Some More Energy Fundamentals — I

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Back in October of 2002, I published **Some Energy Fundamentals** over in our **Blatant Opportunist** library. Shortly after publication, the paper was informally peer reviewed and generally lavishly praised by recognized industry insiders.

Some minor adjustments and corrections were made at that time. Ongoing updates continued largely in our **What's New** and earlier ongoing blog posts.

This established paper appears to continue to generate controversy. Primarily from individuals who will do anything to save the environment. **Except take a science course**. What I thought I would do in this **GuruGram** is expand upon, attempt to clarify, and update some of the earlier concepts...

When and Where Dimes Equal Kilowatt Hours

Thermodynamic fundamentals absolutely guarantee that **any economy will be ultimately driven by its energy inputs**. For obviously, no energy = no economy.

Thus, **every economic transaction has an energy cost associated with it**.

Sometimes these costs are fixed and obvious. Such as paying your power bill. Or that "**Unleaded $2.94**" sign down the street. Other times, the energy cost of a transaction may be obscure or loosely coupled. At first glance "**Avocados 89 cents each**" seems unrelated. But at least in California agriculture, avocados are largely manufactured from diesel fuel.

Yes, energy costs of a transaction may vary with time, subsidies, demand, tariffs, arbitrage, taxes, popularity, and a number of other factors. But long term, they simply **must** average out to a dollar and energy equivalence.

The situation dramatically simplifies when you enter into a buyback agreement with your power utility. **You contractually obligate yourself to equating, say, present dimes and present kilowatt hours**. Thus, the dimes and kilowatt hours become **fungible** and interchangeable commodities.

You can keep score equally well with one or the other.

So, should you have a home pv solar system that generates two cents a day in electricity but **amortizes** out at a fully burdened total system cost of three cents per day, **you clearly have a net energy sink**. The longer you run it, the more conventional energy you are consuming and thus destroying. Or glibly, the longer you run it, the more gasoline (and its equivalents) you are destroying.

But what about the incoming solar energy? It turns out there is a two position switch on your above solar panel. In position "**A**", you destroy a lot of gasoline. In position "**B**", you destroy even more. All the sun can do is **reduce your losses**.

Why Exergy is Important

I am bemused by the "ostrich" approach to exergy. It goes something like this: "**I have never heard of exergy; therefore, it simply does not exist and could not possibly apply to me.**"

Sorry, but exergy is very real. You can start with this **Wikipedia** definition. **Google** alone will give you nearly 100,000 hits. At least some of which are bibliographies with thousands or more entries.

One more time:

Exergy is a measure of the quality and thus the value of energy in its present form. It is basically entropy with an economic value focus. You have this three legged stool of energy, exergy, and entropy. **All three must be considered for any economic and competitive viability**.

Exergy answers the economic question: "How much is this stuff worth in its present form?" Or more specifically: "**What is the reversibly recoverable energy fraction of the original energy remaining?**"

An unstruck match has very high exergy; a slightly warmer room has very little. Electricity is just about the highest exergy stuff around. But unstored **hydrogen gas** is among the lowest. Gasoline typically has one third the exergy of electricity. Because it is difficult to build a gas generator exceeding 33 percent efficiency.

One effective way to measure exergy is to convert the energy to some different form and convert it back. Then see how much you have left. A classic example of wasted exergy is electric room heat. Go from the electricity to the room and back, and only the tiniest fraction of the original value remains. Because of the inherent **Carnot Inefficiency** of any low temperature heat engine.

Large drops in exergy are irreversible and irrecoverable. Economically, they are comparable to, say, stupidly **1:1 exchanging US Dollars for Mexican Pesos**.

Any time there is a major loss of exergy, there might be **competitive alternatives** that destroy less value. These can make more economic sense. For room heat, you can dramatically reduce your exergy losses by about three times with gas heat or five times with a heat pump.

