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This article originally appeared  
in the June 2010 issue of

Outlook

The journal of  
high-performance business

Industry Report | Energy

## From big oil to big algae? **Exploring 12 disruptive new transport fuels**

By Melissa Stark

Driven by concerns about energy security, CO<sub>2</sub> abatement and the desire to create green jobs, low-carbon energy solutions are on the cusp of commercialization. Tomorrow's transport fuels could be harvested, fermented and generated—not pumped out of the ground.

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In a 1925 interview with *The New York Times*, Henry Ford confidently predicted that the transportation fuel of the future would come from “apples, weeds, sawdust—almost anything.”

More than three-quarters of a century later, an overwhelming percentage of the world’s land, air and sea vehicles still run on oil. But while restrictions placed on the fledgling US alcohol fuel industry during Prohibition helped scuttle Ford’s prediction, volatile oil prices, environmental concerns and the potential to create green jobs have once again ignited interest in renewable transport fuels.

Accounting for roughly half the oil consumed globally every year and responsible for as much as 30 percent of all greenhouse gas (GHG) emissions, transport fuels are second only to power generation in their contribution to the planet’s energy and environmental challenge. With that challenge in mind, Accenture has selected 12 disruptive energy alternatives that, in the next five years, have the potential

to replace major portions of today’s hydrocarbon fuels while simultaneously reducing GHG emissions.

For a fuel to be considered disruptive, it needed to meet at least two of the following criteria: It could be scalable—that is, capable of meeting more than 20 percent of the world’s transport fuel demand by 2030; it could produce at least 30 percent fewer GHG emissions than the hydrocarbon fuel it replaces; it would be cost competitive with gasoline at an oil price of between \$45 and \$90 a barrel; or it could be commercialized in five years or less.

Four of the 12 technologies could be described as being evolutionary, meaning they would derive more from assets and resources already available. Five we consider revolutionary because they would enable biofuels to use the existing petroleum distribution infrastructure. The remaining three technologies, focused on electrification, are truly game changers: They overturn the liquid fuel paradigm altogether.

## Evolutionary

### ICE age tech, next-gen ag and trash-to-cash

The four evolutionary technologies would work by stretching today’s assets and resources; and while commercialization challenges remain, these technologies represent “no-regret” solutions that can have a significant impact on CO<sub>2</sub> emissions and boost energy independence today.

**1. The advanced internal combustion engine.** Although the internal combustion engine (or ICE) was a 19th century invention, it still

holds significant performance improvement potential. Given the correlation between GHG emissions and fuel economy, investing in advanced “ICE age” technologies that boost efficiency, such as next-generation direct gasoline fuel injection, can have a profound impact on GHG emissions.

Better yet, squeezing more miles per gallon out of conventional vehicles reduces carbon emissions and boosts energy security in

the same way proponents hope electric vehicles will—but sooner and at significantly less cost. Advanced ICEs meet all four criteria for a disruptive fuel technology: They are readily scalable, capable of delivering significant GHG reductions, cost effective and will likely be introduced in the next five years.

## 2. Next-generation agriculture.

Next-generation agriculture, which also has all four disruptive technology attributes, promises to provide the enhanced crop yields biofuel makers need to compete effectively with hydrocarbon. Clearly scalable, with significant GHG reductions and potentially cost competitive with oil, next-generation agriculture technologies are already beginning to be commercialized. Furthermore, with US corn yields already at nearly twice the world average, applying even basic agronomy practices in markets with low yields has the potential to improve returns dramatically.

Still in its infancy, “new agriculture” promises substantial future growth based on the potential of genetically modified crops to achieve desired characteristics, increase yields, and reduce harvesting and processing costs. Coupled with process innovations, new agriculture can achieve this growth while reducing water and energy consumption.

For cellulosic feedstocks, a major challenge involves the high cost of the crop deconstruction process. Improvements will likely come in this area from optimizing the whole system, from feedstock to production. The first cellulosic processing plants to go on stream will probably focus on feedstocks like corn fiber and corn cobs, which can work with first-generation infrastructure.

