consumers should be able to afford the end product. Increasingly, consumers prefer fuels that are safe and environment friendly, adding another element to consider. These key dimensions of energy security can be summarized as availability, accessibility, acceptability, and affordability.[5]

- Availability captures the global energy resources that dominate current energy mix and are expected to remain the dominant sources of energy for the foreseeable future. Conventional and unconventional hydrocarbon resources are considered. Renewable resources such as wind, solar and biofuels are also included.
- Accessibility addresses barriers to exploring and developing available resources. Barriers include geopolitical factors, financial and human resource constraints, fiscal regimes, need for major infrastructure and technology deployment.
- Acceptability reflects environmental and safety concerns.
- Affordability is ultimately about consumers being able to afford energy services provided to them but it also covers capital and operating cost structures for developing various energy sources.

The following table offers a snapshot of the current status of energy sources.[6] Large hydro facilities are considered separately from biofuels and renewables such as wind, solar and geothermal as they manifest different features. Grading (+/−) is meant to provide an easy way to compare different fuels across the four dimensions.

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[5] The four terms are from *A Quest for Energy Security in the 21st Century: Resources and Constraints*, APERC, 2007.

[6] This interpretation is by CEE and is based on various studies, including CEE's own work, various energy security studies, other scholarly articles, and outlooks produced by the U.S. Energy Information Administration, IEA, and National Petroleum Council.

	Availability	Accessibility	Acceptability	Affordability
Oil	+ conventional resources maturing; discoveries still possible; non-conventional resources becoming commercial	+ ➔ − rising geopolitical risk; rising investment barriers; human resource constraints; infrastructure constraints	+/− most convenient transportation fuel / rising concerns about dependence on OPEC and GHG emissions	+ ➔ − accessibility constraints raising price / world economy has been able to absorb higher price so far but subsidies delay demand response
Natural Gas	++ conventional resources widely available; significant exploration potential; non-conventional resources becoming commercial	+/− need for new infrastructure; rising investment barriers though less than oil; human resource constraints; geopolitical risk is less than oil's	++/− cleaner burning and more efficient than oil and coal, especially for power generation / opposition to new infrastructure	+ rising costs are moderated with LNG availability from low cost sources
Coal	+++ resources available worldwide	++/− some capital and infrastructure constraints (ports, ships, trains)	−−− emissions (particularly GHG); pending IGCC and CCS	++ pending GHG regulation and CCS
Large Hydro	++ size is location specific	++/− some capital and infrastructure constraints	+/− ecological, social and historical impact	+ higher capital but lower operation cost compared to most fossil fuel options
Renewables	++ can be important at local scale but not a major energy supply yet	− ➔ + portfolio standards, subsidies and political commitment rising; limited diffusion of advanced technology	+++ mostly no direct emissions; direct ecological impact considered low	− ➔ + higher economic costs than fossil fuels but inclusion of costs of fossil fuel externalities help
Nuclear	+++ uranium resources available, though uranium processing is constrained	− human resource constraints; limited access to advanced technology	− ➔ + waste disposal, safety and proliferation risks / no GHG emissions	+ higher capital but lower operation cost compared to most fossil fuel options
Biofuels	+ limited supply capacity but technology will help	+/−− natural conditions (land, soil quality, water resource, plant type); distribution infrastructure constraints	+/− depends on feedstock and market; competition with food; water depletion; deforestation; fertilizer use	− cannot compete without subsidies in most cases

Source: CEE.

A complete energy web will allow full exploration of options and choices, individual and societal preferences. It will help inform users and audiences of all types about the considerations, complexities, and framework requirements associated with energy tradeoffs.

And, caveats…

Models are only as good as the assumptions that underlie them, and one of the most widely critiqued assumptions these days is how we human beings acquire and process information and make decisions. For many reasons, but not least the convenience of model building, economists and other scientists have long assumed that people are rational actors. That is, we are unemotional and agnostic about the information we seek and conclusions we form. Importantly, when we make decisions we act to maximize benefits (or profits, or utility), which we can clearly identify, subject to an income constraint. We care most about total wealth. In truth, we are much more complex, more prone to emotion and feeling than models can capture, more influenced by cues and other signals (and so sensitive to branding, peer pressure, and an assortment of tricks used widely by marketers), more sensitive to loss (and thus notorious for selling assets at the wrong time and missing opportunities), and so on. We are, as one economist and author put it, "predictably irrational".[7] Increasingly, researchers are turning to behavioral and cognitive research to discern the differences between outcomes that models based on rational choice might produce as opposed to outcomes using approaches that better capture how we really think, feel, and make decisions and choices.

In many respects the energy web reflects a dip into behavioral components in the energy "space". A great many aspects about how we produce and consume energy are prone to the same errors and incorrect assumptions that behavioral economists identify. It seems natural to delve a bit more into this complex arena, at least enough to be able to think about the direction and possible extent of miscalculations about what the future might hold, given our tendencies. The energy web concept parallels our explorations into energy markets and trading.[8] Our goal is to produce practical tools for exploring ideas about how we perceive energy, economy, and environment tradeoffs and the implications for markets, investment frameworks, technology – in short, our energy future.

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[7] *Predictably Irrational*, by Dan Ariely, 2010, Harper Perennial. Or see Dan's web site, http://danariely.com/. I have replicated the experiment in Chapter 2 of *Predictably Irrational* with many groups, usually comprised of energy professionals, and obtained similar results in every test. For extensive thoughts on rationality and behavioral and experimental economics, see the Nobel prize lectures by Vernon Smith, http://www.nobelprize.org/nobel_prizes/economics/laureates/2002/smith-lecture.pdf, and Daniel Kahnemann, http://www.nobelprize.org/nobel_prizes/economics/laureates/2002/kahnemann-lecture.pdf who was awarded the Nobel for his work on prospect theory and related aspects with Amos Tversky (deceased at the time of award).

[8] See *The Future Landscape of Energy Trading*, http://www.beg.utexas.edu/energyecon/thinkcorner/Energy_Trading_Foss.pdf.