"Green Day": EROI and Why Alternative Energy will be the Future Conventional Energy

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See footnotes at end of text.

"We will make electricity so cheap that only the rich will burn candles," said Thomas Edison as Bell Labs brought about an energy revolution. It was not the first, nor will it be the last. The conventional energy of the future will be created out of our research investments in the present. Coal power plants across the U.S. are currently being retrofitted for – and replaced by – natural gas. These, in turn, will be replaced by a combination of wind, solar, nuclear, and/or another source that has yet to be invented. Petroleum, an ideal transportation fuel as it carries the greatest energy per unit volume[1], too, will eventually be displaced by more sustainable alternatives. Although the day may still be on the horizon, the age of fossil fuels will come to an end. This "Green Day" – defined as the first day in which sustainable energy sources overtake fossil fuels in providing the majority of both (a) transportation fuel and (b) electricity into the grid – will not be forced upon society through a government agenda of enlightened environmentalism, but instead will slowly be a transition as a result of natural market forces. A combination of increasing costs for fossil fuels – the rising of "scarcity rents" as described by Hotelling (1931) – along with falling costs of its substitutes – powered by industrial and technological innovations – will one day tip the scales to turn today's "alternative" fuels into the "conventional" fuels of tomorrow. It is up to energy researchers, planners, and policymakers to ensure that the transition is so smooth that no casual observer notices our impending Green Day.

This future state becomes evident by following current trends in Energy Returns on Investment (EROI) for different energy sources. EROI[2] is the "ratio of total energy produced during that system's normal lifespan to the energy required to build, maintain and fuel the system" (Gagnon, 2008). Similar concepts include energy ratio (Smil, 1994; Uchiyama, 1996), external energy ratio (Mann and Spath, 2001), energy payback ratio (Gagnon, 2008; Meier, 2002) and Lifecycle Energy Assessments (Heinberg 2009; Mulder and Hagens 2008; Murphy et al. 2011). Although these studies have been characterized by differing terms and inconsistent methodologies[3] (Murphy et al., 2011; Brandt and Dale, 2011), they all hint at the same idea: it takes energy to make energy. The more energy that is captured compared to what is needed in its production, the more value can be provided to the user at a lower cost.[4]

No matter the terminology, all use a similar scale where high ratios indicate greater efficiency while lower ratios indicate lower efficiency. Though government policy enacted through taxes and/or subsidies may skew short-term consumption towards a particular source, long-term consumption will always bend towards more efficient sources by the power of market prices. The exception is when global consensus is reached by government entities that a certain form of energy is too detrimental and, therefore, a universal tax is placed on its use with the goal of incorporating the cost of its externalities into its price. If EROI alone was taken into account, coal would still be king at an EROI of 46:1 (Hall et al., 2014). Yet because externalities include sulphur dioxide (a key source of acid rain), nitrous oxide (300 times more potent of a greenhouse gas compare to CO_2), and "air pollutants… known to produce heart and lung diseases, aggravate asthma and increase premature deaths and hospital admissions." (David Suzuki Foundation, 2017)[5], the world is moving away from coal. Universal carbon taxes, equivalent cap-and-trade schemes, or other international government regulation as signposted in the Paris Agreement will further accelerate this process. Canada recently announced a complete transition away from coal by 2030 to meet its climate targets (Viera and McKinnon, 2016), while China suspended the construction of new coal power plants in 29 out its 32 provinces out of health and environmental concerns (Stanway, 2017). How far behind are other, comparatively less harmful fossil fuel sources?