Take POET, the largest ethanol producer in the world. The Sioux

Falls, South Dakota-based company is planning to launch Project LIBERTY, its first commercial-scale, cellulosic ethanol plant, in 2011. By adding cellulosic production to an existing ethanol plant, POET estimates it will be able to produce 11 percent more ethanol per bushel of corn and 27 percent more per acre of corn, while using biomass to power the plant itself.

## 3. Waste-to-fuel.

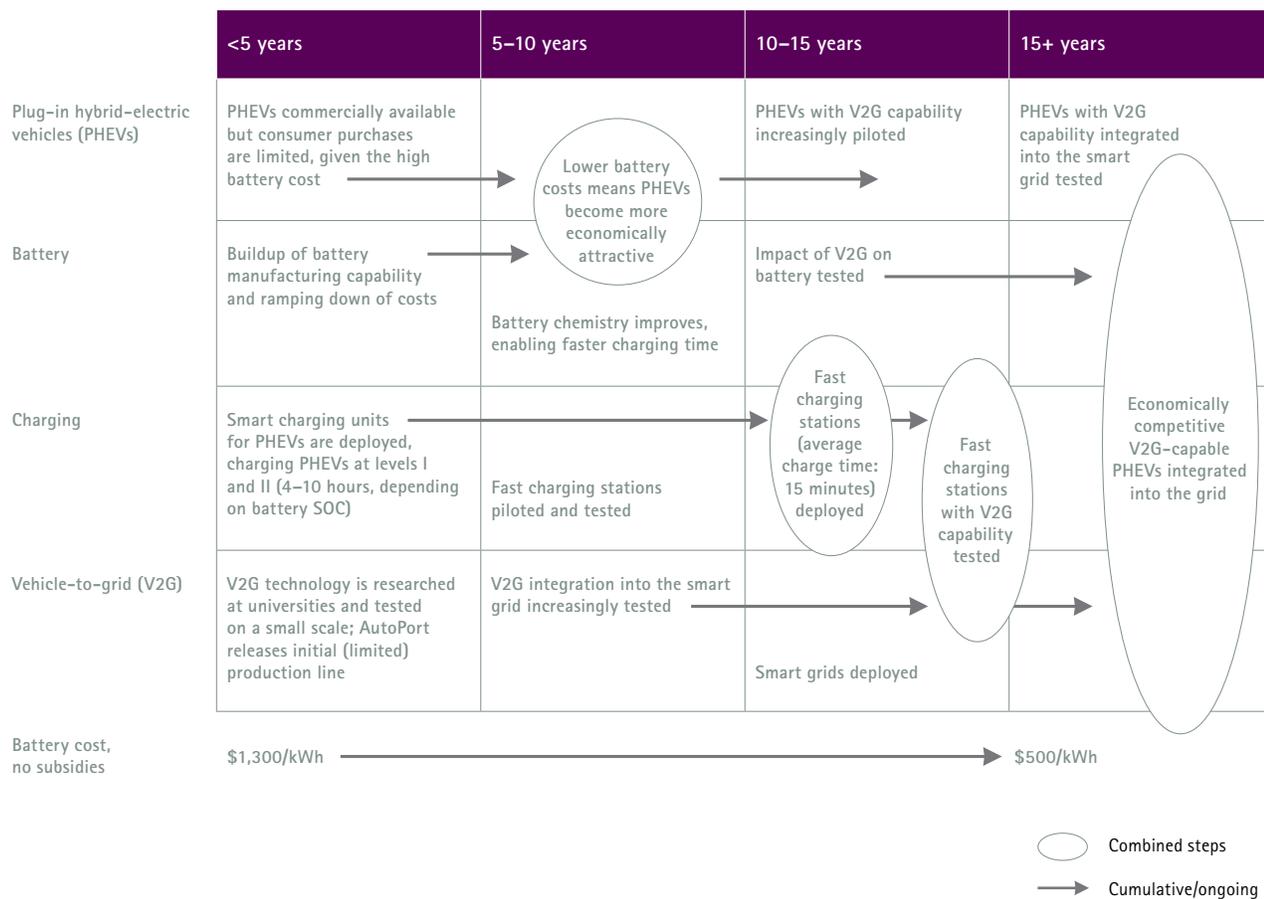
Turning trash into cash—producing transport biofuels from waste—involves technologies found primarily in the laboratory and in pilot stages of commercialization. A wide range of suitable sources of waste exist, including municipal solid waste; agricultural and forestry waste; used fats, oil and greases; and industrial flue waste gases. In parts of Northern Europe with limited landfill capacity, waste-to-fuel processes could ultimately become an important energy source.

