ENERGY INEFFICIENCIES OF BIOFUELS

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CO2SCIENCE & SPPI ORIGINAL PAPER ♦ June 4, 2014

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Citation: Center for the Study of Carbon Dioxide and Global Change. "Energy Inefficiencies of Biofuels." Last modified June 4, 2014. http://www.co2science.org/subject/b/summaries/biofuelsenergyinefficiencies.php.

How efficient is it to produce energy from biofuels-is it more, less, or about the same as from traditional fossil fuels? This mini review summarizes what several scientists have learned when investigating this topic.

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> *Biofuel production cannot, in any significant degree, improve the energy security of developed countries, for to do so would require so vast an allocation of land that it would be impossible for a multitude of reasons.*

Gomiero *et al*. (2010)[1] reviewed the wisdom of proposed appropriation of much of the planet's land and water resources for the purpose of supporting large-scale production of biofuels as replacements for fossil fuels. And in doing so, they came to a number of unfavorable conclusions about the highly-touted enterprise. For starters, they report there is not enough readily available land to produce much fuel from biomass without causing a severe impact on global food commodities, while adding "even allocating the entire USA cropland and grassland to biofuels production, the energy supply will account for only a few percentage points of the USA energy consumption," which suggests "there is no hope for biomass covering an important share of USA energy demand." Noting "the same is true for the European Union," the researchers go on to say "biofuel production cannot, in any significant degree, improve the energy security of developed countries," for to do so "would require so vast an allocation of land that it would be impossible for a multitude of reasons."

Another problem, in the words of Gomiero *et al*., is that biofuel production, including cellulosic ethanol from crop residues and grasslands, "does not appear to be energetically very efficient." In fact, they indicate fierce debates have arisen, over whether the energy output/input ratio of various biofuel production enterprises is 0.2 of a unit above or below 1.0, which seems pretty ridiculous in light of another item they report, i.e., the fact that "our

[1] http://www.co2science.org/articles/V13/N50/EDIT.php.

industrial society is fueled by fossil fuels that have an output/input ratio 15-20 times higher." Indeed, they write recent assessments of the subject demonstrate that extensive biofuels production may actually tend to "exacerbate greenhouse gas emissions and in turn global warming." And they state biofuels "may greatly accelerate" the destruction of natural ecosystems and their biodiversity by "the appropriation of far too large a fraction of net primary production," thus resulting in a threat to their "health, soil fertility, and those key services needed by human society."

In concluding, Gomiero *et al*. warn "biofuels cannot be either our energy panacea, nor supply even a minimal share of energy supply for our society without causing major social and environmental problems." Therefore, they suggest we use our "hard earned money," as they put it, to "help farmers, both in developed and developing countries, to adopt energy saving-environmentally friendly agricultural practices, that can really help to cut greenhouse gas emissions, prevent soil erosion, reduce water consumption, relieve the environment from toxic pollutants, preserve wild and domesticated biodiversity and supply many other services," which is *precisely* what elevated concentrations of atmospheric CO_2 tend to promote (Idso and Idso, 2011; Idso *et al*., 2014). In a final statement, the three scientists advise in their concluding sentence: "We should be careful not to let our 'energetic despair' (or vested interest) lead us to worsen the very same environmental and social problems we wish and need to solve."

Gelfand *et al*. (2010)[2] introduce their work by writing "the prospect of biofuel production on a large scale has focused attention on energy efficiencies associated with different agricultural systems and production goals," but they note "few empirical studies comparing whole-system multiyear energy balances are available." In fact, they say that insofar as they are aware, "there are no studies that directly compare food vs. fuel production efficiencies in long-term, well-equilibrated cropping systems with detailed descriptions of fossil energy use."

To initiate the filling of this data void, Gelfand *et al*. "used 17 years of detailed data on agricultural practices and yields to calculate an energy balance for different cropping systems under both food and fuel scenarios," comparing one forage and four grain systems in the U.S. Midwest that included "corn-soybean-wheat rotations managed with (1) conventional tillage, (2) no till, (3) low chemical input, and (4) biologically based (organic) practices, and (5) continuous alfalfa," where they "compared energy balances under two scenarios: all harvestable biomass used for food versus all harvestable biomass used for biofuel production."

Overall, the three researchers report "energy efficiencies ranged from output:input ratios of 10 to 16 for conventional and no-till food production and from 7 to 11 for conventional and no-till fuel production, respectively." Gelfand *et al*. say their analysis "points to a more energetically efficient use of cropland for food than for fuel production," and that the large differences in efficiencies attributable to the different management techniques they evaluated suggest there are "multiple opportunities for improvement."

