# Beyond a Usage Threshold, NO Form of Energy is Sustainable or Green
## *We are Running Out of "Garbage Dump Space" To Dissipate "Used" Energy Into*

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Abstract: To date, almost all of the research on green/sustainable energy has been concerned with procurement of ever increasing amounts of energy for human consumption. This singular focus only on the supply-side of the problem completely overlooks what happens to the energy after we use it; thereby implicitly making the dangerously wrong assumption that the earth has unlimited capacity to dissipate energy.
In this position paper, we remind the reader that the earth can dissipate only a finite amount of even the greenest of the green forms of energy, while still maintaining thermal equilibria that have evolved over eons. Any long term sustainable energy solution therefore must include a curbing/limiting/controlling our ***demand*** for (and consequently, our ***consumption*** of) energy. Otherwise, even if and even after all the green-house-effects are fully eliminated, the earth still might eventually experience unnaturally large temperature increase because the amount of energy dissipated is too large.

# 1 INTRODUCTION

## 1.1 Background

It is not surprizing that the "supply" of sustainable energy has been investigated in great depth by a large number of researchers, for instance, see (Mackay, 2009) for an excellent exposition on all issues related to the potential sources (i.e., supply) of sustainable energy. This is natural since finding a sustainable supply of energy is essential for long term prosperity (and potentially even the survival) of humanity.

However, this singular focus on the supply-side alone is not sufficient. An equally careful analysis of whether the consumption of ever increasing amount of energy is sustainable; is just as critical for long term survival and prosperity of humanity. In this paper, we point out that the earth has a finite capacity do dissipate energy. The implication is straightforward: even if an unlimited supply of a totally green form of energy were to magically become available, we are not free to use it without restrictions on the surface of planet Earth[2]

[2]Steadily increasing number of scientists are concurring that "Earth" seems to be a misnomer, our planet should be called planet "Ocean", because the existence of water in liquid state is what sets us apart from a gazillion other planets.

### 1.1.1 What is "Green" Energy? what is "Sustainable" Energy?

In the literature the identifiers "green" and "sustainable" are often used together. To add to the confusion, they are also used inter-changeably. For the sake of clarity, we define them separately.
(1) ***Green*** Energy is a form of energy whose generation and consumption does not cause harmful chemical or physical pollution of the environment; or does not lead to large-scale chemical or physical changes in the environment.
(2) ***Sustainable*** Energy is a form of energy whose supply can last for a very long time (or in other words, the supply can be sustained for a very long time). A good example is that of the hydrogen available to us as a constituent of the ocean-water. It can yield energy for a very long time if "cold-fusion" is achieved; or a method of controlling the nuclear fusion reaction can be realized.
(3) ***Renewable*** Energy is a form of energy that can be renewed/replenished, and is therefore also indefinitely sustainable. The prime example being sunlight that we receive on earth.

Note that energy generation from any given source could possess any of the 3 attributes above independently of each other; although keeping on using a sus-

tainable non-green fuel (if one were available) would cause destruction because of the chemical pollution or some large scale change in the environment.
In other words, a sustainable source of energy had better be green as well. However, for the purpose of this article, such constraints are not crucial.

Turning to fuels we use today, burning coal not only produces Carbon-di-oxide ($CO_2$), it also releases mercury and Sulfur-di-oxide ($SO_2$), into the atmosphere. Both of these pollutants eventually rain back down on earth. The first one, mercury finds its way into our food-chain through the rain-water. The latter ($SO_2$), dissolves in rain-water (to various degrees), creating sulfuric acid which causes the "acid-rain" phenomenon.

Burning Petroleum and its derivatives might free us from the mercury and sulfur pollution, but it does generate a substantial amount of $CO_2$, which is a greenhouse gas.

Note that almost all living organisms that have evolved on earth appear to derive the energy that they require for living from a carbon-based cycle. The entire life on earth includes one element in a high degree of concentration: viz., Carbon. For this reason, "Organic Chemistry" which is a traditional name for the branch of chemistry that studies compounds found within and related to living organisms is also known as "Carbon Chemistry".

It is therefore not surprizing that pretty much any fossilized fuel that we know of, is primarily made-up of Carbon. Burning fossil fuels therefore generates $CO_2$, which in-turn helps exacerbate the greenhouse effect. Moreover, none of the fossil fuels (coal, oil, ....) are replenishable, since they can be used (burned) only once.

