NextSTEPS White Paper: Four-Page Summary

Three Routes Forward for Biofuels[1]: Incremental, Transitional, and Leapfrog

This paper investigates the progress and trade-offs among three distinct routes forward for biofuels and their associated technologies. We seek to:

- Highlight policy incentives that encourage certain types of biofuel innovation.
- Spotlight the distinctions between the routes in terms of extent of deployment and financial support.
- Underscore why all three routes should be pursued, some in the near-term for greenhouse gas (GHG) reductions through improvements to existing processes and others in the longer term to achieve deeper GHG reductions through new production processes and consumption patterns —to encourage a transition toward a large-scale sustainable biofuel future.

As a pathway to energy independence and GHG reduction, transportation biofuels present great promise but also great challenges. When President George W. Bush promoted biofuels in his 2006 State of the Union address, overall support was high, particularly from the agriculture industry and energy security advocates. Some environmentalists expressed concern.

When Congress passed the Renewable Fuel Standard (RFS) in 2007, it established a mandate of 15 billion gallons likely to be filled by corn ethanol by 2015—and an expanding target for cellulosic fuels reaching 16 billion gallons in 2022, plus an additional one billion gallons for biodiesel from algae, waste oils, and oil seed crops. The expectation was that corn ethanol would create conditions for cellulosic (and algal) biofuels to leapfrog forward, but that jump has proven difficult. Legislated cellulosic targets were lowered for 2010-2013 due to lack of commercial production—less than one million of cellulosic biofuels were produced in 2013—but future targets remain in place.

Given the slow development of commercial-scale cellulosic and algal biofuels, we examine biofuels' future by characterizing three distinct routes forward.

- **Incremental Route -- progress happens at existing biorefineries, by improving existing production systems**: Notable innovations at existing biorefineries that produce corn ethanol and biodiesel are varied: they include new technologies to extract corn oil from the ethanol co-product stream for sale as biodiesel and animal feed (integrated into about 80% of U.S. corn ethanol plants), switching the plant process fuel to lower-carbon sources such as landfill gas, and many others.

[1] The term "biofuels" encompasses any transportation fuel derived from biomass—organic material derived from living or recently living organisms, such as corn, algae, oil seed crops, and the inedible cellulosic parts of plants such as corn stover and bagasse (sugarcane). This paper focuses on liquid biofuels.

- **Transitional -- firms using existing infrastructure to gain experience with cellulosics**: Biofuel technologies are emerging that could facilitate a transition to large-scale cellulosic production. “Bolt-on” systems are equipment added to existing biorefineries or co-located with them (sharing some infrastructure) allowing processing alongside corn or sugarcane sugar streams. Currently, three types of bolt-on feedstocks are being tested: corn kernel fiber that shares most corn ethanol plant facilities; bagasse that is already processed for electricity at sugarcane plants but requires additional processes for ethanol conversion (and could share sugarcane ethanol plant facilities); and corn stover, the leaves and stalks of maize that, unlike bagasse, is not currently collected. Bolt-ons are transitional in that they generate additional demand and larger markets for the enzymes needed to break down cellulosic material. They also help to increase the knowledge base for handling and converting cellulosic biomass.
- **Leapfrog -- cellulosic and algae investments to produce biofuel, made at new, stand-alone biorefineries.** Currently, about 50 firms are pursuing commercial-scale cellulosic and algae plant in the U.S., with six partially or fully completed. Output from completed plants remains far below capacities, due to financial and technical problems. The next Leapfrog biorefineries coming online this year will provide a fuller picture of their viability.

These three biofuel routes offer tradeoffs on the level of investment risk and carbon emission reduction. Incremental improvements typically have lower financial risk, shorter payback periods, lower capital requirements and higher probability of success (Figure 1). As U.S. biofuel policies come online, these improvements represent the “lowest hanging fruit” for producers. There are questions, however, about what level of policy stringency they can achieve. The incremental route has limited GHG reduction potential, due to both the limits on improvements placed by thermodynamics of existing biorefineries and societal or political concerns about the risk of higher emissions from land use change if use of existing food crop feedstocks were significantly expanded.

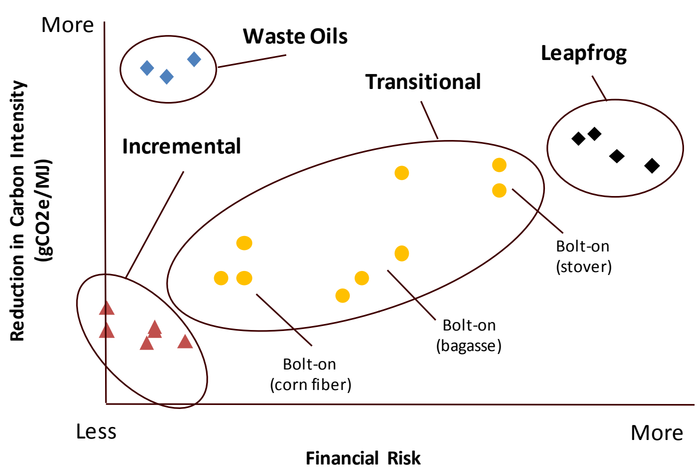

Figure 1: Conceptual graph of CO_2e reduction potential and financial risk of biofuel pathway. Corn fiber is cellulosic material contained in the corn kernel; bagasse is the fibrous material remaining after sugarcane stalks are pressed for juice; corn stover is the corn material left in the field after harvest.