According to Goncalves da Silva (Goncalves da Silva, 2010), "it takes energy to produce energy, even when the primary source is energetically cost free, such as solar or wind," he writes, as he

[2] http://www.co2science.org/articles/V13/N45/B2.php.

considers the oft-neglected energy expenditures involved in readying so-called renewable or free energy technologies for the magnitude of deployment that would be required to offset a significant portion of the enormous amount of the world's total energy production that is currently provided by fossil fuels. The professor notes, for example, that the implementation of *any* desirable new energy-supply technology requires devices that can convert the original primary source into either electricity or transportation fuel in a carbon-free or neutral way, and "the manufacturing, installation, regular operation, and fuelling of such devices involve an energy cost," which for the magnitude of fossil-fuel offsetting envisioned could be huge. He also notes these devices "have a finite lifetime, after which they must be decommissioned and replaced, bringing in additional energy costs," adding "a new energy technology has to be capable of producing enough energy to cover these costs and to generate a surplus for external consumption."

In light of these requirements, and under what he calls "ideal circumstances," Goncalves da Silva examined the deployment rate for any new energy technology, evaluating the net energy output to the existing energy infrastructure, which itself may be in need of significant modification or even wholly new development. This he does via the construction of a general model, the use of which he illustrates with simulations of the deployment of photovoltaic electricity at national and global scales, adding that any real-life situation is bound to show even worse results than those he derives in terms of the net energy delivered to the grid by the new technology.

New technology may actually be an energy sink, instead of an energy source, relative to the global total primary energy supply for many years or decades.

Thus, societies should not place undue hope in new energy technologies to save the world from fossil energies until well after many decades of deployment. Or, it might be added, if ever!

Ultimately, Goncalves da Silva concludes "new technology may actually be an energy sink, instead of an energy source, relative to the global total primary energy supply for many years or decades, depending on its intrinsic energy costs and deployment path, even though stated aims for its gross energy output are achieved." Consequently, he says "to achieve terawatts output from renewable sources, in order to displace massive quantities of fossil energies, will be a slow process, extending over many decades." Thus, societies should "not place undue hope in new energy technologies to save the world from fossil energies until well after many decades of deployment." Or, it might be added, *if ever!*

Focusing on the connection between water and energy production, Mulder *et al.* (2010)[3] conducted a comparative analysis for estimating the energy return on water invested (EROWI) for several renewable and non-renewable energy technologies using various Life Cycle Analyses. This approach mirrors the energy return on energy investment (EROEI) technique used to determine the desirability of different forms of alternative energy, with the technique's most recent application being adjusted to also consider the global warming potentials of the different forms of non-fossil-fuel energy and the greenhouse gases emitted to the atmosphere in the process of obtaining them and bringing them to the marketplace. The reason for bringing water into the equation derives from the facts, as noted by Mulder *et al*., that (1) "water withdrawals are ubiquitous in most energy production technologies," (2) "several assessments suggest that up to two-thirds of the global population could experience water scarcity by 2050 (Vorosmarty *et al*., 2000)," (3) "human demand for water will greatly outstrip any climate-induced quantity gains in freshwater availability (Vorosmarty *et al*., 2000; Alcamo *et al*., 2005)," and (4) the increased need for more freshwater "will be driven by the agricultural demand for water which is currently responsible for 90% of global freshwater consumption (Reault and Wallender, 2006)."

The three U.S. researchers say their results suggest "the most water-efficient, fossil-based technologies have an EROWI one to two orders of magnitude greater than the most water-efficient biomass technologies, implying that the development of biomass energy technologies in scale sufficient to be a significant source of energy may produce or exacerbate water shortages around the globe and be limited by the availability of fresh water."

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Investigating a similar aspect of the debate, Marta *et al.* (2011)[4] analyzed the processes involved in the cultivation of energy crops in the Tuscany region of Italy from the perspective of energy and water costs, focusing on maize (*Zea mays*) and sunflower (*Helianthus annuus*) because of their different water requirements and methods of cultivation. According to the researchers, "the cultivation of energy crops dedicated to the production of biofuels presents some potential problems, e.g., competitiveness with food crops, water needs, use of fertilizers, etc.," and they note "the economic, energy, and environmental convenience of such activity depends on accurate evaluations about the global efficiency of the production system."

[3] http://www.co2science.org/articles/V13/N34/EDIT.php.
[4] http://www.co2science.org/articles/V14/N41/B1.php.