But legislation and financial incentives are needed to expand this industry. If waste feedstock processing is ultimately brought to scale, it could solve two problems simultaneously: It would provide a source of low-cost, low-carbon renewable fuel and at least a partial solution to landfill shortages.

However, the scalability of waste-to-fuel technology remains uncertain, because of the objectives to reduce or recycle waste, coupled with its characteristics of smaller, distributed volumes that need to be aggregated to be processed. Otherwise, waste-to-fuel technologies meet three of the four disruptive technology standards: They would have a positive GHG impact and exhibit favorable economics; there are companies planning to be commercial in less than five years.

## Is there an electric car in your future?

As battery and charging station hurdles fall, electric vehicles will become increasingly competitive. Ultimately, plug-in hybrid-electric vehicles (PHEVs) will be integrated into the "smart" grid and will include vehicle-to-grid (V2G) capabilities that enable the transfer of energy both to and from the grid.



Source: Accenture analysis

Consider Lanzatech NZ of New Zealand. The company has proprietary gas fermentation technology that can produce ethanol from industrial waste gas or "syngas," a gas mixture containing carbon monoxide and hydrogen. The company hopes to fully commercialize the technology by 2013.

**4. Marine scrubbers.** The International Maritime Organization has agreed to limit marine vessel sulfur oxide emissions to 0.5 percent by 2020 from the current 4.5 percent level. Marine scrubbers—shipboard exhaust gas sulfur removal systems—would enable industries to forgo the large capital

investments needed to upgrade refineries to produce more low-sulfur fuel oil.

While marine scrubbing is technically feasible—several companies have successfully tested the technology in demonstration projects—investors so far have remained on the sidelines. Marine scrubbers are scalable; will have a positive impact on GHG emissions by making it possible to avoid upgrading high-sulfur fuel oil to meet the new limit; and will be commercialized by 2011. Cost, however, remains an issue.

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## New transport fuels: Creating public and business value

Tomorrow's transport fuel market will include multitudes of new and old participants, including players in the energy, chemicals, agriculture, pharmaceuticals and consumer electronics industries, as well as governments, utilities and battery manufacturers. As a result, the wave of disruptive new transport fuels heading this way will likely cause governments and industry managers to reassess their strategies for creating public and business value, respectively, in this dynamic new sector.

While each participant likely faces unique challenges, Accenture has identified a number of capabilities most businesses will need to achieve high performance.

- **Make sure technologists lead.** Scientists and engineers need to be in leadership positions, because the investment and policy debate requires participants to know the science and understand the challenges in deploying it. Commercialization success will require companies to provide fact-based explanations to regulators and the public, and to address technical questions frankly and honestly. From a technology perspective, winning firms will have strong R&D capabilities and the ability to integrate different technological solutions.
- **Create flexible partnership and business models.** Cooperation across many industries will drive success. In our research of more than 100 companies, we found that firms currently employ many different operating models because of the need to complement and enhance in-house capabilities, and that preferred business models will emerge as commercialization begins to shape how markets operate.
- **Keep policy makers close.** Industry regulation will evolve with each new technology, and policy makers will make trade-offs across technologies, adding successfully commercialized new fuel solutions as they arise.
- **Develop clear baseline assumptions and actively track the market.** With new technologies being developed almost daily, companies and governments need to understand how fresh information affects their technologies,

go-to-market strategies and regulatory positions. Accenture has developed an approach that analyzes improvement drivers and generates forward-looking S-curves to understand the evolution of costs and markets.

