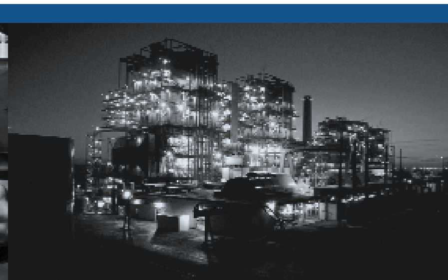
LOOKING BEYOND THE INTERNAL COMBUSTION ENGINE

The Promise of Methanol Fuel Cell Vehicles



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ABOUT THE AMERICAN METHANOL INSTITUTE

ESTABLISHED IN 1989, THE AMERICAN METHANOL INSTITUTE (AMI) serves as the trade association for the methanol industry in Washington and across the United States. As the voice of the methanol industry, AMI works to encourage the development of methanol-powered fuel cells, support the use of clean reformulated and oxygenated gasoline, and promote the use of methanol as an alternative fuel.

AMI member companies produce roughly one-half of the world's supply of methanol. In addition, AMI associate member companies include the premier methanol engineering and service firms.

For more information about the American Methanol Institute, call us at 1-888-275-0768, or drive by our web site at www.methanol.org.

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EXECUTIVE SUMMARY

METHANOL — A LIQUID FUELMADE FROM NATURAL gas or renewable resources — is the leading candidate to provide the hydrogen necessary to power fuel cell vehicles. The American Methanol Institute has prepared this report to introduce readers to methanol fuel cell technology, review the environmental benefits of methanol fuel cell vehicles, examine the likely paths for expanding the methanol fuel market to serve these vehicles, and explore how we get there.

KEY FINDINGS

- Today's internal combustion engine converts only 19% of the useful energy in gasoline to turning a car's wheels. Methanol fuel cell vehicles will achieve efficiencies of at least 38%. Based on this conservative energy efficiency estimate, a future fleet of methanol fuel cell passenger vehicles would achieve a fuel economy of about 55 miles per gasoline-equivalent gallon.

- Daimler-Benz displayed a prototype methanol fuel cell vehicle at the 1997 Frankfurt Auto Show. The compact NECAR 3 features a 50-kilowatt methanol-powered fuel cell that runs the car and all standard features for passenger comfort. The automaker expects to commercialize a methanol fuel cell vehicle in 2004.

- Toyota also showcased a prototype methanol fuel cell vehicle at the Frankfurt Auto Show. Based on the popular RAV4 sport-utility vehicle and operating on methanol, this prototype car has a range of 500 kilometers (310 miles), while demonstrating a hybrid design concept. Toyota has vowed to beat its competition to the marketplace with a methanol fuel cell vehicle.

- At the Detroit Auto Show in January 1998, General Motors Corporation, the world's largest automaker, announced plans to have a production-ready methanol fuel cell vehicle by at least 2004. At the Geneva Auto Show in March 1998, General Motors, through its German subsidiary, Opel, presented a methanol fuel cell-powered Sintra van.

- Germany's Volkswagen has developed a methanol fuel cell vehicle in partnership with Johnson Matthey (United Kingdom), Volvo (Sweden), and the Energy Research Foundation Netherlands ECN, supported by the European Union.

- Georgetown University has taken a major role in the development of methanol fuel cells for transit buses. In 1994 and 1995, Georgetown rolled out three 30-foot buses that were the world's first fuel cell vehicles capable of operating on liquid fuels. In 1998, Georgetown will unveil two methanol-fueled prototype 40-foot transit buses using two different fuel cell technologies.

- The American Methanol Institute estimates that by the year 2010 automakers will have sold at least 2 million methanol fuel cell vehicles worldwide, and that by 2020 the total fleet of methanol fuel cell vehicles on the road will reach or surpass 35 million vehicles. A higher, faster penetration rate could easily be justified, but with the very rapid improvements in this technology, it is difficult to define an upper limit.

- Today's prototype fuel cell vehicles use a steam reformer to split the methanol molecule to produce the hydrogen needed by the fuel cell stack, which then generates electricity to power the vehicle.

- Researchers are developing direct methanol fuel cell (DMFC) technology that does not use a reformer; liquid methanol is injected directly into the cell. It is estimated that the DMFC technology will reach commercial maturity as early as 2008, only four or five years after the initial introduction of steam reformer methanol fuel cell vehicles.

- A few years ago, the fuel cell stack — only one part of the whole fuel cell power system — cost a prohibitive $5,000 per kilowatt. The whole fuel cell system cost (fuel cell stack, methanol reformer, and associated controls) is now down to $500 per kW, and developers are targeting full power system costs in the range of $50 per kW with high-volume production. A 50-kW power system for a vehicle would cost, therefore, about

$2,500, similar to the cost for today's internal combustion engine.

- Driving a methanol fuel cell vehicle will be as convenient as driving a standard gasoline vehicle today, but without the noise. Fewer moving parts means greater reliability and longer vehicle life, reducing the need for expensive financing or leasing.
- Methanol is one of the safest and most environmentally sound fuels available. In the U.S., there are over 180,000 vehicle fires each year in which gasoline is the first material to ignite. A switch to methanol could reduce this to 18,000 vehicle fires, saving 720 lives, preventing nearly 3,900 serious injuries, and eliminating property losses of millions of dollars a year.
- In the United States, the principal air pollutants are carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (unburned hydrocarbons, or VOCs), and particulate matter (PM). Methanol fuel cell vehicles will all but eliminate these pollutants.
- Initial dynamometer emissions tests of NECAR 3 were extremely encouraging. The testing showed that the methanol fuel cell vehicle produced no NOx or carbon monoxide emissions. Hydrocarbon emissions were 0.005 grams per mile, or one-half the Super Ultra Low Emission Vehicle limit set by the State of California.
- Full fuel cycle carbon dioxide emissions — a potent greenhouse gas — from a methanol fuel cell vehicle will be less than half of those for today's gasoline internal combustion vehicle.
- California has a network of nearly 100 methanol refueling stations, serving 15,000 methanol-powered alternative fuel vehicles on the road today. Given California's experience in building methanol fueling stations, we can estimate the gasoline-to-methanol conversion cost to be $50,000 per station.
- It would cost less than $500 million to convert 10% of the stations in California, New York, Massachusetts, Germany, and Japan to methanol operation. Even converting 25% of the stations in these target areas would only amount to $1.2 billion. Assuming that retailing stations are required to cover all of the U.S., Europe, Japan, and Canada, it would still only cost $1.9 billion for 10% of the stations to be converted and $4.7 billion for 25% of the stations.
- In 1998, worldwide methanol production capacity stands at about 11.4 billion gallons (34 million tons), with a utilization rate of just under 80%.
- The world methanol industry has a significant impact on the global economy, generating over $12 billion in annual economic activity while creating over 100,000 direct and indirect jobs.
- Under initial penetration assumptions, we estimated that by the year 2010 automakers will have introduced 2 million methanol fuel cell vehicles; if each vehicle uses 441 gallons of methanol fuel per year, it would produce a demand of 882 million gallons of methanol per year, or less than 8% of current world capacity. By 2020 our estimate of 35 million vehicles would consume 15.4 billion gallons of methanol — roughly 135% of current world capacity.
- Because large-scale methanol plants can be built in 2 to 2.5 years, there should be no problem adding the necessary capacity to meet this kind of demand in the 20-year time horizon.
- Based on 35 million fuel cell vehicles operating on methanol derived from natural gas, annual methanol demand is expected to be 15.4 billion gallons — or natural gas demand of 1.4 TCF (less than 2% of current annual natural gas consumption).
- If only 10% of the natural gas flared each year was made available for the methanol fuel market, it would be enough to power 9.5 million fuel cell vehicles annually.
- Methanol may be made from any carbon source. Wood, coal, municipal solid wastes, agricultural feedstocks, and sewage are all potential methanol feedstocks. Other potential sources of methanol are coalbed methane gas, methane hydrate, and hydrogen from water.
- If two average drivers, one driving a gasoline-powered vehicle averaging 27.5 miles per gallon and the other driving a methanol fuel cell vehicle averaging 55 miles per gallon equivalent, each procured gasoline and methanol at wholesale prices, the driver of the gasoline vehicle would have paid $288 a year while the driver of the methanol fuel cell vehicle would have paid $213.

KEY RECOMMENDATIONS

- ***Elimination of discriminatory fuel taxation.*** Fuels should be taxed on their energy content, not by volume. Currently taxation policies in many jurisdictions discriminate against alternative fuels by taxing clean fuels with relatively lower energy content on a simple volume basis, which encourages the use of gasoline.
- ***Establish fuel tax incentives.*** Tax incentives that encourage both gasoline retailers to provide methanol

pumps and consumers to purchase methanol fuel should be established. Permanent subsidies are not necessary or wanted. What is needed are short-term incentives to help overcome initial obstacles and jump-start the market.

- ***Support vehicle purchase incentives.*** The existing $4,000 federal tax credit for purchases of electric vehicles should be used to assist methanol fuel cell vehicle buyers. This tax credit also should be extended from its current expiration date of 2004 to the year 2010. Support also should be given to President Clinton's proposed tax credits for buyers of ultra-fuel efficient cars.

- ***Encouragement of necessary infrastructure.*** Some combination of incentives may be necessary to make sure that an adequate distribution facility for methanol will be available to service the fuel cell cars as they hit the market in 2004.

- ***Provide credit for methanol fuel cell vehicles in regulatory policies encouraging the use of electric vehicles.*** California, New York, and Massachusetts require that 10% of the vehicles sold in these states in Model Year 2003 must be Zero Emission Vehicles. Regulatory policies and programs should encourage the use of methanol fuel cell vehicles by providing full or partial ZEV credits for these vehicles.

