Betting on Science

Disruptive Technologies in Transport Fuels

Study Overview

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1. Study Overview

Never before has there been so much uncertainty about the future supply and demand of hydrocarbons.

There are a number of reasons for this uncertainty, but technology assumptions are a key driver. New technologies that either have higher yields per unit of energy input, or allow new sources of energy to be cost-competitive have the potential to completely change future supply and demand levels. In addition, future options to reduce greenhouse gases (GHGs) will vary from those being widely considered today. Transport fuels account for approximately 50 percent of global primary oil consumption and up to 30 percent of global carbon dioxide (CO_2) emissions.[1]

Accenture's study looks at technologies in transport fuels that have the potential to "disrupt" the current views of supply, demand and GHG emissions in the next 10 years.

Accenture's research examines the technologies through three lenses:

- **Specific technologies:** What are some of the most interesting technologies that could fundamentally change the supply and demand equation of transportation fuels and/or affect the GHG footprint?
- **Representative companies:** Who are the innovative companies that claim to be close to commercialization of these technologies (that is, will achieve commercialization in less than five years, or by 2014), and what are their thoughts and aspirations?
- **Particular markets:** Where are regulation and private investment going, and what are the implications of this direction for different markets around the world?

For a technology to be considered "disruptive", it needed to meet the following criteria:

- **Scaleable:** Greater than 20 percent potential impact on hydrocarbon fuel demand by 2030.
- **GHG impact:** Savings greater than 30 percent relative to the hydrocarbon it is replacing.
- **Cost:** Competitive at an oil price of $45 to $90 per barrel, at commercial date.
- **Time to market:** Commercialization date in less than five years.

In addition, we divided the technologies into three groups:

- **Evolutionary:** Technologies that stretch today's assets and resources. Although there are still challenges in commercializing these technologies, we believe these are "no-regret" technologies, as they represent actions that can be made today to make a significant impact on CO_2, energy security and the optimization of local resources.
- **Revolutionary:** Technologies that support the creation of fungible fuels, enabling the use of the existing distribution infrastructure. These technologies would remove the distribution infrastructure constraints on the speed and scale of penetration of biomass-based fuel.
- **The game changer:** Electrification and the technologies that are needed for the scale-up of PHEVs and to enable the opportunities that PHEVs could bring in optimizing generation and transportation resources. This section will provide insight into how and how quickly electrification can happen.

The purpose of this study was to demystify these technologies—by providing data on when and what the trajectory might be for commercial viability—and by highlighting the key challenges in economically bringing these technologies to market.

"***Betting on Science***" aims to present a balanced perspective of these technologies and to showcase a glimpse of a future where hydrocarbons are not the only viable transport fuel for mass populations. Fostering a deeper understanding of emerging technologies can help regulators enact policies, and help companies achieve high performance by developing strategies that address GHG issues sooner rather than later.

What drives great companies?

Accenture is committed to uncovering the key ingredients to help each of our clients develop into a high-performance business. Accenture's first biofuels study, *"Irrational exuberance"? An assessment of how the burgeoning biofuels market can enable high performance—a supply perspective* (2007), explored the renewed emphasis of biofuels on the global stage. The following year, we released *"Biofuels' time of transition: Achieving high performance in a world of increasing fuel diversity."* This study further examines the future of fuel diversity, but explores options much broader than biofuels such as vehicle electrification and the evolution of the internal combustion engine. Through our ongoing High Performance Business research, Accenture is committed to helping our clients in all industries achieve high performance. To review findings from our other research and experiences with more than 500 high performers, visit www.accenture.com.

Key findings

As part of this research, Accenture reviewed more than 100 companies, interviewed over 30 and included case studies on over 20 across the 12 technologies that have been covered. The case studies are not Accenture's endorsements of the companies. However, the case studies are important because nothing is more insightful than understanding the views of the players driving the change. We have also analyzed 10 markets, as we believe domestic resources and agendas will continue to drive the solutions.

Tables 3, 4 and 5 later in this section summarize our assessment across the technologies. In almost all cases, at least 2 of 4 criteria (used to determine whether a technology was "disruptive") were met for the technologies featured in this report. Most of the technologies met all four criteria. It is therefore reasonable to believe that these technologies will have an impact on supply, demand and GHG emissions in the relatively near future if successfully commercialized.

This Accenture report highlights the following 10 key findings:

1. **There is low-hanging fruit where the debate should no longer be about "if" or "how," but about "when" and "how fast."** Proactive government regulation has the potential to support and accelerate the sustainable development of these technologies. For example:

   - **Increasing yields without significantly increasing land use**. Hybrid genetics and biotechnology have driven a five-fold increase in average United States (US) corn yields since 1940.[2] Because there is a significant difference in crop yields around the world (see Figure 1), there is still potential to implement similar yield increases in other parts of the world, relatively quickly. For example, better agronomy practices in Malawi increased corn yields from 1.2 million metric tons in 2005, to 2.7 million metric tons in 2006, and then 3.4 million metric tons in 2007.[3] These technologies and practices can (and are) being applied to other crops.
   - **Rewarding improvements in water and energy use.** The reduction of energy and water use, when made a priority, has significant potential to change the GHG footprint. For example, POET has achieved an 80 percent reduction in water use versus ethanol production since 1987.[4]
   - **Supporting the use of waste to create energy or fuel**. Waste is an underutilized feedstock that will be increasingly used for energy or upgraded to increase product yields.[5] The support for the "waste-to-energy" and "waste-to-fuel" markets creates more demand for service providers to collect and transport the waste.
   - **Continuing roll-out of higher-efficiency standards.** The higher-efficiency standards that governments require provide an incentive for companies to continue to improve the miles per gallon (mpg) of their combustion engines. Companies profiled in this report are claiming up to 50 percent improvements, albeit with disparity across markets (for example, in 2009, Europe at 49 mpg and Japan at 46.9 mpg, are almost double the US at 27.5 mpg); this could deliver a significant shift in the forecasted growth in demand globally.

Figure 1. Corn yield trends [6]

Corn yield trends (Bushel per acre)	1990	2000	2005
World average	**59**	**70**	**75**
USA	113	137	149
Argentina	60	93	109
China	74	78	80
Brazil	33	47	54
India	23	29	31
Sub-Saharan Africa	22	24	25

2. **Genetic engineering is transforming biofuel production** (feedstock, deconstruction and conversion), often eliminating, combining or simplifying steps. For example:

- Genetically engineered feedstocks that increase the yield density and reduce the intensity of pre-treatment and required enzyme. There is even research being done to build the enzyme into the feedstock.
- A "diesel" solution through synthetic biology that allows sugar cane to be converted into a clean diesel.
- Microbes that have been able to overcome the toxicity challenges of converting starches and sugars to butanol.
- Genetically modified algae that have higher yields and can be cultivated and harvested at lower cost.