- **Execute effectively.** Companies need to attain project management excellence and successfully optimize their supply chains. Because the cost-per-mile performance of these technologies will compete with gasoline and diesel, maximizing operating margins will help companies ensure long-term profitability.
- **Actively manage risk.** Risk exists in both biofuels and electrification. In biofuels, while government mandates can guarantee a level of demand, their correlation with feedstock availability tends to be very weak, because of a lack of transparency into a fuel's potential supply and cost. New feedstocks will be even more challenging, because no market exists to set prices. In the electricity markets, demand itself represents the uncertainty. In all three cases, players need to find ways to share and manage risk with other stakeholders.
- **Secure long-term, flexible capital.** Even for technologies that will be commercial in five years, actual business scale-up could take longer than anticipated. For technologies that take more than five years to commercialize, companies should recognize they may be in pilot or demonstration stages for many years and thus plan accordingly.
- **Develop market-specific strategies.** Local agendas and local resources will likely drive investments in new transport fuels. To boost their chances of market success, companies should learn from and take advantage of what has already been done around the world.

The move from the oil patch to the grid or the farm will likely happen faster than many companies imagine—which will significantly disrupt the transport fuel business. As a result, governments and industry players alike need to anticipate and prepare for the more complex game this dynamic new multi-fuel world promises.

## Revolutionary Farming for fungible fuels

“Fungible fuels” offer the same or better energy content as today’s hydrocarbons and—here’s the revolutionary part—can be “dropped” into the existing fuel distribution infrastructure. To be fungible, a fuel should offer the same or better energy content as today’s hydrocarbons, and should use the same distribution pipelines, tankers and other assets. Once perfected, these renewable fuels eliminate the distribution constraints on bio-fuels, enabling producers to rapidly scale up operations. They include sugarcane-to-diesel, butanol, bio-crude, algae and airline “drop-ins.” These fuels dramatically reduce GHG emissions.

**1. Synthetic biology: Sugarcane-to-diesel.** Finding a plentiful and lower-cost biofuel with enough energy content to serve as a viable substitute for diesel has become a holy grail of sorts, due to the outsized role that fuel plays in a multitude of key industries, including trucking, construction, maritime and agriculture. Synthetic biology—the design of novel biological systems and living organisms using engineering principles—has recently opened a feasible sugarcane-to-diesel pathway.

Today, companies using these techniques have developed microbes that can convert sugarcane into ultra-clean diesel fuel. If the fuel’s economics can approach those of sugarcane-to-ethanol, sugarcane-to-diesel could have significant potential, given the cost and availability of sugarcane compared with traditional biodiesel feedstocks like palm, soy and rapeseed.

Converting sugars to diesel fuel using synthetic biology is close to

commercial viability, and sugarcane-to-diesel meets all four disruptive technology criteria, with scalability, GHG impact (an 88 percent reduction), cost (the first commercial plant expects costs in the \$45- to \$75-per-barrel range) and time to market (commercialization expected in 2011).