Fossil fuels are therefore neither green, nor sustainable and neither renewable (definitely not renewable at the current consumption rates).

Nuclear energy comes from fission and fusion processes. The only form we can harness right now is fission; fusion cannot be harnessed for energy production yet. Obviously nuclear energy is not "renewable" or replenishable; the nuclear material can be used only once. Fission generates extremely toxic waste products. However, they are in a solid state and therefore can be sequestered (at least in principle) for a long time. Nonetheless, fission is not considered "green".
Finally, the supply of fissile material on earth is not unlimited. Hence, Nuclear fission cannot considered sustainable in the long run; it is considered to be the least-destructive, potentially inevitable "bridge-fuel" until humans figure out something which is sustainable longer and is greener.

#### 1.1.2 Sunlight/Solar Radiation is the Best Known Green, Renewable and Sustainable Form of Energy

In contrast to all prior forms of energy, sunlight, in every sense, is the ultimate form of green and sustainable energy. It is as renewable an energy form as we can think of today or even in the future. (note that burning fossil fuels simply gives back the small fraction of solar energy stored by life-forms on earth a long time ago).

Most other forms of renewable energy (for example hydroelectric generation from dams or wind farms) go back to solar energy (because sunlight causes the water-vapor and the rain that fills-up the dam. Likewise, sunlight is primarily responsible for heating/cooling the earth unevenly, thereby creating winds).

## 2 LET US GO COMPLETELY "GREEN"

### 2.1 Consider only using Sunlight

Since sunlight is the most clean, green and sustainable form of energy, we should only use sunlight as far as possible.
But there are a few problems with sunlight. The most important one being that it is inherently highly distributed. The energy-density of sunlight is considerably lower than the energy density delivered by the chemical bonds in fossil fuels or the nuclear bonds in fissile material. Therefore, a substantial amount of aggregation over a nontrivial amount of geographical area is required to effectively harness solar energy.

#### 2.1.1 A Hypothetical Question: Suppose Humans were to Become Capable of Creating Huge, Ultra-ultra Thin Artificial Spheres/Mirrors in Space (Call them "mirroons") to Reflect more Sunlight onto the Earth. Should We Put up those "mirroons" to Get More Solar Energy?

Let us think for a moment as to what happens to the energy that we use. In high-school physics, everyone learns that:

1 ***Energy cannot be created or destroyed,***[3] ***it only changes form***

[3]Except in nuclear reactions where mass gets converted into energy

2 Moreover, all known processes that consume or produce energy are known to conform to the ***fundamental laws of Thermodynamics***. In particular ***At an abstract level, every single process that involves energy-exchange can be modeled as a Carnot Cycle and therefore must dump at least some portion of the input energy, as the "unused" portion into a "low temperature reservoir"***

But there is ***only one low temperature reservoir*** that we know of, (which we all also happen to share), viz., the ***surface of planet Earth/Ocean.***

Therefore it can be seen that ***all the energy that is used*** for every single action (from breathing, to the fuel used to run cars, airplanes, ships, and all energy used for heating/cooling, all electricity we produce,...) ***eventually gets transformed into entropy/disorder/ waste-heat on the earth's surface.***

For example, consider transportation: first and foremost, assuming that all objects involved in transportation are at rest before and after the transport operation, the kinetic energy of motion is zero at both the start and the end. In other words, there is no net change or net gain in the kinetic energy of any component of a transportation system. Typically, there is no chemical change in the objects being transported which means that energy does not get converted into/saved as chemical energy. Likewise, electric charge, temperature and other attributes of the objects being transported are not expected to and do not change much as a result of the trip.

That only leaves a consideration of "potential energy". Here, we first observe that most trips we undertake are "round trips", wherein, since the starting and ending place is the same, there is no net change in potential energy. Even when the trip is not necessarily a "round trip" (for example, when raw materials, finished goods are transported at various stages of industrial production), there is no known preferential bias toward moving objects upwards against gravity (in which case, they gain potential energy). Therefore, there is no net gain in "potential energy" as a result of any/all of our transportation activities. There are extremely few exceptions to this: rarely do we lift huge things and put them permanently on top of mountains or sky-scrapers.

It is therefore clear that all the energy used for transportation must eventually dissipate as friction (of some sort, including electric "resistance") against the transport conduit (which is typically a road surface when the transporter is a terrestrial vehicle; water-drag in case of ships and friction created by collisions against air molecules in case of airplanes). Friction eventually coverts all the kinetic energy of motion into waste-heat that cannot be further exploited in any other way.

