Review: How Can We Outlive Our Way of Life?

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"Have the guts to consider the silent consequences when standing in front of the next snake-oil humanitarian." -Nassim Nicholas Taleb in The Black Swan

I believe our generation faces a sobering choice: Take serious steps to reduce our fossil fuel usage now - and this will undoubtedly entail some amount of hardship - or leave it to our children to face a great deal of hardship. I firmly believe this is our choice, and we must look to solutions that move us in that direction. I also believe that if most people understood that we are pushing a very serious problem onto our children - instead of assuming scientists and engineers will solve the problem - then we would collectively pursue a solution with far greater urgency.

Berkeley Professor Tad Patzek, who has written many articles that are critical of our present attempts to replace fossil fuels with biofuels, has just published a new article in which he also discusses solutions:

How Can We Outlive Our Way of Life? (PDF download)

Many of you know Tad Patzek as the co-author of a number of papers with David Pimentel. If you are pro corn-ethanol, then you have probably been conditioned to discount everything Professor Patzek writes. But even if you disagree with his corn ethanol position, there is still a lot to take away from this paper. Patzek's conclusion on cellulosic ethanol is the same as my own: The status of cellulosic ethanol has been exaggerated and over-hyped, and the solution that we really ought to be pursuing is electric. The abstract of the paper reads:

> In this paper I outline the rational, science-based arguments that question current wisdom of *replacing* fossil plant fuels (coal, oil and natural gas) with fresh plant agrofuels. This 1:1 replacement is *absolutely* impossible for more than a few years, because of the ways the planet Earth works and maintains life. After these few years, the denuded Earth will be a different planet, hostile to human life. I argue that with the current set of objective constraints a *continuous stable solution* to human life cannot exist in the near-future, unless we *all* rapidly implement much more limited ways of using the Earth's resources, while reducing the global populations of cars, trucks, livestock and, eventually, also humans. To avoid economic and ecological disasters, I recommend to decrease all automotive fuel use in Europe by up to 6 percent per year in 8 years, while switching to the increasingly rechargeable hybrid and all-electric cars, progressively driven by photovoltaic cells. The actual schedule of the rate of decrease should also depend on the exigencies of greenhouse gas abatement. The photovoltaic

> cell-battery-electric motor system is some 100 times more efficient than major agrofuel systems.

The paper is highly technical, which will turn off many people. But what I enjoy - and I believe is one of my strengths - is to distill technical information and present it so that it is more readily digestible for the layperson. My hope is that this essay succeeds in doing that.

The paper was presented at the 20th Round Table on Sustainable Development of Biofuels in Paris, and therefore contains a lot of Europe-specific discussion and recommendations. The paper covers a lot of ground. Petroleum depletion is discussed, and the business-as-usual scenario is discarded as simply not possible. Cellulosic ethanol is covered, with a close examination of the energy efficiency of Iogen's plant in Ottawa. This result is then compared to the energy efficiency claims of the six proposed demonstration plants in the U.S. The last section compares the potential of photovoltaic cells to biofuels for mitigating our depleting fossil fuel reserves.

Summarizing the Paper

Introduction

In the introduction, Professor Patzek states that world production of conventional petroleum peaked in 2006, and will decline exponentially within a decade. He suggests that heroic measures such as infill drilling, horizontal wells, and enhanced oil recovery methods can stem the decline initially, but this will lead to a steeper decline rate later on. He extrapolates the current per capita use of petroleum with the growth of population in the U.S., and concludes "*that the US and the rest of the world soon will be on a head-on collision course*." He also states that the U.S. currently uses 33 times as much energy in transportation fuels
than is required to feed the population.

