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Take a Closer Look: Biofuels Can Support Environmental, Economic and Social Goals

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Abstract

The US Congress passed the Renewable Fuels Standard (RFS) seven years ago. Since then, biofuels have gone from darling to scapegoat for many environmentalists, policy makers, and the general public. The reasons for this shift are complex and include concerns about environmental degradation, uncertainties about impact on food security, new access to fossil fuels, and overly optimistic timetables. As a result, many people have written off biofuels. However, numerous studies indicate that biofuels, if managed sustainably, can help solve pressing environmental, social and economic problems (**Figure 1**). The scientific and policy communities should take a closer look by reviewing the key assumptions underlying opposition to biofuels and carefully consider the probable alternatives. Liquid fuels based on fossil raw materials are likely to come at increasing environmental cost. Sustainable futures require energy conservation, increased efficiency, and alternatives to fossil fuels, including biofuels.

Why We Need Biofuels

Access to high quality energy sources is strongly linked to prosperity and human well-being (1). Economies benefit when they produce biofuels, a dynamic observed in both developed and developing nations. Indigenous biofuel production increases energy security. Producing perennial biofuel feedstocks can improve water and soil quality, biodiversity, and wildlife habitat compared to landscapes dominated by annual crops. Biofuels can also enhance rural employment and food security.

Because photosynthesis consumes CO₂ and because perennial crops can accumulate soil carbon, biofuel production and utilization can be carbon neutral and even reduce net atmospheric CO₂. Thus low-carbon energy scenarios developed by diverse organizations foresee wide spread use of biomass for energy (**Figure 2**). Biomass provides an average of 138 exajoules of primary energy across these five scenarios, or about one quarter of total global primary energy. These scenarios use biomass primarily to satisfy energy needs that likely cannot be met by other renewables. For example, aviation and ocean shipping require liquid fuels and liquid fuels are strongly preferred for long-haul trucking. Biofuels are only one part of a sustainable energy portfolio, but it is highly unlikely that we can achieve a sustainable transportation sector without biofuels.

Many materials used by society can be recycled, but fossil fuels cannot. Economic activities based on massive fossil fuel consumption are therefore inherently unsustainable. Extracting and using oil, natural gas and coal exposes humankind to air and water pollution and to escalating climate challenges. Thus both economic self-interest and ethical considerations require that we develop sustainable alternatives to fossil fuels, including biofuels (2).

Sustainability and Biofuels

Progress towards more sustainable energy sources requires continual improvement in meeting current energy needs while preserving options for the future. For example, biofuels should be integrated with

sustainable agriculture and forestry systems. Managing such systems requires ongoing assessment to identify better options. The complete system (feedstock production, logistics, conversion technologies, energy types, co-products, transport and delivery systems, and engine or power technology) must be compared to alternatives, including fossil fuels. Stakeholder engagement in developing and evaluating sustainability attributes is critical. Stakeholders determine baseline comparisons, consequential effects and how tradeoffs, synergies, and targets evolve. Following this approach, a broadly endorsed “win-win” role for perennial biomass crops was recently established in the United Kingdom (3).

Biofuels are relevant as the US and other nations develop energy and climate policies. More sustainable biofuel production pathways today allow society to better meet tomorrow’s climate and energy goals. Economic and geopolitical concerns are strongly influenced by energy resources. A nation that develops renewable energy options is stronger and more resilient over the long term.

Short Term Challenges to Biofuels

Short term challenges impeding biofuels include the policy environment, technology and infrastructure. These near term challenges must be overcome before biofuels can contribute substantially to longer term “win-win” opportunities for improved environmental, social and economic outcomes. We first discuss short term challenges and then longer term “win-win” opportunities.