In the case of **electrolysis** from high value sources (such as grid, wind, or pv) even smelting aluminum or refining copper can often end up a higher and better use of the electricity. As is pumped storage. Exergy is the key and crucial reason that **guarantees** that hydrogen from high source value electrolysis flat out ain't gonna happen.

Why True Net Energy is Important

Here's a recent third party newsgroup post that I feel is an excellent summary of the present status of net energy pv...

> **"There can only be one logical explanation for solar PV amounting to an insignificant portion of the energy supply."**
>
> **"It's not that there isn't enough sand for terawatts of solar PV. It's not that everyone just loves to burn hydrocarbons. It's not because government regulations prohibit building solar PV (in fact, quite the opposite is true — government subsidies abound.) It's not because solar PV is politically unpopular."**
>
> **"It IS because building and installing enough solar PV to make even a minor contribution to the energy supply is a foolish allocation of resources."**
>
> **"Plain and simple: If it was otherwise, solar PV would be a real contributor and it isn't."**
>
> **"No matter how you do the accounting to come up with 'net payback', the present 'net payback' of hydrocarbon generation plants must be better because solar PV is not over-taking hydrocarbon generation."**

A proof of the above statement is that **not one public utility anywhere ever is presently using solar pv for fully burdened avoided cost peaking** that is free of subsidies, R&D writeoffs, or greenie PR. Very simply...

> **To date, solar pv costs way too much.**
>
> **Causing it to remain a net energy sink.**

At present, gasoline is a true net energy source in that **it takes approximately one quart of old gasoline to deliver one gallon of new**. Conversely, it takes many conventionally generated kilowatt hours of energy to presently pay for a newly delivered solar pv kilowatt hour.

Subsidies, of course, do not help in the least. First, **most subsidy money is simply stolen**. Second, alternate energy subsidies have a long and rich history of being outrageous fiascos. Third, the true cost of a subsidy (including collection and admin costs) will at least **triple** its face value. Sort of an "iceberg effect"...

It makes no economic or environmental sense whatsoever for subsidies that pay people to put obsolete and known defective gasoline destroying net energy sinks on inappropriate rooftops.

A case can be made that **the present California pv subsidy fiasco might end up setting back net energy pv by over five decades**. Per **this analysis**.

Curiously, net energy sinking has to get a lot **worse** before it can ever hope to get better. The zillions of new investment dollars now being thrown at the emerging pv technologies that might someday provide energy breakeven represent a rather huge additional energy sink and drain on the economy.

Regardless of ultimate success, **net energy is the key.**

Why Amortization is Important

Many economic activities require a large upfront investment to provide a smaller but steadier return over a much longer period of time. In the case of an alternate (or conventional) energy system, old dollars are invested ahead of time so they produce daily average returns of kilowatt hours that equate to new dollars.

The process of spreading out an investment over a long time period is known as **amortization**. One very useful amortization calculator **appears here**.

If the daily energy income exceeds the amortized investment cost, you have a net energy source.

If the daily energy income is less than the amortized investment cost, you have a net energy sink.

Note that **paying cash up front does not change anything**. Because of an economic **excluded opportunity cost** that usually ends up largely equivalent to finance amortization.

Note also that having "paid off" an investment before it wears out is simply an **accelerated depreciation**.

Let's look at a curious amortization example...

A small scale pv system owner pays $2500 retail for a synchronous inverter and its installation on a system that averages 1500 peak watts.

What percentage of the value of the electricity generated is consumed by the cost of the inverter?

Assume that the utility buyback is ten cents per kilowatt hour. About 7.5 kilowatt hours per day will be generated from a 1500 peak watt panel, for a net energy income of 75 cents per day. Or $22.50 per month

Assume the financing is ten years at ten percent. The daily interest and principle payment on the inverter amortizes out to $33.04 per month.

Their inverter will then consume approximately 150 PERCENT of the value of ALL the electricity that is sent through it.