Background

In this section, Professor Patzek outlines five constraints that impact humanity's survival, followed by possible solutions given these constraints. The constraints include exponential population growth, overuse of the earth's resources, and our current political structure in which "more is better." He presents two solutions to our current situation: 1). Go extinct; or 2). Fundamentally and abruptly change. The *status quo* is not an option, as Patzek believes it will lead to solution (1). I understand that many doubt that (2) is possible, which is why they believe we are doomed. Personally, I believe the most likely solution is a combination of the two. People will go extinct as food and energy become unaffordable (this is happening even now), but there will be pockets of fundamental and abrupt change. Fast recognition and adaptation - both on a personal and governmental level - are going to be very important.

Patzek examines the impact of fossil fuel usage on population growth, and concludes that of the present world population, "*4.5 billion people owe their existence to the Haber-Bosch ammonia process and the fossil fuel-driven, fundamentally unstable 'green revolution,' as well as to vaccines and antibiotics*."

He comments that too many in society consider themselves more knowledgeable about energy matters than they really are, and this is why we aren't urgently confronting the problem. As his 2nd conclusion of the paper, he writes:

> Business as usual will lead to a complete and practically immediate crash of the technically advanced societies and, perhaps, all humanity. This outcome will not be much different from a collapse of an overgrown colony of bacteria on a petri dish when its sugar food runs out and waste products build up.

He concludes this section by pointing out that we have been conditioned to think that technology is almost magic and will solve our problems. He quoted a biofuels expert who suggested "*Biotechnology is not subject to the same laws of chemistry and physics as other technologies. In biology anything is possible, and the sky is the limit*!"

Efficiency of Cellulosic Ethanol Refineries

This section was extremely interesting to me. Real energy efficiencies of cellulosic ethanol plants (which presently exist only on paper or in demonstration scale) are hard to come by. Those 4:1 or 8:1 energy returns that you often see claimed are hypothetical; nobody in the cellulosic ethanol business has demonstrated anything like this. Professor Patzek attempts to shed some light on this subject. In his words:

> I start from a "reverse-engineering" calculation of energy efficiency of cellulosic ethanol production in an existing Iogen pilot plant, Ottawa, Canada. I then discuss the inflated energy efficiency claims of five out-of-six recipients of $385 millions of DOE grants to develop cellulosic ethanol refineries.

Using published information, Professor Patzek calculated the efficiency of the Iogen plant. He defined the efficiency (albeit by an equation that could have been more clear) as the BTUs of ethanol produced, divided by the theoretical maximum. His calculated efficiency of the process was 20%; input 1 BTU into the process and return 0.2 BTUs, for a net of -0.8 BTUs. This calculation is in the same form as Dr. Wang's gasoline efficiency calculations - the initial BTUs of the feedstock are counted as an input into the process, and then the processing energy is counted against it. In simple terms, if you take 1 kilogram of wheat straw, add in the distillation energy and take credit for the heating value of the lignin, you have the denominator of the equation. The numerator is the heating value of the ethanol that was produced from that kilogram of wheat straw. If you started with 1 BTU of straw, and produced 1 BTU of ethanol, the efficiency is then governed purely by the distillation energy (essentially the amount of external energy required to drive the process).

Of particular note, the equation did take a credit for the lignin, which is always the assumption that cellulosic ethanol proponents use to obtain inflated energy returns. However, the most significant piece of the calculation for me - and one that Patzek did not call attention to - is that if you look at only the distillation energy (the 2nd term in the denominator of Eqn 1), it is 55% greater than the ethanol that is yielded from the distillation. That means that production of 1 BTU of cellulosic ethanol requires a distillation step that consumes 1.55 BTUs.

The reason for this is one I have stated numerous times. As Patzek writes "*there is ca. 4% of alcohol in a batch of industrial wheat-straw beer, in contrast to 12 to 16% of ethanol in corn-ethanol refinery beers*."

I do note that if you take **full** credit for the heating value of the lignin, it just barely satisifies the distillation requirement. If you run through the math, the lignin BTU credit gives an energy balance of 1.05, which is worse than the 1.3 of corn ethanol plus by-product credits. But remember, the lignin in the process is not dry. It is very wet. Drying co-products in a corn ethanol plant requires a substantial input of energy. If lignin is to be used in a cellulosic ethanol plant, it will have to be dried.

