position refiners where they need to be. In that context, the GTL issue becomes very simple: Do they buy it or make it?

Diesel engines, the most visible current pollution villain, are about to morph into the White Knight that cleans up the air and saves America's most popular vehicles. Their foul-smelling, smoke-belching ways will be changed by a super-clean designer fuel that enables more efficient, cleaner-burning engines and extremely effective emission controls-and sets the stage for fuel cells. There will be no escape of particulates to see or hydrocarbons to smell-at first, on light duty vehicles, and down the road, on heavy vehicles. That will take care of one big barrier to change-the stigma of diesels as dirty. It's not the engine; it's the fuel. And once the fuel is changed, the dirty image will disappear. These efficient, high-performing new engines will take care of the "vroom" factor as well.

When a zero-sulfur grade regulation comes down, the alternative that can deliver the following will suddenly move from desirable to

compelling:

- A fuel that not only enables future efficient, clean-engine technology but gets immediate improvement in existing vehicles;
- That is backed by an enormous resource base of raw material (natural gas) that guarantees security of supply far into the future, and

whoe conversion mitigates a serious greenhouse problem-the flaring of associated gas;

- That has compatibility backward and forward as well, satisfying existing and transitional engines while creating a distribution system for the eventual fuel cell, too.

In the competition to choose the low-sulfur alternative, the latter factor could push synthetic fuels over the top.

That means a substantial, growing market for low-sulfur fuels by the time the infant GTL industry can build the plants to supply it. The timing is perfect.

Sulfur-free synthetic fuels are thus leading candidates for a central role in transitional solutions heading toward the ultimate goal of near zero emissions

In the next decade there may be little incentive to invest in more expensive conventional refining capacity if GTL proves the safest place to be. It is a green tool refiners can use to take the environmental initiative in the era of low-sulfur fuels, just as leading companies did a generation ago in removing lead from gasoline.

Prior to the recent oil-price crunch, GTL was steadily gaining acceptance as a viable option for converting remote shut-in gas reserves into booked assets of great value. Recent trends in the auto and refining industries and pressures to reduce greenhouse gases (carbon dioxide, methane, oxides of nitrogen) under the Kyoto Protocol on climate change, plus the aggressive moves by EPA, the state of California and the European Union, ratcheted GTL's standing to a new level. No longer is GTL "just" a technology with great potential and a promising future. The new perception is that of an imminent major player in the energy industry, an important tool for refiners, and an enabler for the auto industry, a veritable environmental Rossetta Stone.

Conclusion

The diesel engine was an obvious choice to boost fuel economy. But prior to the advent of GTL, no one anticipated that a new designer fuel for the diesel engine would turn out to be the secret to cleaning up the air also-and enabling fuel cell technology as well. That surprise outcome, in concert with recent regulatory moves, is setting the stage for inevitable rapid growth of a new synthetic fuels industry.

The clamor for natural-gas-based synthetic designer fuels has a ring of inevitability because of its source. It is not the sound of the self-interested tooting their own horn. The noise is coming not from the ranks of GTL technology suppliers and producers, but from others who are set on exploiting these unique fuels to solve their own problems. It is their call.

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the fuel contains no sulfur, the processor could eliminate the sulfur-cleanup step and achieve lower volume, mass, and cost. The synthetic fuel makes possible high efficiency while preserving the ability to use the current fueling infrastructure. In fact, the same fuel could be used for both fuel cells and diesel power systems.

As Epyx observed: "The ability to handle infrastructure friendly fuels will be an important differentiator on the path to successful introduction of fuel cell vehicles."

Immediate Opportunities for Alternatives

The lack of generally available alternatives has frustrated policymakers' efforts to achieve environmental progress through mandates for cleaner fuels and engines for government fleet vehicles. Under DOE's Clean Cities Program, 10% of the designated market was supposed to be alternative fuels by 2000 and 30% by 2010, with 50% of the product to be domestic in origin.

Progress has been held up by a stubborn fact of life: All DOE-designated alternative fuels, with one exception, require new engines or major modifications. The exception is biodiesel, whose limited supply-less than 5,000 bpd in 1998 and costs in excess of $3 per gallon-prevented suppliers from seizing a great ground-floor opportunity. The soybean-based product could not be expected to satisfy more than a tiny fraction of the projected 600,000-b/d demand in 2010. The way is therefore open for other fuels to win certification and serve that market. GTL synthetic fuels meet all the environmental requirements of the Clean Air Act of 1990 and should qualify as well as an alternative fuel under the Energy Policy Act of 1992. Syntroleum is currently conducting the necessary tests at Southwest Research to apply for certification.

