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1 EXECUTIVE SUMMARY

In December 2009, we published Biofuels 2010: Spotting the Next Wave to provide a comprehensive market analysis of the global biofuels market. That report focused primarily on first- and second-generation ethanol and biodiesel. While first- and second-generation biofuels account for more than 99% of current global biofuel production, a number of important technologies are on the brink of commercialization that produce “drop-in” fuels with the same chemical characteristics of petroleum. In creating this report, Third and Fourth Generation Biofuels: Technologies, Markets, and Economics Through 2015, we wanted to examine the key players, technologies, and market applications that will drive the adoption of advanced biofuels.

First- and second-generation biofuels like ethanol and biodiesel have a number of inherent limitations that make them less than ideal as a long-term replacement for petroleum. The primary feedstocks for first-gen ethanol (corn and sugarcane) and biodiesel (rapeseed, soybeans, and palm) are all food-based crops that compete for scarce cropland, fresh water, and fertilizers. These fuels cannot be used in unmodified engines above small blends and are not applicable to the jet fuel market. While U.S. policy has mandated that increasing amounts of corn ethanol be blended into the domestic gasoline supply (15 BGY by 2015), the U.S. already appropriates 30% of its corn supply to displace about 6% of its gasoline consumption. While the coming years will see the commercialization of second-generation “cellulosic ethanol,” the lack of dedicated E85 fuel pumps and Flex-Fuel Vehicles (FFVs) as well as the encroachment upon the E10 “blend wall,” the limited energy density of ethanol, and the lack of ethanol-specific pipelines illustrate the challenges in depending upon ethanol as a long-term petroleum mitigation strategy.

Given that 2 billion people in “Chindia” are currently undergoing their industrial revolutions, combined with global population increases of 80M per year and increases in standards of living for non-OECD populations, we forecast global petroleum consumption to more than offset gains in corporate mileage efficiency and electrification of a portion of the transportation fleet. Combined with the fact that supplies of easily accessible “light sweet” crude are declining and oil prices are back above $80/bbl, the national security, environmental, and economic consequences of global dependence upon petroleum as a primary energy source is again at the forefront of policy discussions. The question of whether third- and fourth-generation biofuels are potential solutions is the basis of this inquiry. Some of the questions that this report attempts to answer include:

» What are the different types of advanced biofuels and which of them are relevant?
» What are the key technological pathways and what are their scale-up trajectories?
» Will advanced biofuels be price-competitive with petroleum without subsidies? If so, when?
» What are the short-, medium-, and long-term economics of algae, metabolically enhanced biofuel, and synthetic biofuels? Will any of these technologies ever displace significant volumes of liquid petroleum products?
This report is derived from conversations with more than 20 companies, as well as leading VCs, policymakers, and leading scientists in both academia and the private sector. Our interest in third-generation algae is driven by its superior yields (1,500-8,000 gal/acre/yr), ability to grow on marginal (non-crop) land, thus circumventing the “food vs. fuel debate,” capacity to thrive in brackish and/or saline water, and potential to recycle carbon from industrial power plants and remediate wastewater. Our discussions with leading algae companies like Solazyme, Solix, Sapphire Energy, Aurora, Algenol, Algae Systems, and Live Fuels suggest that the near-term economics will be driven by co-products and co-services while long-term cost improvements will occur as the steps of growth, harvesting, de-watering, drying, and oil extraction are consolidated. We believe that as oil prices increase, algae biofuels will achieve cost parity with petroleum in 2017/2018, resulting in 5.6 billion gallons of global production against 7.2 BGY of nameplate capacity in 2022.

While no commercial algae projects are expected for several years, there are a handful of fourth-generation facilities producing commercial volumes of “drop-in” fuel today.

Most thermo-chemical processes like biomass-to-liquids (BTL) or upgrading via “hydroprocessing” are extensions of commercial gasification or downstream petroleum refinery processes. While the logistics and costs of producing renewable diesel, gasoline, and jet fuel are currently more expensive and complex than refining petroleum, high diesel
taxes in Europe combined with cap-and-trade and continent-wide biofuel mandates are some of the reasons why European companies like ENI, Galp, Neste Oil, and Choren have commercial facilities that are either operating or will begin operating in the near future.

Fourth-generation biochemical methods largely involve the metabolic engineering of organisms to secrete biobutanol, ethanol, or drop-in fuels. Given that biochemical methods are extensions of fermentation, great opportunities exist for companies to leverage idle ethanol plants and drive down capital costs. Companies like Amyris, Gevo, and LS9 are utilizing this strategy and we expect commercial-scale projects to come online within the next two years.

**FIGURE 1-2: GLOBAL FOURTH-GENERATION BIOFUEL PRODUCTION IN BGY 2016-2022**

In 2010, we forecast global fourth-generation drop-in fuel production of 170 MGY, scaling to 19 billion gallons in 2022. One of the reasons why we are sanguine about the prospects for fourth-generation biofuels is that drop-in fuels are the only realistic short- to medium-term alternative for airplanes and long-haul diesel trucks. The battery constraints in electric vehicles suggest that such vehicles are only applicable to passenger and fleet vehicles. As such, the aggressive targets of the U.S. Air Force and other industry-wide consortia suggest that drop-in fuels represent the long-term future of biofuels.

By 2022, third- and fourth-generation biofuels should account for 28% of the global 88.5 billion gallons of biofuel production. Whereas biofuels currently displace 4.3% of global
gasoline and 1.5% of global diesel consumption, we forecast that by 2022, biofuels will replace almost 9% of the global jet fuel market, 8.4% of gasoline, and 7.4% of diesel.

If petroleum prices reach $250/bbl in 2022 --- as we believe is very likely --- 88 billion gallons of biofuel production will be a $567B industry. Combined, third- and fourth-generation biofuels will have a wholesale market value of $159B.
### FIGURE 1-5: COMPANIES DISCUSSED IN THIS REPORT

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Source: GTM Research
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