Furthermore, even if the lignin is dry, no other energy inputs into the process have been considered (so this is not a complete energy balance calculation). In other words, if those inputs were all free (of course trucking the biomass back and forth will require significant energy inputs), and the lignin was dry, you would get 1.05 BTUs of cellulosic ethanol out for a lignin input of 1 BTU. Even presuming that Iogen has made major advances recently, it is not surprising why they have been slow to build a commercial facility; they know the score. Patzek concludes:

> The Iogen plant in Ottawa, Canada, has operated well below name plate capacity for three years. Iogen should retain their trade secrets, but in exchange for the significant subsidies from the US and Canadian taxpayers they should tell us what the annual production of alcohols was, how much straw was used, and what the fossil fuel and electricity inputs were. The ethanol yield coefficient in kg of ethanol per kg straw dmb is key to public assessments of the new technology. Similar remarks pertain to the Novozymes projects heavily subsidized by the Danes. Until an existing pilot plant provides real, independently verified data on yield coefficients, mash ethanol concentrations, etc., all proposed cellulosic ethanol refinery designs are *speculation*.

Patzek then addresses the six proposed cellulosic ethanol plants that were awarded $385 million USD by the US Department of Energy. For reference, he gives the energy efficiency of Sasol's coal-to-liquids (CTL) process as 42%, the efficiency of an average oil refinery as 88% (and I can verify that this number is spot on), and that of an optimized corn ethanol refinery as 37%.