- ***Provide additional incentives for fuel cell vehicle consumers.*** Provide states with the authority to allow single-occupant drivers of methanol fuel cell vehicles to use high-occupancy vehicle (HOV) lanes.

- ***Encourage the use of CMAQ funds for methanol fueling station construction.*** With funding levels expected to exceed $1 billion per year for the federal Congestion Mitigation and Air Quality Improvement Program, municipalities should be encouraged to use this funding to help install methanol fueling stations.

- ***Support the fuel cell work of the Partnership for a New Generation of Vehicles.*** This public/private partnership has identified fuel cell vehicles as one of its technology options for developing highly efficient vehicles. Given the strong support for methanol fuel cell vehicle development evidenced by the world's automakers, this technology should be given a higher priority.

- ***Increase funding for research in direct methanol fuel cell technologies.*** The direct methanol fuel cell holds the greatest promise of reducing emissions and improving energy efficiency for a broad array of applications. Federal funding for DMFC development has been minimal and fragmented. The efforts of national laboratory, university, and private researchers should be directed to accelerating the pace of development of this technology.

- ***Encourage the development of strategic alliances.*** A number of strategic alliances have already been formed to support the introduction of fuel cell and alternative fuel vehicles. Broad-based strategic partnerships that involve the automotive, methanol, natural gas, and oil industries, along with government, should be encouraged.

BEYOND THE INTERNAL COMBUSTION ENGINE

"No one is saying the pistons and crankshafts that have powered automobiles and the auto industry for more than a century will disappear right away. But automakers from Tokyo to Stuttgart to Detroit have reached a surprising consensus on an idea deemed heretical not long ago: A fundamental shift in engine technology is needed."

Wall Street Journal, January 5, 1998

EFFORTS TO DIMINISH THE ENVIRONMENTAL DAMAGE OF rapidly growing automobile use have, for the past 50 years, focused initially on adding control devices to the internal combustion engine and recently on producing cleaner gasoline. This strategy has dramatically reduced emissions from the newest cars being put on the road, but the strategy has its limitations. In the United States, emissions from 190 million cars, trucks, and buses account for about half of all air pollution — more than 80% in major cities — and one-third of carbon dioxide emissions, which are believed to contribute to global climate change.

Our reliance on gasoline has serious energy security and economic consequences. More than one-fourth of the world's oil production is consumed in the U.S., which every year imports about one-half its oil. This costs American consumers about $60 billion per year, and as taxpayers they spend about $30 billion to protect their oil interests in the Persian Gulf. With the transportation sector almost completely reliant on oil, future availability and possible price shocks are major policy concerns.

Many thoughtful people have concluded that the 100-year reign of the petroleum-fueled, internal combustion engine must begin to give way. In its place, we need a clean, advanced-technology vehicle that retains all the performance and consumer convenience of today's automobile while breaking our dependence on oil. Fortunately, it is now clear that fuel cell vehicles will soon be available to meet this challenge.

Fuel cells have undergone astonishingly rapid development in the past two years, and in fact fuel cells already provide clean, stationary electric power. A host of smaller applications for fuel cells as battery replacements in consumer electronics like cellular phones and laptop computers will enter the marketplace in the next few years. Another market opportunity is to use fuel cells as an alternative to high-polluting, small two-cycle engines sold each year in nearly 8 million pieces of portable power equipment — lawn mowers, chainsaws, and leaf blowers. While these are promising markets for fuel cells, clearly the vehicle market dwarfs all others, and is the central focus of many fuel cell developers and this report.

Methanol — a liquid fuel made from natural gas or renewable resources — is the leading candidate to provide the hydrogen necessary to power this technology for vehicle applications. The commercialization of methanol-powered fuel cells will offer practical, affordable, long-range electric vehicles with zero or near-zero emissions while retaining the convenience of a liquid fuel. By 2004 or sooner, fuel cells operating on methanol will power a variety of cars and buses in the U.S. and worldwide.

The American Methanol Institute has prepared this report to introduce readers to methanol fuel cell technology, review the environmental benefits of methanol fuel cell vehicles, examine the likely paths for expanding the international methanol fuel market to serve these vehicles, and explore how we get there.

WHO IS DEVELOPING METHANOL FUEL CELL VEHICLES?

"Daimler-Benz … the firm that brought the world the petrol-engined car 100 years ago, is about to launch the product most likely to kill it."

The Economist, October 25, 1997

PRESTIGIOUS BUSINESS PUBLICATIONS SUCH AS *Business Week* (May 27, 1996), *The Economist* (October 25, 1997), the *Wall Street Journal* (January 5, 1998), and *Fortune* (March 30, 1998) have run major, feature-length articles on the rapid technological progress and ambitious plans manufacturers have for introducing fuel cell vehicles. Automakers and component suppliers are spending billions of dollars to develop these advanced technologies. The industry leaders include Daimler-Benz, Toyota, General Motors, Ford, Chrysler, Nissan, Honda, Volkswagen, Volvo, Ballard Power Systems, and International Fuel Cells.

Even the best battery-powered electric vehicles (EVs) are constrained with very short ranges between recharges, which can take eight hours or more. Methanol fuel cell vehicles offer virtually all the environmental benefits of battery EVs, the performance and range of today's internal combustion engine, and the convenience of filling up with a liquid fuel without the energy security risks of further dependence on crude oil.

The broad-based industrial commitment to fuel cell vehicles derives from their inherent energy efficiency and low emissions. Today's internal combustion engine converts only 19% of the useful energy in gasoline to turning a car's wheels. Methanol fuel cell vehicles are projected to achieve efficiencies of at least 38% while bringing smog-precursor emissions close to zero and cutting greenhouse gas emissions by 50% or more.

Fuel cell vehicle efficiencies in excess of 38% may, however, prove possible in the future. Based on the conservative energy efficiency estimate of 38%, a future fleet of methanol fuel cell passenger vehicles, with performance, design, and styling comparable to today's vehicle mix, would achieve a fuel economy of about 55 miles per gasoline-equivalent gallon instead of 27.5. Moreover, the move to a fuel cell electric drive train will facilitate innovative changes in design and materials. For this reason the public/private Partnership for a New Generation of Vehicles anticipates that a fuel cell vehicle comparable to today's Ford Taurus or Chevrolet Lumina will get about 80 miles per gasoline-equivalent gallon.

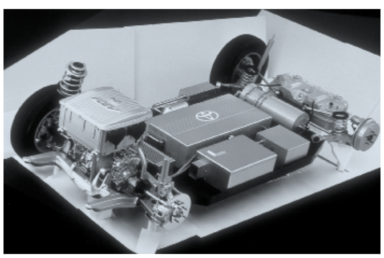
Because of the likelihood of future advances in design and materials, no one can say at this time what would be the fleet average of all methanol fuel cell vehicles and types, from small economy to big luxury cars. Certainly this fleet average would compare very favorably to today's internal combustion engine fleet.

Daimler-Benz and Ballard Power Systems are orchestrating a powerful development and production effort that unites their respective capabilities with other world industrial leaders. In Nabern, Germany, the automaker has assembled a team of approximately 135 researchers in its Fuel Cell Product Center. Daimler has invested $320 million in Ballard Power Systems, a Canadian company on the cutting edge of fuel cell development and manufacturing that has about 330 researchers in its employ. The Ford Motor Company joined the team in December 1997, by making a $420 million-dollar commitment to the Daimler-Ballard group.

Daimler-Benz displayed a prototype methanol fuel cell vehicle at the 1997 Frankfurt Auto Show. The compact NECAR 3 features a 50-kilowatt methanol-powered fuel cell that runs the car and all standard features for passenger comfort. Earlier versions — the NECAR I and NECAR II — were fueled by gaseous hydrogen stored in bulky high-pressure cylinders, as is Daimler's fuel cell-powered transit bus called the NEBUS. Daimler used vans for its first two fuel cell vehicles, while the space-saving features of liquid methanol fuel allowed the automaker to produce the NECAR 3 in its smallest passenger car.

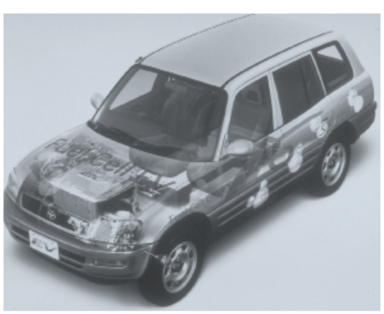
Daimler-Benz will begin offering its first commercial fuel cell bus for fleet testing in 1999, with fully commercial series versions available in 2004. DBB Automotive (the Daimler-Benz/Ballard/Ford joint venture) plans to complete work on its prototype series car — the NECAR 5 — in late 1999, and intends to build 40,000 methanol-powered fuel cell drive trains in 2004. The company believes that with a production volume of 250,000 vehicles per year, the fuel cell vehicle will be cost-competitive with traditional internal combustion cars.

Toyota, another major industry developer of methanol fuel cell technology, has vowed to beat Daimler to the marketplace. With hundreds of researchers in its fuel cell program, Toyota also showcased a prototype methanol fuel cell vehicle at the Frankfurt Auto Show. Based on the popular RAV4 sport-utility vehicle and operating on methanol, this prototype car has a range of 500 kilometers (310 miles), while demonstrating a hybrid design concept quite different from the Daimler prototype.



Toyota's fuel cell RAV4 employs a 25- kilowatt fuel cell that works in conjunction with a downsized electric vehicle battery pack. The batteries are constantly recharged from the fuel cell. Regenerative braking provides additional electric power to charge the batteries.