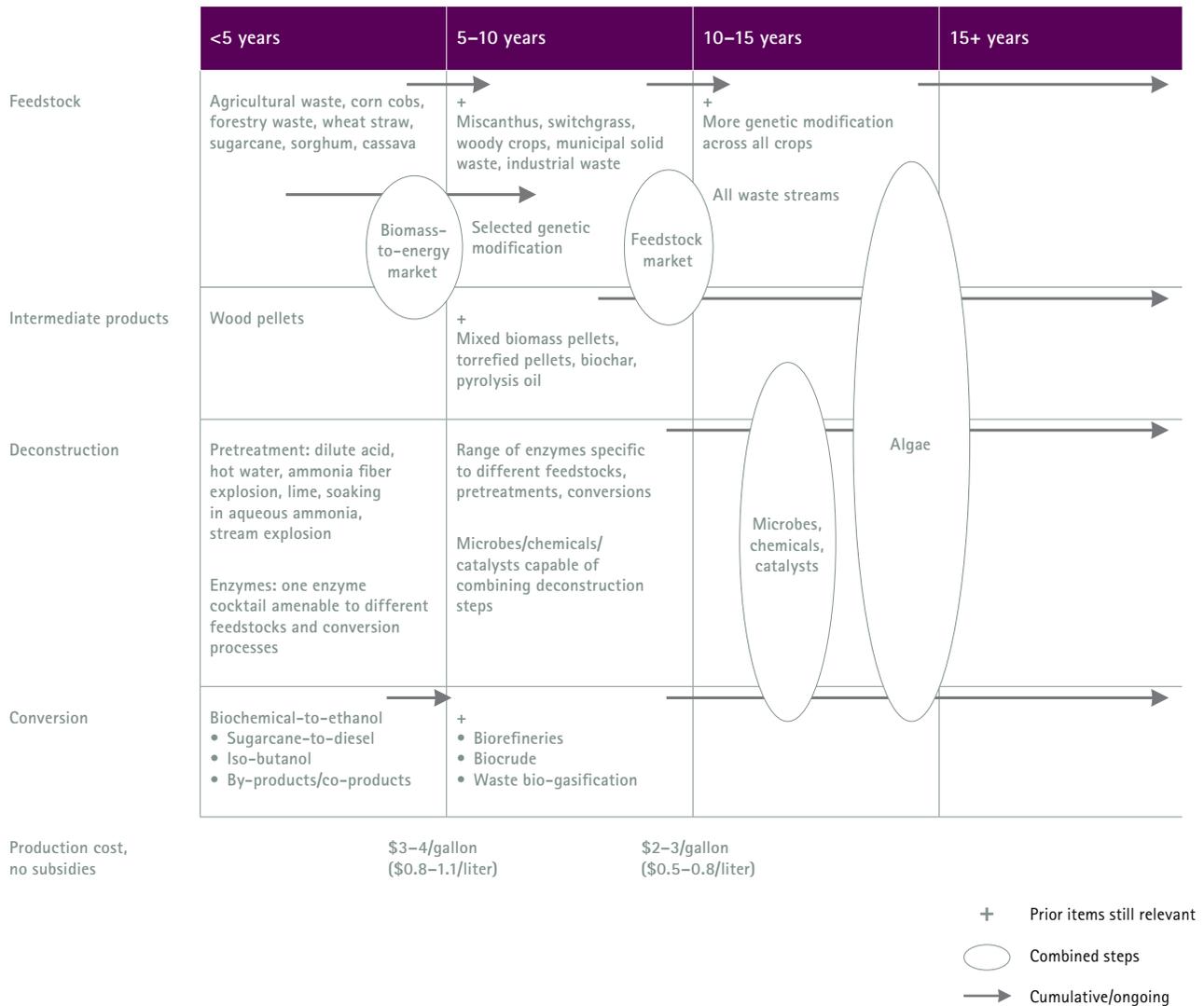
One trailblazer in this field is Amyris Biotechnologies, a California-based renewable products company. Amyris has developed a process that alters the metabolic pathways of microorganisms such as yeasts, creating living “factories” that produce molecules with defined practical applications. One product from this process is a renewable diesel fuel that has two times the energy density of hydrous ethanol and that burns cleanly (compared with traditional diesel fuel) with low particulate emissions.