Figure 2. Wider applications of genetic engineering

	Application	Examples of players
Feedstock	• Genetically modified crops, with improved characteristics: - Drought/disease resistance - Faster, improved yield, more uniform growth - Decreased nutrient requirement - Greater seed durability - "Single harvest only" growth	• Mendel • Ceres • Monsanto • Syngenta
Enzyme	• Genetically enhanced microbial enzymes that are: - More efficient: achieve higher sugar yields - More cost effective: requires lower dosage, lower temperatures - More resilient to range of inhibitors produced upstream • Crop-produced enzymes (hydrolytic enzymes to reduce subsequent pre-treatment)	• Genencor • Novozymes • Edenspace • Zymetis
Conversion	• Biofermentation/biocatalytic conversion: microbe-based conversion of either sugar-to-fuel (diesel, gasoline) or syngas-to-ethanol • Microbes are cheaper than conventional catalysts, continually regenerate, can be engineered to be tolerant to more impurities and operate at a broader range of temperatures/pressures	• Mascoma • QTEROS • Amyris • LS9, Inc. • Gevo • Solazyme
By/co-product upgrading and other products	• Engineered organisms produce chemicals, with increased yield and productivity • Upgrading of byproducts of biofuel production (e.g., glycerin) process using modified organisms for the fermentation process (cheaper than traditional petrochemical route)	• GlycosBio

3. **Algae could exponentially increase available feedstock.** In a 2007 Accenture biofuels report, we estimated that first-generation feedstocks for ethanol and biodiesel (for example, sugar cane, corn, cassava, sweet sorghum, sugar beet, soy, rapeseed and palm) could provide for 10 to 15 percent of global fuel transportation demand. Accenture's view today is that these first generation feedstocks could stretch further, particularly with the inclusion of waste and the continued evolution of the feedstocks as noted above; however, scale is still limited by available biomass. The synthetic biology (sugar cane to diesel) and butanol pathways are also limited by the same feedstock constraints. However, the addition of algae used as feedstock, with its incredibly high yields, changes the game on potential biofuel feedstock availability (see Table 1).

Table 1. Comparison of algae and soybean resource requirements[7]

	Soybean	Algae*
Gallons oil/year	3 billion	3 billion
Gallons oil/acre	48	1,200
Total acres	62.5 million	2.5 million

*Based on algae grown in open ponds with daily productivity of 10 grams/m^2 with 15 percent triacyglycerol (TAG).

However, of all the technologies Accenture has reviewed in this study, we believe that algae will be the most difficult and will take the longest to achieve commercial scale. Furthermore, based on our review of more than 20 players, it will take significant long-term commitment to reduce our current cost estimates—ranging from approximately $2 to $8 per liter ($8 to $30 per gallon) and to scale-up the production of strains and processes that are company-specific, environment-specific (i.e., location and conditions), and have multiple interdependent steps. However, this report contains case studies of three algae companies, all of whom claim that they will reach the first commercial plant stage in less than five years. If they are successful, then the scale-up of algae may be seen more quickly. In addition, recent commitments by ExxonMobil to invest $600 million in algae research in cooperation with Synthetic Genomics; Chevron's investment in Solazyme; Valero's investment in Solix; Shell's investment in Cellana; and the recently announced Joint Development Agreement between BP and Martek, suggest that the major oil companies are in algae for the long term. Although Accenture believes it will take 10 years for algae to reach commercial stage, the companies featured in this report could prove us wrong.

4. **Technologies and assets will be combined and evolve.** The lines between technologies and how they will be commercialized are gray. Accenture's view is that the final scale will be achieved by a combination of first- AND second-generation technologies—rather than by any one technology in isolation. There is increasing creative application of multiple technologies to the process of using biomass to produce different products, while continuing to reduce costs. For example:

- **Custom application of novel technologies for multiple, differing processes** – Amyris, LS9, Gevo, Solazyme and Glycos Biotechnologies are all using synthetic biology techniques in their fermentation processes. However, as they produce different products or use different feedstocks, we have classified them differently in this report.
- **Integrating new technologies into existing plants** – Examples include retrofitting existing ethanol plants into butanol plants (Gevo), or sugar cane ethanol to diesel (Amyris), or corn ethanol to also process cobs (POET), or refineries to process bio-crude (Licella, Ensyn).

- **A blurring of the traditional chemical processes** – Companies are combining biochemical and thermochemical processes, particularly in the processing of waste (for example, LanzaTech and Coskata's "hybrid" processes).
- **Deriving benefits from integrating existing processes with other technologies** – The importance of pretreatment for cellulosic ethanol production (for example, when using grasses as a feedstock) is an element of the value chain that is now also applicable to some bio-crude technologies (for example, catalytic hydrothermal upgrading a.k.a. Cat-HTU).

5. **Batteries are the "feedstock" of electrification and constrain its potential.** The case for the electrification of vehicles is well understood. This is evidenced by the regulatory and private support for plug-in hybrid electric vehicles (PHEVs). However, in the same way that feedstock characteristics and supply constrain the potential of biofuels, battery characteristics and supply constrain electrification, highlighting a number of challenges that need to be overcome.

   Today, only lithium-ion batteries can provide the necessary energy density and power density required for PHEVs. However, lithium is expensive, combustible, and scarce (there are currently only 11 major producing countries, dominated by South America, with a number of sources being remote and difficult to access). Production is also concentrated in three countries: China, Japan and South Korea. Given these constraints, many of the countries supporting electrification of vehicles are increasingly recognizing that developing battery capabilities is as important as supporting the purchase of PHEVs or building charging infrastructure. For example, the US has earmarked $2.4 billion for battery development[8], and both A123 and GM are building lithium-ion battery manufacturing plants in Michigan.[9] Although this addresses some of the production risks, the United States will still need to import almost all of the lithium required.

6. **Electrification heralds two key players in transport fuels—utilities and battery manufacturers.** The transport fuels industry has been dominated by international oil companies (IOCs) for decades. Although there are some successful independents in different parts of the oil value chain, it has been difficult for new entrants to compete with the capital strength and asset/distribution control of the IOCs and national oil companies (NOCs). Utilities are a different story. Unlike agribusinesses entering big oil, where the distribution was controlled by the IOCs, utilities will not rely on IOCs for distribution. Utilities have the capital strength and a distribution infrastructure that could make cars running on electricity a reality. Many lithium-ion battery manufacturers are also large global players (for example, Panasonic). Provided governments and automotive companies continue to be supportive, utilities and battery manufacturers are well-positioned to make electric vehicles a reality.

Table 2. Both utilities and battery manufacturers are well-positioned to play a successful role in the future of transportation[10].

		Business segments	Financials	Pilot
Utility	Pacific Gas and Electric Company	Supplier of electricity, natural gas, hydroelectric power	2008: $40.9 billion (total assets); $14.6 billion (operating revenues)	Piloted plug-in Prius in 2006. Testing four EVs (Ford Escape PHEV, Scion e-box BEV, Mitsubishi i-Miev and a second Toyota Prius PHEV) in their own fleet.
Battery manufacturer	Panasonic	Digital audio-visual communication networks; home appliances; components and devices; Panasonic Electric Works; other (welding, trading, EV energy)	2008: $69 billion (total assets); $83.5 billion (sales)	Ni-MH batteries already mass-produced for hybrid electric vehicles (HEVs) at several manufacturing facilities, since 2000. Plans to expand lithium-ion manufacturing bases (Osaka and Wakayama, Japan).
International oil company	Chevron	Exploration and production (oil, natural gas); manufacturing, marketing and transportation; other (chemicals, mining, power, technology)	2008: $161 billion (total assets); $265 billion (sales)	

7. **At least in the next five years, possibly even 10, PHEV scale-up is not dependent on comprehensive "smart" grids.** Although many of the pilots testing PHEVs are related to smart grid initiatives, it should be clear that the initial scale-up of PHEVs does not require a *comprehensive* smart grid. For example, in the National Renewable Energy Laboratory's study to assess the impact of PHEV penetration rates on Xcel Energy's Colorado territory, it was concluded that up to 500,000 PHEVs could be supported without the need for additional network capacity.[11] It is true that off-peak charging is absolutely critical if the cost benefits of running vehicles off grid power are to be maximized without large-scale investment. This could initially be performed with a meter or timer to "turn on" the charging during off-peak hours (for example, between 1 a.m. to 5 a.m.), without the need for a full smart grid. In the medium term, there will need to be some intelligence built into the system, as the utility will need to monitor and bill for the charging. In addition, there are companies looking at software to charge vehicles under centralized control (for example, allowing the consumer to subscribe to a plan, with a third party acting as an aggregator).[12] This would simplify matters for the utilities in terms of managing the load to the grid, as the utility could collaborate with a third party to optimize charging. However, the scale-up of PHEVs will need to be monitored due to the eventual stress, wear and additional capacity requirements it will place upon the grid. In the long run (10 to 20 years), when there is significant penetration of PHEVs, a smart grid would be beneficial in optimizing the additional load and taking advantage of opportunities such as vehicle-to-grid (V2G).