Toyota's design draws extra power from the batteries to supplement the fuel cell during acceleration. The batteries also enhance the vehicle by providing instant power, avoiding the short warm-up that some prototype fuel cell reformers require to reach maximum power output.



Due to its high fuel economy, Toyota believes that once, in production its fuel cost to the consumer will be half that of conventional gasoline vehicles, and it is likely that this estimated cost will decline even further with improved design and manufacturing experience.

At the Detroit Auto Show in January 1998, the world's largest automaker — General Motors Corporation — announced plans to have a production-ready methanol fuel cell vehicle by at least 2004. GM has had an extensive fuel cell development program operating for over a decade. The automaker led a U.S. government-industry team with over $23 million in funding from the Department of Energy to develop a methanol fuel cell propulsion system. This project was so successful that GM has foregone further government support to develop its technology in house. GM expects its fuel cell vehicle to get 80 miles per gasoline-equivalent gallon on methanol, with a range comparable to, or perhaps even greater than, today's car.

At the Geneva Auto Show in March 1998, General Motors, through its German subsidiary, Opel, presented a methanol fuel cell-powered Sintra van. The Sintra is a four-seater, with a 50-kilowatt (kW) electric motor. GM is focusing much of its fuel cell research and development at Opel's Global Alternative Propulsion Center in Germany.

Also in Europe, Germany's Volkswagen has developed a methanol fuel cell vehicle in partnership with Johnson Matthey (United Kingdom), Volvo (Sweden), and the Energy Research Foundation Netherlands ECN, supported by the European Union. Volkswagen plans to unveil a functioning prototype vehicle at the EXPO 2000 in Hannover.

For 14 years Georgetown University has taken a major role in the development of methanol fuel cells for transit buses, supported by the U.S. Federal Transit Administration and the Department of Energy. In 1994 and 1995, Georgetown rolled out three 30-foot buses that were the world's first fuel cell vehicles capable of operating on liquid fuels. In 1998, Georgetown will unveil two methanol-fueled prototype 40-foot transit buses using two different fuel cell technologies. International Fuel Cells has provided

Georgetown with a 100-kW phosphoric acid fuel cell, and DBB Fuel Cell Engines is building a 100-kW proton exchange membrane (PEM) fuel cell.

These are hybrid buses, using batteries to provide surge power and as storage for electricity created by regenerative braking. The use of methanol fuel gives these buses a range comparable to diesel buses, and they can be refueled as easily and quickly. The buses are expected to have virtually no emissions of nitrogen oxides (an ozone precursor) and particulate matter (soot), less than one-tenth the hydrocarbon emissions and only 2% of the carbon monoxide emissions of the cleanest compressed natural gas buses on the road.

It is projected that the number of vehicles worldwide will increase from 600 million today to 1 billion by the year 2015. The introduction of large numbers of low-emission, energy-efficient methanol fuel cell vehicles is not only needed but well within reach. Based on announcements from various automakers and the political and regulatory pressure to introduce advanced-technology vehicles, the American Methanol Institute estimates that by the year 2010 automakers will have introduced at least 2 million methanol fuel cell vehicles worldwide, and that by 2020 the total fleet of methanol fuel cell vehicles on the road will reach or surpass 35 million vehicles.

A higher, faster penetration rate could easily be justified, but with the very rapid improvements in this technology, it is difficult to define an upper limit. Figure 1 depicts this modest growth of the methanol fuel cell vehicle fleet from 40,000 vehicles in 2004 to 35 million vehicles in 2020.

PROJECTED GROWTH IN METHANOL FUEL CELL VEHICLE FLEET

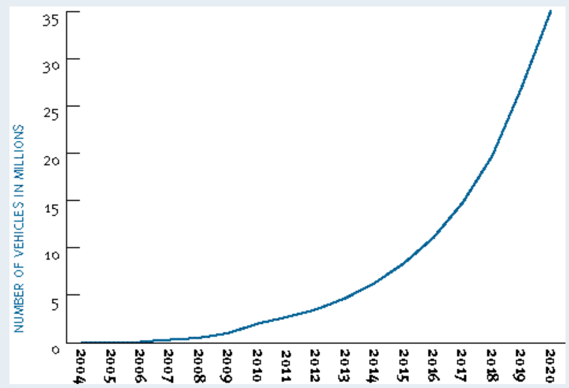


Figure 1

WHAT TYPES OF FUEL CELLS ARE THERE?

"Fuel cells have long supplied electricity on spacecraft, but they are priced like crown jewels, hopelessly beyond the pocketbooks of the motoring public. In the last decade, however, development work has shrunk the bulk and price of a version suitable for ground vehicles by roughly a factor of ten."

Fortune, March 30, 1998

A FUEL CELL REVERSES THE PROCESS OF ELECTROLYSIS in which an electric current breaks down water into its constituent oxygen and hydrogen gas. In 1839, British scientist Sir William Robert Grove's discovery that hydrogen and oxygen gas can be recombined to produce water and electric current gave birth to the fuel cell.

A fuel cell has two electrodes — an anode and a cathode — placed on opposite sides of a conducting electrolyte. Hydrogen atoms are introduced at the anode, then stripped of their electrons to become hydrogen ions (or protons), which pass through the electrolyte to the cathode. The electrons travel around the electrolyte to get to the cathode, creating the desired external electric current. At the cathode the electrons are reunited with the hydrogen ions and combined with oxygen to produce water. Individual fuel cells are only a fraction of an inch thick and can be "stacked" in series to meet whatever voltage demand is required for an application.

All fuel cells need hydrogen in some form. On vehicles, hydrogen can be stored as a cryogenic liquid or as a pressurized gas. But liquifying hydrogen is expensive and storing this extremely cold fuel on a vehicle is a difficult engineering task. Storing hydrogen as a gas requires significant energy expenditure for compression, stringent safety precautions, and bulky, heavy storage tanks. Methane (natural gas) is used as a hydrogen source in some fuel cell designs for large stationary electricity generating stations. But it, too, presents many of the drawbacks of cryogenic liquefaction or compression when considering mobile applications with weight and space limitations.

Metal hydride storage of hydrogen is possible. However, weight constraints currently limit the potential range of a vehicle with this particular hydrogen storage technology. Carbon nanofiber hydrogen storage also has been proposed by some researchers. However, this technology is very far from commercial development.

Methanol emerges as the ideal hydrogen carrier for vehicles because it is liquid at room temperature and ambient pressure. Methanol is a simple molecule consisting of a single carbon atom linked to three hydrogen atoms and one oxygen-hydrogen bond. Releasing the hydrogen from its bonds in a methanol molecule is easier to accomplish than for other available liquid fuels. Moreover, methanol fuel contains no sulfur, which is a fuel-cell contaminant, has no carbon-to-carbon atomic bonds, which are hard to break, and has a very high hydrogen-to-carbon ratio. In fact, a gallon of methanol fuel contains even more hydrogen than the same volume of cryogenic liquid hydrogen.

TYPES OF FUEL CELLS

Alkali Fuel Cells

This is the most expensive fuel cell and has been used extensively in the American space program, using platinum and gold on the anode and cathode. A very efficient fuel cell, but impractical in mass transportation.

Molten Carbonate and Solid-Oxide Fuel Cells

The molten carbonate operates at 600° C, and the solid oxide operates at 1,000° C. Both of these fuel cells are expensive and difficult to operate.

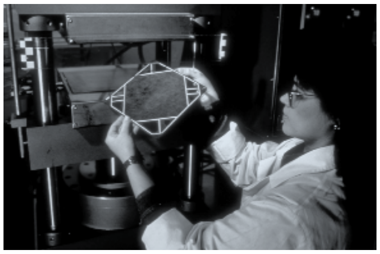
Phosphoric-Acid Fuel Cells

The cells operate at 150–175° C. They have been mounted on prototype buses and may be well suited to this application and in stationary power applications.

Proton Exchange Membrane (PEM) Fuel Cells

Proton exchange membrane fuel cells have a solid electrolyte and operate at about 80° C. This is approximately the same temperature as water in the radiator of an automobile. These fuel cells, like the alkali cells, use platinum as the reaction catalyst.

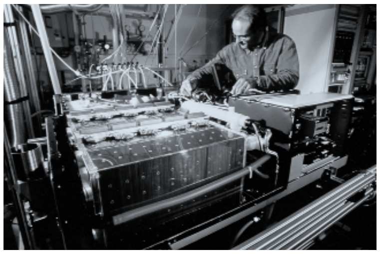
The proton exchange membrane or "PEM" fuel cell is the leading contender for vehicle applications. There are two principal PEM fuel cell types under commercial development.



The first type, the gaseous PEM, operates on hydrogen gas. The second type, or liquid PEM, feeds liquid methanol directly into the fuel cell (other, more expensive liquid hydrogen carriers have also been tried in the laboratory, but the direct methanol fuel cell shows the most promise for commercialization).

The "gaseous" PEM ▪ In this type of fuel cell, hydrogen gas is required for the fuel cell stack to operate. Hydrogen can be stored directly on board the vehicle. However, a gaseous fuel imposes severe penalties in weight and cost. Therefore, developers are focusing on liquid hydrogen-containing fuels. These fuels require reforming to deliver hydrogen to the fuel cell, and methanol is the ideal choice.

Operating at relatively low temperatures, a methanol steam reformer easily splits the methanol molecule to produce the hydrogen needed by the stack, which then generates electricity to power the vehicle.