Thus, in this example, the owner clearly has created a net energy sink even if their pv panel costs are **zero**.

Fortunately, high volume production, standardization, and panel internalizing of inverter circuitry should eventually reduce the ultimate costs of synchronous inversion down into the nine dollar range. This is an easily solvable problem.

Some pv Solar Math

At noon on a clear summer day in Arizona, the incoming solar energy will often be around 1000 watts per square meter on a properly oriented surface…

At its very best, incoming solar energy will be about 1000 watts per square meter.

This incidence must first be derated for any angular mismatch. Optimum panel orientation depends on your latitude, the time of day, and the time of year. **Here** and **here** are two useful sources of panel orientation info. Many more can be found through the usual **Google** searches.

While a tracking panel can obviously gather in more energy than a stationary one, a tracking system will usually be more costly, more complex, less sturdy, require more attention, and will likely be more sensitive to wind or snow loading.

The difference between optimal tracking and fixed seasonal orientation is typically only **fifty percent** or so. Which can present severe limits to tracking economics and overall system desirability.

One useful source for tracking devices and info is **Zomeworks**.

This incidence must secondly be derated for such things as days of available sunshine, cloud cover, effective area versus total area, aging effects, surface grime, air pollution, shading, demand, downtime, and system lifetimes...

Solar energy is an extremely diffuse resource.

The total energy density and the real-world time availability of pv recoverable solar energy can easily end up disappointingly low.

As we saw in **Energy Fundamentals**, all recent photovoltaic devices are severely limited in their conversion efficiencies. Ten percent conversion at the output of the synchronous inverter terminals is exceptionally good present technology...

The best available pv system conversion efficiency at its synchronously converted grid output terminals is about ten percent.

With a thousand watts of incoming solar energy on a well oriented one meter panel, you will be lucky to get one hundred peak watts of useful electricity.

There are fundamental physical and thermodynamic limits that restrict increasing panel efficiency significantly on a cost effective basis...

A kilowatt of peak pv electrical power will demand at least ten square meters of active panel.

Typically, a solar facility will need a lot more space than the active panel areas. In this industry defining **Springerville** example, the actual land area ends up more than **four times** the effective panel area. Approximately **23** watts per square meter of land and an area conversion efficiency of just over **two percent**.

Obviously, a pv solar system will not work at night. The pv system downtime is inherently high. Perhaps 80 percent when normalized to noon output.

A useful rule of thumb is that you get five kilowatt hours of energy per good day per peak panel kilowatt...

A panel that might produce 1 kilowatt of power at noon is likely to produce only 5 kilowatt hours of energy during a full day.

Thus, solar peak power capacity has to be about **four or five times higher than conventional coal or nuclear** for equivalent long term energy sustained output.

A utility's **avoided cost peaking** charges can be taken as a maximum reasonable price to pay for any new alternative net energy system.

This forms a "parity point" at which pv solar can at least hope to begin to seriously displace conventional energy sources. What is the maximum installed and fully burdened system cost that can approach this "breakeven" value?

Assume that present peaking costs are one dime per kilowatt hour. Assume a one kilowatt peak power panel that in fact can produce five kilowatt hours of grid returnable and salable energy per day. The total production will be fifty cents per day. Or fifteen dollars per month.

Assume ten percent financing and a ten year amortization. **this site** tells us that an investment of $1135 will have a monthly payment of $15. Thus $1.14 appears to be the breakeven costs for pv solar to at least threaten to eventually become a viable alternate net energy source…

About ONE DOLLAR PER PEAK WATT can be the magic number for serious net energy pv production.

That is the TOTAL SYSTEM cost, including the synchronous inverter, all labor and shipping, amortization, and all related lifecyle expenses.

Panel costs would have to approach FIFTY CENTS per peak watt to support such a system.