Policy environment Supportive policies and regulations are essential for energy market penetration. Biofuel investment in the US is hindered by the E10 “blend wall”, changes in RFS targets, low energy prices, and political discourse about ending the RFS. Lower volumetric energy content of ethanol relative to gasoline reduces fuel economy and driving range. Recent fuel economy and GHG emission regulations promote electric propulsion, natural gas, and hydrogen with little mention of biofuels. Transparent and dependable price signals are essential to support capital investments required to

68 deploy available biofuel technologies. All technologies need time to mature and drive costs down
69 through operational experience and scale (4).

70 Technology Challenges for Second Generation Biofuels Second generation biofuels are based on
71 cellulosic (non-food) biomass. Effective technologies to densify, stabilize, handle and store raw
72 cellulosic biomass must be developed in order for this industry to expand to large scale. Biomass
73 residues, forest biomass, energy crops, and municipal solid waste offer unique opportunities and
74 challenges in collection, transportation, shipping, and logistics. Co-location with first generation ethanol
75 plants may facilitate second-generation biofuel production by leveraging existing production facilities
76 and fuel distribution networks. Drop-in biofuels (hydrocarbons similar to gasoline and diesel) could ease
77 implementation compared to ethanol via integration into the existing fuel and vehicle infrastructure,
78 however their economic feasibility and large-scale production are not yet demonstrated.

79 Infrastructure Although drop-in biofuels might require fewer infrastructure changes, ethanol is the only
80 biofuel likely available at large scale in the next 5 to 10 years, and ethanol will require additional
81 infrastructure. For example, using E85 (85% ethanol in gasoline) in flexible fuel vehicles has the greatest
82 near-term consumption potential but requires increased refueling capabilities at gas stations.
83 Enhanced biofuel capability in vehicles and refueling infrastructure are significant implementation
84 challenges. Adequate lead time is required for vehicle manufacturers and fuel providers to adjust their
85 systems.

86 **Meeting the Challenges: Some “Win-Win” Opportunities**

87 Cellulosic Biofuels and Sustainable Agriculture Sustainable agriculture strives for cropping systems and
88 management practices that more efficiently use land, sunlight, nutrients, and water to produce crops.
89 Proper management can reduce GHG emissions and enhance soil and water quality. Secure, stable

biofuel markets would create incentives for producers to invest in sustainable agriculture technologies and for input-reducing agricultural practices to be more widely adopted.

Many objectives of sustainable agriculture are well-served by increased cellulosic biofuel production.

For example, corn stover biomass production increases with corn grain yields. In high yield areas, excess stover may interfere with subsequent crops. Conventional tillage to manage this stover releases additional soil carbon and increases fossil fuel use. Using sustainably-harvested stover for cellulosic biofuels can minimize these impacts. Combining stover harvest with winter crops may permit greater removal of stover, increase sustainable biofuel production, reduce nitrate losses to water and nitrous oxide emissions to air, improve water quality, and increase soil carbon levels (5).

Use of perennial feedstocks provides additional opportunities to integrate bioenergy production into agricultural systems and enhance valuable ecosystem services. For example, perennial grasses reduce soil erosion compared to annual crops while retaining nutrients, improving water quality, and building soil organic matter. Integrating perennials into long-term crop rotations can increase organic matter while breaking pest and disease cycles.

Integrated feedstock production and land availability The five scenarios summarized in **Figure 2** foresee a significant need for biofuels that may be met by a mix of wastes and residues as well as energy crops, if rigorous sustainability standards are applied. Biomass production from existing cropland can be increased via harvested winter crops (6), crop residues or native species planted to provide ecosystem services. Efficiencies gained by better integrating biofuel and animal feed production could increase food security and promote soil, water and biodiversity conservation (5). These assessments also suggest potential for increased feedstock production in some regions now used for low-intensity grazing and generally exclude forests, current and anticipated cropland, land needed for human development and protected land. (Protected land is actually increased in some scenarios to enhance biodiversity.) Land

choice for energy crop production requires careful analysis and consideration of direct and indirect socio-environmental effects.