Even without such a tax, fossil fuels are losing their EROI advantage. Figure 1[6] below reflects EROI ratios with current energy returns of fossil fuels with today's technology. An EROI ratio of 1:1 indicates that it took as much energy to produce that unit as is available to consume. Corn-based biofuels show little promise as they have EROI ratios calculated at 1.3:1 (Yaritani and Matsushima, 2014) or even below 1:1 (Pimentel and Patzek, 2005) depending on the methodology, barely more than what it takes to produce them. The incentive for their continued production is based off of continued subsidies by the US federal government. Likewise, the EROI from the Canadian oil sands, because of the necessary inputs on the front-end and the refining on the back-end, is only slightly better at 2.5:1; meaning that it only produces 1.5 times the energy it took to produce it after costs of production are subtracted. When the price of oil is sufficiently high, profits can still be extracted from these sources – but they still face a disadvantage compared to others. Moving from bottom to top of Figure 1, fracking for shale oil has become considerably more efficient over time and can now be done profitably for as little as $35 a barrel (Mlada, 2017). Fracking for natural gas is only slightly more expensive per MmBTU, mainly due to back-end costs including compression, transportation, storage, and others. If the lower price is sustained, indicating greater energy efficiency, fracking will displace more expensive, unconventional forms such as the oil sands and offshore drilling. But it is impossible to tell how long the current ratios will last. Aucott and Mellilo (2013) find exceptionally high EROIs for the early fracking wells, but they also note their numbers may be misleading because the earliest well sites were in "sweet spots" – places with a combination of favorable geology and minimal government regulation – and will soon be depleted.

This temporary boost in EROIs is underlying cause of the collapse of oil prices in late 2014 as the market became flooded with cheap energy. But this will not last. Yaritani and Matsushima (2014) find natural gas from fracking to be between 17:1 to 12:1 depending on methodology, while Berman (2015) estimates that the EROI of the unconventional natural gas industry will stabilize between 10:1 to 5:1 in the long run. Though the EROI of fracking could be higher as the industry becomes exceedingly efficient, it also may face increased government regulation that offset these efficiencies. This decline in EROIs of unconventional oil and gas would follow the same larger pattern of decline in EROIs for the discovery and production of all petroleum and natural gas over the past few decades (Smil, 1994; Hall, 2008; Guilford et al. 2011; Gagnon 2008). Conventional oil and gas have fallen from 30:1 in 1995 to about 18:1 today (Gagnon, 2008; Yaritani and Matsushima, 2014).[7] These falling EROIs will be reflected in long-run price increases of fossil fuels as "scarcity rents" rise in accordance with the additional expenses to obtain these resources.[8]

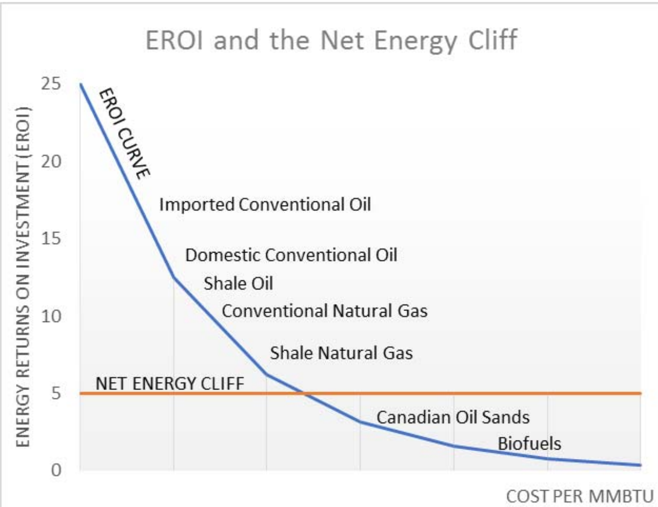

Figure 1: EROI and the Net Energy Cliff

Sources: Net Energy Cliff is EROI necessary for industrial society in Hall (2008); shale natural gas from Berman (2015); all other data as averages from Murphy and Hall (2010).

This would not be a cause for concern itself, except for the fact that high oil prices are directly tied to economic growth. Economists estimate that a 10% rise in oil prices translate to an approximate global GDP loss of approximately 0.55 percentage points (Awerbuch and Sauter, 2005; Birol, 2004; Jones et al., 2004; Mork et al., 1994), while a sustained oil price of greater than $100 per barrel can induce global recession (Rubin, 2009). Furthermore, Gagnon (2008) theorizes that industrial society needs a minimum EROI of 3:1 to stay above this "Net Energy Cliff", a ratio necessary for widespread motorized transit. Hall (2008) similarly argues that an even greater EROI of 5:1 is necessary to maintain even a limited functioning industrialized civilization. As the quality and quantity of each fossil fuel source is sliding down the EROI curve over time, a society dependent solely on fossil fuels would be slowly moving towards the Net Energy Cliff. Though exceptionally controversial, popular literature (Roberts, 2004; Heinberg, 2015; Kunstler, 2012) on "peak oil" warns of a day of reckoning where unprepared "society" is forced to make a sudden transition to alternative energy due to resource depletion, and dire consequences are the result.