The presence of the reformer in this design has advantages and disadvantages. An advantage is that the reformer rapidly and efficiently delivers hydrogen to the fuel cell from a liquid fuel that is easy to distribute and store on the vehicle. The disadvantage is that the reformer may produce trace emissions as it burns some of the methanol and hydrogen to provide the necessary heat of reaction. Moreover, the reformer adds weight, complexity, and cost to the overall system.

Gasoline also can be used as a hydrogen source in a gaseous PEM; however, the commercial development of this technology is less advanced than the methanol steam reformer PEM. The process by which gasoline fuel — or methanol, ethanol, and natural gas — is broken down to feed into the fuel cell is referred to as "partial oxidation." Partial oxidation (POX) today is less fuel efficient than steam-reforming, and also adds weight, complexity, and cost to the overall power system. While the gasoline POX system is still being developed in the laboratory, the methanol steam reformer PEM fuel cell has demonstrated its potential in on-the-road prototype vehicles, and is likely to be on board the first commercial fuel cell vehicles.

The "liquid" PEM ■ The second type of PEM fuel cell is the direct methanol fuel cell, developed by NASA's Jet Propulsion Laboratory in Pasadena, California; the University of Southern California; the California Institute of Technology; and others. No reformer is needed in this fuel cell: methanol is injected directly into the cell. There the liquid methanol reacts to form electricity and carbon dioxide. Because of its simplicity, compact size, and near-zero emissions, the potential for the direct methanol fuel cell is great, but its commercial development lags significantly behind the methanol steam reformer PEM.

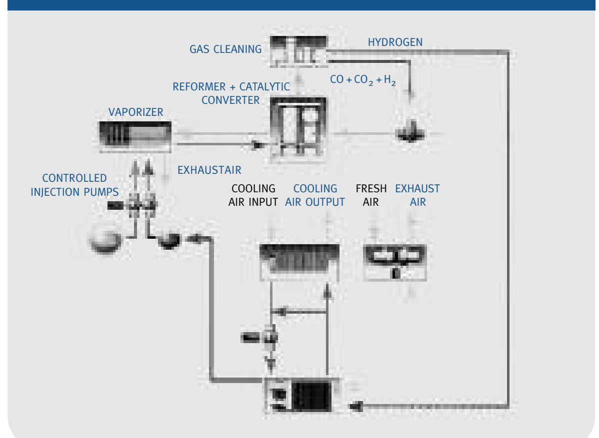
It is distinctly possible that the direct methanol fuel cell will become a universally available power source very early in the next century. It is ideal for a range of small consumer applications such as cellular phones and laptop computers, portable power equipment like lawnmowers and leaf blowers. Larger applications like cars and buses, stationary power and even train locomotives are also targeted markets. Many consumer product manufacturing giants and major automakers recognize the potential and are working to develop the direct methanol fuel cell.

PEM Challenges ■ The challenges facing PEM fuel cell developers are threefold: reduce the cost to build the electrode "plates"; reduce the amount of expensive platinum used as the catalyst; and design a cheap and effective membrane. Enormous progress has been made in each area. A few years ago, the fuel cell stack — only one part of the whole fuel cell power system — cost a prohibitive $5,000 per kilowatt. The whole fuel cell system cost (fuel cell stack, methanol reformer, and associated controls) is now down to $500 per kW, and developers are targeting full power system costs in the range of $50 per kW with high-volume production. A 50-kW power system for a vehicle would cost, therefore, about $2,500, similar to the cost for today's internal combustion engine.

Ballard Power Systems has led the way, reducing plate costs from $100 per plate to about $1. Working with Johnson Matthey, Ballard Power Systems has dropped its platinum costs to about $140 per car, not much more than the cost for platinum used in the catalytic converters in an internal combustion engine's exhaust system. The major manufacturer of membranes, Dupont, has announced that future membranes will cost as little as $10 per kW when large production volumes are achieved.

Many of the challenges facing reformer developers are being met with equal zeal. From a cold start, reformers need to produce hydrogen quickly. Much progress has been made in this area; for example, Johnson Matthey's "HotSpot" methanol reformer has achieved start-up times of 20 seconds for 50% hydrogen production, and full production in only 50 seconds. Its fuel processor system is also highly efficient, releasing 89% of the hydrogen contained in the methanol fuel. Daimler-Benz engineers have reduced the weight of the evaporator, which supplies the reformer, from 300 kilograms to just three kilograms, while increasing process efficiency.

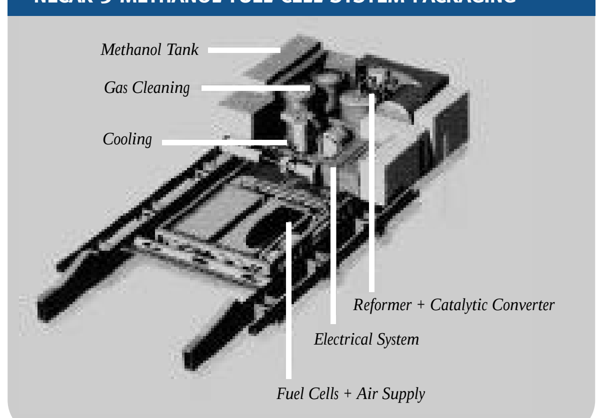
DAIMLER-BENZ METHANOL FUEL CELL SYSTEM



Source: Daimler-Benz

Figure 2

NECAR 3 METHANOL FUEL CELL SYSTEM PACKAGING



Source: Daimler-Benz

Figure 3

WHAT IS THE RELATIONSHIP BETWEEN THE METHANOL REFORMER FUEL CELL AND THE DIRECT METHANOL FUEL CELL?

"This invention has vast potential to improve the environment by providing clean energy in a portable form."

Nobel Prize Laureate George Olah, University of Southern California

VIRTUALLY ALL FUEL CELL DESIGNS REPRESENT an enormous step toward cleaning up the air. However, with the exception of compressed hydrogen and the direct methanol fuel cell (DMFC), all fuel cell vehicle designs require some kind of steam reforming or partial oxidation to release the hydrogen in the fuel.

These processes can create nitrogen oxide (NOx) emissions which, even in very small quantities, can compromise air quality when multiplied by millions of vehicles in use. NOx is an essential precursor to the formation of ground-level ozone, or smog. Because the DMFC breaks methanol into hydrogen and oxygen directly without requiring steam reforming or partial oxidation, there are no NOx emissions from the vehicle.

There is, therefore, a relationship between the reformer methanol fuel cell and the direct methanol fuel cell that exists between no other combination of fuel cell technologies: the extremely clean methanol reformer fuel cell vehicles will build the infrastructure that will support the introduction of DMFC vehicles. It is estimated that the DMFC technology will reach commercial maturity as early as 2008, only four or five years after the initial introduction of steam reformer methanol fuel cell vehicles.

The DMFC holds more promise for eliminating NOx emissions altogether than any liquid fuel cell vehicle. In this regard the DMFC is the true "zero emission" vehicle. The DMFC offers other significant benefits due to its inherent design simplicity. Eliminating the need to include a steam reformer and its associated controls will reduce vehicle weight and costs, and increase fuel economy.

SCHEMATIC OF THE DIRECT METHANOL FUEL CELL

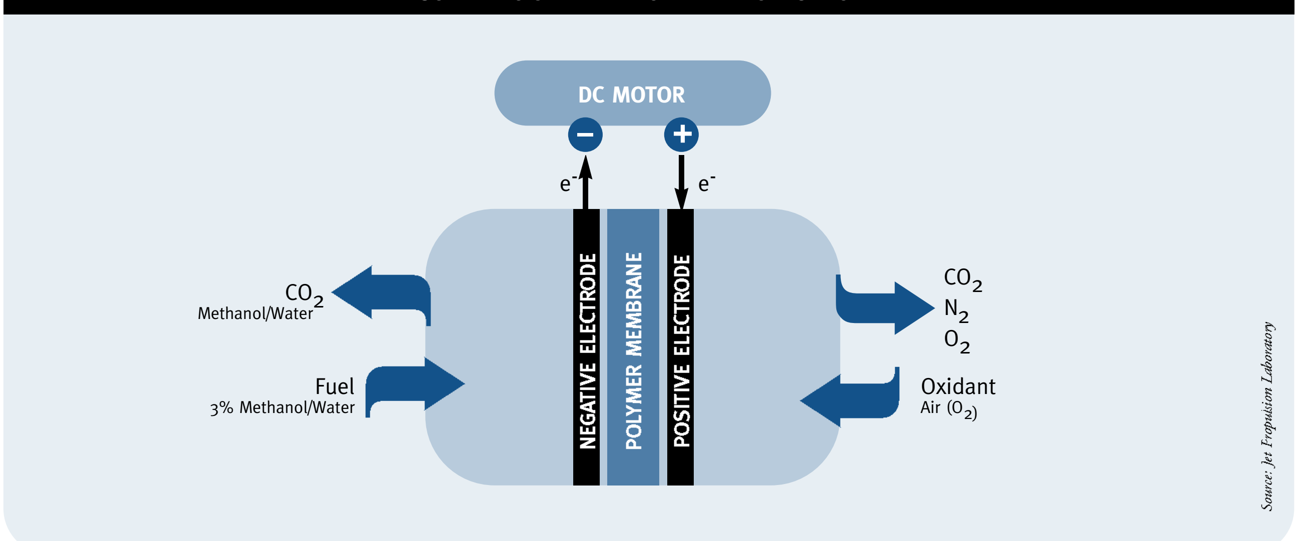


Figure 4

WHAT WILL IT BE LIKE TO OPERATE A METHANOL FUEL CELL VEHICLE?

"Like battery-powered electric vehicles, fuel-cell cars are quiet and have few moving parts, increasing reliability and durability. They can go from 0 to 60 in ten to twelve seconds, similar to average gasoline-powered vehicles."