Even if we "store" energy temporarily via regenerative breaking, and/or charging batteries, eventually, it gets used to move the same transporter again at a later time, or for lighting or heating/cooling on-board the transporter vehicle; and therefore must eventually dissipate as waste-heat/entropy.

We leave it to the reader as an exercise to show that energy used for heating or cooling also eventually dissipates as entropy/disorder/waste-heat.

### 2.1.2 Quality of Energy, Thermodynamic Irreversibility

A clarification is in order here (more in-depth treatment of the following material can be found in text-books such as (Moran, MJ, Shapiro, HN, et. al., 2010); or at university course-websites like (Greitzer et al., 2013; MIT staff, 2003); or on wikipedia (Wikipedia, 2010; Wikipedia, 2012)...,) The important word here is "waste-heat". It turns out that different forms of energy have different levels of "quality" associated with them (Wikipedia, 2010). Energy of a higher quality can be converted into another form of energy with a lower quality easily via spontaneous or naturally occurring processes. The degradation of quality can be measured by a thermodynamic metric known as "Irreversibility" (Greitzer et al., 2013; Wikipedia, 2012). As the name implies, energy of a lower quality cannot be converted into energy of a higher quality without spending (a substantial amount of) additional energy.

Electricity is one of the highest quality/form of energy (Wikipedia, 2010), and therefore it is easy to convert electricity into mechanical work (through electric motors) or heat (resistive heating) or light (via light bulbs). Kinetic Energy of motion is of lower quality than electricity, but higher quality than heat (Wikipedia, 2010), and therefore it can be easily converted into heat (by friction via braking). But to convert it into electricity requires a generator which has its own losses. Unfortunately, "heat" happens to be one of the lowest grade/form of energy (Wikipedia, 2010). The higher the temperature, the higher the quality of heat. Therefore by burning fossil fuels, or via nuclear fission, we can generate very high temperatures or in other words "heat" at a high temperature and then convert a small portion of it into mechanical work or electricity as per the Carnot-cycle (the most fundamental rule governing heat engines).

In view of the above, note that ideas such as "build huge antennas and radiate microwaves away to get

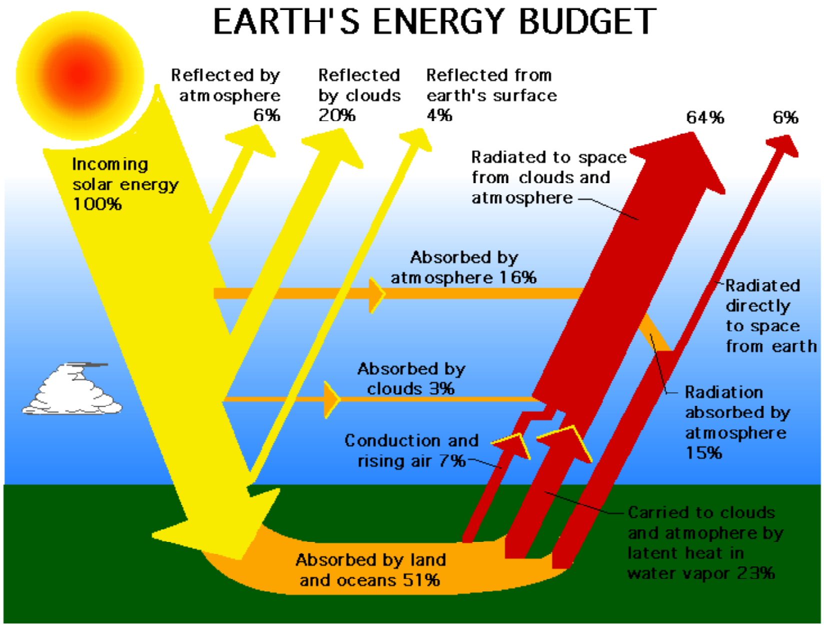


Figure 1: Graphic illustrating the balance of inbound and outbound energy flows (from Wikimedia, original by NASA).

rid of excess energy" or build "high power lasers to radiate excess energy away" are wrong and will not work for the following reasons: both Microwaves and Laser light are energy forms of higher quality. Accordingly, it requires a substantial amount of energy of lower quality to generate microwave radiation, and even more amount of energy to produce a powerful laser beam. A sizable portion of that energy (used to generate the microwaves or laser light) itself gets dissipated as waste heat, completely defeating the purpose.