On the opposite end of the risk spectrum is Leapfrog, expected to have a relatively low carbon intensity as long as the dedicated energy crops used as feedstocks are not grown on land under pressure for other use. Leapfrog technologies can also unlock important resources—like organic fractions of municipal waste—which have no land use risk and few alternative uses. But Leapfrog plants may remain costly to move to maturity.

Between the two is Transitional. Bolt-ons may increase ethanol per-acre yield of corn by 5 % and 30% for corn fiber and stover, respectively. But the Transitional route is limited in its maximum GHG benefit because the U.S. total corn acreage is not expected to greatly expand and would raise the prospect of greater land-use impacts if it did.

A strongly implemented Incremental route could improve the GHG performance for the next 10-15 years but then appears likely to flatten out. By contrast, the aggregate GHG reductions of an aggressive Leapfrog route could surpass Incremental by 2025 and eventually be much larger. Figure 2 demonstrates our best estimate of new biofuel production from each of the three routes and the GHG savings if: (1) we assume a 1:1 replacement of existing fuels and (2) we assume the carbon intensities values used in today's policies (see call-out box for caveats). Assessing GHG reductions from biofuels ultimately requires a comprehensive analysis of topics about which researchers continue to grapple, involving modeling of complex ecological and economic systems, and the inherent uncertainty that such efforts entail.

Use of Carbon Intensity Estimates in Policy

Life cycle assessments (LCAs) of biofuels typically start by summing effects of inputs and outputs of an individual biorefinery or fuel production system to estimate the environmental impact of one unit of fuel. When used in policy, the estimate is often used to derive the environmental standing of one fuel compared to another. This assumes a one-to-one substitution between the fuels, which in reality is usually not the case. More fundamentally, the LCAs truncate the system boundary to the production system and ignore potential environmental impacts beyond. Policy has recognized that assessment of emissions from a vastly expanded biofuel industry needs to account for land-use changes prompted beyond the biofuel supply chain through global market effects. Plevin, Delucchi, and Creutzig[2] (2013) discuss the inappropriate use of currently available LCA methodologies as an assessment of environmental impact. This paper acknowledges those concerns while focusing on a narrower topic: the rated carbon intensities (CIs) of current and potential future biofuels.

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[2] Plevin, R., Delucchi, M., Creutzig, F., 2013. Using attributional lifecycle assessment to estimate climate-change mitigation benefits misleads policy makers. Journal of Industrial Ecology, 18, 1.

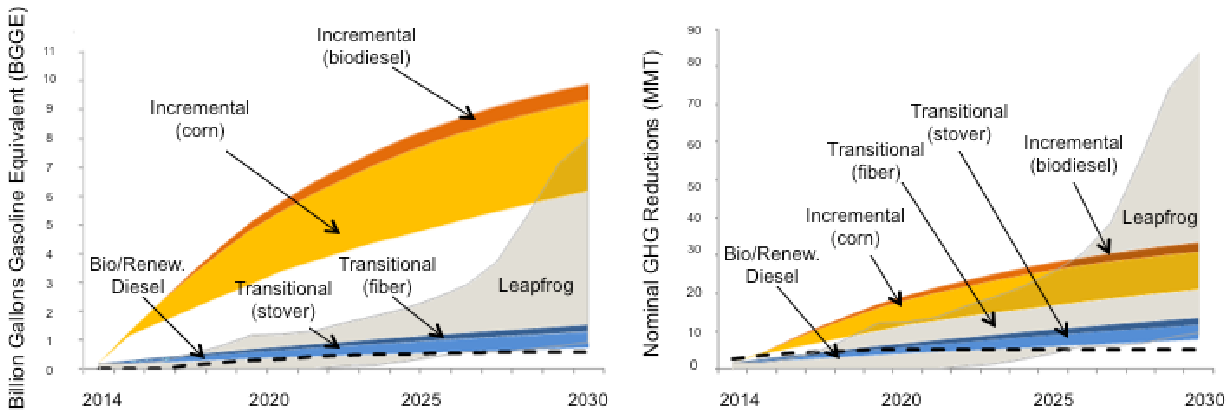

Figure 2: Maximum fuel production if specified route is aggressively pursued (left) and associated GHG reductions (right) in U.S.

Policy Incentives and Conclusions

It is important for policymakers to recognize the distinctions between the routes and how specific policy formulations may incentivize one route over the others. California's Low Carbon Fuel Standard (LCFS) has tended to incentivize Incremental in particular and potentially Transitional for their process efficiency improvements and CO_2e reduction efforts at existing biorefineries. As future policies become more stringent requiring deeper carbon intensity reductions, however, biofuel companies may be incentivized more toward Leapfrog routes.

We conclude that no route guarantees long-term success, particularly for overall CO_2e reduction, and that all three should be pursued. The Incremental route, and to a lesser extent the Transitional route, show potential for near-term, GHG reductions to existing processes. But the U.S. will need large-scale use of Leapfrog technologies—or some similar low-carbon liquid fuel solution—to achieve deeper GHG reductions given the space and weight constraints of certain transportation sectors. Indirect effects such as land-use change must also be robustly weighed. While this research examines many ethanol-based routes to biofuel expansion (since these are developments we are currently seeing in the U.S.), greater use of cellulosic material may require drop-in pathways given substantial demand constraints on ethanol.

To move toward a large-scale, sustainable biofuel future in 2030 and beyond will require continued technology development, but also a policy environment that ensures large-scale, low-carbon, advanced solutions are implemented.