Los Angeles Times, August 13, 1997

DRIVING A METHANOL FUEL CELL VEHICLE WILL BE as convenient as driving a standard gasoline vehicle today, but without the noise. Background traffic noise will be much louder than the hum of the electric motor. Owning a methanol fuel cell vehicle, however, will be a very different experience. There will be no oil and filter changes. Many common maintenance repairs such as valve jobs, ring jobs, starter replacements, timing adjustments, and timing belt replacements will disappear. Fewer moving parts means greater reliability and longer vehicle life, reducing the need for expensive financing or leasing. The methanol fuel cell vehicle will be significantly easier to own and operate, and will save its owner time and money.

An issue now being addressed is the start-up time of steam reformer methanol fuel cell vehicles. Current prototypes take a few minutes to start up. Some hybrid (fuel cell and battery) vehicle designs may bypass the problem by providing initial power with batteries, switching to the fuel cell when it has reached full output. Improvements in the steam reforming process itself will reduce vehicle start-up time.

The methanol fuel cell vehicle also will offer some unexpected benefits in terms of portable power. With 50,000 watts of electric power, a methanol fuel cell vehicle will be a portable energy plant providing eight to 10 times more output than portable gasoline generators, which retail for $1,000 to $1,400 and have rated capacities of 5,000 to 6,500 watts (or more than $200 per kW). Vehicles equipped with DC/AC inverters may provide abundant power for camping, construction sites, and other activities. If hurricanes, ice storms, or heavy rains have downed power lines, it would even be possible to run many homes from a properly equipped fuel cell car.

WHAT ARE THE SAFETY AND HEALTH IMPACTS OF METHANOL FUEL USE?

"Methanol improves the performance of the cars because of its high octane, but that's not why we use it. We use it because it is safer. It greatly reduced the risk of fire."

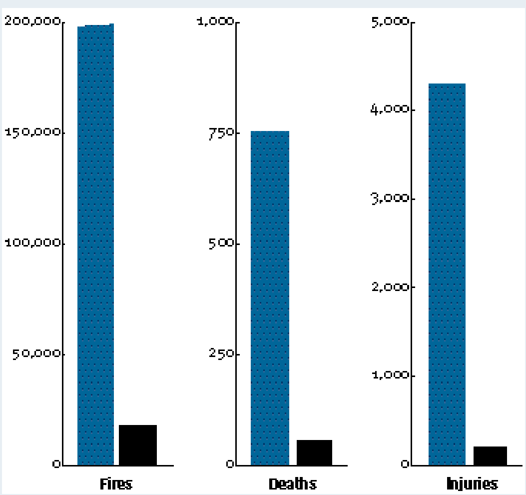
Phil Casey, Technical Director, Indy RacingLeague

METHANOL IS ONE OF THE SAFEST AND MOST environmentally sound fuels available. In fact, its fire safety advantages along with its performance characteristics have made methanol the fuel of choice for the Indianapolis 500 since the mid-1960s. The same careful handling procedures used for gasoline and other fuels should be observed for methanol.

Pure methanol (M-100) is much harder to ignite than gasoline and burns at a much slower rate — about 60% slower. Methanol also burns much cooler, releasing its energy at one-fifth the rate of burning gasoline. While under ideal daylight conditions methanol does burn with an invisible flame, fuel related fires typically combust some type of material that will impart color to the flame. Unlike gasoline fires, methanol fires are extinguished simply and quickly: by just pouring water on the flame. For these reasons, methanol is a much safer fuel to use in a vehicle.

The U.S. Environmental Protection Agency estimates that using methanol as the country's primary automotive fuel would save hundreds of lives each year. In 1986, there were 180,000 vehicle fires in which gasoline was the first material to ignite. A switch to methanol could save 720 lives, prevent nearly 3,900 serious injuries, and eliminate property losses of millions of dollars a year.

FUEL-RELATED VEHICLE FIRES, DEATHS AND INJURIES



Gasoline *(FEMA and NHTSA Data)* Methanol *(EPA Projection)*

Figure 5

Methanol is a different fuel than gasoline. Some of the current fuel-wetted rubber and aluminum parts used in gasoline cars are not compatible with methanol, so different elastomers and other materials must be used. Given the automotive industry's experience in building 15,000 methanol flexible-fuel cars, there is extensive experience in building methanol-compatible vehicles.

Methanol is naturally occurring in the environment; and is biodegradable in aquatic habitats. As is the case with gasoline and diesel fuels, improper handling and storage of methanol — particularly from leaking underground storage tanks — has the potential to contaminate groundwater. However, methanol presents a lower environmental risk than gasoline. It dissolves quickly to low concentrations that are eliminated much more rapidly than gasoline by natural bacteria, both when exposed to air and when air is limited such as underground. The use of double-walled containment tanks and leak detection monitors greatly reduces the likelihood of methanol spills.

All motor fuels are poisonous and should be handled with care. There are three ways humans come in contact with fuels: by skin absorption, ingestion, and inhalation. When in contact with skin methanol will feel cool, and any affected areas should be washed thoroughly with soap and water. Methanol, like gasoline or diesel fuels, should never be ingested. Since gasoline vapors are classified as a probable human carcinogen by the U.S. Environmental Protection Agency, long-term exposure to gasoline vapors is more hazardous than exposure to methanol vapors. According to the key findings of a methanol hazard assessment conducted by the Environ Corporation, "methanol is not genotoxic and there is no evidence to indicate, nor reason to believe, that it would be carcinogenic."

The human body naturally contains some methanol, and it is found in many parts of our diet, including fresh fruit and vegetables. The body even makes methanol from Aspartame-sweetened diet beverages. In fact, you receive more methanol by drinking a can of diet soda than you would be exposed to from a dozen fill-ups of a methanol fuel cell vehicle at a self-service pump.

WHY ARE METHANOL FUEL CELLS GOOD FOR THE ENVIRONMENT?

"Fuel cells allow us to disconnect motor vehicle travel from pollution, which is an incredible feat — something that has been 100 years in the making. It allows us to transform transportation for the 21st century. When you consider that the world's automobile population is doubling every 25 years, a fuel-cell technology that is clean and efficient is exactly the sort of technology that is required for the 21st century."

Jason Mark, Union of Concerned Scientists

THE INTRODUCTION OF METHANOL FUEL CELL VEHICLES will have major environmental benefits in several areas. First, methanol fuel cell vehicles will greatly diminish the transportation sector's role as a source of local urban air pollution. Second, methanol fuel cells will significantly reduce this sector's contribution to the global greenhouse effect, producing less than half the carbon dioxide emissions of today's internal combustion engine on a life-cycle basis, depending on the efficiencies achieved. Third, methanol fuel cell vehicles will greatly reduce the threat to water quality in the oceans and on the land. In the following sections we will review the methanol fuel cell's impact on these three major areas of pollution.

HOW WILL METHANOL FUEL CELL VEHICLES ADDRESS URBAN AIR POLLUTION?

AIR POLLUTION IS ASSOCIATED WITH LARGE metropolitan areas where many vehicles, homes, and industries are found. In the United States, the principal pollutants regulated by the Clean Air Act and its amendments are carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (unburned hydrocarbons, or VOCs), and particulate matter (PM).

Methanol fuel cell vehicles will all but eliminate these pollutants. A substantial benefit to air quality and the public health may be anticipated as a result. As can be seen in Figures 6, 7, and 8, by moving away from combustion, methanol fuel cell cars will be minuscule emitters of the criteria pollutants described here. Figure 6 estimates the average lifetime vehicle emissions for cars operating in the Los Angeles Basin, while Figures 7 and 8 examine the ozone potential and nitrogen oxide emissions for the vehicle and the fuel distribution system, including the exhaust emissions for tanker trucks delivering fuel to retail stations and spillage that occurs during vehicle refueling.

Initial dynamometer emissions tests of NECAR 3 were extremely encouraging. Although the tests were for a hot operating vehicle and too few for statistical extrapolation, they showed that the methanol fuel cell vehicle produced no NOx or carbon monoxide emissions. Hydrocarbon emissions were 0.005 grams per mile, or one-half the Super Ultra Low Emission Vehicle limit set by the State of California.

The methanol fuel cell vehicle is an intrinsically clean vehicle. Even the cleanest gasoline internal combustion engine vehicle will not be as clean as a methanol fuel cell vehicle. The gasoline vehicle depends on elaborate control technologies and computerized diagnostics to maintain its cleanliness.

In the absence of proper maintenance and sophisticated inspection or diagnostic procedures, the gasoline vehicle can enter a failure mode that may emit hundreds and even thousands of times the legal limits of pollution. Over time, as the vehicle passes from one owner to

CRITERIA AIR POLLUTANTS

Carbon Monoxide (CO)

Carbon monoxide results from the incomplete combustion of any fuel in the cylinders of a vehicle. It is emitted at all times from traditional gasoline vehicles, but the highest quantities are present when the weather is cold and vehicles take longer to warm up. Toxic to humans, it impedes the body's ability to absorb and distribute oxygen.

Volatile Organic Compounds (VOCs)

VOCs have been the object of intense pollution control efforts. One major source is unburned fuel that passes through the cylinders of vehicles and out the exhaust. VOCs also evaporate directly from gasoline, whether in the refining and distribution process ("upstream") or while refueling. They also escape from the vehicle when it is not in use. Many constituent elements of VOCs that evaporate from gasoline are not carcinogens. In the presence of sunlight, VOCs from gasoline are the most reactive in forming ground-level ozone, or "smog," which damages human lungs and causes eye irritation.

