The Renewable Electron Economy Part IX: What is Renewable Energy Anyway?

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I've been posting on the Electron Economy/Renewable Electron Economy for the past 9 months but have been relying on the Justice Potter Stewart definition ("knowing it when I see it") of renewable energy. Most people tend to define renewable energy by listing certain natural resources: "Oh, its wind, solar, geothermal, wave, tides, etc." Some hopefully more illuminating definitions do exist: a Google Web search reveals the following range:

* "a naturally occurring raw material or form of energy that will be replenished through natural ecological cycles or sound management practices"

* "an energy resource that is replaced rapidly by natural processes"

* "a natural resource that can replenish itself over time"

I think it is possible to come up with a more rigorous, more specific definition that gets closer to the reality of renewable energy, even though there will always be an element of complexity and imprecision in the definition.

Interactive Definitions of Energy

Renewable energy is one of a group of terms that you might call interactive definitions of energy: energy as it matters to people, not the energy concepts that are usually taught in basic physics and chemistry classes.

Pure physicists have no use, for instance, for the concept of "primary energy", which is useful in power engineering and energy economics. "Primary energy" means the type and amount of energy or fuel that needs to be input to produce a certain finished "secondary" energy product. Coal, natural gas, or uranium can function as the primary energy to produce electricity and crude oil or tar sands can function as the primary energy for finished petroleum fuels. Renewable fuels can function as primary energy too: incoming sun, wind or water falling can be seen as the primary energy for electricity or bio-energy. The efficiency of an energy conversion process is measured by how much of the incoming energy is converted to the useful output form of energy (secondary, tertiary, quaternary).

The "primary"-ness of primary energy has only to do with the fact that this is the form in which humans first find the energy resource. It is an interactive definition of energy; in pure physics the only primary energy is that of the Big Bang 13 billion years ago. In the practical world, humans are interested in energy as a resource not as simply an object of scientific study.

The assessment whether something can function as primary energy, an energy resource and furthermore what type of resource it is, renewable or non-renewable, is an interaction between the human variables and the natural or given variables. People need to have discovered or invented a

technology to convert primary energy into a usable secondary form and the energy needs to in some way improve upon human beings natural capabilities.

To make a clear definition of naturally occurring energy types, it helps to differentiate a few concepts in interactive energy, the energy that matters for human use.

Energy Flux, Energy Stores and Energy Events

To arrive at a more precise definition of renewables, I've worked out three broad categories that differentiate energy in relationship to human use and timescale: energy flux, energy stores, and energy events.

* Energy flux is good scientific concept that describes the flow of energy or matter in any number of different ways. Flux is the Latin word for flow but flux has the advantage of not have the concrete image of a flowing liquid or river associated with it. Fluxes can come and go. Gravitational and electromagnetic fields can be described as having a flux. Material in a liquid or gas can be described as having a flux or flow rate. Best of all, the strength of energy flux can be measured in watts per square meter: energy flow through a cross-section of space. Energy flux is not necessarily constant but can vary over time. Energy flux can be naturally occurring or manmade (light from a bulb, for instance).

* Energy stores are what they sound like, a place or substance where energy is stored. An energy store is only an energy store (for human use) if humans have a technology to convert the store into useful energy: uranium 235 is only an energy store if people have a nuclear reactor and uranium 238 would only be an energy store if there is a fast neutron reactor and a fuel reprocessing cycle. The total mass-energy of a substance, i.e. the "E" in E=mc^2, is a huge number but is not an energy store as we humans do not yet have the technology to completely annihilate matter into energy. All energy stores are potential energy but not all potential energy can function as an energy store (think of rocks on the tops of mountains, for instance). Energy stores allow people to time the energy conversion to approximately when or exactly when the energy use is required; they are also exhaustible. Energy stores can be natural or artificial, the latter being "energy storage". Energy stores can be measured in units of energy like joules, BTUs, kWh, barrels of oil equivalent etc.

* Energy events are irregular but not necessarily uncommon events with a strong energetic dimension like lightning, hurricanes, tornadoes, earthquakes, volcanic eruptions even meteor impacts. People cannot count on energy events happening though some are more common than others; they are however very important for the history of the earth and life. Energy events tend to have a disruptive effect upon human plans and occupy a disproportionate place in our imaginations and mythology. Energy events are not as important in defining useful energy types as they are, as yet, not useable by human beings. Energy events can theoretically be measured in units of energy (joules, etc.) and also as a function of units of power (watts, etc.) over time.

While these concepts might seem abstract I'll demonstrate below how they can be used to define renewable and non-renewable energy.

Characterizing Energy

Non-renewable Energy

* Fossil Fuel – All fossil fuels are energy stores given our current technology. We have the

technology to tap into the energy of most fossil fuels and can time the release of their energy according to our timetable.

* Fissionable Fuels – Uranium and plutonium can both function as energy stores with current technology. We have the technology to time the release of their energy, though they are not as responsive to control as fossil fuels

As non-renewable energy is exhaustible, it makes sense that it functions as an energy store.

Renewable Energy

* Solar - Solar energy is natural energy flux from the sun in the form of electromagnetic radiation measurable in watts per square meter. On earth's surface it is periodic, variable but consistently available within the course of days, weeks and months. The energy is not exhausted by use.