8. **There will be increased activity in the airline and marine industries on options to reduce GHG**. Airline and marine have not received as much attention from government and private investors as road transport, but with viable solutions available to reduce GHG, these sectors will likely be the focus of much regulatory and private investment attention in the next few years. We expect these technologies to take longer than five years to scale for a number of reasons:

   - Marine and aviation are difficult to regulate at a market level, as they are global industries with strong, cross-border industry bodies such as the International Maritime Organization and the International Air Transport Association (IATA).
   - Time is required for the industry and regulators to have the same dialogue that the road transport players and regulators have been having for the past five or so years, with the aim of looking for cooperation and compromise.
   - Aviation biofuels and marine scrubbers are not commercially competitive to traditional fuels—that is, jet fuel for aviation and low sulfur fuel oil (LSFO) for marine. Aviation biofuels and marine scrubbers will be additive to what is being done today, and will come with additional costs, hence regulatory support will be needed to assist the roll-out of these technologies.
   - For aviation, there is a question of whether there will be enough biofuel feedstock to meet both the road and air biofuel demand.
   - For marine, a further constraint is *when* improvements can be made to existing fleets and *how often* ships are replaced.

9. **Markets will optimize around their own domestic agenda, local resources and local economic development opportunities.** Today, transportation fuels are dominated by globally traded and efficiently produced hydrocarbons. It is hard to imagine that a fragmented market would provide an improvement. However, what the global hydrocarbon market does not do is make optimal use of local resources, force diversity (and therefore increased security) of supply, and allow governments to put a price on the level of GHG abatement it believes it can afford and achieve. In our review of markets, we see Brazil looking at technologies that maximize the value from sugar cane; South Korea and Japan very focused on electrification; and the United States and China exploring all options. The suite of technologies will likely be the same, but the weighting will differ dramatically by market, as illustrated in Figure 3.

Figure 3. Government and private support (between 2004 and 2008) across the 10 markets.[13]

	Evolution				Fungible Fuels					Electrification			
	Next Generation ICE	Next Generation Agriculture	Waste-To-Fuel	Marine Scrubbers	Synthetic Biology	Butanol	Bio-Crude	Algae	Airline Drop-Ins	PHEV/EV+ Electrification Of Engines	Batteries	Charging	Vehicle To Grid
US	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI
Canada	PI	PI	PI	PI			PI	PI		PI	PI	PI	
UK	PI	PI	PI	PI	PI	PI	PI*			PI	PI	PI	
Germany	PI	PI	PI	PI	PI		PI	PI		PI	PI	PI	
France	PI	PI	PI			PI*	PI*			PI	PI	PI	
Netherlands	PI	PI	PI				PI	PI*		PI	PI	PI	PI
China	PI	PI	PI			PI	PI	PI		PI	PI	PI	
Japan	PI		PI			PI			PI	PI	PI	PI	PI
South Korea	PI	PI	PI		PI					PI	PI		
Brazil	PI	PI	PI		PI			PI		PI		PI	

Key

Neither regulation/targets *nor* gov't incentives/investment
One of either regulation/targets *or* gov't incentives/investment
Both regulation/targets *and* gov't incentives/investment

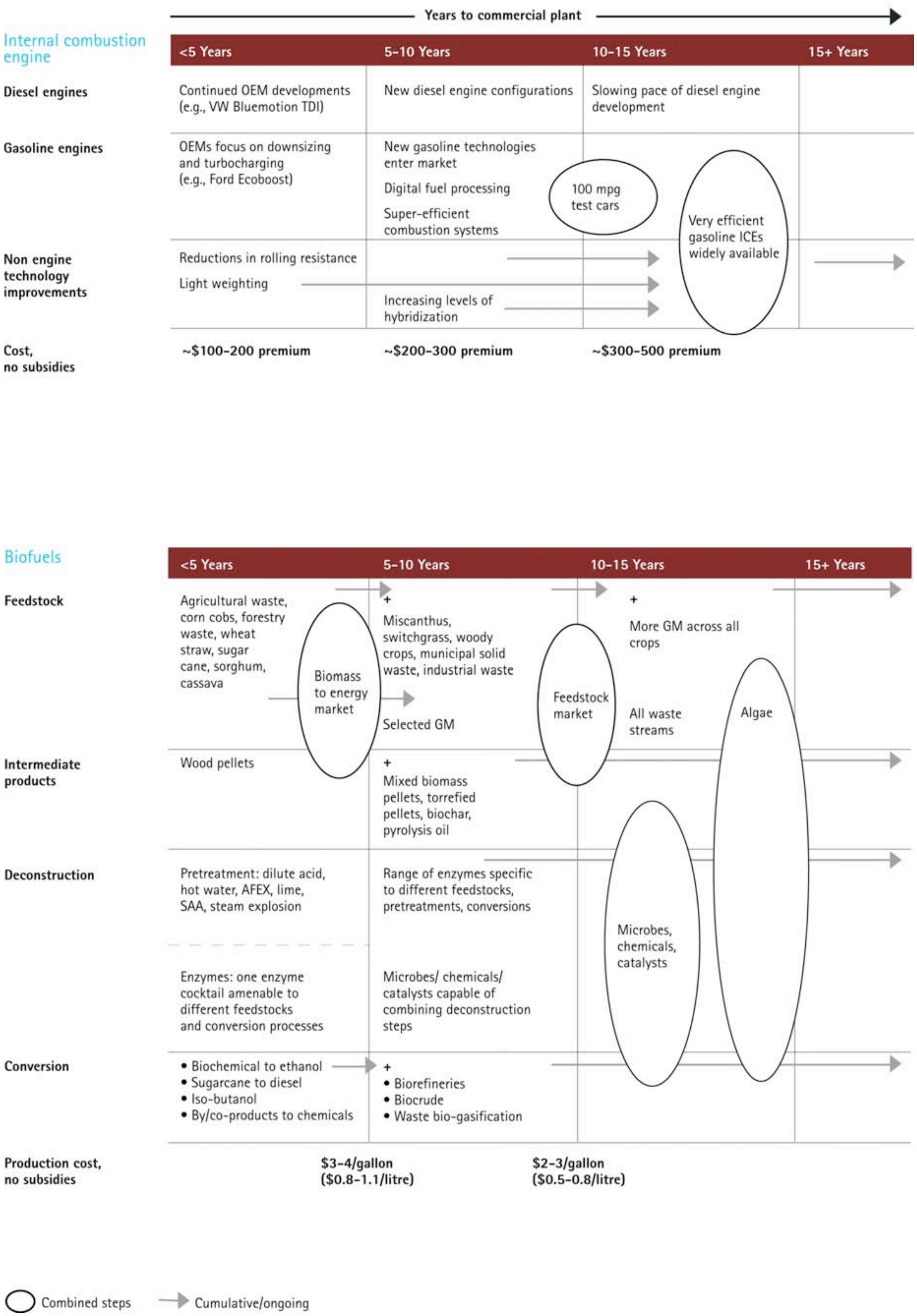
PI - Is there a company or plant developed with this technology.
PI*-Investment by an IOC (for example, Shell, BP, Total) not in IOCs headquarters country
Note: investor can be from another market but the company and investment is in this country

10. **The trajectory of supply, demand and GHG footprint of transport fuels is being reshaped now.** In five years, we will be looking at a different landscape of fuel supply, fuel demand and options to reduce GHG than is currently forecast today given the pipeline of disruptive technologies. It is important that these technologies be considered when forecasting supply and demand. As with any technology, improvement in the cost per mile can be anticipated as technologies mature and the industry gains experience. However, Accenture believes that with the right policies, practical fact-based information on the opportunities and constraints and, most importantly, continued commitment by government to research and development (R&D)—the use of alternatives can be scaled up even sooner. Although there are uncertainties around some technologies (for example, algae, airline drop-ins and electrification), the private activity and government support of these technologies indicate that they too will impact supply and demand.