Nitrogen Oxides (NOx)

Nitrogen oxides are a byproduct of combustion and are emitted by all internal combustion vehicles. NOx is one of the key ingredients in the formation of smog, a major human health hazard in many cities around the world. Ozone cannot be formed without NOx. Through secondary chemical reactions in the air, nitrogen oxides also contribute significantly to the PM pollutant category.

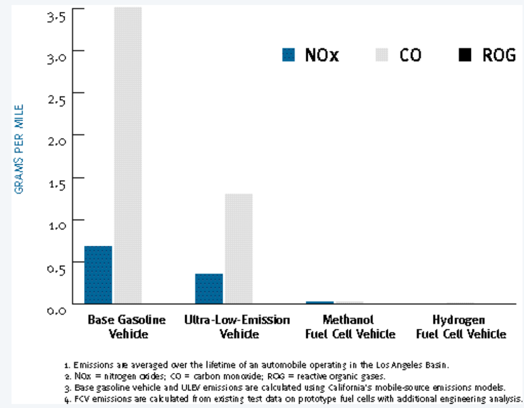
Particulate Matter (PM_{10})

PM_{10} is a broad category of dust and soot particles less than 10 microns in diameter. These particles are small enough to lodge deep in lungs and cause damage. Recently, particulate matter has come to be seen as an actual threat to the public health and may contribute to as many as 40,000 deaths annually in the United States.

another, it tends to be less and less well maintained, and its emissions increase. In contrast, the methanol fuel cell vehicle can pass from owner to owner and its pollution profile will remain very low: zero in some pollutant categories, close to zero in others.

Methanol fuel cell buses will be cleaner than today's cars. In many cities, transit buses are a major source of NOx and particulate matter ("soot") emissions. In the past, transit buses have compensated for their high-pollution emissions levels by carrying many more people than a typical car. Now Georgetown University estimates that its methanol fuel cell bus, full of people, will produce even less pollution than one of today's cleanest, best maintained gasoline-powered automobiles, which typically carries only one person.

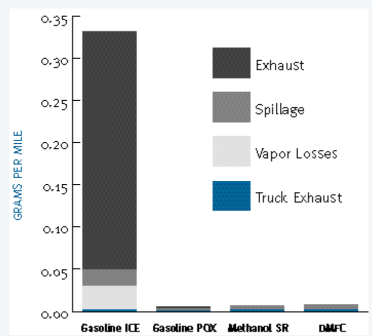
AVERAGE EMISSIONS FROM AUTOMOBILES IN LOS ANGELES



Source: "Zeroing Out Pollution," Jason Mark, Union of Concerned Scientists, May 1996

Figure 6

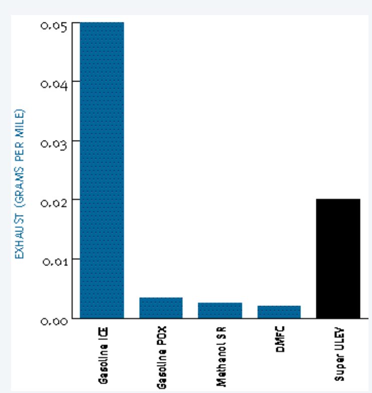
OZONE EMISSION POTENTIAL FOR LOCAL EXHAUST AND FUEL-CYCLE SYSTEMS



Source: Arcadis

Figure 7

LOCAL EXHAUST AND FUEL-CYCLE NITROGEN OXIDE EMISSIONS



Source: Arcadis

Figure 8

However, even these extremely low levels of emissions from the methanol fuel cell vehicle may understate the potential for this technology to control pollution. With the second generation direct methanol fuel cell vehicle, on-board CO, NOx and particulate matter emissions would drop to zero. There might still be tiny levels of VOCs due to the evaporation of small quantities of methanol from the fuel system, but even these could be eliminated with a closed fuel system.

STEADY STATE TRANSIT BUS EMISSIONS

FUEL	POWERPLANT	HC	CO	NOx	PM
Diesel	DD Series 50*	0.10	0.90	4.70	0.04
CNG	DD Series 50	0.80	2.60	1.90	0.03
Diesel	Cummins C8.3	0.20	0.50	4.90	0.06
CNG	Cummins C8.3	0.10	1.00	2.60	0.01
Methanol	94 Fuji Fuel Cell	0.09	2.87	0.04	0.01
Methanol	98 IFC Fuel Cell**	<0.01	<0.02	n/a	n/a
96 Standards		1.30	15.50	5.00	0.05
98 Standards		1.30	15.50	4.00	0.05

ALLEMISSIONS VALUES IN G/BHP-HR

* with converter ** IFC test results

Source: Georgetown University

Figure 9

HOW WILL METHANOL FUEL CELL VEHICLES ADDRESS THE GREENHOUSE EFFECT?

"Even when taking into account the carbon monoxide formed during reforming, methanol emissions are less than 50% of those from a conventional vehicle of similar size. This low level is due to the inherently better energy conversion efficiency of the fuel cell, and also in part because methanol contains relatively less carbon per unit of chemical energy than petrol."

Toyota Motor Company

GLOBAL EMISSIONS OF "GREENHOUSE GASES" — gases such as carbon dioxide and methane blamed for an increase in average world temperatures — have come under increasing scrutiny. In December 1997, a major international treaty was signed in Kyoto, Japan, to try to bring the spectrum of greenhouse gas pollutants under control. Major changes in industrial production and consumption of energy will be needed to reduce the greenhouse impact of human activity on the planet.

The higher inherent efficiency of the methanol fuel cell vehicle will play a role in helping get better use out of the fuel the world consumes, and thus lower the transportation sector's contribution to the greenhouse effect. The most current techniques for methanol production capture 70% of the energy that is in the feedstock natural gas. When methanol fuel is put in the fuel cell vehicle, the vehicle turns at least 38% of that 70% into useful power. The result is that at least 26.6% of the total methane energy is captured for transportation use. By contrast, today's gasoline refining captures about 90% of the energy in crude oil, but the internal combustion engine converts only 19% of that energy into useful power. The relative contributions of production and vehicle efficiencies to the final energy use efficiency of each vehicle and fuel type are shown in Figure 10.

Another way to analyze the greenhouse effect is to consider the total output of carbon dioxide, from a fuel's

FUEL CELL EFFICIENCY

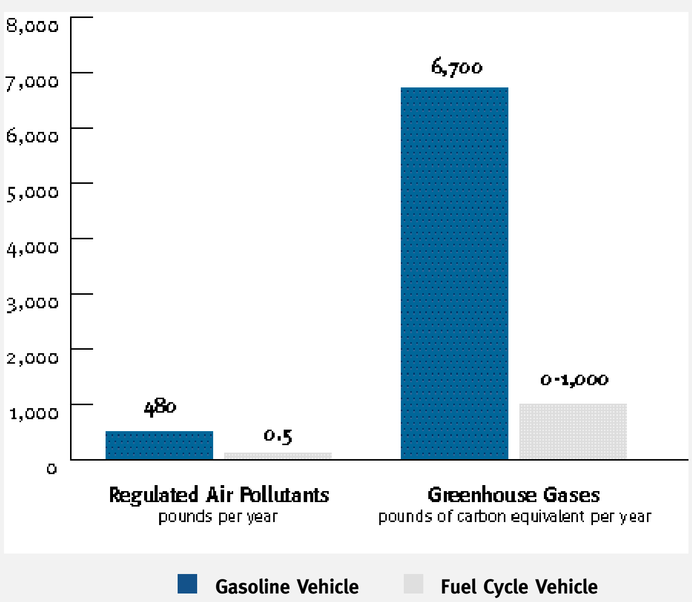
	METHANOL FUEL CELL	GASOLINE ICE
Production Efficiency	70%	90%
Vehicle Efficiency	38%	19%
Total Efficiency	**26.6%**	**17.1%**

Figure 10

point of extraction from the ground to its final use in a vehicle. This is called a full fuel cycle analysis — or "well-to-wheel" view — and includes the carbon dioxide released from the actual use of fuel on the vehicle as well as the additional gases released during the finding, manufacture, and transport of the fuel. Figure 11, based on a forecast using assumptions that take into account vehicle design improvements, shows that the full fuel cycle carbon dioxide emissions from a methanol fuel cell vehicle will be less than half of those for today's gasoline internal combustion vehicle.

Figure 11 also considers the many ways to make methanol from renewable feedstocks. All organic materials contain the carbon and hydrogen needed to make methanol. Biomass production is often thought of in terms of wood or other croplike products. One of the most likely introductions of biomass into methanol production could come from capturing the gases created from municipal wastewater treatment plants and landfills. Landfills and sewage facilities give off methane — a highly reactive greenhouse gas — into the environment. Capturing this methane and turning it into methanol would result in a significant "greenhouse benefit."

EMISSIONS FOR A TYPICAL TWO-CAR FAMILY



1. Based on average emissions totaled over 22,800 miles per year of travel.
2. Gasoline vehicle with a fuel economy of 28 mpg.
3. Fuel cell vehicle operating on renewable fuel, either hydrogen or methanol.

Source: "Zeroing Out Pollution," Jason Mark, Union of Concerned Scientists, May 1996

Figure 11

HOW WILL METHANOL FUEL CELL VEHICLES REDUCE THE THREAT OF POLLUTION TO FRESH WATER AND THE OCEANS?

THE METHANOL FUEL CELL VEHICLE, WHOSE invention and commercialization has been driven by air quality, energy security, and consumer considerations, will also prove to be a major advance for the protection of water quality on land and in the ocean.