There are at least 12 GTL projects in operation or in various stages of development

As EPA weighs its decision on a separate near-zero diesel fuel for light duty vehicles in 2004, the prospective availability of synthetic fuels will be a significant encouraging factor. EPA is also aware of a substantial added bonus from such a step. Existing light duty diesels account for about 5% of current US diesel fuel consumption, or just over 100,000 b/d. This group, which currently escapes the stricter regulation imposed on gasoline-powered vehicles, is a ripe target for cleanup-if an option were to be available, and one should be. If only half the proposed GTL plants go ahead, they can easily produce the 100,000 b/d needed by 2004 to switch existing light duty vehicles to a clean fuel.

Based on tests using a GTL diesel, merely switching to such a sulfur-free, aromatics-free, odor-free, smoke-free fuel could yield major improvement without engine changes. The indicated reductions are carbon monoxide 46%, hydrocarbons 38%, particulates 30%, and oxides of nitrogen 8.3% from the more than 3 million light duty diesels now operating in the US.[17] That kind of opportunity to clean up existing vehicles

will not go unnoticed-nor will the fact that the same fuel can also power fuel cells.

Which Alternative?

There is a low-sulfur fuel avalanche roaring down on the fuels industry. Federal officials and the auto industry see it as the only solution to achieving the fuel economy and emissions reductions they desire. State officials say a national low-sulfur fuels standard would have the same benefit as removing 50 million cars from the road.[18] Very low sulfur fuels are coming. They will be required not just for autos and light duty vehicles 4 years from now but within the next 10 years, for heavy trucks and buses, off-road vehicles, railroads and ships. The latter is the source of 30% of sulfur oxides in the Los Angeles area, according to a study there. The only questions are just how strict the standards will be, and whether a sulfur-free diesel grade will be part of the package finally adopted.

The low-sulfur avalanche will bury those who do not become a part of it. On the other hand, it offers handsome opportunities to those who can come up with an acceptable alternative. The separate near-zero sulfur diesel grade is especially intriguing. Even as they oppose this proposal, refiners are fighting an uphill battle. They are certainly weighing their options in case it is approved-and GTL technology has to be high on the list.

Having said they cannot make 5 ppm sulfur diesel, at least not in any real volume-some say they cannot reduce sulfur to 30 ppm-refiners have left the field open to others for the next decade. Some have suggested that crude-oil refiners are virtually conceding the field.[19] Even if they can make the exacting product, synthetic fuels hold other attractions. Crude-based diesel by definition will not qualify as an EPACT fuel. Without a certified alternative fuel, suppliers will forfeit this worthwhile business. Also, looking 10 years ahead, 5-ppm sulfur product might not be good enough for fuel cells, the market of the long-term future that refiners will not want to abdicate to others. More desulfurization investment, more severe operations and other processing tricks will help a lot. But they may not

ignition engine designs in SUVs, thereby gaining the 40% fuel improvement inherent in that type of power plant, and they can achieve the reduced pollution through advanced emissions control technology enabled by the clean fuels.

EPA may have something else in mind in considering this separate fuel grade. The government/industry Partnership for a New Generation of Vehicles is seeking to develop a midsize car that achieves at least 80 mpg and reduces emissions. Many believe the EPA has light-duty, low-sulfur diesel in mind for that car, creating yet another use for this industry-changing fuel.[8]

Auto companies have been quick to jump aboard the low-sulfur bandwagon. Ford Motor Co. says it will equip all diesel-powered vehicles with particulate control devices, nominally by 2005, provided a guaranteed supply of sulfur-free fuel is available.[9] To meet new super-tight California emission standards, says DaimlerChrysler, "there's no other path than fuel." [10]