    Throughout our report, we have assessed each of the technologies based on the four criteria of scaleability, GHG emissions, cost and scale. In isolation, the technologies we selected look promising, with most meeting all four criteria. However, it is important to note that all of the technologies are "in play" now, and that there is a race to commercialization. The success of one technology will impact the potential market of the others. We do believe in more diversity in technologies.

    Figure 4 is Accenture's view of how the market may evolve over the next 15+ years. It is based on our analysis of each technology, the current cost, the S-curve, the challenges and the improvement drivers. The chart is limited to the technologies covered in this report, and although we will have missed technologies that will be successful, we do believe that these are the most promising. We have presented our best estimate of costs, but have stayed away from predicting market share as this chart would look very different were it cut individually for each of the 10 countries in the report.

Figure 4: How will some of the key technologies continue to evolve?



Years to integrated value chain

Electrification

	<5 Years	5-10 Years	10-15 Years	15+ Years
PHEV	PHEVs commercially available but consumer up-take limited given high battery costs undermining economics	Lower battery costs means PHEVs become more economically attractive	PHEVs with V2G capability increasingly piloted	PHEVs with V2G capability integrated into the smart grid tested
Battery	Build up of battery manufacturing capability and ramping down of costs	Battery chemistry improves enabling faster charging time	Impact of V2G on battery tested	
Charging	Smart charging units for PHEVs being deployed, charging PHEVs at levels I and II (i.e. between 4-10 hours depending on battery SOC)	Fast charging stations being piloted and tested	Fast charging stations deployed (avg.15 min charge) Fast charging stations with V2G capability tested	Econo-mically competitive V2G-capable PHEVs integrated into the grid
V2G	Vehicle-to-grid technology being researched at universities and tested on a small scale AutoPort releases initial (limited) production line	V2G integration to the smart grid increasingly tested	Smart grids being deployed	
Battery cost (no subsidies)	**$1300/kWh**			**$500/kWh**

Aviation

	<5 Years	5-10 Years	10-15 Years	15+ Years
Design improvements	Winglets retrofitted to existing aircraft Efforts at fleet renewal	Next generation of aircraft design		
Operational improvements	More efficient flight paths, ascents and descents	Improved air traffic control systems	Nascent use of biofuels in next-generation fleet	
Biofuel drop-ins	Continuation of trial flights using 50% biofuel drop-ins in one engine	First 100% bio-blend used in trial flight Wider deployment of bio-jet production facilities	Slow introduction at one or more hub airports	
Cost, no subsidies	**10% premium over crude price**	**10% premium over crude price**	**Higher premium due to feedstock supply constraints and conversion costs**	**Aviation biofuel processes more efficient but still a premium due to feedstock supply constraints**

Marine

	<5 Years	5-10 Years	10-15 Years	15+ Years
Scrubbers	Scrubbers commercially available. Limited take-up given size of investment, perceived complexity and low HSFO-LSFO differential	Lighter, smaller, more efficient scrubbers Some integration into ship design depending on customer fleet	Economically competitive scrubbers integrated into new-build ship design	
Port infrastructure for environmentally-friendly waste product disposal	Initial deployment	Wider deployment		
Operational improvements		Slower sailing speeds adopted to reduce emissions		
Design improvements	Some light weighting	Widely deployed light-weighting		
Business case	**Driven by time spent in ECAs and age of vessel and HSFO-LSFO cost differential**	**Driven by time spent in ECAs and age of vessel and HSFO-LSFO cost differential**	**Driven by global legislation and significant cost increase of LSFO**	

Combined steps — Cumulative/ongoing

Tables 3, 4 and 5 summarize Accenture's assessment of the technologies in this report against the four disruptive criteria: scaleable, GHG impact, cost and time to market. In almost all cases, 2 out of 4 of the criteria were met, and in most cases all were met.

Table 3. Summary of disruptive technology criteria assessment: Evolutionary

	Scaleable	GHG impact	Cost	Time to market
Evolutionary				
Next-generation internal combustion engine	✓	✓	✓	✓
	With existing infrastructure and manufacturers already on board, rolling out internal combustion engine improvements will be one of the easier technologies to implement.	With VW and Toyota internal combustion engines already coming close to 50 mpg, improvements to these engines could deliver 100 mpg by 2030.	In most cases, improvements in internal combustion engines will have a lower cost to implement than building electric vehicles (EVs)/ hybrid electric vehicles (HEVs)/ plug-in hybrid electric vehicles (PHEVs).	For the first wave of improvements (i.e., the OEM and start-ups in this report), it is likely that some will be commercialized in the next five years.
Next-generation agriculture	✓	✓	✓	✓
	Energy cane, miscanthus, sweet sorghum have the highest estimated ethanol yield potential (more than 9,000 liters per hectare) and can be grown in a wider range of geographies/ land types (for example, marginal).	Energy crops/root biomass are carbon negative overall, with available data suggesting savings of 31 to 89 percent compared to replaced hydrocarbon fuel.	Latest estimates for most energy crops suggest costs below \$0.50 per liter. With continued improvements, this makes them cost competitive with oil at (or possibly even below) \$65 per barrel. Pretreatment and enzymes are probably closer to \$0.79 to \$1.06 per liter (\$3 to 4 per gallon) today, but Accenture believes this should continue to improve, with targets closer to \$0.53 to \$0.79 per liter (\$2 to \$3 per gallon) by commercialization.	There are already demonstration plants using corn cobs and wheat straw and plantings of various grasses and sorghum. Commercial sales of dedicated energy crops have already begun, with a well-established market for genetically enhanced/modified conventional row crops.
Waste-to-fuel	?	✓	✓	✓
	High theoretical feedstock availability and modular conversion technologies, but collection and transportation logistics that are not reliant upon hydrocarbons may prove the crunch point.	Some incineration processes are fairly GHG intensive. More advanced techniques offer better emissions reduction performance, and it is likely that a reduction in GHG will be a requirement.	Feedstock costs represent a considerable proportion of biofuel production costs; with under zero or even negative feedstock costs (for example, due to tipping fees), the economics of waste-to-fuel processes appear favorable.	Hybrid technology is the furthest away, but several prominent players are aiming to be commercial within three years.
Marine scrubbers	✓	✓	?	✓
	Need to identify/engineer a winning technology solution and standardize production process to achieve scale, but it is expected that this technology will prevent at least 20 percent of the current HSFO market from switching to LSFO.	Will avoid significant increase in net CO_2 emissions by offering alternative to upgrading HSFO to meet IMO's sulfur emissions limits for marine transportation.	Dependent on differential between HSFO and LSFO and on where the vehicles operate. It is expected that for some vehicles it will make sense while for others it will not.	Commercialization expected by 2011—for at least one company.

