Energy Efficiency: The Critical Systems Lifetime Measure

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Introduction

Two major societal changes have occurred over the last 30 years that demand attention. One is the dramatic growth in the number of people worldwide who are wealthy and the surprising extent of their wealth. The second is the increased dependency of people throughout the world on electricity as a primary energy source or apparatus with a critical energy component. This is best appreciated via the spread of personal electronic devices and the incorporation of electronics as starters, controllers and monitors in systems driven primarily by other fuels.

Affluence is and has been a prime driver for political power and consumption throughout history. Each generation expects to be richer than the one before. Enabling societies, common to great empires (democratic or not), promote both wealth accumulation and vertical mobility. The post-WW II economic democratization dramatically increased vertical mobility enshrining it as a totem of a desirable society. We can conclude that these trends are going to continue and at an increased rate. In the absence of extreme economic events, wars or natural disasters people do not willingly decrease their standard of living.

Problem

Personal (and corporate) wealth is a critical value as the wealthy use a grossly disproportionate fraction of goods and services and emit a non-linearly disproportionate amount of carbon dioxide (CO_2) NTNU (Hertwich and Peters 2009)[1], independent of country boundaries. The NTNU data show that for individuals with an annual per capita income of $10K or less their average per capita CO_2 emission is 1 metric tonne. However, as per capita annual income increases to $1M, the per capita CO_2 emission rises 15-fold with an average increase over that income range of 7X. Thus, to a first approximation, 14% of the people in the world (the affluent) emit as much CO_2 as do the remaining 86% of the populace. This increase, while evident for all forms of consumption, is not uniform across consumption categories, e.g., food increases far less than does transportation. Despite these data the general idea that an improved planet rests on an ever-widening distribution of an ever-improving standard of living continues unabated. The objective of making ever more people ever wealthier implies ever-increasing pollution and an ever more imperiled ecosystem, i.e., a transfer of resource benefits to humans and burdens to all non-human systems, though with an obvious and ultimate adverse effect on human beings. The business as usual (BAU) strategy is one of "kick the can."

A key question then is how to support these trends without also compromising the environment by increasing the amount of greenhouse gases and other pollutants released into our atmosphere, oceans, streams and land. The environment is not a stand-alone proxy for forests and ocean, etc. but the very real ecosystem on which modern society is predicated, i.e., the infrastructure of the social fabric (e.g., NYC subway, train and vehicular tunnel systems). Traditional responses to this conundrum are salvation via "technology" and more unfettered capitalism as innovation is "hindered" by regulations in every sphere, i.e., unleash the creative "juices." While popular we consider such comments as superficial at best, counter to existing data and divisive at worst.

Approach

We propose three integrated approaches to achieving the goal of increasing affluence without further damage to the ecosystem, i.e., of achieving long-term benefits without incurring unacceptable short-term costs:

1. Changes in counting and accounting,
2. Changes in systems wide energy efficiency measurement and performance, and
3. dramatic increase in development, promotion and use of green energy.

Importance of Energy and Energy Efficiency

The most critical supply element for any society is energy – fuel, food and water (the ultimate reactant). The four essential energy characteristics are current availability and price, and anticipated change in future availability and price. Because of their emotional criticality each of these supply elements is heavily

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See footnote at end of text.

subsidized (directly, indirectly and via externalities), preserved as critical stores, and supported by considerable military might, all devoted to maintaining a constant supply.

The value of energy is in the work it can support. Thus energy efficiency along the entire supply-demand chain can be seen as an efficiency exercise targeted at converting the smallest number of source Joules into the largest number of product - Joules/sec or heat or chemical reactions. System efficiency thus corresponds to the overall energy cost needed to achieve a given end, over a defined period. This means that each step in the supply and demand chain exhibits a quantifiable degree of efficiency. However, typical measurements are highly siloed, often top down approximations, and commonly do not represent system values [http://en.wikipedia.org/wiki/Life_cycle_analysis].

On the supply side, key actions are the processes wherein fuel is conditioned to be transformed from raw fuel-stuffs, through extraction, transformation, storage, transport, and local redistribution, each with its attendant losses and inefficiencies, to provide a fungible, energy-dense product that is available on demand 24/7 (Figure 1) with electricity as a preferred energy carrier. On the demand side the operations include local storage, distribution, and a multiplicity of end uses - each with its attendant losses, wastage and inefficiencies. The difference between the theoretical energy available from the raw fuel-stuff to the end use is termed the *beneficial energy*, here defined as Output = f (inputs), i.e., μ*energy; thus a greater value for μ corresponds to more energy efficiency. Conversely, the less efficient this system, the more primary energy has to be used to realize the desired end work product.