Increased Fuel Efficiency with Reduced GHGs and Improved Public Health High octane, mid-level ethanol blends (e.g., 30% ethanol in gasoline), if widely available, could increase engine efficiency, reduce ethanol's mileage disadvantage, and reduce GHG emissions (7). This would require cooperation by the auto and fuel industries and regulatory agencies to develop the necessary specifications and to make these new fuels widely available. Achieving high octane gasoline via intermediate ethanol blends reduces aromatics and other toxic components in gasoline and avoids intensive refining of crude oil, thereby improving public health outcomes while simultaneously improving fuel efficiency and reducing GHGs.

Enhanced Rural and International Development Biomass production and processing to produce biofuels can benefit rural communities by increasing employment opportunities and expanding the tax base that supports community services (8). Biomass transport costs strongly motivate biofuel processing near the farms or forests where feedstocks are produced, thereby creating diverse jobs requiring different skill sets (9).

Biofuels can assist international development and poverty alleviation. Some biofuels can be deployed in underdeveloped economies, using minimal infrastructure and locally-adapted crops such as sorghum in sub-Saharan Africa. By pooling crops, small-grower cooperatives can produce both liquid fuels and electricity, directly improving local access to energy. The related agricultural investment strengthens existing infrastructure and increases farm and non-farm incomes. One dollar in agricultural investment supports about four dollars improvement in gross domestic product, far exceeding other investments (10). Using bioenergy locally would improve conditions for many poor people without requiring additional transportation infrastructure. Because most people in the least-developed countries

participate in agriculture, increased agricultural income strongly improves overall welfare and increases food security (11).

Food Security As mentioned above, increased agricultural income from biofuels and increased production of cellulosic biomass for biofuels have strong potential to increase food security. Likewise, corn acreage and price have responded to rising oil prices that made ethanol a cheaper octane source for gasoline than petroleum, and to rapidly increasing demand in Asian markets for soybeans. These events combined to increase commodity prices and also increased corn production domestically and worldwide. Thus markets responded to increased demand for corn used for biofuels by increasing corn supplies worldwide (12).

Biofuels and Sustainable Aviation Rapid, economically-accessible travel by jet aircraft is a both a privilege and an enabler of the modern age. This privilege depends completely on high energy liquid fuels. The aviation industry is committed to improving its overall sustainability, and has embraced sustainable jet fuel as part of the solution. The attached Supplemental Information highlights how the aviation industry and its public-private stakeholders joined forces to address sustainability in a system-wide approach that embraces and relies upon the development of second-generation biofuels.

In Conclusion The authors of this article have differing perspectives and expertise, but we all recognize that sustainably-deployed biofuels can contribute to solving challenging problems, including food and energy security, climate change and environmental degradation caused by current agricultural and forestry practices. While the desirable outcomes of sustainable biofuel production and use are not guaranteed, they are certainly achievable. In contrast, we cannot see how continued massive reliance on liquid fuels from fossil materials can achieve positive environmental outcomes, especially higher-carbon options such as oil sands, deep water drilling, natural gas-to-liquids and coal conversion. Thus

158 biofuels deserve a closer look. Sustainably deployed biofuels help can help society achieve many “win-
159 wins” by supporting important environmental, economic, and social goals.

160

161 **Description of Supplemental Information**

- 162 1. Bioenergy Contribution in Low Carbon Energy Scenarios (Data, Assumptions and References)
- 163 2. Aviation’s Approach to Second-Generation Renewable Fuel Development.