Table 4. Summary of disruptive technology criteria assessment: Revolutionary

	Scaleable	GHG impact	Cost	Time to market
Revolutionary				
Synthetic biology: Sugar cane-to-diesel	✓	✓	✓	✓
	Theoretically constrained only by sugar cane availability. However, a key challenge is scaling up the process, at a competitive cost. Currently less than 3.8 million liters per year, mLpy (1 million gallons per year, mgpy) produced in pilot facilities, although commercial-scale production has been demonstrated in other industries.	Will be similar to sugar cane (88 percent reduction)	Estimated costs for first commercial plant are expected at $45 to $75 per barrel.	Building of commercial plants due to start in 2011, with commissioning in 2013.
Butanol	✓	✓	✓	✓
	A fungible fuel with a wide range of applications that can be produced from a wide range of possible feedstocks. New processes have been proven at pilot scale, with demo plants on the way.	Aim is for 80 percent reduction based on use of combined heat and power.	Target approximately $50 to $60 per barrel of oil.	Commercialization expected by 2014.
Bio-crude	✓	✓	✓	✓
	As with all biomass conversion processes, feedstock is the most likely bottleneck.	GHG balance depends on the process used, but the best have a GHG impact significantly above 30 percent.	With the anticipated scaling efficiency and technology, bio-crude from both pyrolysis and catalytic hydrothermal upgrading are expected to be competitive within this range.	Companies projecting commercial operation within five years.
Algae	✓	✓	?	?
	Algae is plentiful and high yielding, but there is the challenge of which strain or strains—that is, need to identify/engineer a high oil-yielding and highly productive strain and standardize production process to achieve scale.	Technology to sequester CO_2 from power plants being developed by several companies.	Target approximately $60 per barrel of oil. This is currently aggressive given the National Renewable Energy Laboratory estimate of $2.24 to $8.45 per liter ($9 to $32 per gallon), which is consistent with our research findings.	Commercialization not expected for another 10 years, although some companies have made commitments for earlier dates.
Airline drop-ins	✓	✓	?	?
	Although it is still to be determined whether there will be enough feedstock for an airline biofuel to account for 20 percent of jet fuel, the combination of design improvements and biofuel could reduce fuel consumption by 20 percent.	Will likely be part of the requirement.	Producing a biofuel that can replace jet will be one of the more expensive processes because of the tight specification.	Technology has been proven; it is reliant on regulation as production costs may be above $45 to $90 per barrel of oil.

Table 5. Summary of disruptive technology criteria assessment: The Game Changer

	Scaleable	GHG impact	Cost	Time to market
The Game Changer: Electrification				
PHEV/ EV/ electrification engines	?	✓	?	✓
	The Electric Power Research Institute estimates that under a medium-penetration scenario, PHEVs could reach more than 40 percent of new market vehicle sales. But, on the more conservative end, some studies estimate a figure of only 4 percent of new vehicle sales by 2020.	PHEVs can achieve substantial savings in GHG emissions over internal combustion engines. While their savings are no greater than those of HEVs in an integrated gasification combined cycle scenario, they are able to play the fuels off of each other to ensure the greatest economic and emissions savings.	PHEVs can run at an equivalent price of $0.25 per liter ($0.75 per gallon), but the battery premium over an internal combustion engine is still $4,500 to $6,000 and a HEV is $2,000 to $2,500, revealing a key cost dependency.	The first PHEV was launched in China in 2008 with all major OEMs releasing models in the next two to three years.
Charging	?	✓	✓	✓
	Market growth will be dependent on the up-take of plug-in hybrid electric vehicles.	A number of pilots are currently demonstrating the ability to use intermittent renewable energy sources, such as wind or solar, to charge vehicles at the charging points.	Utilities and/or businesses would own the charging points (estimated at approximately $5,000 per unit) and would offer subscriptions to consumers, competitive at $40 per barrel of oil, dependent on consumer preferences.	Charging points are currently commercially available and are being rolled out as part of pilots across the globe.
Vehicle-to-grid (V2G)	?	✓	?	?
	V2G will gain momentum in vehicle fleets, but is unlikely to reach 20 percent impact in the consumer market by 2030.	While savings will vary by market, V2G has the potential to reach up to 99 percent savings over the hydrocarbon it is replacing if renewable energy is optimized.	At full scale, target estimates are that V2G will be competitive at between $40 to $60 per barrel of oil for plug-in hybrid electric vehicles and, in theory, at $0 per barrel of oil for electric vehicles (as the consumer would be able to sell power back to the grid). Furthermore, potential revenue streams from providing ancillary services to the grid could offset these costs, rendering the technology even more cost competitive. However, there are considerable assumptions in these assumptions.	AC Propulsion already has developed a vehicle with bidirectional power flow, and the communications systems required to support V2G are currently in demonstration phase. AutoPort is in limited production of electric vehicles with V2G built-in, indicating V2G could be commercially available within the next five years.

Summary of Key Findings:

Disruptive Technologies

Evolutionary

Next-generation internal combustion engine

Next-generation internal combustion engine. Significant gains are achievable, which are often overlooked. In-house developments by original equipment manufacturers (OEMs), coupled with best-in-class start-up technologies, will mean that the automotive industry as a whole can make significant advances in the efficiency of the internal combustion engine. Getting more miles per gallon out of conventional vehicles achieves the same end-goals of lowering carbon emissions and increasing energy security as the movement toward the electrification of transport. While there are significant requirements for infrastructure and incentives to bring about the widespread electrification of vehicles, improvements to the internal combustion engine could be quickly deployed and assuage many of the voices currently clamoring for change.

Next-generation agriculture

Stretching further with innovation and technology. New agriculture is in its infancy. There is significant potential for improvement, particularly given the historic advances made with genetic modification (GM) of crops to obtain desired characteristics, increase yield and reduce harvesting and processing costs. This is coupled with the innovation seen in first-generation players to drive down costs, energy and water use, and GHG emissions. The biggest challenge is in the deconstruction stage, with high costs for pretreatment and enzymes. These costs have to go down, but improvements will come from optimizing the whole system, from feedstock to production.

Waste-to-fuel

An important feedstock source. The production of transport fuel from waste is a nascent technology, largely in the lab and pilot stages of commercialization at present. Subsequently, while there are small local government pilot projects in place, there is little legislative support or financial incentive to develop the technology at the current time. However, if the technology can be brought to scale, then waste feedstock processing could solve two problems at once—a source of low-cost, low-carbon renewable fuel, and a solution to the ever more critical issue to landfill reduction. With such obvious benefits, it would seem likely that this technology is suitable for a much larger role in the world's future transport fuel mix.

Marine scrubbers

Alternative to upgrading refineries and increasing refinery CO_2. This technology could avoid both the need for significant capital investment to upgrade refineries to produce more low sulfur fuel oil (LSFO) and greater dependence on costlier, low sulfur crudes. It also has the potential to significantly and economically reduce emissions from seagoing vessels beyond that which can be achieved by simple fuel switching. Marine scrubbing is technically feasible—several companies have successfully tested the technology on demonstration projects. However, the final technology winner has not yet been identified, with investment dollars currently spread across seawater and fresh water solutions.

Revolutionary

Synthetic biology: sugar cane-to-diesel
Close to commercial viability. The world has long awaited a biofuel diesel solution. Synthetic biology applied to the sugar-to-diesel pathway changes this situation. If the economics could come close to the sugar cane-to-ethanol economics, then there would be significant potential in diesel markets given the cost and availability of sugar cane (compared to the traditional biodiesel feedstocks such as palm, soy and rapeseed). The use of synthetic biology to convert sugars to diesel has advanced significantly in the past one to two years, and it is close to commercial viability. Two companies, Amyris and LS9, are planning to break ground on commercial plants in 2011, with production starting by 2013.
Butanol
Application of synthetic biology could resolve issues. Fuel from butanol is a highly desirable product with energy content similar to gasoline—higher octane and less affinity to water—meaning it can be transported through existing pipelines, use existing infrastructure and be blended with gasoline at ratios much higher than ethanol. However, there are issues hampering the production of butanol and the economics are unproven. Researchers are looking to adapt traditional butanol production (via the ABE or acetone-butanol-ethanol process) by consolidation of process steps and potential genetic modification of bacteria. Genetic engineering and advances in synthetic biology could also lead to breakthroughs from companies such as Gevo and Butamax, who have proven the technology at pilot scale and are both planning commercial plants in the next few years.