Among the key insights from this diagram are 1) the many opportunities for efficiencies on both the supply and the demand side, 2) the fact that progressively more efficient end-use profiles can dramatically affect the ratio of centralized vs. distributed energy production, and 3) the idea that energy investments can be redistributed to future benefits.

Cost of Energy

Energy efficiency's contribution to overall energy price is substantial but limited. For example, (Gillingham, Newell et al. 2009) showed that estimates of overall cost-effectiveness of efficiency standards for residential appliances is $3.3 billion/quad saved in 2000, while cost-effectiveness of Demand-Side Management is $2.9 billion/quad. Those authors argued that if all of the energy savings were in the form of electricity, their estimates would suggest cost saving of 3.8 cents per kilowatt-hour and 3.4 cents per kilowatt-hour for appliance standards and utility Demand-Side Management, respectively.

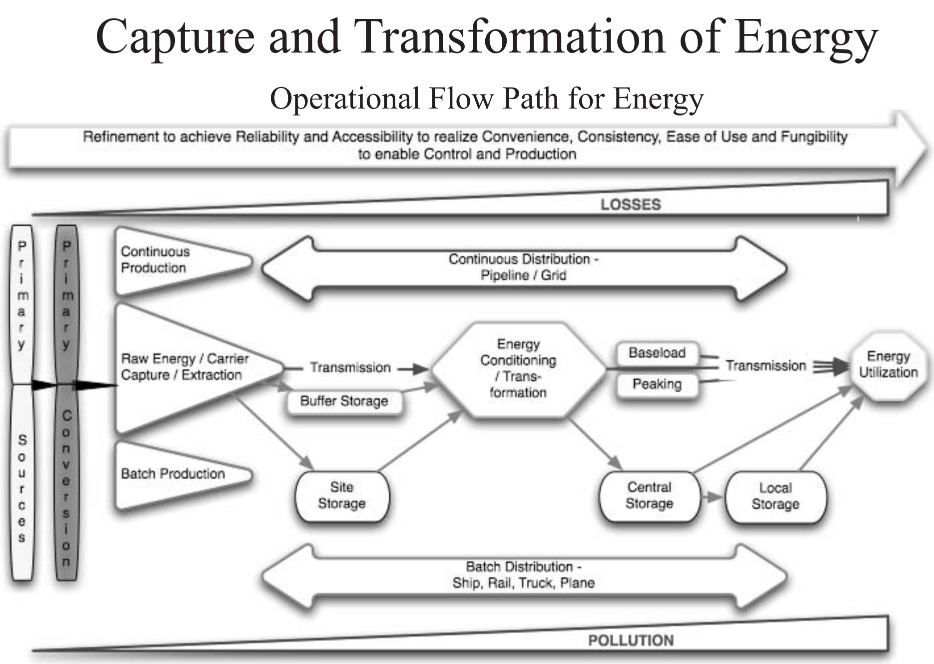

Figure. 1. Summary flow of energy processing, storage, distribution and use.

Offsets by subsidies and externalities only makes the fractional contribution of efficiency that much less potent. These offsets impose biases in the overall system performance – at times desired, at times grandfathered, at times a perverse redistribution of wealth. These biases, whether by design, secondary to social or economic rules, by self-serving behavior, or by chance, slow the rate and magnitude of incorporation of innovative change into the BAU. A low cost for energy (as might be facilitated by increased efficiency) is not necessarily a desirable consequence from a systems perspective, as it will promote inefficiency including vampire energy and delay efficiency innovation. "Necessity is the mother of invention," here the English proverb has been defined as "when the need for something becomes imperative, you are forced to find ways of getting or achieving it" thus including all of the key actions – invention, innovation, introduction and incorporation (Oxford Dictionaries).

Innovation

A major question in today's world is how to most effectively introduce innovation in large, risk-averse industrial systems, such as power plants, to achieve the most efficient (system level) energy production, delivery, and use that maximizes benefits while minimizing work, use of materials, pollution, ecodamage, etc. Pollution control regulations are a poor substitute for systems management and for a culture of excellence. Fundamentally, energy producers do not attempt to solve a vexing problem. Solving the innovation problem is important to achieve real improvement in energy use needed to support broadening and deepening of affluence. The McKinsey Report (Dobbs 2011) addressed the benefits from efficiency and reducing energy use. What is critical is the relatively low cost and the benefit/cost ratio. As long as costs (burdens) can be pushed along to the final consumer there is no driver for component performance. To achieve this, accountability must be changed at every step in the process. Current supply chain efficiencies are top down driven when we need either a bottom up approach or one mandated on a system-wide basis by government or industry (commonly working together) to assure uniformity of performance and to mitigate the risk of and undue benefit realized by free-riders. In the U.S. compliance is commonly voluntary, not so in other democratic states, the difference being the relative strength of government vs. business interests.