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Figures

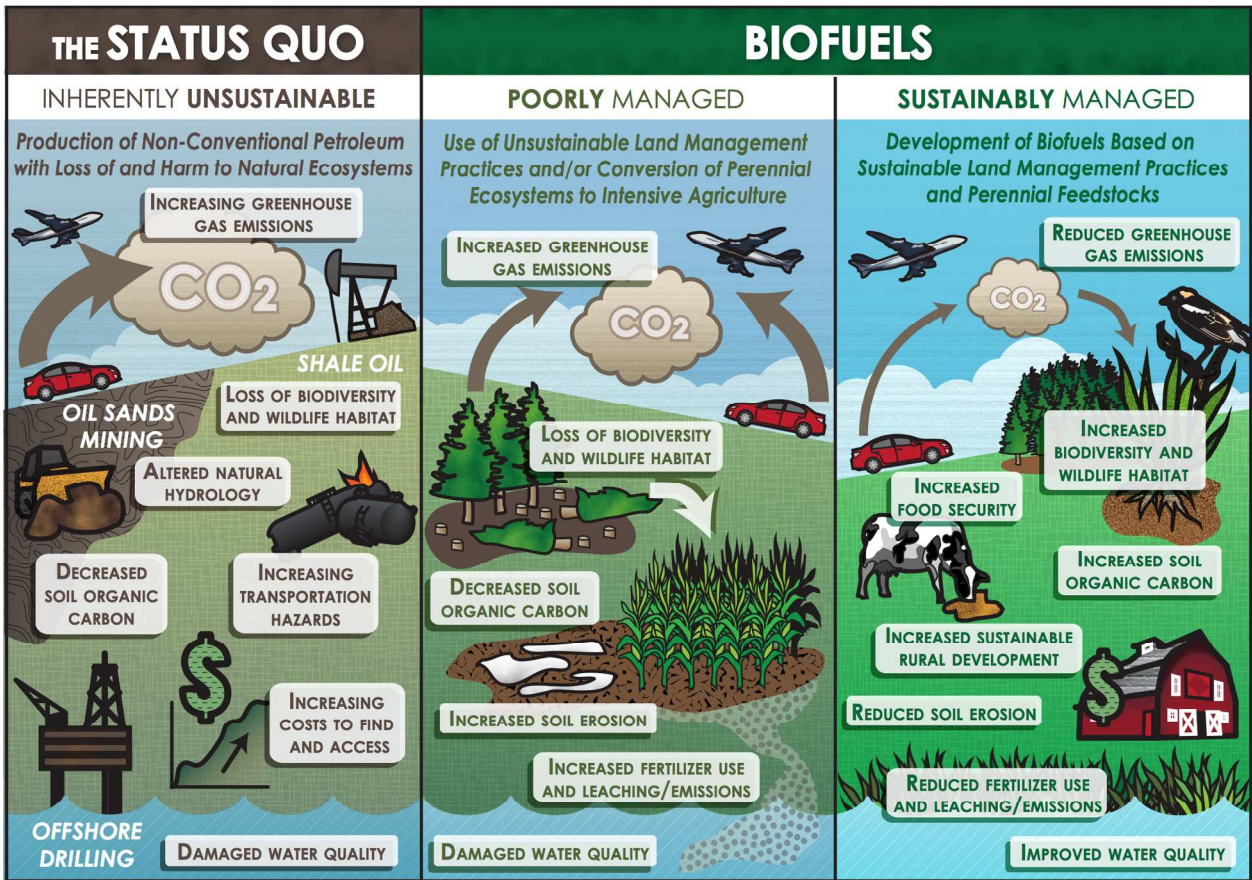


Figure 1: Social, Economic, and Environmental Impacts of Different Methods of Liquid Fuel Production: A Visual Comparison.