**2. Butanol.** A “four-carbon” alcohol, biobutanol provides improved energy content compared with two-carbon fuels like ethanol. As a result, it offers energy content more similar to gasoline but with higher octane levels, and is less sensitive to water than ethanol. This last point makes it possible to transport biobutanol through existing petroleum pipelines and infrastructure and to blend it with gasoline at ratios much higher than those possible with ethanol.

In the past, several issues, including toxicity in the fermentation process and resulting low yields, hampered butanol production. But today, companies have developed microbes or biocatalysts and associated processes able to overcome these challenges. Biobutanol meets all

# The biofuels bounty

Biofuels will benefit from continued yield improvements as well as from the introduction of new intermediate products, such as mixed biomass pellets, and more efficient deconstruction processes. Algae, which hold significant biofuel promise, probably will not be fully commercialized for 10 years.



Source: Accenture analysis

four requirements for a disruptive technology: scalability, potential GHG reductions of 80 percent, target cost per barrel of \$50 to \$60 and commercialization by 2014.

Butamax Advanced Biofuels, a BP and DuPont joint venture formed to develop and market biobutanol, intends to bring the fuel to market at a cost that competes with ethanol. The company focuses on all aspects of biobutanol development, produc-

tion, distribution and commercialization. It plans to begin commercial operations in the next few years.

**3. Biocrude.** Biocrude is an intermediate product that renewable energy players can further process into any type of transport fuel, just like petroleum crude. Made by converting the cellulose and lignin in biomass such as trees and grasses into a green hydrocarbon, biocrude has enormous potential because it is

Biocrude has enormous potential because it is a renewable alternate to diesel, jet fuel and gasoline.

a renewable alternative to diesel, jet fuel and gasoline that is capable of using existing petroleum infrastructure. But many challenges remain.

Several technologies can currently turn biomass into biocrude, including one that involves thermochemical decomposition and a subsequent upgrading process. With relatively little extra investment, these technologies can take advantage of existing refining and distribution infrastructure, and could lead to a breakthrough in the adoption of renewable fuels worldwide. Biocrude meets all four disruptive technology criteria. It is scalable, although as with all biomass conversion processes, feedstock availability could be a bottleneck; it could have a GHG reduction impact greater than 30 percent; it is expected to be cost competitive; and it will likely be commercialized within five years.

Licella, an Australian technology startup, has developed a proprietary process for the production of bio-oil called catalytic hydrothermal upgrading, and it has a modular plant ready to scale up to full commercial volumes. Licella's product is stable and does not suffer from rapid deterioration the way some similar oils do. As a result, plants can be located away from refineries, providing a substantial logistical advantage.

**4. Algae.** Although offering yields 25 times greater than soybeans, algae-based fuels can cost an uncompetitive \$8 to \$30 per gallon to produce, and algae could require genetic modification to meet its full potential as a fuel.

Instead of using algae as a feedstock (photosynthetic algae), some companies are experimenting with different applications where algae is fed sugars and subsequently produces

oils that can be converted to an intermediate or diesel (heterotrophic algae). Algae-based fuels are scalable and will have a major impact on GHG emissions, but as mentioned above, they are currently too expensive, and they will take up to 10 years to commercialize.