Meanwhile, Western Europe is creating an even larger role for the new fuel-efficient, low-emission diesel engines, portending greater growth for low-sulfur diesel at the expense of more highly taxed gasoline.[11] Exploiting breakthroughs in fuel-injection technology, European auto makers are already marketing diesel-powered cars that are peppier, cleaner, quieter, and more efficient than ever. This development is projected to boost diesel auto's Western Europe market share from 22% in 1998 to an estimated 33% in 2003. In view of European Union sulfur reductions ordered for both diesel and gasoline by 2005, DaimlerChrysler warns, if the US does not move quickly, "North America will become the natural dumping ground for high sulfur fuels."[12]

Trends in costs of making lower-sulfur fuels are also generating pressures for changes in sources-from products refined from crude oil, whose costs continue to rise, to synthetic fuels, whose costs are moving down in the face of steady advances in the new GTL technology. The two are moving toward parity. There are at least 12 GTL projects in operation or in various stages of development, and the prospective availability of these supplies nas become a significant factor in decisions about emissions limits, engine design and fuel choices.

- Joint research involving vehicle makers and fuels suppliers and, in some cases, the government is a major driver for change in the direction of synthetic diesel and other low-sulfur fuels.

As one example of what's happening, the Dodge PowerWagon, a new concept truck, traveled the country this year, demonstrating the sharply reduced emissions possible from a standard diesel engine burning a sulfur- and aromatic-free "designer fuel" from Syntroleum.[13]

Navistar, the diesel engine and vehicle maker has demonstrated that its new green diesel technology engine can meet EPA's Tier 2 emission standards. It can do so while producing half the particulate matter emissions of the best compressed natural gas engines.[14] Navistar's new T44E diesel engine, installed on a rear-engine school bus with a continuous regenerative trap, used an ultra-lower sulfur diesel fuel (less than 5pm). This system also dropped hydrocarbon emissions below measurable levels, eliminating the odor that is such an image problem for diesels.

A favored future technology for medium and heavy-duty trucks and buses, the hybrid electric, also relies on ultra-low sulfur diesel. GM/Allison Transmission Division has a hybrid-electric bus, powered by a clean fuel supplied by BPAmoco, now in revenue service on the New York City Transit system. The vehicle/fuel combination reduces emissions by 70%.[15]

Such transitional technology has a big edge over radically new technology based on infrastructure considerations alone. Distributing synthetic fuels could be as simple as substituting the new fuel for a single grade of gasoline at the service station.

Sulfur-free synthetic fuels are thus leading candidates for a central role in transitional solutions heading toward the ultimate goal of near zero emissions. Hydrogen may be the ideal fuel cell fuel, but a H2 distribution system for just a small percentage of total vehicles would entail staggering costs, and would not be backward compatible. Infrastructure considerations thus favor on-board fuel processors to convert gasoline or something else into hydrogen for fuel cells. This issue then boils down to which fuel lends itself to efficient on-board conversion. Methanol has gotten most of the attention, but it too has infrastructure, safety and other drawbacks that leave an opening for candidates without these problems.

EPA could hardly have imagined all the far-reaching implications of a separate sulfur-free fuel. What if this product that is key to the successful transitional engines-the more efficient, lower emission diesels and hybrid/electrics--is also suitable for on-board conversion to hydrogen? Recent successes are pointing in that very direction! In tests conducted at Argonne National Laboratories, synthetic fuels made by the Syntroleum Process were successfully reformed into the hydrogen fuel for fuel cells.

Epyx Corp. has successfully demonstrated high efficiency and low emission operation of a fuel cell power system using a Syntroleum synthetic fuel and a Plug Power fuel cell stack.[16] Since

without reasonable expectation of adequate fuel supplies at affordable cost? Consumers tell pollsters they are willing to pay more for a cleaner environment. But how much more?

● Will new fuels be backed by adequate raw material that insures plentiful supplies not just for the near term but for several decades down the road?

These are legitimate concerns. The archives of the recent past are replete with heralded automotive and energy technologies that so far have failed to pan out. Many of these failures are fresh in the minds of auto and oil industry executives and the motorists who use their products today. Some of the false starts stemmed from economic barriers to rapid changes in infrastructure-a big hurdle facing most new alternative fuels. Backward compatibility obviously will give any new fuel a big advantage over rivals that lack this crucial characteristic.

Drivers for Change

Daunting as the barriers may be, the forces for change appear irresistible:

● Environmental and health concerns, sharpened rather than diminished by progress, continue to drive accelerating public demands for reductions in industrial and transportation emissions of all kinds.