Paths to Drive Innovation

One path to promoting and realizing energy efficiency rests on changes in counting and accounting. There is much discussion concerning the validity and utility of GDP (or its variants) as a measure of beneficial economic activity since the neutrality of the measure treats all transactions equally a situation akin to the number line having no negative numbers. While there are many alternate "green"-GDP metrics they often incorporate a "feeling state" and other normalized humanitarian values that make them contentious to one group or another. Part of the new metric we advocate is based on component and system efficiency (there are some similarities to EIO-LCA and other analyses); this will be discussed in a separate paper.

Neutralizing all subsidies and externalities is another step in this direction, save those immediately needed during the infancy of a technology. Assembling and assigning distributed fractional costs is another. Imputing costs imposed on nature is a third (see below). This last may be accomplished by assuming the cost of complete restoration. This allows the ability to impute environmental damage cost by means of alternative replacement. None of these measures likely will be more than 70% accurate, if that, but they are a good start towards developing appropriate methods and measurements. This is a good example of where the excellent should not kill the good.

A particularly valuable change is exercising full, immutable accounting, achieved through a variation on traditional double entry bookkeeping. Traditionally every asset is matched by a liability inasmuch as the corporation is a construct owned by its investors. Here an analogy is made such that every benefit has listed an offsetting cost. The parallel idea is that nature per se is not owned by an individual or group but is a fund from which one makes withdrawals and is obligated to make in kind remuneration While we are not asserting a return (continuance for many religious groups) of such a non-secular relationship,we are asserting that the current "man as god" value set is a typical subject/object relationship where abuse and devaluation of the object is inherent. Moral suasion is not a viable path to remedy this inherent deficit. Assigning a value to ecosystems has been particularly difficult to accomplish. It can be done if the value of industrial processes needed to realize a full systems-wide, full value, zero-base were used as the imputable cost. The value would be argued but a judgmental and insurable value would be achieved over time.

Personal responsibility, by piercing the corporate veil, is a most effective enforcement strategy. Reconsideration of Directors and Officers insurance is the ready vehicle for such changes. Immutability is a central consideration as current accounting methods are, to be kind, flexible; they present a rationalization that is used to tell a desired story, in other words propaganda parading as plausibility. This flexibility and fungability is very costly – accounting, as a transactional cost, accounts for 45% of the U.S. national income under ordinary conditions (Wallis and North, 1986) and far more in acquisition costs. In addition, as evidenced by write downs commonly seen after mergers or purchases of collateralized debt instruments in the recent economic collapse, and in all prior collapses, even the most sophisticated purchasers are readily duped by a variety of accounting "procedures" (Reinhart and Rogoff, 2009).

Carbon dioxide remediation is one example to be considered. There are three pathways to address the problem; one being carbon capture and storage (CCS), a second carbon capture and conversion (CCC), and a third, decreased carbon production. The last is critical if electric vehicles were actually to contribute to decreased CO_2 emission instead of transferring the load to stationary power plants, as is the current situation. Path one and two are designed to support the continued use of hydrocarbon fuels and hydrocarbon combustion systems, particularly in the production of electricity. Path two diminishes carbon dioxide release through recycling, but the reductive energy has to derive from some exogenous source and in view of the second law will cost more than was derived in the primary oxidation. Path three provides for alternative electricity production methods.

Each of these paths can be compared along economic and energy taxes using a fully costed, non-subsidized, non-externalized, worst-case model on a zero-basis, all expressed in terms of μ, system-based energy efficiency. If, for example, carbon capture and storage would impose a dollar cost of $20-25/MWh for a coal burning power plant and $14/MWh for a natural gas burner and a loss of 20-25% of current delivery capacity; this is equivalent to about $43-45/tonne of CO_2 for capture and an additional $5/tonne for transportation and initial storage. The last value assumes BAU transaction costs but given the contentious nature of the process transaction costs for saline aquifer storage will be far greater than for oil displacement storage and could add several more dollars to the cost. The coal-fired plant provides an additional cost transfer in terms of medical and ecosystem damage that is on the order of several hundred billion dollars annually. If that burden were avoided the dollars could be used to buy solar, wind or tidal energy, or lessened line loss, etc. The result would be to provide the same level of electric power for the same dollars but without the human and ecosystem damage. This approach focuses on achieving the beneficial end in the most expeditious manner while avoiding make-work options. It should be noted that the presence of a raw energy source and the ability to harvest it while necessary is not a sufficient argument to use it. Were it otherwise the country would be fully denuded of trees, as once was the case for eastern old growth forests.