Bio-crude

High potential to leverage infrastructure but few technologies. Bio-crude is an industry with enormous potential, but with many challenges to overcome. The benefits of a bio-crude that could take advantage of existing refining and distribution infrastructure with little extra investment are clear, and could lead to a breakthrough in the adoption of renewable fuels worldwide. Given this potential, what is most surprising is how few companies and technologies there are, compared with many of the other technologies covered in this report. There are uncertainties over the technology, but with the right level of investor funding, bio-crude could be a disruptive technology for transport fuel.

Algae

Incredible yields but many variables, little industry consensus and high cost. Technologically, the algae industry is very fragmented—possibly the most fragmented of all of the industries covered in this report. There are many players, and the oil industry (including Shell, ExxonMobil, BP, Valero and Chevron) is looking at a range of methods to eliminate steps in the process to reduce complexity and cost. As companies try to find the lowest cost option, several different operating models are emerging. In this report, Accenture has provided case studies of companies with plans for commercial production within five years. However, there are considerable technical constraints. In ExxonMobil's announcement of its investment in Synthetic Genomics, the company stated that "significant work and years of research and development still must be completed," with the key challenge being "the ability to produce it [algae] in large volumes which will require significant advances in both science and engineering".[14] It is therefore likely that it may take more than current estimates of five years in order to reach commercial scale.

Airline drop-ins and design/operational innovation

Drop-ins are now feasible, but feedstock availability remains an issue. The aviation industry will face increased pressure to increase efficiency (because of the cost of fuel and competitive nature of the market) and reduce carbon emissions. The outlook for airline biofuels is positive as it is one of the few ways to reduce emissions and many of the technology challenges have been overcome. However, the scale is questionable given the feedstock supply constraints and the competing demand for biofuels in road transport. This demand for feedstock will continue to support developments in high-yielding feedstocks such as algae and also provide support to other alternatives to diesel for cars and trucks, i.e., save the feedstock for jet fuel (where there are limited alternatives to biofuels) versus using it for road. Improvements in design and operational efficiency will continue to be important.

The Game Changer – Electrification

PHEVs

High potential, but battery cost and availability remain challenges. Plug-in electric vehicles have received increasing amounts of attention from government and industry, indicating they will be part of the future vehicle landscape, with PHEVs likely to be the most disruptive model within the next five years. PHEVs benefit from lower-running costs than both internal combustion engines and HEVs, as well as extended driving range over EVs, but the capital cost of the battery and availability limitations still need to be overcome for the economics to work favorably without regulatory incentives. Moreover, while PHEVs have the potential to be emission-free, the reduction in GHG emissions is highly dependent on the generation mix and will therefore vary by country. The ability of the grid to withstand PHEV penetration rates will further vary by country. However, using smart, off-peak charging, the grid will be able to manage initial PHEV penetration and enable load leveling for utilities.

Charging

Controlled charging infrastructure development benefiting from government support. Controlled charging enables utilities to manage energy demand more effectively and consumers to benefit from lower off-peak tariffs. This will be key in delivering the aspirations of widespread electrification of vehicles. Municipalities across the globe have announced ambitious roll-outs of charging point infrastructure. The growth of the controlled charging market will be heavily dependent on the uptake of plug-in electric vehicles and how incentives for the growth of PHEVs and EVs are driven/managed by policymakers and businesses.

Vehicle-to-grid (V2G)

A long-term opportunity, dependent on significant PHEV/EV scale. V2G is technically feasible with demonstration projects currently underway. These projects vary in focus, with some assessing the communications between the vehicle and the grid, some looking at how to maximize vehicle storage to increase the quantity of renewables being used, and some looking at a more integrated smart grid offering. All projects, albeit in the early stages, have proven that V2G has the potential to significantly disrupt the supply and demand relationships—with end-electricity consumers potentially becoming an essential grid storage resource—and change both the electric power and transport fuels landscapes. However, to reach this potential, V2G is dependent upon the commercialization of electric-drive vehicles, cooperation between the various industry players, and the education of consumers. Initial electrification initiatives will determine the latter's potential success.

Summary of Key Findings:

Markets

Brazil

Brazil's transportation consumption is fairly balanced between diesel and non-diesel (ethanol and gasoline) demand and consumes approximately 19 billion liters of gasoline, 37 billion liters of diesel, 19 billion liters of ethanol and 800 million liters of biodiesel per year. Brazil is the second largest producer of ethanol and is the largest exporter of ethanol. It is focused on maximizing the value of its sugar cane. Government regulation supports the development of next-generation agriculture and use of sugar cane waste. The sugar cane-to-diesel pathway is also seeing private activity as companies such as Amyris and LS9 look to locate production in Brazil.

Canada

The Canadian transportation sector is predominantly a gasoline market and consumes approximately 42 billion liters of gasoline, 16 billion liters of diesel, 0.6 billion liters of ethanol and 93 million liters of biodiesel per year. Government support is focused on next generation internal combustion engine (ICE), next-generation agriculture, waste-to-fuel, marine scrubbers and PHEV/EV. Canada's large land mass, forestry industry and refining infrastructure make it a logical fit for next-generation agriculture, waste-to-fuel and bio-crude, and we have seen private activity with companies such as Iogen (cellulosic ethanol), Enerkem (municipal solid waste), and Ensyn (bio-crude). The government is also emphasizing PHEV/EV with a federal roadmap expected in 2010 that will extend its current rebates and incentive system, which are highly regional due to the utilities infrastructure.

China

China's transportation sector is predominantly a diesel market and consumes approximately 38 billion liters of gasoline, 92 billion liters of diesel, 1.6 billion liters of ethanol and 0.6 billion liters of biodiesel per year. China is aggressively moving into both biofuels and electrification. It expects biofuels to meet 15 percent of transportation needs, and has been able to effectively roll out ethanol. It plans to have the highest number of PHEVs/EVs in the world and is the second-leading producer of lithium-ion batteries. Government support is focused on next-generation agriculture, PHEVs/EVs and batteries. China is also investing in developing butanol and algae. We are seeing significant private activity in China, both from local players as well as international players. For example, Novozymes, COFCO, and Sinopec are working together to develop ethanol from crop waste.[15]

China – continued

PetroSun China already produces algae for other uses; Jiangsu Lianhai Biological Technology Co Ltd has invested $80 million to produce butanol in Haimen city, and BYD launched the first PHEV in 2008.

France

The French transportation sector is predominantly a diesel market and consumes approximately 13 billion liters of gasoline, 39 billion liters of diesel, 0.4 billion liters of ethanol and 1.3 billion liters of biodiesel per year. France has one of the highest average mpg, increasing to 65 mpg by 2020, is a large producer of both ethanol and biodiesel and fairly balanced in its consumption and production of both, and was also a first mover in electrification with the French government announcing a target of 100,000 EV/PHEV by 2012. Government support focuses on next-generation ICE, next-generation agriculture, and PHEV/EV. Private activity in these areas is significant. For example, Renault-Nissan expressed its intention to become the world's largest electric car manufacturer; French battery manufacturer Saft, in a joint venture with Johnson Controls, is building a lithium-ion battery plant, and next-generation agriculture investments and R&D are being made by Total, Tereos and Unigrains.