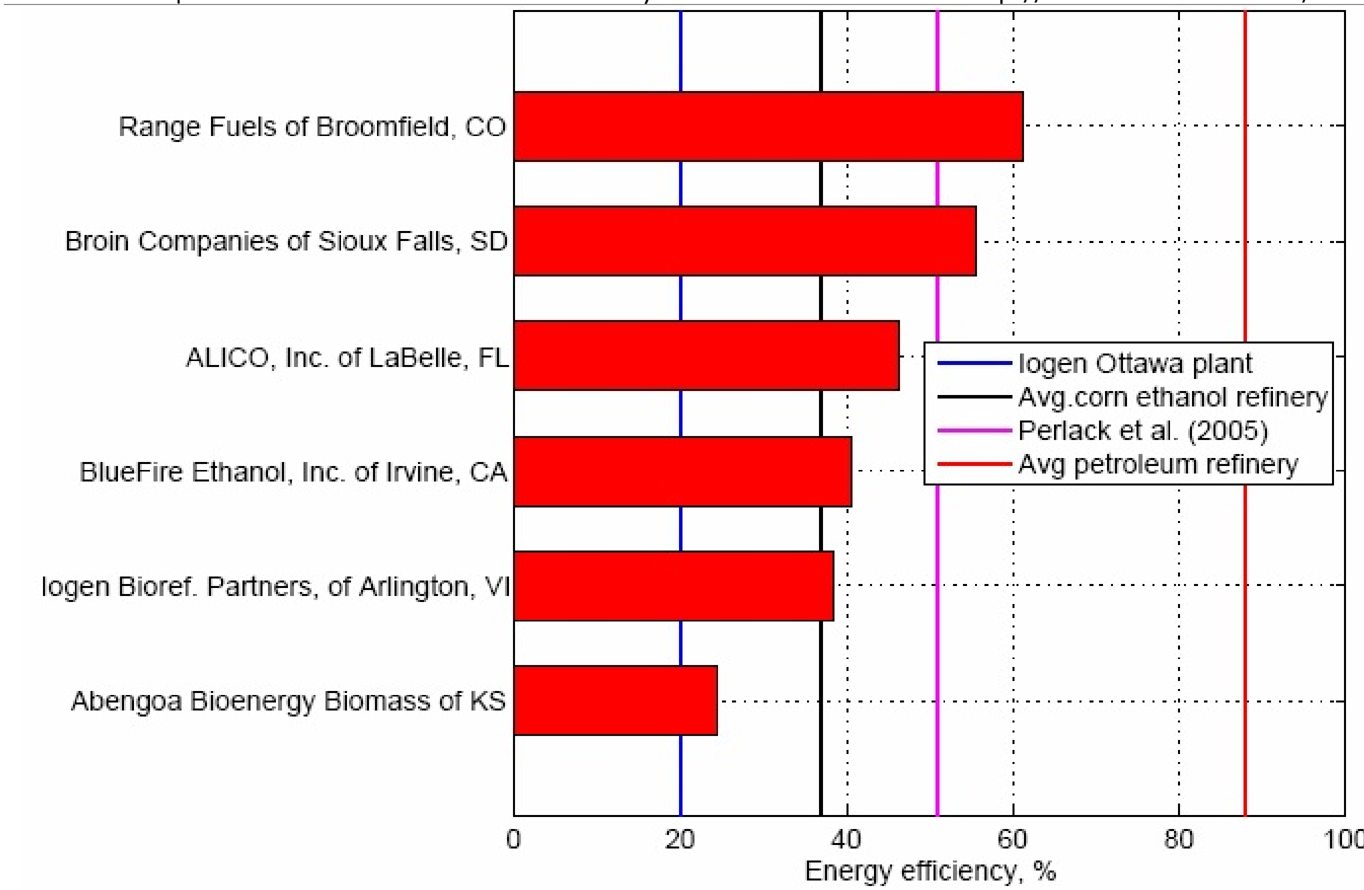

Figure 1. Inflated Energy Efficiency Claims of Announced Cellulosic Ventures

Figure 1, from Patzek's paper, compares the claimed efficiencies of the various cellulosic ventures. Of the six proposed plants, only Abengoa, reporting 25% estimated energy efficiency, was close to Patzek's reverse-engineered efficiency for Iogen. The other five all claimed energy efficiencies in the 40-60% range. The most optimistic was Vinod Khosla's former Kergy (now Range Fuels) venture. See the last section of Cellulosic Ethanol vs. Biomass Gasification for some discussion on Kergy. This process is actually a gasification process, and as such won't have the same sorts of issues that Patzek documented for Iogen. But I don't think in an apples-to-apples comparison they can beat a CTL process on efficiency, because it is much easier to handle coal than biomass (not that I endorse CTL). They are also going to have one problem that the others don't, and that is the production of significant amounts of various mixed alcohols.

There are theoretical reasons why cellulose is unlikely to produce an ethanol concentration in the range of corn ethanol. Patzek writes that at "*about 0.2 to 0.25 kg of straw/L, the mash is barely pumpable*", and states that this straw concentration will result in a fermentation beer of 4.4% ethanol at a maximum. Yet five of the proposed plants are claiming energy efficiencies that are as great or greater than those of corn ethanol plants.

Where Will the Agrofuel Biomass Come From?

In this section, Patzek tackles an issue that I have also addressed: Where could we get that much biomass to begin with? Patzek asks and answers: "*Where, how much, and for how long will the Earth produce the extra biomass to quench our unending thirst to drive 1 billion cars and trucks? The answer to this question is immediate and unequivocal: Nowhere, close to nothing, and for a very short time indeed.*"

In the interest of brevity, I won't go into the details of this section. It is a discussion of Net

Primary Productivity and Net Ecosystem Productivity, as well as the USDA/DOE billion ton vision - *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply* (PDF download). The short of it is that Patzek argues that the biomass is simply not available, and attempting to grow and process enough biomass to continue the business-as-usual model "*would be a continental-scale ecologic and economic disaster of biblical proportions*."