Methanol fuel cell vehicles will not need engine oil to lubricate pistons. Each gallon of engine oil can contaminate up to one million gallons of fresh water. This will eliminate a major “nonpoint” or “area” pollutant from the nation’s storm drains, landfill dumps, waterways, and underground aquifers.

Methanol is intrinsically less damaging to the environment. No one would argue that the accidental release of methanol into the environment would be a good thing, but it would be much less dangerous than oil or gasoline spills. Methanol is used to facilitate the breakdown of municipal sewage as part of the treatment process before discharge into sensitive oceans or rivers. Methanol is easily biodegradable in aerobic and anaerobic environments.

Methanol is water soluble. In the unlikely event of a major methanol fuel spill, marine and coastal wildlife would not be covered with crude oil tars. The Exxon Valdez accident contaminated 1,200 miles of coastline — the equivalent of the U.S. west coast from San Diego to Seattle. If, by contrast, we imagined that three times the Exxon Valdez spill — 30 million gallons of methanol — were spilled in a similar accident, the fuel would dissipate into the water very rapidly: At a depth of 500 feet and at a distance of one mile from the spill, concentrations would average one-hundredth of one percent, low enough for biodegradation to occur quickly.

WHERE WILL PEOPLE BUY METHANOL FUEL?

“Mercedes-Benz believe that adding methanol pumps at gas stations would be no greater obstacle than adding pumps for unleaded gasoline was. The experience with today’s alternate fuel internal combustion vehicles argues for the Mercedes side in that dedicated methanol and ethanol pumps are showing up at gas stations already. If fuel cell vehicles come along that are both cleaner and more efficient than today’s cars, stations would have even greater incentive to install methanol pumps.”

AutoWeek, March 3–9, 1997

CONSUMERS HAVE COME TO EXPECT NEAR UNIVERSAL availability of fuel for their automobiles. A massive distribution network at the retail level is one of the great historical achievements of the oil industry. In the United States, nearly $100 billion in undepreciated capital is invested in the infrastructure to produce, refine, distribute, and retail market motor fuels, and each year over $10 billion is spent to maintain and upgrade this network. This extensive network includes 200,000 retail gasoline stations and 30,000 diesel stations. The existing methanol infrastructure is well established to deliver product to its chemical company consumers located throughout the world. This system includes significant maritime movements on vessels as large as 45,000 tons, and Methanex, the world leader in methanol production and marketing, has announced plans to introduce a 96,000-ton vessel in 1999. For delivery to inland locations, an extensive barge, rail car, and tanker truck network already exists to feed most locations in the U.S. and Europe. Expansion of the

system would likely be required if methanol fuel demand increased significantly. However, the cost of expanding the existing system will be embedded in the price of methanol.

California already has a network of nearly 50 public methanol refueling stations and 50 additional stations operated by public and private fleets — to service 15,000 methanol-powered alternative fuel vehicles on the road today. Given California's experience in building methanol fueling stations, we can estimate the gasoline-to-methanol conversion cost to be $50,000 per station. Based on this estimate, a nationwide retail system in the United States could be installed for less than $1 billion at 10% of the gasoline stations. The initiation of an ongoing, widespread upgrade program to install methanol pumps could allow incremental costs to be lower than this projection.

This is still a fraction of the $6 billion spent by the oil industry to introduce reformulated gasoline (RFG), or the $1.4 billion spent each year to upgrade the retail gasoline network. Funding for the federal Congestion Mitigation and Air Quality Improvement Program (CMAQ) is expected to climb to over $1 billion per year, and is used by municipalities to encourage the use of alternative fuel vehicles, carpooling, bicycles, and transit. One of the largest environmental programs, CMAQ funding could be used to help begin building a methanol fueling station infrastructure.

The most likely methanol fuel distribution development scenario for fuel cell vehicles does not depend on a decision to create a complete system overnight. It is likely that fuel cell vehicle introduction will focus initially on the three states in the U.S. requiring the sale of Zero-Emission Vehicles by 2003 (California, New York, and Massachusetts), as well as Germany and Japan. These highly populated areas are strong candidates for early adoption of fuel cell vehicles because they tend to have higher levels of pollution and at the same time offer maximum scale efficiencies for the first wave of methanol fuel infrastructure. More customers for each fuel pump means greater profitability and faster growth in the crucial early phases of the combined methanol and fuel cell industries. By simultaneously introducing their methanol fuel cell vehicles in Germany and Japan as well as in the United States, foreign producers such as Daimler-Benz and Toyota will get larger production runs, which will help lower costs.

As shown in Figure 12, it would cost less than $500 million to convert 10% of the stations in these target areas to methanol operation. Even converting 25% of the stations in the target areas would only amount to $1.2 billion. Assuming that retailing stations are required to cover all of the U.S., Europe, Japan, and Canada, it would still only cost $1.9 billion for 10% of the stations to be converted and $4.7 billion for 25% of the stations.

The governments of Germany and Japan, like the American federal and state governments, will also be pleased to see reduced dependency on foreign oil imports and improved environmental quality. The strategy of introducing methanol fuel in major urban centers first will also put off the day that pipeline distribution will be necessary in remote inland markets, giving the methanol fuel industry the time to build up the high-volume business that will justify these costs.

INFRASTRUCTURE COST ESTIMATE FOR SELECTED COUNTRIES

	EXISTING STATIONS	10% OF STATIONS Cost $50K (millions)	25% OF STATIONS Cost $50K (millions)
CALIFORNIA	11,700	59	146
NEW YORK	6,504	33	81
MASSACHUSETTS	2,600	13	33
GERMANY	17,632	88	220
JAPAN	59,990	300	750
TARGET REGIONS SUBTOTAL	**98,426**	**492**	**1,230**
CANADA	13,782	492	172
REST OF UNITED STATES	167,088	835	2,089
REST OF EUROPE	100,212	501	1,253
TARGET REGIONS TOTAL	**477,934**	**1,897**	**4,744**

Assumes installation cost of $50,000 per methanol station.

Figure 12

Clearly, establishing a methanol retail infrastructure is not cost prohibitive when compared to the billions being spent by fuel cell developers. It is estimated that the dramatic rise of the share price of Ballard stock equates to a market capitalization for the company of $8 billion. Relative to the size of the economies involved, establishing a methanol fueling network is an extremely small investment, especially when compared to the expected benefits.

The participation of the oil industry may be essential in establishing a methanol fuel network. Although the costs of installing methanol storage and pumping facilities are low, the costs of real estate, buildings, and developing brand name recognition are many times higher. Today's drivers need the convenient availability they enjoy with gasoline. The easiest way to achieve this is if their current fuel suppliers — the oil companies — begin to retail methanol.

Many of the world's largest oil companies are also the world's largest holders of natural gas reserves. These companies are beginning to look at methanol as an ideal way to "monetize" their natural gas by turning it into a useful and easily transportable commodity. The improved efficiency of the methanol fuel cell vehicle and methanol's relatively low production cost will enable retail methanol stations to earn a profit on their investment.

The initial development of a methanol fuel distribution system also could take advantage of less expensive alternatives. Not every filling station will need a $50,000 upgrade. Aboveground storage tanks costing less than $20,000 installed can be placed in low-volume locations or in fleet facilities to initialize fuel distribution. As volume increases these, aboveground stations can be replaced with larger underground tanks. The aboveground tanks can then be moved to a new location, helping the fuel network spread still farther.

WILL THE METHANOL INDUSTRY MEET THE DEMAND FOR TRANSPORTATION FUEL?

"In 2010, according to forecasts, the world's oil-thirsty economies will demand about 10 billion more barrels than the [oil] industry will be able to produce. A supply shortfall that large, equal to almost half of all the oil extracted in 1997, could lead to price shocks, economic recession and even wars."

Scientific American, March 1998

WERE THE SUPPLIES OF AVAILABLE OIL INFINITE, the introduction of methanol fuel cell vehicles would still make environmental sense. But oil is limited. Today, oil supplies are ample, and gasoline is cheap. Cheap energy is the engine of economic prosperity, and competition can ensure that today's low costs are preserved for the future. However, such competition cannot come from oil products alone: the U.S. Energy Information Administration estimates that worldwide oil demand will increase by 60% by the year 2020. By some estimates, the growth of oil production will begin to taper off by 2010, particularly from non-OPEC fields. Since production will be outstripped by the growth in demand, oil price shocks and their resulting economic recessions may be on the horizon. We may not run out of oil in the foreseeable future, but we very likely will run out of cheap oil.

The only real question of pragmatic value is whether there is enough material to make the methanol that we need for the new transportation era. Here the answer is unambiguous: ***Methanol supply will not be limited, because the sources of methanol production are large, diverse, and, in the long term, renewable.*** In an era of political uncertainties, where methane gas resources are to be found is perhaps of greater significance than how much is estimated to be there in absolute terms.

HOW MUCH METHANOL WILL BE NEEDED TO SERVE THE METHANOL FUEL CELL VEHICLE MARKET?

In 1998, WORLDWIDE METHANOL PRODUCTION CAPACITY stands at about 11.4 billion gallons (34 million tons), with a utilization rate of just under 80%. The world methanol industry has a significant impact on the global economy, generating over $12 billion in annual economic activity while creating over 100,000 direct and indirect jobs. Methanol and its derivatives are a widely used transportation fuel and chemical commodity, used in manufacturing products such as fiberboards used in home construction, "Spandex" fibers used in clothing, recyclable plastics, windshield washer fluid, and cleaner-burning gasoline.

Given our estimates of vehicle market penetrations, we can make several assumptions about the demand for methanol fuel. Under initial penetration assumptions, we estimated that by the year 2010 automakers will have introduced 2 million methanol fuel cell vehicles: if each vehicle uses 441 gallons of methanol fuel per year, it would produce a demand of 882 million gallons of methanol per year, or less than 8% of current world capacity.

