Sustainable Energy – My Exploration

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Outline

How I got interested in Sustainable Energy:

Great expectations meet cold reality

Including the hollowness of some apparently great ideas, such as:

"Going off the Grid!" OR "Buying an earth-friendly electric car!"

Leading me to another **inconvenient truth**: It's all about sustainable energy **SYSTEMS**

Which almost no one had studied (including me) but which, when studied, offer hope

A conclusion that led me to create this class / website

Looking ahead:

Why you really should follow my basic science + "back-of-the-envelope" calculations

Then a quick but important lesson about Energy vs. Power:

Their simple but important distinction – that we muck up by using crazy units

(Written / Revised: July 2019)

*I am **not** a specialist in energy*

But I am an applied scientist, with deep roots in the field of "optoelectronics"

That field focuses on the conversion between light and electrons – More accurately:

The use of light energy to liberate electrons **from** their bonds

Or the emission of light when electrons fall back **into** their bonds

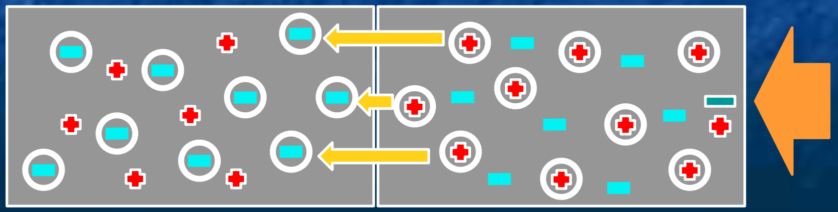
At Bell Labs, we used this to build digital fiber-optic telecommunication systems

Which required extremely fast, but not necessarily efficient, conversion

But another optoelectronic device targets conversion efficiency, and not speed:

The photovoltaic cell (a.k.a. "solar cell") – also pioneered by Bell Labs

(From their pictorial explanation
in my first solar energy note set):



*So while I am **not** a specialist in energy*

Optoelectronic devices **ARE** based on the same physics and the same materials

Which meant that I've traveled in pretty much the same scientific circles

And I've thus met a lot of people working on solar energy

Including friends who went on to found two U.S. solar energy companies

Those colleagues extolled the virtues of, and progress in, solar energy development

Pronouncing, for instance, that:

"When cost drops below $X.YZ per watt

the use of solar energy is going to explode!"

Then cost dropped to that level, but solar energy did NOT explode

Which was not only professionally disappointing – it got personal!

Because I'd become a father, and then a grandfather

And I worry a **LOT** about the future my little granddaughters will face

That compelled me to figure out WHY my friends' dreams were falling short

Leading me, over the better part of decade, to pour over almost every

energy news article, paper and book that I came across

Which yielded an epiphany when I read David J.C. Mackay's extraordinary book:

Sustainable Energy: Without the Hot Air [1]

Because MacKay, based on his own crusade for understanding, taught me that:

It's all about building viable energy SYSTEMS!

1) Which is available as a very reasonably priced paperback, or via free fully authorized downloadable chapters at:

https://www.withouthotair.com/

Or to put it another way:

Energy things, even fantastic energy things,

will not just click together to give us the clean sustainable energy we need

That will happen only if these "things" work well together

Supporting each other's strengths and weaknesses

And doing so at an acceptable cost (both monetary and ecological)

But what made MacKay's book so convincing was that:

He didn't argue this point - he demonstrated it (time and time again):

Via back-of-the-envelope calculations

drawing upon little more than high school science

I've long embraced the same learning & teaching technique

So let me now provide a preview of this class / website

via a couple of my own (quick & illustrated) calculations:

For such calculations we don't need superb accuracy:

Accuracy is required when you get around to BUILDING something

But my focus is on deciding if we should even TRY building it!

For that decision you don't need superb accuracy

But you **do** need to have important "ball park numbers" at your finger tips

Things like:

Average U.S. household consumes 901 kW-hours of energy / month

Maximum solar power to the earth's surface is ~ 1 kW / m^2

And, if you're talking about cars, 1 horsepower is ~ ¾ kW

And, it turns out that such numbers are a lot easier to keep in your head

if you sacrifice a little accuracy by using simpler, rounded, numbers

*Onward: A **personal** energy fix is really appealing*

Especially when contemplation of whole energy systems is overwhelming and/or

we're completely bummed by the collapse of U.S. political leadership

Bloggers thus extol simple solutions, such as just "Going Off the Grid!"