* Wind – Wind energy is also a recurrent natural energy flux, measurable in w/m2 and variable over time. Wind energy is derived from solar energy flux that replenishes wind energy. Theoretically one can capture 100% of the energy of wind in a given place but it will return with sufficient atmospheric heating.

* Hydropower – hydropower is a recurrent natural energy flux, potentially measurable in w/m^2 that is often paired with an artificial energy store. It is dependent upon two opposing natural energy fluxes, solar radiation (water evaporation) and earth's gravitational field. In the era of fossil fuels, hydropower has been easily integrated into our energy system because it so readily lends itself to artificial storage (dams).

* Biomass – biomass functions a natural energy store that is replenished by renewable energy flux (solar energy) but limited by availability of water and the fertility of the local soil. People and other living things compete for the energy contained in biomass so its usable energy content can deteriorate quickly depending on local conditions. Biogas and biofuels, both derivative of biomass can also function as energy stores. The energy content of biomass can be measured in joules, BTUs, etc.

* Wave – Wave energy is recurrent natural energy flux derivative of wind energy occuring on the surface of bodies of water. Though measureable in watts/m^2, it is better measured by watts/m wavefront, as most energy is contained at or near the surface.

* Tidal – Tidal energy is recurrent periodic natural energy flux derivative of the interaction of the gravitational field (also energy flux) of the moon and the earth. With a tidal barrage, tidal energy can be stored. It can be measured in watts/m^2

While the above are fairly easy to characterize the two below are a little more controversial and complicated:

* Geothermal – Geothermal is a complex phenomenon derivative of radioactive decay of elements in earth's core, mantle and crust that heat rock and water in the crust. A geothermal well taps into a combination of geothermal heat flux from the mantle and crust and stored heat in the rock that is slowly replenished by heat flux through the rock. There is controversy about whether geothermal is renewable because the rate of heat extraction by people sometimes exceeds the rate that it is replenished by heat from the surrounding rock and the mantle below. Geothermal is both an energy store and energy flux.

Geothermal energy is expressed both as a rock temperature (which could be converted into joules) and as a heat flow in watts/m^2. Geothermal energy flux can also diminish or stop in a given location as conditions change in earth's mantle.

* Ocean Thermal Energy Conversion (OTEC) – OTEC has not yet been commercialized but uses the difference in temperature in tropical ocean waters between the surface water and deep water to run a heat engine. OTEC could be considered "cold mining" of the deep waters and the question remains whether warmer water will cool and sink fast enough to replenish water extracted from the depths: whether the downward flux replenished the stored cold of the deep water. There may be serious climate consequences if deep water gets too warm because of this type of cold extraction. In the current terminology, OTEC taps into an energy store that may or may not be replenished by natural energy flux within a human usable time scale.

Defining Renewable and Non-Renewable Energy

Using these categories, one can define non-renewable energy more easily than renewable energy.

"Non-renewable energy sources are energy stores with zero or a minute rate of replenishment relative to its depletion by human beings. Most non-renewable energy sources are converted to usable energy by thermal or nuclear reactions. Non-renewable energy sources have stored the natural energy flux of Earth's biological and geological past or of the formation of elements in the early history of the Universe"

Renewable energy on the other hand, appears both as natural energy flux and as an energy store. It is interesting to note that the types of renewable energy that, in the course of the 20th century were most well integrated into the customary energy mix (hydroelectric, geothermal, and biomass) are both either energy stores or have traditionally been integrated with an energy store.

Here is a hopefully more rigorous if somewhat long definition of renewable energy that only resorts to using a list in the second sentence:

"Renewable energy sources are types of natural energy flux useful for human ends regularly occurring on or near Earth's surface and, additionally, useful natural energy stores that are replenished by natural flux within the timeframe of conceivable human use. All known renewable energy sources originate in, or are close derivatives of, electromagnetic radiation of our Sun, the Earth's and Moon's gravitational fields and heat radiating from earth's interior. Renewable energy sources are practically inexhaustible though some sources such as geothermal and ocean thermal energy conversion may become locally depleted by human use at a rate that exceeds replenishment by natural flux."

I believe the first sentence is sufficient but the next sentences add a little more detail.

A Paradigm Shift in Power Engineering

Have we learned anything by drawing the distinction between energy flux and energy stores? One pattern that becomes very clear is that conventional energy system is heavily dependent and focused upon energy stores. The ability to time the release of energy from coal, natural gas, uranium, petroleum, dammed rivers or biomass has been a key support for how we manage our energy system and the electric power grid. We can call this the conventional energy paradigm, where energy is defined as a stockpile of fuel in tandem with the appropriate energy conversion devices.

If we are going to build a renewable electron economy, there needs instead to be a focus on how to capture and monitor the strongest or most readily available renewable energy flux and also how to supplement this with non-polluting energy stores where possible. The management of an electric grid with renewable energy flux means investment and innovation in three areas: energy capture devices, storage devices, and more sophisticated natural flux monitoring. The latter has been used already for demand forecasting (weather effects power and energy demand) but now it will also forecast supply, doubling or tripling its importance in the equation. This means more collaboration than ever between meteorology, geology and power engineering. It also means a paradigm shift in how the managers and planners of the electric system and grid discuss energy: changing from the relatively static world of naturally occurring energy stores to deal with the dynamic world of energy flux will take time, effort, and innovation.