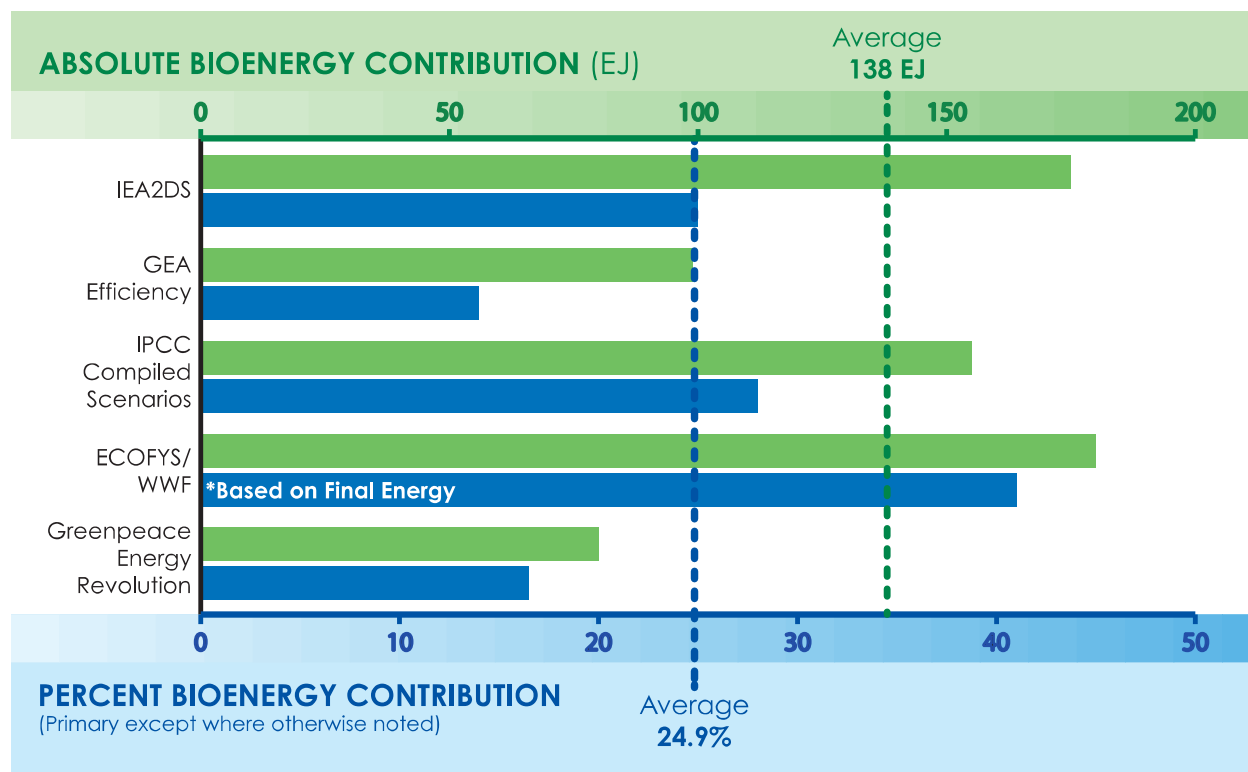


Figure 2: The Contribution of Bioenergy in Prominent Low Carbon Energy Scenarios. IEA 2DS: International Energy Agency Two Degree Scenario; GEA Efficiency: Global Energy Assessment Efficiency Scenario (“Illustrative” efficiency scenario, representative of a range of efficiency pathways); IPCC Compiled Studies: a) Absolute data are the median of 42 scenarios with CO₂ concentrations by 2100 < 440 ppm; b) Percentage data based on dividing a) by the average of total primary energy in two low carbon scenarios selected as being illustrative; ECOFYS/WWF: ECOFYS scenario developed in collaboration with the World Wildlife Fund (includes 21 EJ of algal oil); Greenpeace Energy Revolution. A summary of the data and assumptions and citations are included in the Supplemental Information.