The solution to this dilemma is for what is now called "alternative energy" to become the "conventional energy" of the future. This will occur through a combination of nuclear, wind, solar, and other sources. What differentiates these sources from fossil fuels is that the declining EROI framework in Figure 1 no longer applies as these sources (1) will have increasing EROIs over time through continual technological improvement, and (2) do not face resource depletion (scarcity) rents. Nuclear power, though not traditionally considered an alternative energy source, will most likely have a role to help maintain the "baseload" production – the minimum amount of electricity needed for the grid at any given time. Nuclear power allows for electricity creation to respond to fluctuations in demand, as opposed to all other alternatives which merely scavenge energy from the environment on semi-predictable patterns. EROI estimates for nuclear power vary greatly mainly due the many kinds of technology and differing regulatory frameworks that add to the cost of production, with some studies putting the number between 40:1 and 60:1 while others place it much lower. Most studies find that the EROI of nuclear is greater than or equal to 5 (Lenzen, 2008), which is where Hall (2008) places the Net Energy Cliff.

Wind and solar have competitive EROI returns in the present, but the future is even more promising. Technological breakthroughs for wind and solar power are announced almost on a weekly basis. Recent studies put the EROI of wind power at up to 18:1 in 2010 and then rising to a maximum of 20:1 by 2012 (Kubiszewski et al., 2010; Lambert et al., 2012). The most recent meta-study on photovoltaics put the EROI at 7:1 (Gupta and Hall, 2011), but Mann et al. (2013) describes how the current rapid rate of small efficiency improvements in capturing sunlight is leading to large differences in the EROI. At the current pace of improvement, module efficiency by 2020 will reach 21%, equivalent to an EROI of 25:1, which is a greater EROI for all but the most productive fossil fuel sources. That said, EROIs on renewables need to be tempered, given the current lack of large-scale electricity storage partially mitigates their usefulness.

What is exciting is not where these technologies currently are, but where they are going. And the necessity for them to get there. Carbon taxes may accelerate the trend, but it is not the driver of our future energy transition. Soon enough, due to the increasing EROIs of renewable energy and the decreasing EROIs of fossil fuels, the Green Day will be upon us. It's up to us to make this transition as smooth as possible; one where the only noticeable change is the "engine under the hood."

Footnotes

[1] An observation that was first made by former Secretary of Energy Stephen Chu (Gold, 2014).

[2] Calculated as $EROI=E_{out}/E_{in}$

[3] Disagreements include (1) where to stop counting inputs, from point of extraction to point of use; (2) what exactly counts as inputs; and (3) which variation of a certain technology to include.

[4] The numbers presented in this paper should be understood at averages with their own standard errors, unless noted otherwise.

[5] David Suzuki Foundation in summarizing research from the Pembina Institute, Israel and Flannigan (2016).

[6] Numbers in Figure 1 are not intended to be precise, as significant debate remains on the best methodology. The intention of the graphic is to illustrate (1) the relationship between EROI and market costs and (2) relative position of various energy sources bases on previous literature.

[7] Coal follows this same pattern. Falling from 80:1 in the 1980s to a mean of 46:1 today (Hall et al., 2014).

[8] Hotelling (1931) showed that, for depletable resources, prices should exceed marginal production costs, even if the oil market is perfectly competitive. Profits are derived from these 'scarcity rents, which serve as the incentive for a producer to continue to offer supply in the present instead of withholding supply until the price rises even further. This 'Hotelling principle' is explicably tied to speculation and may be a factor that drives prices even higher in oil markets (Hamilton, 2008).

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