It is therefore clear that once the heat has been dumped into the "low temperature reservoir" it is useless, it cannot be converted into other forms of energy without spending lots more energy, which would defeat the purpose of trying to get rid of that "wasted-heat".

Now that we have established that pretty much all energy used on earth eventually dissipates as waste-heat on the surface of the earth, the next question is why has the earth not already heated up by now?

# 3 ONLY WAY OUT: RADIATE TO SPACE

The answer is that the earth does lose a substantial amount of energy via thermal radiation, (also known as black-body radiation) into space. In fact this is the only way Earth is known to dissipate thermal energy out of it's system.

Since one half of the earth is always facing the sun all the time, the earth keeps getting solar energy input all the time. Yet, there is no runaway temperature increase observed on its surface. Rather, we are fortunate to be blessed with steady temperatures in the narrow range that is suitable for life. The (more or less or approximately) constant temperatures on the surface of the earth imply that there must be no "net" energy accumulation. Therefore the energy continually being input from the sun must be being dissipated to create a delicate thermal equilibrium.

## 3.1 Thermal Equilibrium on Earth

Figure 1 illustrates the Earth's energy budget. It was taken from Wikimedia (NASA staff, 2004), where it is available for download under the GNU public license (the wikipedia page also gives full credits, indicating that the original source was NASA)

In Figure 1, the sum of powers associated with all outbound arrows, which is the total power exiting the earth is

$$\begin{array}{rcccl} \{\text{reflected power} & = & 30\% & = & (6+20+4)\% \\ + & & + & & + \\ \text{radiated power}\,\} & = & 70\% & = & (64+6)\% \\ \hline \text{total outbound power} & = & \multicolumn{3}{l}{100\% \approx \text{input-solar-power}} \end{array}$$

### 3.1.1 Black-body Radiation: Quick Refresher (Wikipedia, 2013)

Thermal radiation power output of a black body is given by the Stefan–Boltzmann law:

$$P = \sigma \cdot A \cdot T^4 \quad (1)$$

where the constant of proportionality $\sigma$ is the Stefan–Boltzmann constant and $A$ is the radiating surface area.

For surfaces which are not black bodies, the emissivity factor $\varepsilon(\nu)$ needs to be included (where $\nu$ is the frequency of the radiation emitted, and $\varepsilon$ is a fraction). Approximating emissivity to be constant across the frequency spectrum (which holds true, especially around the peak emission wavelength), the formula for the power output becomes

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4 \quad (2)$$

This type of theoretical model, with frequency-independent emissivity lower than that of a perfect black body, is often known as a gray body.

From the above, it can be derived that the net power radiated out is proportional to the difference of fourth powers of the absolute temperatures $T_b$ and $T_s$ of the radiating body and the surroundings, respectively:

$$P \propto \left({T_b}^4 - {T_s}^4\right) \quad (3)$$

Therefore it is clear that the ***only way to dissipate excess heat via thermal radiation is by increasing the temperature $T_b$ of the radiating body (which is the surface of the Earth in this analysis)***

# 4 DISCUSSION AND CONCLUDING REMARKS

Let $\mathscr{S}_{\boldsymbol{E}}$ denote the total amount of solar-energy in Joules which the earth receives each year (it has been relatively steady across large time-spans and can be approximated to be a constant). We know for a fact the earth has been dissipating that much energy forever, creating a thermal equilibrium. It is therefore clear that as long as we keep our usage of energy to be a sufficiently small fraction of $\mathscr{S}_{\boldsymbol{E}}$, we should not run into problems with thermal equilibria we've known forever. Therefore for the purpose of ensuing analysis, it is useful to focus on the ratio of the total energy used per year (denoted by $U$) to $\mathscr{S}_{\boldsymbol{E}}$

### 4.0.1 How Close Are We to the Limit?

Using, data from The United States EIA (Energy Information Administration, an agency specifically created by the U.S. federal government to gather accurate energy consumption data and make forecasts) (EIA staff, 2013), in the year 2010, humanity consumed 524 quadrillion i.e., $524 \times 10^{15}$ BTUs (British Thermal Units) of Energy. The solar energy input to the earth has been estimated to be about 173 Peta-Watts = $173 \times 10^{15}$ Watts (NASA staff, 2004). Converting BTUs into Joules to obtain the amount of energy used annually and calculating the Joules received from the sun (by multiplying the wattage by the number of seconds in a year) and taking the ratio, we get the fraction:

$$\begin{aligned} f &= \frac{U}{\mathscr{S}_{\boldsymbol{E}}} = \frac{524 \times 10^{15} \times 1055.05585}{173 \times 10^{15} \times 365.2425 \times 86400} \\ &\approx 0.0001012664497 \quad (4) \\ &\text{note that} \\ f &> \frac{1}{10000} = 10^{-4} \quad (5) \end{aligned}$$