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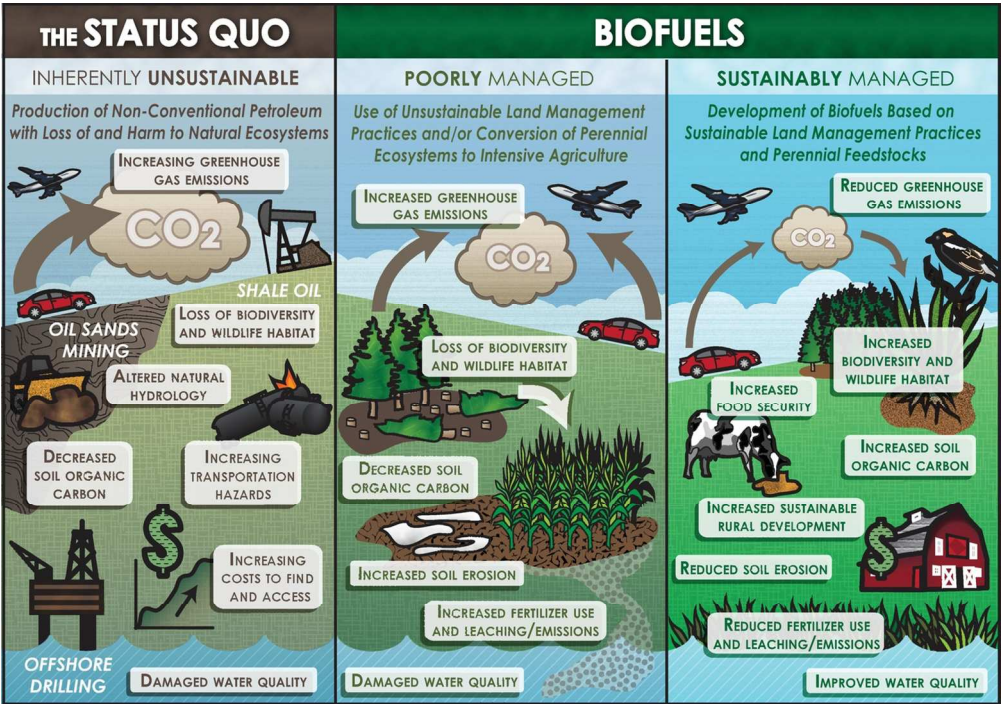
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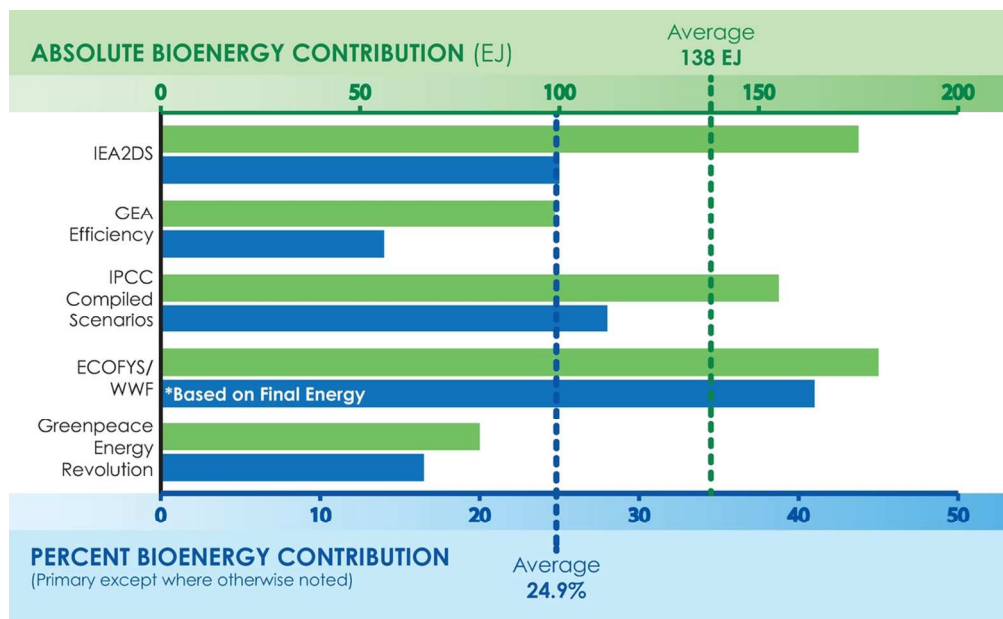
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References