Unfortunately, there is a key point that many pv solar proponents seem to avoid addressing entirely…

It makes no economic or environmental sense to sell a dime's worth of conventionally generated peaking energy and then use that dime to buy the same amount of solar pv generated energy.

All you have is some "paint it green" nuclear or oil or coal equivalent TRANSFER payments.

To DISPLACE traditional sources, solar pv simply has to provide NEW NET ENERGY.

Thus TWENTY FIVE CENTS per peak watt panel cost in today's dollars is a much more likely threshold for long term pv solar net energy viability.

While the argument can be made that conventional power costs are likely to sharply increase in the future, the costs of creating, delivering, and maintaining panels are likely to disproportionately increase as fast or faster.

Fortunately, we now have some…

New developments that MAY lead to net pv solar energy

Contrary to popular belief, most technologies do **not** keep improving forever. Eventually their fundamental limitations catch up with them and they hit the wall. And then they get blown out of the saddle by newer and better replacements.

Conventional silicon pv is an absolutely terrible way to produce electricity. The material is intractable to work with, it has lousy optical properties, has no hope of large area processing, requires thick sections for conversion, is costly to process, is extremely fragile, has high waste, demands excessive energy, and has recently become scarce and expensive.

The only tiny thing going for it is that **it was by far the best we had**.

As we saw in **Energy Fundamentals**, not one net watthour of conventional silicon pv energy has ever been produced. And I strongly feel it is unlikely that it **ever** will. It seems to me that **today's old technology panels are largely a sucker bet**.

Fortunately, we have some new brand new genuine breakthrough technologies that appear to have the capability to approach a quarter per peak watt. And can ultimately deliver net new energy. The three close in biggies are…

> **CIGS Sheets**— This new acronym stands for **Copper - Indium - Gallium - Diselenide**. A new photovoltaic material that can easily be processed by the roll in mile long flexible sheets using economic and low energy inkjet and similar technologies common to the printing trades. Less than one percent of the comparable silicon thickness is needed for conversion. While efficiencies and reliability appear comparable. Although still on a steep learning curve, the materials are now shipping in near production quantities. **Nanosolar** is one leading proponent.

> **Quantum Dots**— In a normal large size pv cell, any energy below the workfunction threshold is lost as waste heat. Energy at the workfunction threshold knocks loose an electron. Any "spare change" energy above the workfunction threshold is also lost as waste heat. But by going to new nanoscale quantum dots, the above workfunction energy can instead be used to knock loose one or more additional electrons. Thus dramatically improving pv efficiency for shorter light wavelengths and uv. An early development was covered **here**.
>
> **Tetrapods**— A tetrapod is a unique nanoscale four legged structure. Over a reasonable range, it allows its work function to be tuned more or less independently from its semiconductor makeup. Which can move a maximum efficiency point into the visible spectrum from silicon's fixed infrared. Or allow several different tetrapods to be tuned to several different optimums for improved efficiency. A recent major development **appears here**.

What is unique about these three new approaches is that **they are not in any manner exclusive**. Synergy can be used in second generation devices to mix and match their best traits.

The companies involved in active pursuit of these new technologies newly include **NanoSolar**, **First Solar**, **Global Solar**, **Daystar**, **HelioVolt**, **Miasole**, **Solyndra**, and **International Solar Electric Technology**.

We also have these three dark horse candidates not quite as far along that may prove of extreme value...

> **Metalloradicals**— Plants have long been good at using sunlight to knock electrons loose through photosynthesis. The basic underlying method was discovered only a decade back and was found to center on **metalloradicals**. Per this **original paper**. There are four or five closely interlinked processes that involve a special form of a manganese cluster and an organic radical. Variations on the process could produce liquid fuels, electricity, and carbon capture. One example of current research appears **here**. Future developments appear extremely promising.
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> **Nanoantennas**— Building "solar crystal sets" that directly pick up light with antenna structures and then rectifying the energy could in theory bypass and dramatically exceed present pv efficiency limits. One pioneer in this field was Alvin Marks. Some **Recent Research** seems to have now solved the antenna and energy gathering half of the problem by using ultra miniature antennas formed from low cost common conductors. Unfortunately, the rectification problem remains. But might possibly be addressed with metalloradicals or dye molecules.