The last path, permanent decrease in carbon production could be achieved by redirecting the carbon tax imposed on electricity produced by hydrocarbon combustion as an investment either for green energy research development and engineering or for green energy installation. Thus, much as the energy industry is funding portions of the smart grid and improved household appliance efficiency, it would underwrite the disappearance of coal and oil-fired power generation. This is not a life-threatening situation for corporate entities involved in energy reduction as they have been expanding into alternative energy for some time. Rather it forces a redistribution of their portfolio to mutual benefit. It will impact on their profits for some initial period but such is the cost of being a licensed oligopoly.

A further examination looks to the issue of where one is placed after implementing such a policy. For example, following a CCS regimen for a decade the situation is status quo. Thus, CCS represents the beginning of a recurrent cost cycle to no improved position. CCC on the other hand could reduce the amount of oil or natural gas used further along a production chain. However, it is critical that the energy form used to achieve this benefit is green, neutral of another hydrocarbon. Either of the first two paths present obvious advantages. This is especially the case for path two, if waste heat could be harnessed to facilitate the conversion of CO_2 to methanol or CO or another beneficial compound.

Thus the availability and price of fuel is nominally the limiting element in maintaining a given standard of living. But this is way too simple as price, like all fractions, hides more than it illuminates. Given a certain price ($/MW, for example) the real issue is the cost ($) that can be managed by decreasing cost per MW or decreasing the number of MW needed for the task. Our argument is that the best position is to hold the line on cost (or even to increase it thereby promoting innovation) while improving efficiency in order to decrease energy costs and to devote the differential to next generation energy production and a cleaner environment. In sum, efficiency allows an improved standard of living combined with a decrease in CO_2 emissions today and into the future by the use of carbon tax funds to develop new, non-polluting, low risk energy supplies. Maintaining the price, or even increasing it not only obtains efficiency but it also mitigates growth in consumption.

Summary

The purpose of this work is to introduce the idea of an integrated, systems-wide efficiency measurement for energy-related processes. We examine how this concept can be applied to energy systems and consider how this idea would impact energy policy.

As noted, the object of an energy system is to realize work – movement, heat, chemical reaction, information processing, etc. – that can be performed at any time or distance arbitrarily separate from the time/space locus of the primary energy source. Energy will be reported in Joules, work as Joules/sec. The energy transformation, transmission/distribution, storage and use steps are shown in Figure 1. In order to yield consistent energy accounting the energy value of subsidies is subtracted from the energy output;

similarly the cost of clean up to a zero-base is also subtracted so that no externalities are allowed. For example, if natural gas escapes during well drilling, the energy cost of remediation is subtracted from the overall energy output. Similarly, all of the work lost, medical impairment and attendant costs, are subtracted from the effective energy output from a coal burning power plant. This approach normalizes the energy efficiency of a given energy source over its lifetime.

Traditionally, pollution was seen as the cost for standard of living. Technology was assumed to remediate pollution if, as and when economically justified. We propose a third way that is removed from the pollution/standard of living trade-off. Our path involves integrated, system wide and inherent efficiency to provide more benefits with less pollution. Changes in counting and accounting reinforce this new path and promotes new innovations. The move to green energy avoids fully dealing with the problem of greenhouse gas remediation altogether by replacing current hydrocarbon-based power plants based on the inverse of their efficiency. That is, increasing standard of living for ever more people can be most effectively attained by three steps: 1) introduction of a fully transparent counting and accounting system, 2) rewarding companies on the basis of the engineering efficiency of their processes, and 3) deliberately transforming the energy supply from one based on hydrocarbon fuels to one based on solar, wind, and tide, geothermal and fusion - at the expense of all other fuel-stuffs. To repeat more succinctly – more transparency, more honesty, more efficiency, more collective good, more growth, a more broadly available improved standard of living.

Footnote

[1] See also http://carbonfootprintofnations.com/content/wealth_and_responsibility/

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