Photovoltaic Cells vs. Agrofuels

The analysis of Iogen's energy balance and this final section were for me the gems of this paper. In this section, Patzek looks at a square meter of land, and compares the energy potential of various biofuels, solar power, and wind power. He also shows the amount of energy if this square meter was an oil field producing oil for 30 years, but that limits the discussion to a very small fraction of the earth's surface. Also, as Patzek wrote, "*this resource is finite and irreplaceable and after 30 years there is no producible oil left in it*." So, I am not going to focus on the oil comparison in this section.

For his comparisons, Patzek looked at photovoltaic cells, wind turbines, corn ethanol, sugarcane ethanol, corn stover ethanol, and Acacia and Eucalyptus for FT-diesel, ethanol, or electricity. He uses the actual demonstrated solar capture efficiency of these processes. Figure 2 shows how the various sources stacked up:

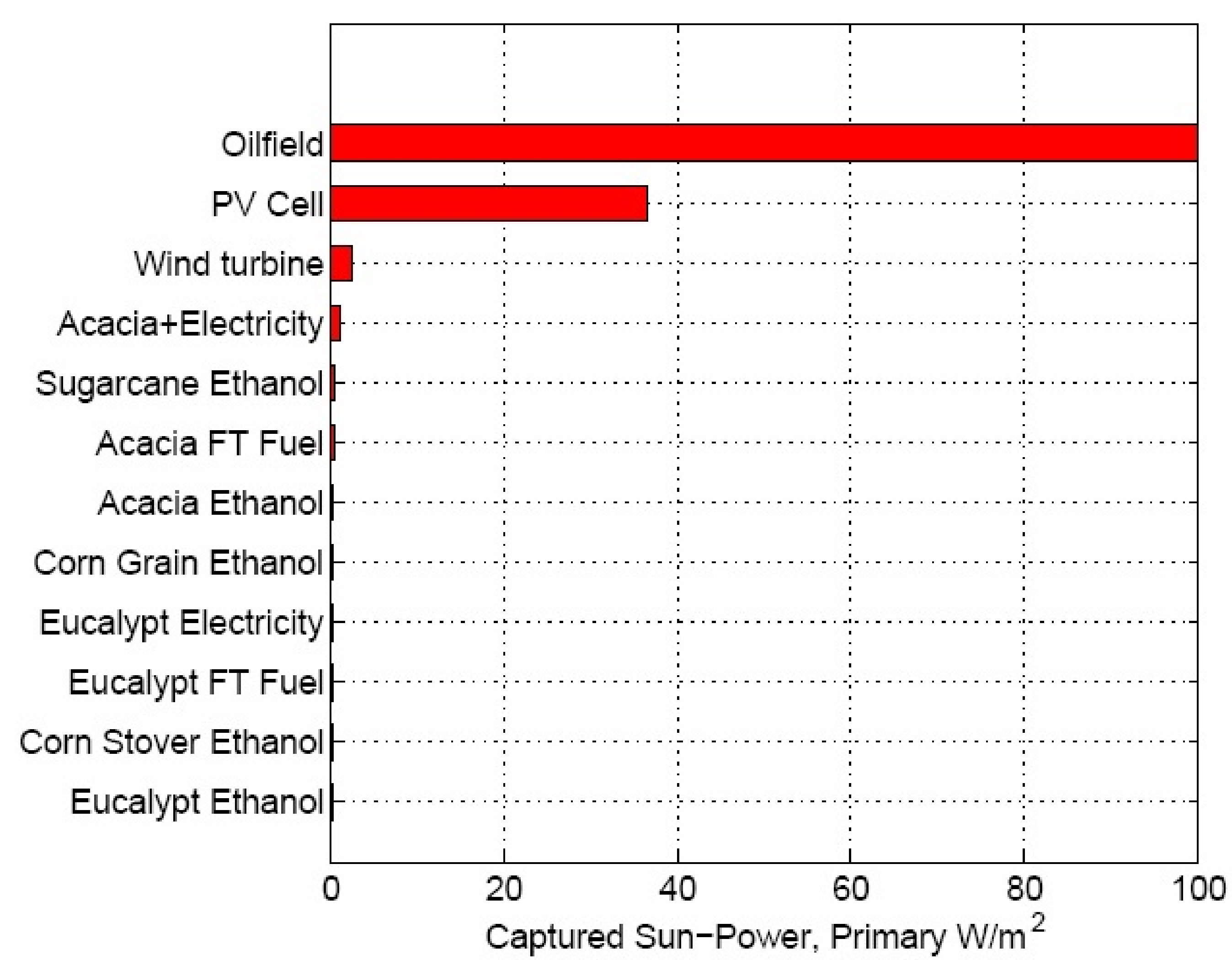

Figure 2. Professor Patzek's Comparison of Various Renewable Options

As shown in the figure, based on Professor Patzek's methodology solar PV is the only option considered that has a legitimate chance to offset a fair portion of our current oil production. Wind came in a distant second. Of the biomass applications, Acacia for electricity ranked the highest. It is significant to note that the top three options all involved production of electricity.

Interestingly, while the solar capture of sugarcane ethanol ranked lower than those three options, Patzek comes to the same conclusion that I did in my essay Brazilian Ethanol is Sustainable. He writes:

> Because of the unique ability of satisfying the huge CExC [RR: Defined as cumulative exergy consumption] in cane crushing, fermentation, and ethanol distillation (0.41 W/m2), as well as fresh bagasse + “trash” drying (0.27 W/m2), with the chemical exergy of bagasse and the attached “trash,” **sugarcane is the only industrial energy plant that may be called “sustainable.”**

Patzek also performs a calculation designed to show how much area is needed to drive a hypothetical car 15,000 miles per year on some of the energy options. He concludes that "*for each 1 m2 of medium-quality oil fields one needs 620 m2 of corn fields to replace gasoline with corn ethanol and pay for the free energy costs of the ethanol production. Similarly, one can drive our example cars for one year from ~30 m2 of oil fields, 90 m2 of photovoltaic cells, 1100 m2 of wind turbines, and ~18000 m2 of corn fields*."