Which, most commonly, calls for covering your rooftop with solar cells

Let's examine this possibility (sampling some upcoming class / website material):

The average U.S. household uses 901 kilowatt-hours of **energy** per month [1]

So for a thirty day month that works out to an average **power** consumption of:

$$\textbf{Power}_{\textbf{household average}} = \textbf{(901 kW-hrs) / (30 x 24 hrs) = 1-¼ kilowatts}$$

1) U.S. Energy Information Administration FAQs: https://www.eia.gov/tools/faqs/faq.php?id=97&t=3

So then, how many solar cells will our home require?

At noon, in the summer, with clear skies, solar power to the earth's surface is:

$\text{Power}_{\text{peak solar}}$ ~ 1 kilowatts per square meter of surface area

The best solar cells convert sunlight at about **20% efficiency** and thus:

$\text{Power}_{\text{peak solar electricity}}$ ~ 200 watts per square meter of solar cells

To get our required 1-¼ kW per household, we'd the need ~ **6 m^2 of solar cells**

Something like this, which appears both do-able and likely affordable:

Figure: http://www.theepochtimes.com/n3/2054773-utilities-partner-with-solar-companies-to-bring-energy-to-the-grid/

But inside that house, at night, it would look like this:

Now this photo **actually** depicts nighttime inside a Victorian era farm house

But you'd have no more nighttime power inside a purely-solar-powered home

Photo: http://www.dailymail.co.uk/femail/article-1241772/Im-frozen-time-What-like-live-TVs-Victorian-Farm-electricity-running-water-outside-loo-5c.html

UNLESS you store a lot of that daytime solar energy!

Which is going to require a lot of **expensive / bulky storage batteries**

AND **a lot more solar cells**

because our daily **average** U.S. household power is 1-1/4 kW

So when the sun **IS** shining, we need to collect a lot **more** than 1-1/4 kW

Let's first run through the facts in words, then calculate based on a simple figure:

- On average the sun is up 50% of the time = 12 hours / day

- Once it rises, solar intensity increases until noon, then falls toward sunset

- Maximum solar energy intensity = 1 kW / m^2

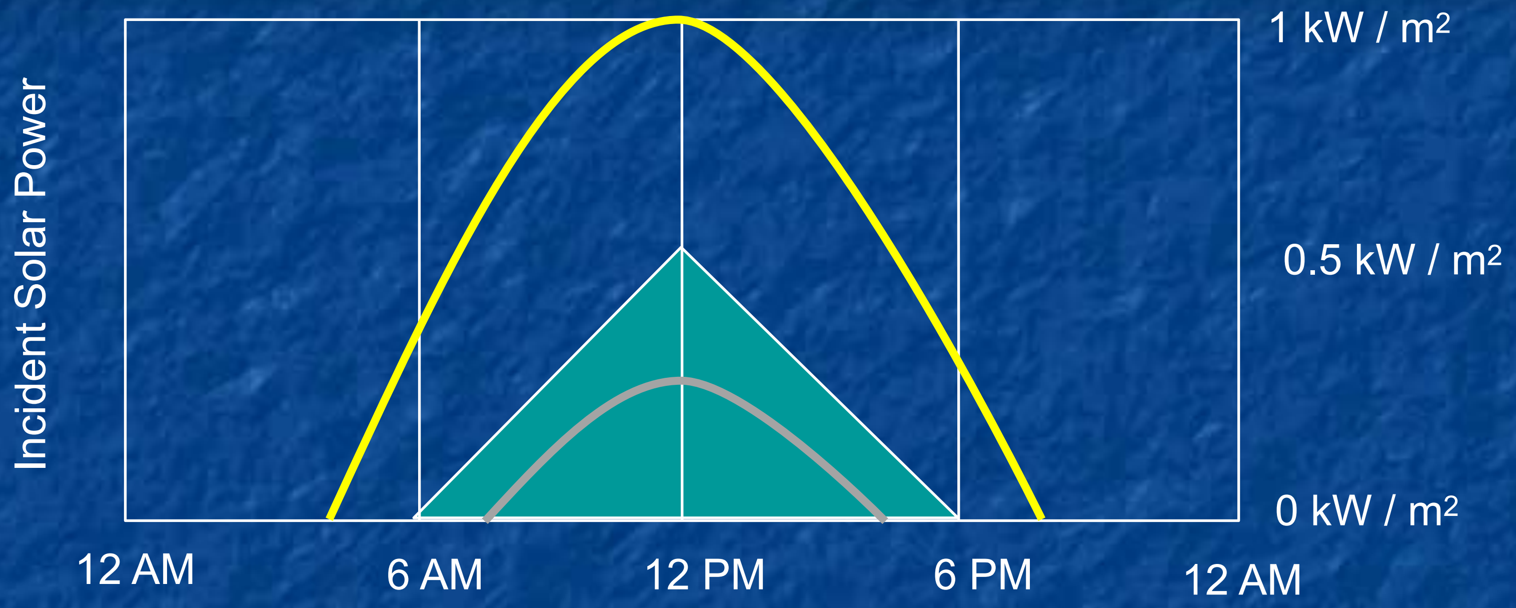
But that occurs ONLY AT NOON, IF THE SUN IS DIRECTLY OVERHEAD