● These demands translate into legislation and regulations for progressively lower emission levels that push or exceed the limits of current fuels and engine technology.

EPA, encouraged by developments in both industries, is taking even stronger action than in the past by raising passenger car standards sharply upward, by extending these standards to light duty vehicles that have enjoyed more lenient limits, and by bold new initiatives into fuels regulation-notably

Supplies of several hundred thousand barrels per day of essentially sulfur-free fuel may be needed by the middle of the next decade

sulfur content. Because sulfur clogs and impairs anti-pollution devices, EPA has proposed to cut the sulfur content by at least 90% over the next 5 years.[5] Auto companies are asking for 99%, and they may get it. And aromatics are likely to be next!

The agency also asked for comment on early introduction of a near zero-sulfur diesel for the potential emerging class of light duty trucks and SUVs starting in 2004. Beginning in the year 2004, manufacturers would have to start producing vehicles that are 75 to 95% cleaner than those rolling off the assembly lines today. This is an interim step en route to the zero-emission requirement within the next decade.

EPA and the Department of Energy appear to be poised to put more teeth into their Clean Fuel Fleet Vehicle, Alternative Fuel Vehicle, and Clean Cities programs designed to encourage cleaner alternative fuels and force them into use. DOE has ordered acceleration of federal fleet purchases of AFVs, and there are state and industry purchase incentives. DOE is also plugging the loophole in earlier rules that required agencies to purchase AFVs but not alternative fuels.[6] Federal regulators have learned that it is one thing to issue an order to purchase AFVs, but quite another for the desired Alternative Fuel to be available. In many cases fleet vehicles, expensively equipped to run on alternative fuels as ordered, continue to burn gasoline instead of compressed natural gas (CNG) or alcohol because the mandated fuels are not available where needed. But today, fleet managers are in technical compliance with the directive to buy the AFV!

● Several special interest groups-all the makers of novel engines from hybrid-electric to the zero-pollution fuel cell, together with their prospective alternative fuels suppliers-are themselves potent drivers for change also.

● The auto industry itself-seeing the regulatory handwriting on the wall– is certainly a powerful force for change-notably, in pushing for removal of most sulfur in diesel fuel and gasoline. Manufacturers are designing their most advanced engines and emission controls around sulfur-free fuels-notably, the unique aspects of synthetic fuels. It was the Engine Manufacturers Association and some auto companies that asked EPA to require retailers to offer a separate, essentially sulfur-free (less than 5 ppm) grade of diesel fuel for SUVs and other light duty vehicles.[7] Such a step would spark major changes in the auto and fuels industries.

Auto companies are elated at the breath-taking vistas opened up by the move. Lower-sulfur fuels across the board will enable them to take advantage of new, more efficient engine designs and emissions-control technology, which cannot be used with fuels.

containing current sulfur levels. In particular, they see a way to save their most profitable product-sport utility vehicles. Without major engine changes, the popular SUVs, whose gas-guzzling ways have set manufacturers up for huge fines for inability to comply with CAFÀ standards, cannot meet California's 2004 emission standards. With availability of an ultra-low-sulfur diesel fuel, they see a way to do both. They can substitute new compression

An Aura of Inevitability for GTL

Auto makers, struggling to meet future fuel economy and emission standards, cannot comply with either, using present engines and fuels. Refiners are challenged to produce the fuels required to comply with upcoming fuel and emission standards using existing refinery equipment and raw materials.

Federal and state regulators, on the other hand, seem in no mood to back off. Judging from recent signals, they are certain to raise the environmental bar even higher. Emboldened by breakthroughs in engine and fuels technology, the Environmental Protection Agency sees an opportunity for clean-air gains heretofore unattainable. The key is the availability of low-sulfur fuels required to utilize the advances in engines and emission control technology-a clean fuel that exploits the diesel engine's ability to deliver 40% greater fuel economy and 50% lower emissions of carbon dioxide greenhouse gases, compared to gasoline engines, is a key focal point of the auto industry. "We have the engines to do the job," auto companies are saying. " Give us the low-sulfur fuel, and we will do it." Synthetic diesel is such a product. The developers of newly economic GTL technology are positioning to be ready to provide it.