Improved Thermoelectrics— Any heat or light to electricity converter is inherently limited to a **Carnot Efficiency**. Which is not all that bad when very high temperature differentials are involved. Unfortunately, most older thermoelectric converters do not even remotely approach decent efficiency. And remain fairly useless except for a few arcane apps. A brand new solid state device approximates a nearly ideal **Ericsson Cycle** and shows some promise. Some recent info is found **here**.

Why Economy of Scale is Still Important

Very few individuals will go out and build their own nuclear power plant. Or a combined coal mine and thermal generator. The obvious reason being that traditional power plants are ridiculously more cost effective when built in very large sizes. Which has created the **myth** that pv solar has no economies of scale. And that home built individual stand-alone systems should reign supreme.

In reality, **economics of scale remain very real and very compelling**. The power utilities today are the primary market for new net energy pv panels. They have incredible buying power combined with being able to guarantee production quotas for new ventures. More importantly, they have the ability to **standardize** a product that can be drop-in **leased** to the end user.

Without any installation or finance or maintenance or compliance hassles.

Obviously, smaller stuff sold retail to individuals in small quantities will end up inherently more costly than larger stuff sold wholesale to large corporations. Enough to tilt lease versus buy in favor of most end users leasing.

A present proof that economies of scale still matter is that **virtually all of the new current CIGS production is going to major power utilities**. And will continue to do so at least for the next few years.

An interesting point not often discussed…

A pv energy farm requires very little water.

Which makes larger ones a perfect match for Government and Indian lands in the arid and largely cloud free American West.

Why the Grid Will Remain Supreme

Yet another solar pv myth is that everybody will soon be able to go offgrid with their own stand alone independent systems. In reality, **the existing power grid is the essential core to new net energy pv solar**.

First because…

No known means of pv solar electricity storage is remotely as cheap, as simple, as effective, as efficient, as low in equipment demands, as safe, or as reliable as synchronous inversion to the public power utility grid.

And secondly because…

The peak afternoon pv solar generation is often a good match to the peak power demands of the public power utility grid.

While replacing by far the most expensive of conventional peaking power resources.

Another obvious benefit of the grid is its ability to **average out** local or regional shading on a partially cloudy day.

Yes, an argument can be made that the power grid cannot really store anything. Instead, you have **interchangeable and fungible commodities**. If you put some nickels in a piggy bank, it usually does not matter if you remove a **different** set of nickels later on.

One way to look at power grid "storage" is as a super efficient **electricity to coal converter**. When pv solar is synchronously returned to the grid, the pile of coal sitting outside the baseline power plant does not diminish nearly as fast.

The role of power utilities may change somewhat as net energy pv solar becomes significant. Utilities are more likely to focus on **brokering** of power and **leasing** of panels and such rather than on primary energy production.

So long as pv solar remains a smaller fraction of the total generated electrical output, the grid will remain an outstanding means of converting solar to 24/7 availability. Offgrid uses of pv solar electricity are now and likely will always remain an uneconomic and tiny fraction of the total.

For More Help

The original **Energy Fundamentals** paper appears **here**. Related materials can be found in our **GuruGram** and **Blatant Opportunist** library pages. As well as in our **What's New** and earlier series of blogs.

My personal research into alternative energy solutions lies in the realm of **Magic Sinewaves**. These are some newly discovered mathematical sequences that can promise to significantly improve both the efficiency and quality of most power conversion electronics. An intro tutorial appears **here**, a development proposal **here**, and an executive summary **here**.

Consulting services seminars, and development services on these and related topics are available. You can email **don@tinaja.com**. Or call **(928) 428-4073**.