Germany

The German transportation sector is predominantly fairly balanced between gasoline and diesel demand and consumes approximately 29 billion liters of gasoline, 33 billion liters of diesel, 0.6 billion liters of ethanol and 3.8 billion liters of biodiesel per year. With strong automotive and agricultural sectors, Germany has one of the highest average mpg, increasing to 65 mpg by 2020, and is the largest producer and consumer of biodiesel. Government support focuses on next-generation ICE, next-generation agriculture, waste-to-fuel, marine scrubbers and PHEV/EV. For example, there is no tax on second-generation biofuel and E85 ethanol until 2015; the government is setting ambitious targets of 1-5 million EV/PHEV by 2020-2030, and 50 percent of waste materials have to be reused or recycled by 2020. Key private activity includes: Petrotech AG has invested in a biodiesel plant based on municipal/industry waste; BMW's megacity vehicle; and, the $2.7 billion (9.1 percent) stake in Daimler AG by the United Arab Emirates's Aabar Investments, which includes a planned partnership for the development of electric vehicles and innovative compound materials.[16]

Japan

The Japanese transportation sector is fairly balanced between gasoline and diesel demand and consumes approximately 59 billion liters of gasoline, 58 billion liters of diesel, 0.5 billion liters of ethanol, and 0.2 billion liters of biodiesel per year. Japan has the highest mpg in the world and has had a long focus on electrification and is the world's leading producer of lithium-ion batteries. Japanese manufacturers have shifted to hybridization and electrification, with all having EVs, HEVs and/or PHEVs, rather than focusing on improvements in ICE. Japan is also leading in municipal solid waste (MSW) combustion plants and has the only commercial plasma arc MSW plants in the world.

Netherlands

The Dutch transportation sector is predominantly a diesel market and consumes approximately 6 billion liters of gasoline, 9 billion liters of diesel, 0.2 billion liters of ethanol and 0.3 billion liters of biodiesel per year. The Netherlands is not a significant producer of biofuels, but it does have a large refining industry and Rotterdam is the port where most imported ethanol and biodiesel enters Europe. Government support and private investments have focused on waste-to-fuel, electrification and bio-crude. For example, like much of Europe, there is an acute shortage of landfill availability, leading to some of the first significant investments into commercial waste-to-fuel facilities, such as a $142 million waste-to-biodiesel plant planned.[17] The Amsterdam "smart city" will look at integration of PHEVs into the smart grid, and two bio-crude players, KiOR and HVC, are present in the Netherlands.

South Korea

The South Korean transportation sector is predominantly a diesel market and consumes approximately 10 billion liters of gasoline, 17 billion liters of diesel, and 0.1 billion liters of biodiesel per year. South Korea has a strong automotive sector and is the third-largest producer of lithium-ion batteries. Government support has focused on next-generation ICE, with a recently announced fuel standard target of 40 mpg by 2015, requiring a 54 percent improvement in vehicle efficiency, and electrification, with a duty incentive for green cars. Key private investment includes: GM Daewoo is planning to manufacture PHEVs from 2010; and LG Chem will provide the batteries for the GM Volt. SK Energy, the largest refining company, is also investing significantly in researching biofuels.

United Kingdom

The United Kingdom transportation sector is fairly evenly balanced between gasoline and diesel demand and consumes approximately 24 billion liters of gasoline, 26 billion liters of diesel, 0.15 billion liters of ethanol, and 0.35 billion liters of biodiesel per year. The UK is not a significant producer of biodiesel, although the Vivergo and Ensus plants will come on-stream between 2009 and 2010, increasing ethanol capacity to approximately 837 mLpa (420 mLpa Vivergo and 400 mLpa Ensus). The focus of government support has been on biofuels, through the Renewable Transport Fuel Obligation (RTFO), and electrification (which has increased in the last year, with the UK Committee on Climate Change predicting that up to 40 percent of new cars in 2020 could be EV/PHEV). There has also been an increase in waste-to-fuel activity due to the lack of landfill capacity, marine scrubbers with companies such as Krystallon based in the UK, and butanol with plans for the Vivergo ethanol plant to add on butanol production capacity.

United States

The United States transportation sector is predominantly a gasoline market and consumes approximately 539 billion liters of gasoline, 169 billion liters of diesel, 26 billion liters of ethanol and 1.4 billion liters of biodiesel per year. The US is the only country active in all of the technologies covered in this report. Of the 25 case studies, 18 are based in the US. On the biofuels side, the Renewable Fuels Standard program has set the target for 36 billion liters of ethanol, stimulating investment in new agriculture and waste-to-fuel. Its energy, security and climate change agenda is driving the investment in fungible fuels, with the establishment of three Department of Energy centers and a large National Renewable Energy Laboratory program focused on further development of next-generation biofuels. The American Recovery and Reinvestment Act of 2009 created a $787 billion in economic stimulus spending and tax incentives. For example, already $2.4 billion has been pledged to improve US battery manufacturing capability, and there is a target of 1 million PHEVs on the road by 2015.

Key Challenges

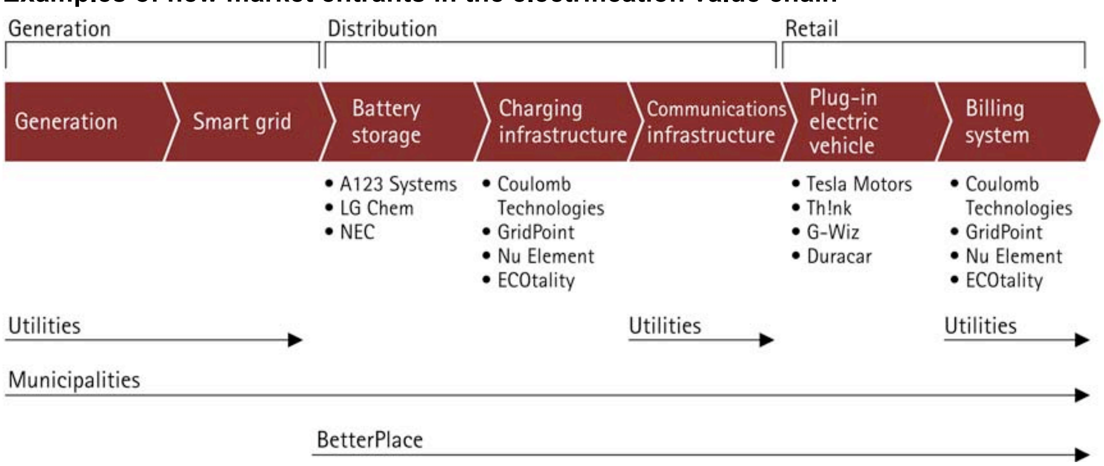
The cost and time to commercialization and scale-up of the technologies are heavily impacted by the current situation and specific challenges.

These include:

- **Improvements are limited to new vehicles.** For many of the technologies (most next-generation internal combustion engine improvements, ethanol beyond the 10 percent blending limit, electrification) the key constraint is turnover of the vehicle fleet. For example, in 2007 the median age of a passenger vehicle in the United States was 9.2 years, meaning turnover will be almost a decade.[18]
- **Ethanol blending wall.** The US is close to the 10 percent limit of ethanol that can be blended into current gasoline vehicles, and the allowable share of corn ethanol specified in the Renewable Fuels Standard (RFS) program. There is a movement by the American Coalition for Ethanol (ACE) to increase the blending wall to 15 percent[19]—although only flex-fuel vehicles (FFVs) are currently allowed to use blends containing more than 10 percent ethanol, there is evidence to suggest that blends of up to 15 percent will not damage gasoline engines[20]—and to increase the allowable corn ethanol share of the RFS. This would buy the industry time to commercialize and roll out cellulosic ethanol. If the blending wall does not change, then the pace of the industry will be constrained by the roll-out of FFVs and the ethanol refueling infrastructure. US Secretary of Agriculture, Tom Vilsack, and Senate Agriculture Committee Chairman, Tom Harkin, have both expressed their support for the US Environmental Protection Agency (EPA) to authorize a higher blend;[21] a decision by the EPA is expected by the end of 2009.