### 4.0.2 Back-to the Question in Sec. 2.1.1

In light of the above facts, let us try to answer the hypothetical question raised in Section 2.1.1. as to whether or not we should try to divert extra sunlight toward the earth.

Note that if we (humans) were able to get even 1% extra energy from the sun (in addition to $\mathscr{S}_{\boldsymbol{E}}$) each year, in 100 years we would have dissipated extra amount = (2 $\mathscr{S}_{\boldsymbol{E}}$). Such a continual accumulation (above the safe limit $\mathscr{S}_{\boldsymbol{E}}$) is bound to cause a noticeable increase in the average temperature on the surface of the earth over several centuries.

Thus, even without the presence of greenhouse gasses, unlimited consumption of even the greenest forms of energy by itself would still lead to the same dreadful end result: runaway global warming with disastrous consequences (albeit more slowly as compared with the case where the generation and release of greenhouse gases is not controlled).

### 4.0.3 Let $U$ Be Capped Well Below $\mathscr{S}_{\boldsymbol{E}}$; Can We Use that Energy $U$ without Restrictions?

Finally we address another interesting line-of-arguments that follows:
The earth gets a fixed amount of solar energy ( $\mathscr{S}_{\boldsymbol{E}}$ ). Independent of whether or not we turn it into electricity or other of forms energy in the interim, the original input energy is finally dissipated as waste-heat and is radiated away. Coupled with the assumption that the total amount of energy the sun gives us is way more than we need, we should be able exploit the incident sunlight without restrictions?

Our response is 3 fold:

1. This reasoning already admits what we set out to

demonstrate, viz., the total energy usage $U$ cannot exceed a certain cap/threshold = $\{\tau \mathscr{S}_{\mathbf{E}} : \tau \ll 1\}$. The only question that remains at this point concerns the distribution of the energy used (while satisfying the cap on the total amount used).

2. Note that the calculations above ignore the heat generated from uncertain events such as volcano eruptions, earthquakes (move tectonic plates against huge friction), large forest fires, ... etc. If those were to be accounted/provisioned for, then the "slack" available (i.e., the amount of energy we can safely consume while maintaining current thermal equilibria) might turn out to be even smaller.

3. Finally, besides the total amount of energy dissipated, ***the distribution of solar energy on earth is equally important***. For example, it is well known that about 2/3 of the input solar energy goes into creating the Weather and Ocean patterns that have evolved over eons. ***It is wrong to simply dismiss the light falling into the deserts as "wasted energy"***.

For a concrete example, suppose that the entire Gobi desert in Central Asia and the high and dry plateau of Tibet and other arid highlands on the rain-shadow side of Himalayas were to be covered with solar panels (to harness the supposedly "wasted" energy); and the energy aggregated (electricity) were to be used in cities far-away.

Such a big energy diversion could cause a failure of the monsoon-rains that sustain about 2 billion people in the Indian subcontinent and south-Asia, leading to droughts and related calamities on an unprecedented scale (because one of the main reasons for the regular occurrence of the monsoon in south Asia is the uneven heating of the above mentioned deserts and arid highlands, together with the northern plains of India; starting from early summer/spring in April each year. This causes a relatively low pressure area which sucks the air from "neighboring areas" that are mostly covered by the Indian Ocean. The air trying to rush-in is therefore richly moisture-laden. The high barrier presented by Himalayas helps squeeze out even more moisture, resulting in monsoon rains (between mid June through September)). These rains are essential to sustain about 1/3rd of world's population and a rich bio-diversity of flora and fauna in the tropical rain forests.

## 4.1 Conclusion

Only supply sided viewpoint completely misses these critical issues. Any long term solution must also include limiting the demand for (and as a result, the consumption of) energy. This could require ratcheting down human population and making our lifestyles less energy intensive, which may seem unrealistic at this point in time. However if these facts are ignored, we might perish in our own entropy. If we let that happen, then we cannot call ourselves "intelligent" species.

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