Which only happens in summer, in some parts of the world

- And intensity plummets with heavy air pollution and/or clouds

Putting all of that into a figure depicting our average day:

Yellow = Clear summer day **Gray** = Non-summer and/or cloudy day



Green = An eyeball approximation of **average** day's solar power

Area of triangle = power x time = average solar **ENERGY** per day per square meter

= (1/2) (base) (height) = (1/2)(12 hours)(0.5 kW/m^2) = **3 kW-hours/m^2**

(**1/8 th** of what we might have carelessly calculated from 1 kW/m^2 x 1 day!)

With that now averaged solar energy:

With quality solar cells converting sun power to electrical power at ~20% efficiency

We'd generate ~ (0.2)(3 kW-hr/m^2) ~ **0.6 kW-hours/m^2** of energy per day

But a U.S. household's time averaged power consumption of power is 1-¼ kW, thus

We'd consume ~ (24 hours)(1.25 kW) = **30 kW-hrs** of energy per day

So that typical household, **now also packed with batteries**, would need:

~ (30 kW-hrs) / (0.6 kW-hrs/m^2) = **50 square meters of solar cells**

Which would look more like this:

(A lot less do-able & affordable!)

Photo: http://www.benarasolar.com/our-product-range/rooftops/

But if there was a LONG stretch of bad daytime weather:

And doesn't every year include a couple weeks of dark unbroken clouds?

Then evenings would soon once again look like this:

UNLESS we **ALSO** maintained a backup electrical connection to the good old **GRID**

And there goes the first of our personal energy fixes right out the window!

*With the GRID **back** in the picture, a more plausible alternative is:*

Share large solar farms - because they are now about twice as cost-effective

Locate them all over the country - to take maximum advantage of

regions with more intense sun and better weather (such as our Southwest)

Requiring efficient long-distance transmission of electrical power

Which, we'll learn, is actually not possible with today's power line technology

So you begin to see why MacKay claimed it was all about ENERGY SYSTEMS

Which quickly become extremely complex (and in need of innovation)

So let's consider another alternative which alone might not solve the problem,

but would surely represent a big personal contribution **towards** a solution:

Buy an earth-friendly electric car!

Maybe even one of these, from Elon Musk:

But where would **it** get power?

Well, why not cover **it** with solar cells?

Calculating: ~ (3 m^2) (1 kW /m^2) (20% power conversion efficiency)

=> 600 watts (peak) ~ **0.8 horsepower**, at noon, on a sunny summer day

=> 0 watts (or horsepower) before dawn / after sunset

OK, but loaded with batteries, it could charge in a sunny parking while I'm at work!

Calculating: ~ 300 watts (average) over 8 hours => 2.4 kW-hrs ~ 3.2 hsp-hrs

Which you could then USE during your 1 hour commutes morning and evening

Which would give you an average of 3.2 hsp-hrs / 2 hrs = **1.6 Horsepower!**

Pssst! I've got a lawn mower with twice that horsepower:

So (again) you'd better rely on the GRID to charge those batteries!

But that Grid could **also** be earth-friendly if it were based on something like this

Which would thereby maintain the earth-friendliness of your electric car!

Except that, at present, only ~ 7% of U.S. power is supplied by wind

and less than 2% by solar [1]

*1) A state-by-state breakdown of power plant types is given in my lecture on **Carbon Fuels***

Background photo: https://cleantechnica.com/2014/01/24/forget-intermittency-nrel-says-wind-energy-can-boost-grid-reliability/

Whereas ~ 27% is now supplied by coal, and another 35% by gas [1]

For **coal-based power** a better illustration of you and your Tesla would be:

Background photo bought from: ungnoilookjeab/123RF.com

NOT so earth friendly!

NOTE: Natural-gas power plants CAN have a carbon footprint up to 50% smaller

But **only** if they use technology explained in my note set on **Fossil Fuels** (pptx / pdf / key)

[1] (For an overview of U.S. energy, see my note set **U.S. Energy Production and Consumption** (pptx / pdf / key)

Conclusion? Single energy technologies just cannot stand alone!

Our rooftop solar cells needed batteries to power our homes at night

And to overcome spells of bad weather, we still need our Grid connection

Which works better if it can draw upon solar energy from far away . . .