- **Acceptance of genetic engineering.** Genetic engineering is a key lever in using biomass to produce fuel. Although this technology has been applied in the drug industry for over 20 years,[22] many countries, particularly in Europe, have legislation that restricts the use of genetic modification (GM). For example, in the EU, legislation such as the "Directive on the Deliberate Release into the Environment of Genetically Modified Organisms" (2001) and the "Regulation on Genetically Modified Food and Feed" (2003) demand approval before GM plants can be used commercially. This is only granted under certain conditions (proven safety, freedom of choice, labeling and traceability). However, while cloning of human genetic material remains an ever-contentious issue, with strict legislation either banning the process outright, or limiting what can be done for research only, acceptance of GM for fuel production is slowly growing.
- **Feedstock logistics.** In the new agriculture section, we noted that harvesting and preprocessing could make up to 50 percent of the feedstock costs. For new feedstocks, the infrastructure and processes required to effectively harvest and transport these materials to the refining plants will be a key focus area.
- **Cooperation across players in the electrification value chain.** Electrification requires significant cooperation across players who have not worked together before. The business models and value chain collaboration required across local governments, utilities, OEMs, battery and charging companies to really scale electrification of vehicles remain a significant challenge. There are pilots in almost all of the markets profiled. In each case, we find variations, for example on capital investment, revenue sharing, method for optimizing charging time, battery and charging time assumptions, technology that supports charging and billing, the extent to which smart grid is used, and the extent to which V2G (the services the PHEV/EV can provide to the grid) is explored. Figure 5 illustrates the electrification value chain and the number of different players who need to be aligned to bring this technology to market.

Figure 5. Players in the electrification value chain;
Examples of new market entrants in the electrification value chain



- **Leveraging of current asset base and distribution networks.** It is important for biofuels, marine scrubbers and electrification to leverage as much as possible of the asset infrastructure that exists.

  - Biofuels: New build plants are expensive, so new producers need the ability to leverage the existing ethanol and hydrocarbon infrastructure and to optimize the provision of fuel to customers. This will, in some cases, require the coming together of hydrocarbon and biofuel value chains, but will be important in driving down scale-up costs.
  - Marine scrubbers: Ensuring the solution is optimized for the current fleet will be critical given the time it takes for the fleet to turnover.
  - Electrification: Understanding the state of the network, how much off-peak capacity is available and how to manage wear on the infrastructure will be key to evaluating short-term capital investment needs.

- **Agreement on standards, measurement and monitoring.** It is important for all the technologies to agree and roll-out standards quickly—whether they are fuel specifications, emissions, charging, etc.—because a lack of standards will create inefficiencies and increase the commercialization/scale-up costs. In addition, these standards need to be enforced and, in some cases (for example, marine scrubbers), strictly monitored.

Implications for High Performance

So what does this impending shift in future transport fuels mean for government or companies today? We believe the transport fuel market of the future will include players from different industries (including governments, utilities, energy, chemicals, pharmaceutical and consumer electronics to name a few) who will bring different capabilities and assets that will shape the market.

For each entity, the capabilities required for high performance will differ depending on their current objectives, capabilities and, in the case of companies, go-to-market strategies.

However, Accenture does see a few common key capabilities for achieving high performance:

- **Scientists and engineers in leadership positions.** Most companies entering this market will have product and process patents around their technologies and processes. Strong R&D capability is a necessity as we are looking for breakthrough solutions. Integration of the technology with other technologies will also be an obvious capability. However, equally key to successful commercialization are leadership and communication and the ability to provide fact-based explanations to regulators and the public and to address often technical questions frankly and honestly. For governments, this means that more scientists will be chosen for key energy department roles.
- **Partnering and business model flexibility.** Commercialization of these technologies will take cooperation across many industries. In reviewing more than 100 companies, we have found plans for many different business models, from traditional plant joint ventures to fully integrated ventures, with capabilities across the value chain, including different models for different markets. In all cases, partnering is key to complementing in-house capability, whether to access the feedstock, the battery, the customer market, the infrastructure or capability. Also, the business models will evolve as commercialization starts to shape how the market will operate.

- **Close to government and policy makers.** Regulation will evolve as more information becomes available on new technologies and policy makers will make trade-off decisions across the technologies. For example, the RFS program does not specifically mention the contribution from synthetic biology (sugar cane to diesel) or algae, but if these technologies are successfully commercialized and have the currently estimated GHG impact, it is expected that the fuel categories as defined within the RFS program would be modified to include them.
- **Clear baseline assumptions and active tracking of the market.** Technologies are being developed now, and announcements come daily. Companies and governments need to be clear on their assumptions on the key improvement drivers that drive down the cost to commercialization and subsequent cost/mile. Understanding how new information impacts their technology, go-to-market strategy or regulatory positions is critical. For example, at Accenture, we use improvement drivers and S-curves to illustrate our view of cost at maturity and market evolution. When ExxonMobil announced the investment in Synthetic Genomics, it did make us look again at our current assumptions on GM algae. Other examples are the announcements to build lithium-ion manufacturing capability in the US. Again, this made us look at what we believed were the constraints to the scale-up of electrification.
- **Execution – project management excellence, supply chain optimization.** With the race to commercialize, the advantage of operational excellence in delivering projects on budget and on time and developing efficient and optimized supply chains should not be underestimated. Cost/mile of these technologies will continue to compete with gasoline and diesel, so maximizing the operating margins, particularly given the initial capital investment required, will be key to long-term profitability. In the companies we interviewed, there was emphasis on how the scale-up was going to happen and how they were doing this at the lowest possible cost, leveraging existing assets.
- **Contracting and risk management.** There is risk in both biofuels and electrification. On the biofuels side, although the mandate guarantees a level of demand, there have historically been very weak correlations with feedstock. For next-generation agriculture, this will be even more challenging as there is no market to set the price of the new feedstocks. In the electric markets, it is the demand that is most uncertain. In all cases contracting will be important to managing risk.
- **Long-term and flexible capital.** Time (how long things will take) is one of the biggest uncertainties of this market. Probably the best example is the Internet where the take-up curve, although it eventually got there, did not follow the growth path estimated by many in 1998. Even for the technologies that will be commercial in five years, scale-up could be slow or fast. For those technologies that will take more than five years, companies need to recognize that they may be in pilot or demonstration stages for many years.
- **Market-specific strategy.** Investments in new types of transport fuels will be driven by the local agenda. We strongly believe in increasing diversity of markets. Our research model is one of blended teams to leverage the most of what has been done around the world with the critical local filter, as nothing can replace local insight and local knowledge, particularly as understanding of the drivers of the domestic agenda and the local context is absolutely critical.

Accenture invites you to explore much more in the balance of the detailed report—including sections on technologies, the companies bringing these technologies to market, and the individual markets. We include a sidebar on hydrogen and a guest commentary by Daniel Kammen (Co-Director, Berkeley Institute of the Environment, and Founding Director, Renewable and Appropriate Energy Laboratory, RAEL) and Derek Lemoine (Energy and Resources Group, University of California, Berkeley), on the transition to electric vehicles. We contrast a utility company's perspective on electrification, with an integrated oil company's perspective on both biofuels and electrification. In summary, Accenture hope that this report will provide a detailed framework with which you can fuel your own discussions on business strategies and government legislation, as we all globally seek to conquer the challenges of greenhouse gas emissions and the potential for future hydrocarbon shortages.

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