Their work was conducted using a 50-year climatic series of meteorological data from 19 weather stations scattered across the Tuscany region to feed the crop model CropSyst for the simulation of crop production, water requirements and cultivation techniques, with the final results being used to define the real costs of energy crop cultivation. With respect to their findings, the six scientists state, first, "the energy balance is positive only considering the more efficient system of irrigation, whereas in the rest of the cases the energy invested is greater than the energy returned." Second, they report "the water need for bioethanol production is too high considering the trend and the distribution of precipitation in the region in addition to water requirements of the other productivity sectors," noting "more than 1,000 liters of water are required for producing one liter of bioethanol," which implies "the cultivation of energy crops in the reserved areas of the region will almost double the actual requirement of the agricultural sector in Tuscany." As a result, the Italian researchers from the University of Firenze conclude "the cultivation of maize and sunflower for energy production cannot be considered a sustainable choice in Tuscany," even at the present time. And it should also be noted the demands upon energy, land, and water resources will only grow larger, as the world's population grows by a couple billion people on its temporal trek towards AD 2050.

York (2012) set out to determine the extent to which alternative energy sources displace fossil fuels, stating it is a fundamental assumption of the Intergovernmental Panel on Climate Change and many energy analysts that "each unit of energy supplied by non-fossil-fuel sources takes the place of a unit of energy supplied by fossil-fuel sources." However, he goes on to say that "owing to the complexity of economic systems and human behavior, it is often the case that changes aimed at reducing one type of resource consumption, either through improvements in efficiency of use or by developing substitutes, do not lead to the intended outcome when net effects are considered," citing Sellen and Harper (2002), York (2006), Polimeni *et al*. (2008), Druckman *et al*. (2011) and Hubacek and Guan (2011). Using an approach that controls for the principal driving forces of national per capita demand for fossil-fuel energy derived from coal, gas and oil, and which also tests for displacement, York accounted-in four different models-for the amount of energy per capita obtained from non-fossil-fuel sources (hydropower, nuclear, geothermal, solar, wind, tidal and wave energy, combustible renewables and waste) and measured in the same units of energy as that obtained from fossil-fuel sources.

In regard to the question posed in the title of his paper - *Do alternative energy sources displace fossil fuels?* - York says the answer is "yes, but only very modestly," noting that "across most nations of the world over the past fifty years, each unit of total national energy use from non-fossil-fuel sources displaced less than one-quarter of a unit of fossil-fuel energy use and, focusing specifically on electricity, each unit of electricity generated by non-fossil-fuel sources displaced less than one-tenth of a unit of fossil-fuel-generated electricity." Such findings, in the words of the University of Oregon (USA) researcher, "challenge conventional thinking in that they indicate that suppressing the use of fossil fuel will require changes other than simply technical ones such as expanding non-fossil-fuel energy production."

Yang and Chen (2012)[5] write as background for their study that "interest in bio-ethanol as a substitute energy supply for nonrenewable fossil fuels has been growing since [the] 1990s in

5 http://www.co2science.org/articles/V15/N35/C2.php.

China," and they say that "after Brazil and the US, China has recently become the third largest ethanol producer and consumer." In this regard, however, they note after it was suggested by Chambers *et al*. (1979) that the production of corn-ethanol might use more energy than it delivers, "numerous studies of the net-energy value of the bio-ethanol have been reported in many countries," and they cite a group of 26 reports that "provide very different results, with net energy values ranging from highly positive to negative." In an effort to shed more light on the topic, in their study "nonrenewable energy cost instead of overall energy cost is calculated and compared with the amount of energy delivered to society through the sum of nonrenewable energy (NE) embodied in all resources entering the supply chain of corn-ethanol processes in China, including agricultural crop production, industrial conversion, and wastewater treatment," while "an indicator of nonrenewable energy investment in energy delivered is devised to reveal the extent of NE cost of corn-ethanol over that of the energy produced."

Based upon their analyses, the two researchers determined "corn-ethanol production requires 0.70 times more nonrenewable energy (NE) production than the energy content of ethanol produced," leading them to conclude "the goal of NE conservation could not be achieved by corn-ethanol production with the technology conditions prevailing in China." In addition, they say "NE cost is just one aspect of biofuels production," and "more questions concerning water crises and cultivated land use have emerged, with the most serious problem of competition for land between corn-ethanol and food," since "food security is an inevitable concern for China with limited land resources compared with a huge population."

Clearly, energy from biofuels is not as efficient as some have made it out to be.

In light of these several facts, Yang and Chen report China's Ministry of Agriculture has "insisted on developing biofuels without competing with grain for land," citing Wei (2008); and they indicate this policy has "substantially dampened the momentum of corn-ethanol development in China," noting it is clear the country's central government "ruled out the feasibility for China to use staple food grains for fuel because of the paramount priority of food security."

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