Refiners protest the impracticality of draconian sulfur standards, and they have a point. They may not be able to produce such fuels economically from a crude stream that has grown heavier and higher in sulfur for the past 10 years. The only other viable raw material option is natural gas. Proven deposits are equivalent to at least 500 billion bbl of oil.[1] There is also the future possibility of economically tapping the virtually limitless deposits of gas found in hydrates on the ocean floor. Syntroleum's recent patent for a method to recover and convert hydrates via GTL technology points in that direction.

Hydrates hold an estimated 200,000 TCF of gas in the US alone, compared to 1,400 TCF of total conventional gas resources, and 400,000,000 TCF worldwide, compared to 5,000 TCF for the world's known gas reserves. In pushing for sharp reductions in sulfur, therefore, EPA is not just blindly betting on some hoped-for technological windfall. It may be implicitly playing the GTL card.

To auto makers, low sulfur fuel is the silver bullet that removes the barriers to the fuel-efficient, ultra-low emissions engines they have waiting in the wings. They view products like super clean synthetic fuels as the enabler of new engine and emissions-control technology that will usher in the era of still cleaner air sought by regulators and the public while permitting compliance with stiff Corporate Average Fuel Economy (CAFÀ) standards as well.[2]

Two years ago, conventional wisdom was that synthetic fuels would never be sold neat, that it would be used only for upgrading higher-sulfur fuels. The EPA's recent proposal requiring a separate ultra-clean diesel for city use would change everything. It would create instant, significant demand for neat synthetic fuels.

Barriers to Acceptance

Of the many combinations of fuel and engine options under consideration-electricity, CNG, hydrogen, ethanol, methanol, hybrid electric vehicles, fuel cells--most would require new technology, major changes in distribution infrastructure, or both--and would raise substantial questions as to performance, adequacy and reliability of fuel supply, or consumer acceptance. The barriers to rapid incorporation of new technologies include powerful political forces for the status quo tied to existing technologies:

- Refiners, with billions of investment at stake and a secure demand for current products, have limited motivation to make expensive additional investments in cleaner fuels-especially if pushing existing technology offers diminishing returns. There are qualified exceptions-BPAmoco and Shell have embraced efforts to reduce greenhouse gases such as CO2, methane, and oxides of nitrogen. In addition, BPAmoco is introducing a series of lead-free, lower-sulfur fuels in 40 major cities around the world.[3] But even these environmental leaders are not willing to endorse the accelerated pace of US regulators.
- Fuel retailers, too, with additional billions of sunk investment, oppose any new system that renders their infrastructure obsolete or requires major expensive modifications.[4]
- The "vroom factor"--Motorists like their current vehicles. They have historically refused to trade them in for replacements that are not equal or superior in performance, convenience, range, driving fun, pride of ownership, and safety.
- Backward compatibility-Will current vehicles be able to use new fuels with little or no modification? Will owners of current vehicles find them obsolete or impossible to maintain when new technologies are embraced?
- Concern over the adequacy of supply and demand for new fuels-Will refiners and marketers invest in new fuel systems if they fear costly assets will be stranded for lack of demand? Will consumers buy expensive new vehicles when there is a chance that fuel will be unavailable or grossly inconvenient? Will automobile manufacturers risk huge investments in new engines and vehicles

The convergence of events in the automotive and fuels industries, highlighted by an abruptly tightening environmental noose, is rapidly ordaining a crucial role for the infant Gas-to-Liquids (GTL) industry. Research, regulatory and market forces are coming together to create a preferential demand for these unique fuels early in the next millennium. The desire to monetize stranded gas reserves was the original motivation to develop GTL technology. But the crucial role of low-sulfur fuels in advancing the causes of cleaner air and greater fuel economy will likely trigger the first commercial projects and give the nascent GTL industry a giant push forward. Supplies of several hundred thousand barrels per day of essentially sulfur-free fuel may be needed by the middle of the next decade. It stands to reason that the alternative with the fewest barriers to change will be the one most likely to succeed in capturing this market. The principal barriers to GTL are rapidly falling. Several companies say the technology is ready and getting better, that the economics are right for a pure product that can command a 15/20-cent premium, and most of the forces for change are demanding such a product. GTL projects now on the drawing boards, therefore, are the leading candidates to meet this demand.

Fuels for the Future

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