1. Lambert, J. G.; Hall, C. A. S.; Balogh, S.; Gupta, A.; Arnold, M. Energy, EROI and quality of life. *Energy Policy* **2014**, *64*, 153-167.
2. Buyx, A.; Tait, J. Ethical framework for biofuels. *Science* **2011**, *332* (6029), 540-541.
3. Haughton, A. J.; Bond, A. J.; Lovett, A. A.; Dockerty, T.; Sünnerberg, G.; Clark, S. J.; Bohan, D. A.; Sage, R. B.; Mallott, M. D.; Mallott, V. E.; Cunningham, M. D.; Riche, A. B.; Shield, I. F.; Finch, J. W.; Turner, M. M.; Karp, A. A novel, integrated approach to assessing social, economic and environmental implications of changing rural land use: a case study of perennial biomass crops. *J. Appl. Ecol.* **2009**, *46* (2), 315-322.
4. Babcock, B. A.; Pouliot, S. B. Feasibility and cost of increasing US ethanol consumption beyond E10. *CARD Policy Briefs*, **2014**, 14-PB 17, 1-15.
5. Dale, B. E.; Bals, B. D.; Kim, S.; Eranki, P. Biofuels done right: Land efficient animal feeds enable environmental and energy benefits. *Environ. Sci. Technol.* **2010**, *44* (22), 8385-8389.
6. Feyereisen, G. W.; Camargo, G. G. T.; Baxter, R. E.; Baker, J. M.; Richard, T. L. Cellulosic biofuel potential of a winter rye double crop across the U.S. corn-soybean belt. *Agron. J.* **2013**, *105* (3), 631-642.
7. Jung, H. H.; Leone, T. G.; Shelby, M. H.; Anderson, J. E.; Collings, T. Fuel economy and CO₂ emissions of ethanol-gasoline blends in a turbocharged DI engine. *SAE Int. J. Engines.* **2013**, *6* (1), 422-434.
8. Kilkenny, M.; Partridge, M. D. Export sectors and rural development. *Am. J. Agric. Econ.* **2009**, *91* (4), 910-929.
9. Jonasson, E.; Helfand, S. M. How important are locational characteristics for rural non-agricultural employment? Lessons from Brazil. *World Dev.* **2010**, *38* (5), 727-741.
10. *World Development Report 2008: Agriculture for Development*. The World Bank: Washington, DC, 2008; DOI: 10.1596/978-0-8213-7233-3.
11. *The State of Food Insecurity in the World: How does international price volatility affect domestic economies and food security?* Food and Agriculture Organization of the United Nations: Rome, Italy, 2011; <http://www.fao.org/docrep/014/i2330e/i2330e.pdf>.
12. Tyner, W. E. Biofuels and food prices: Separating wheat from chaff. *Global Food Secur.* **2013**, *2* (2), 126-130.



Social, Economic, and Environmental Impacts of Different Methods of Liquid Fuel Production: A Visual Comparison.
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The Contribution of Bioenergy in Prominent Low Carbon Energy Scenarios. IEA 2DS: International Energy Agency Two Degree Scenario; GEA Efficiency: Global Energy Assessment Efficiency Scenario ("Illustrative" efficiency scenario, representative of a range of efficiency pathways); IPCC Compiled Studies: a) Absolute data are the median of 42 scenarios with CO₂ concentrations by 2100 < 440 ppm; b) Percentage data based on dividing a) by the average of total primary energy in two low carbon scenarios selected as being illustrative; ECOFYS/WWF: ECOFYS scenario developed in collaboration with the World Wildlife Fund (includes 21 EJ of algal oil); Greenpeace Energy Revolution. A summary of the data and assumptions and citations are included in the Supplemental Information.

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