And lawn mowers provide better transportation than a Grid-deprived electric car

But that electric car is no longer earth-friendly when plugged into the U.S. Grid

So we must push for big improvements in the way that Grid is powered

(Countering our "leadership's" efforts to make the Grid a lot worse!)

THESE are some of the (many!) reasons that David MacKay (and I) conclude that:

Plausible solutions require the re-invention of WHOLE ENERGY SYSTEMS

Which is why **this class/website** is all about such whole energy systems

*But energy **systems** are incredibly complex PUZZLES*

In which one energy technology is just a single piece

And those pieces are often really, really frustrating

Because their shapes are often poorly defined, or even still changing!

And assembling them into an acceptable **system** requires **more** than technology

In fact, that puzzle's assembly generally requires / involves:

Science + economics + politics + journalism + sociology + pop culture . . .

Image adapted from: http://determinedtosee.com/?p=1032

"But I'm not sure that I can handle all of that!"

"Because I don't really have enough time"

OR

"I don't really have **that** broad an interest"

OR

"I don't really have a strong enough science or technology background"

In response, let me quote the farewell card sent to me by a former student:

"This is your world.

Shape it or someone else will."

That quotation was attributed to Gary Lew

So bear with me / stay with me

David MacKay wrote a superb book (downloadable, for free, from his website):

Sustainable Energy without the Hot Air [1]

And I have long specialized at introducing students to technological fields

With significant success (see this website's **about** webpage: link)

BOTH David's book and I also target students (and citizens) of ALL backgrounds

BOTH of us teach via sensible, comprehensible, word explanations,

calling upon illustrations, based upon science you DID study in high school

(which we both take the time to remind you about)

If you do bear with me / stay with me, you will be empowering yourself

by eliminating dependence on "experts" in favor of your own answers

1) Downloadable at: https://www.withouthotair.com/

You are probably still skeptical

I know that many of my in-classroom students certainly still were at this point

But David and I **will** work to convince you

In the meantime let me close by clearing up a possible earlier point of confusion:

Power vs. Energy

Are they the same? NO! Are they closely related? YES!

POWER = How FAST we produce or use ENERGY

Which means that Energy = The sum (over time) of power produced / used

Although that sum must become an "integral" if the power is varying

The MKS metric unit of ENERGY is a Joule

The MKS metric unit of POWER is a Watt = 1 Joule / second

I **do** use the metric system because:

It is what is used **everywhere else** in the world

Where much/most of even "our" technology is now manufactured

And metric **is** simpler than the "Imperial System" now abandoned by even the British

But, for some crazy reason, energy people muck it up!

Because they seem to despise the metric energy unit of Joules

And to avoid (virtually EVER) using Joules, they invert things:

1 Watt = 1 Joule / second => 1 Joule = 1 Watt-second

But 1 Watt-second turns out to be a very small amount of energy

And one second is not all that much time

So energy people instead prefer expressing ENERGY in units of a:

kilowatt-hour = (1000 Watts)(3600 seconds) = 3.6 million Joules

Though (to enhance the confusion?) they then often switch from:

kilowatts to megawatts (10^6) or gigawatts (10^9) or even terawatts (10^{12})

and from hours to months or even to years

And ancient/largely-abandoned units still try to sneak in:

Examples of which include:

A **British Thermal Unit** (~ energy of completely burning down one match): [1]

= a bit more than ¼ watt-hour ~ 1055 Joules

A **Ton** (used in air conditioning = cooling energy of 1 ton of melting ice): [2]

= 12,000 British Thermal Units = 3.5 kilowatt-hours = 12.6 million Joules

A **Horsepower** (self-explanatory):

= a hair less than ¾ kilowatt

Nevertheless - To **finally** wrap this presentation up:

1) https://www.eia.gov/energyexplained/index.cfm?page=about_btu
2) http://www.energyvanguard.com/blog/55629/Why-Is-Air-Conditioner-Capacity-Measured-in-Tons

Important takeaway from this mini Energy vs. Power lesson:

If an article claims (as they frequently do!!) that a new technology or power plant:

Produces XYZ kilowatts of energy!

The author doesn't know what he/she is talking about and his/her

article (website / press release / politician's speech) should probably be ignored

And while it is technically correct to state that the technology or power plant:

Produces XYZ kilowatt-hours of energy!

That claim is useless if you aren't told over what interval that energy is produced

That is, give me a tiny hand-cranked generator, and a whole lot of time,

and I too could create XYZ kilowatt-hours of energy (if I live long enough!)

= Why the distinction between Energy and Power IS ultimately very important

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This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.