However, one key item not addressed in this essay - and for me the key to making this vision work - is improving energy storage technology. Patzek presumes continued improvement of battery technology. In fact, he writes "*With time the batteries will get better, and electric motors will take over powering the vehicles*." Is that a reasonable assumption? I don't know. I would have liked to have seen this explored in a bit more detail. One hopes that this isn't a situation in which Patzek is presuming "those guys will figure it out."

Professor Patzek's Conclusions

I will let Professor Patzek's conclusions speak for themselves. Here are some excerpts:

> In this paper I have painted a radical vision of a world in which fossil fuels and agrofuels will be used increasingly less in transportation vehicles. Gradually, these fuels will be replaced by electricity stored in the vehicle batteries. With time the batteries will get better, and electric motors will take over powering the vehicles. The sources of electricity for the batteries will be increasingly solar photovoltaic cells and wind turbines. The vagaries of cloudy skies and irregular winds will be alleviated to a large degree by the surplus batteries being recharged and shared locally, with no transmission lines out of a neighborhood or city.
>
> I have shown that even mediocre solar cells that cost 1/3 of their life-time electricity production to be manufactured are at least 100 times more efficient than the current major agrofuel systems. When deployed these cells will not burn forests; kill living things on land, in the air, and in the oceans; erode soil; contaminate water; and emit astronomic quantities of greenhouse gases.

> Finally, no future transportation system will allow complete "freedom of personal transportation" for everyone. I suggest that good public transportation systems will free many, if not most people from personal transportation.

My Conclusions

I am not sure whether Professor Patzek believes that biofuels have no place at all among our future energy options. In my opinion, there is a place for them, albeit in niche applications and not as a major energy source. I think we will continue to have a need for some long-range transportation options (e.g., shipping, airline transportation) that would be difficult to electrify. But for the most part, the future has to be electric. The sooner we shift focus from biofuels to electric transportation, the better.