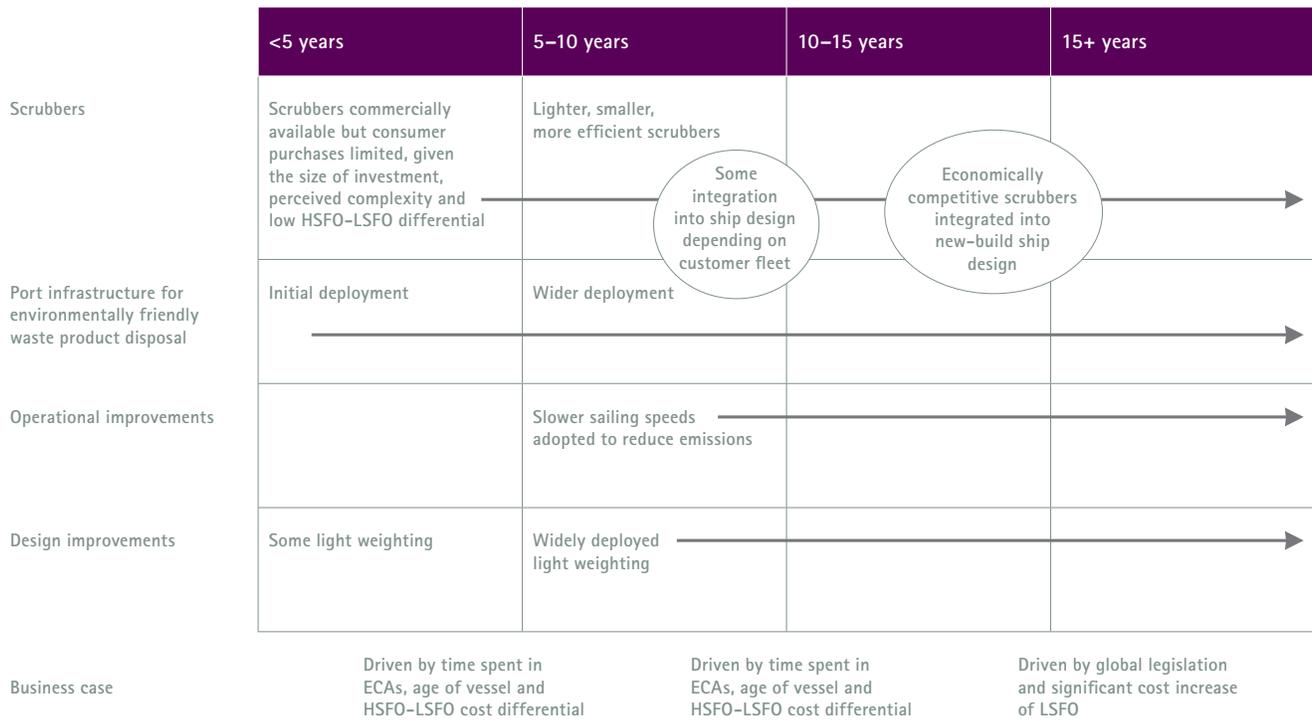
South San Francisco-based Solazyme, a pioneer in algal biotechnology, uses proprietary strains of wild and engineered algae with its own cutting-edge technologies to produce renewable oils for a number of markets, including transport fuels. Solazyme is the only next-generation microbial fermentation company to have delivered significant quantities of fuel, and it has several contracts to deliver advanced biofuels from algal oil to the US military.

**5. Airline drop-ins.** Market and regulatory forces are increasing pressure on the aviation industry to boost energy efficiency and reduce carbon emissions. Biofuels represent a viable way for the industry to cut greenhouse gases, since many of the technology challenges have already been overcome.

Test flights have proven the technical feasibility of aviation biofuels, which can be dropped without modification into the current aviation fueling infrastructure. In addition, aviation biofuels have significant potential to reduce emissions, although feedstock availability remains an issue. And given the current cost of drop-ins, feedstock supply limitations and competition from road transport for these fuels, being competitive with current jet fuel and meeting scale requirements could be major issues. While airline drop-ins satisfy the scale and GHG impact criteria, they currently do not meet disruptive technology cost and time-to-market criteria.

## Scrubbing sulfur at sea

Marine scrubber technology provides a shipboard method of removing sulfur emissions, enabling fleets to meet new, tighter regulations. Within 15 years, economically competitive scrubbers will be routinely integrated into new ship designs.



- HSFO High-sulfur fuel oil
- LSFO Low-sulfur fuel oil
- Combined steps
- Cumulative/ongoing

Source: Accenture analysis

## Game changers

### Betting on advanced batteries

What about electricity, something of a granddaddy of alternative energy? The cost and performance of advanced batteries are the biggest challenges to the electrification of transport. Plug-in hybrid-electric vehicles, or PHEVs, could become the most disruptive technology of all, but without regulatory incentives, the upfront cost of batteries will limit broad uptake.

Charging infrastructure will play a key enabling role in achieving mass PHEV use, while vehicle-to-grid

technology, which remains more than a decade away from commercialization, will ultimately enable two way communication and optimization between the electric car and the grid.

1. **Plug-in hybrid-electric vehicles.** Plug-in electric vehicles (PEVs), which include both PHEVs and non-hybrid “pure” electric vehicles, have received increasing amounts of attention and support from governments and industry alike, and they will probably become part of the vehicle landscape within the

## For further reading

"A climate for change," *Outlook*, September 2008

"Biofuels' Time of Transition—Achieving High Performance in a World of Increasing Fuel Diversity" (Accenture, 2008)

"Irrational Exuberance—A Supply Perspective" (Accenture, 2007)

next five years. PHEVs provide greater environmental benefits and lower operating costs than either ICEs or hybrid-electric vehicles, and they offer an extended driving range, compared with pure electric vehicles.

But the industry must still overcome the high capital costs associated with PHEV batteries for the economics to work favorably without regulatory incentives. Moreover, while PHEVs could potentially operate emission-free, GHG emissions reductions depend largely on the electricity source (for example, coal, natural gas or nuclear power) and will therefore vary by market. PHEVs meet the GHG impact and time-to-market criteria for disruptive technologies. But battery constraints could limit their scalability, and they currently cost \$4,500 to \$6,000 more than comparable ICE vehicles.

**2. Charging technology.** Large-scale PEV charging will require grid optimization. For example, maximizing the charging that occurs during off-peak electricity demand hours would enable electric utilities to manage energy demand more effectively and consumers to benefit from lower off-peak rates. As a result, charging technology will play a key role in expanding the penetration of plug-in electric vehicles, and municipalities worldwide have already announced ambitious PEV charging infrastructure launches.

The scalability of the controlled charging market will depend largely on demand for PEVs, which

itself requires support and incentives from policymakers and industry. Otherwise, controlled charging fits our definition of disruptive in that it will have a significant GHG impact, it supports a fuel cost competitive with \$40-per barrel oil and it is currently being rolled out in pilot projects across the globe.

**3. Vehicle-to-grid (V2G) technology.** Technically feasible, full-scale vehicle-to-grid commercialization will require high PEV penetration levels. (V2G seeks to establish a two-way power flow between the grid and plugged-in PEVs.) Key areas being tested are V2G information flow, expanded vehicle energy storage and the creation of an integrated smart grid. V2G could significantly disrupt conventional electricity supply and demand relationships—with electricity end users potentially becoming an essential grid storage resource. As a result, V2G could change both the electric power and transport fuel landscapes. The technology currently meets only the GHG impact criteria, where it can potentially achieve GHG reductions of up to 99 percent.

The Delaware-based Mid-Atlantic Grid Interactive Cars Consortium (aka, MAGICC), which includes members from across the United States, helps to develop V2G technology that enables a bidirectional power flow to and from the grid, making it possible to transfer high power to the grid at a very low cost.

The transport fuel industry is about to enter an innovative and exciting era, as newly commercialized alternative fuels and advanced technologies combine to lower GHG emissions, open new industries and compete to reduce dependence on the petroleum barrel. In 10 to 15 years, for example, advanced ICEs will likely achieve 100 miles-per-gallon fuel efficiency; algae could power entire fleets of trucks, trains and tractors; and consumers will routinely travel in PHEVs integrated into smart grids.

Unlike the distant dream of Henry Ford, these fuel technologies are emerging now, and affected industries need to begin planning today to take full advantage of the new transport fueling options coming tomorrow.

## About the author

**Melissa Stark** is the Clean Energy lead for the Accenture Energy industry group. She has more than 16 years' experience in management consulting, working across all sectors of the energy industry. Ms. Stark is based in London.

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