By 2020 our estimate of 35 million vehicles would consume 15.4 billion gallons of methanol — roughly 135% of current world capacity — and would require significant capital investments in new methanol production plants. Because large-scale methanol plants can be built in 2 to 2.5 years, there should be no problem adding the necessary capacity to meet this kind of demand in the 20-year time horizon.

Increases in methanol plant capacity to meet transportation fuel demand will mean new plants with the most advanced technologies: today's newest plants at 70% efficiency are nearly 10% more efficient at capturing the energy in methane than their predecessors of ten years ago. Adding new production capacity will push the industry standard toward the new technology norm. Even though very large new methanol plants are expected to cost about $1 billion to produce 10,000 tons per day of methanol (enough to power about 2.6 million methanol fuel cell vehicles), economies of scale and potential energy integration will lower production costs.

In past decades, the oil industry has amortized billions of dollars of investments across trillions of gallons of retail sales. The methanol industry will do the same. If the methanol industry were to match its historical wholesale price record of the last two decades, wholesale fuel costs per methanol fuel cell vehicle would be 26% less per year than for traditional gasoline vehicles. In addition, continuing improvements in vehicle efficiencies will further reduce fuel costs per mile driven for methanol fuel cell vehicles.

IS THERE ENOUGH NATURAL GAS?

PROVEN WORLD RESERVES SHOW THAT NATURAL GAS is an abundant resource. In 1996, reserves stood at 4,991 trillion cubic feet (TCF) with annual consumption of 78 TCF, which implies 64 years of consumption at current levels before existing proven reserves are depleted. However, additional uses are expected and new gas finds are occurring regularly with the full extent of recoverable reserves not easily determined today.

Based on 35 million fuel cell vehicles operating on methanol derived from natural gas, annual methanol demand is expected to be 15.4 billion gallons — or natural gas demand of 1.4 TCF (less than 2% of current annual natural gas consumption). If we made the unrealistic assumption that the total estimated world car population of 1 billion ran on methanol fuel cell vehicles by 2020, related natural gas consumption would still only be 40 TCF per year, or roughly 50% of current consumption.

There are vast quantities of natural gas worldwide that are not conveniently located to serve local energy markets. However, by converting the natural gas to methanol, it becomes possible to access these large reserves for use in the transportation sector. In the Western Hemisphere, Chile, Venezuela, and Trinidad are perfect examples of areas with large gas reserves and limited local markets. These and other areas are ideal candidate producers of methanol for the developing fuel cell market.

The existing reserves are clearly plentiful and additional significant natural gas finds are likely. However, in the next sections we will review other potential methanol feedstocks that offer even more plentiful supplies of raw materials.

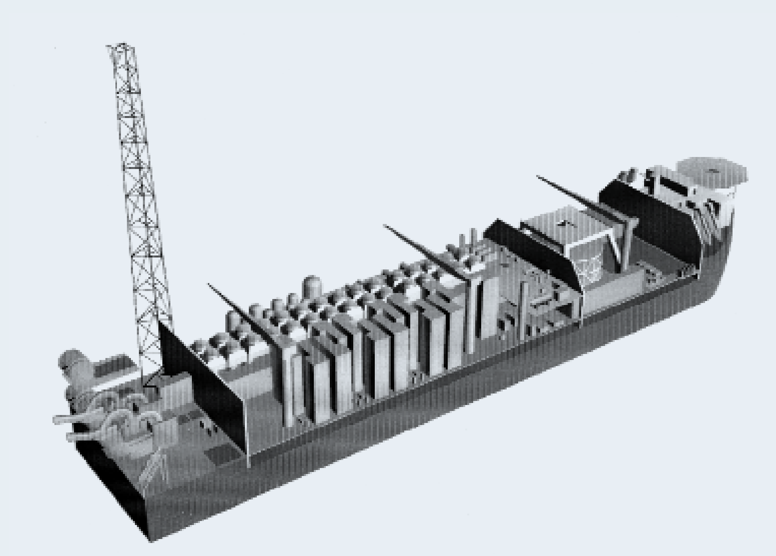
WILL METHANOL BE MADE FROM FLARED NATURAL GAS?

BOTH IN THE UNITED STATES AND AROUND THE world, great quantities of natural gas cannot be economically recovered. About 3.8 trillion cubic feet annually are flared and vented. Offshore natural gas offers a tremendous opportunity for methanol production because much of it cannot be economically connected to pipelines. If only 10% of flared gas were made available for the methanol fuel market, it would be enough to power 9.5 million fuel cell vehicles annually.

More offshore natural gas will be discovered, and floating methanol production plants will provide a means of economically recovering this resource. Ocean-based facilities for producing methanol, Floating Production, Storage, and Offloading Systems (FPSOs), are under development. One of the major developers of this production system is Kvaerner Process Technology, which by 2001 will have the technology available for licensing.

ICI Katalco developed methanol production technology in the early 1990s specifically for offshore applications of FPSOs. The first 54,000 ton-per-year development plants started in Australia in 1994, was built by BHP on land to test the novel concepts incorporated into the technology by ICI prior to its use offshore. The principal

FLOATING PRODUCTION, STORAGE, AND OFFLOADING SYSTEM (FPSO)



Source: Kvaerner

Figure 13

features necessary for remote offshore location are pressurized compact reforming technology; minimum process water; steam venting and effluent; structured packing distillation; and full automation. BHP's expectation is to go offshore with a world-scale plant early in the next decade.

Worldwide, 11 trillion cubic feet of natural gas released from drilling oil are routinely pumped back underground. If all of this methane could be captured for methanol production, it alone would power over 250 million fuel cell vehicles annually.

WILL METHANOL FUEL CELLS HELP BUILD A MARKET FOR THE USE OF RENEWABLE FEEDSTOCKS FOR METHANOL PRODUCTION?

METHANOL MAY BE MADE FROM ANY CARBON source. Wood, coal, municipal solid wastes, agricultural feedstocks, and sewage are all potential methanol feedstocks. Although there is no theoretical obstacle to making methanol from wood or agricultural by-products, the process of gathering these resources is labor-intensive and production costs have been prohibitive. The cultivation of dedicated wood biomass crops for methanol production may prove to be economical in the future.

Biomass production of methanol may begin where the cost of producing the fuel is offset by other benefits. Municipal solid waste disposal and sewage disposal both meet the criteria. Landfill methane and sewage processing accounts for about 11% of all methane released by the United States into the atmosphere. Currently most landfill methane is vented into the air. If landfill materials were processed through methanol manufacturing facilities, then this contribution to global warming would stop.

Methanol can also be made by gasifying dried sewage sludge. Such a facility is already being operated in Berlin by the SVZ subsidiary (Sekundarrohstoff-Verwertungszentrum) of Berliner Wasser Betriebe, Germany's largest water supply and sewage disposal company. The facility employs 350 people, produces up to 75 megawatts of electricity, and has a methanol production capacity of over 33 million gallons per year. The facility is an important demonstration of the technical feasibility of methanol production as a form of waste disposal.

Gasification of municipal solid waste offers the same kind of opportunity, and also has been under active development. This has a wide variety of potential applications, of which processing landfilled waste into fuel is one. The Hynol process for methanol production is under development at the University of California at Riverside. Biomass processing tests will include local energy crops, municipal wastes, sewage sludge, landfill gas, and waste wood.

If 30 cities produced 30 million gallons of methanol a year — which SVZ in Berlin is doing with its sewage — enough fuel would be made to power 2 million fuel cell vehicles an average of 12,000 miles per year. Municipal solid wastes ought to permit this number to be doubled. Such production could generate benefits for the environment in multiple areas of impact: reducing waste, reducing air pollution, and reducing the greenhouse gas impact of our transportation system.

ARE THERE OTHER POTENTIAL METHANOL FEEDSTOCK SOURCES?

NATURAL GAS IS SO ABUNDANT THAT IT IS LIKELY to be the methanol feedstock of choice for decades. But for those who worry about the depletion of this resource, there are many other sources of methane on the planet. Some of them, like coalbed methane, are already in commercial production. Others, such as methane hydrate, are the subject of intense scientific interest but are developmentally further off. The total picture shows that there are many thousands of years of feedstocks for the production of methanol when all resources are considered.

Figure 14 shows how many years of operation for 1 billion passenger vehicles could in theory be derived from these various methanol feedstocks. It does not take into account other uses of natural gas, but the overall picture is quite clear: this is an abundant resource. Descriptions of these other sources follow below.

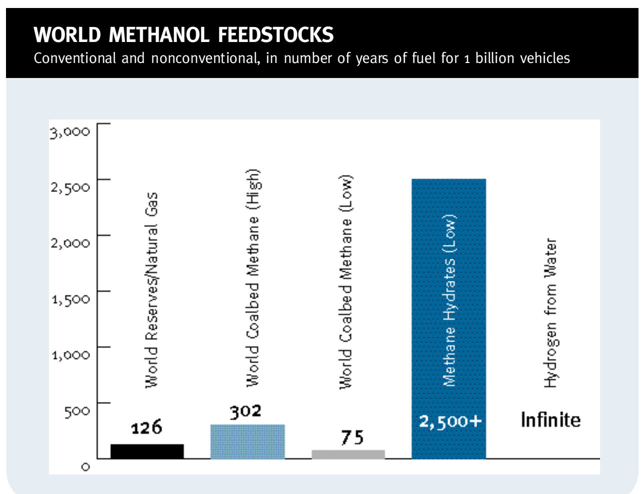


Figure 14

Coalbed methane is gas that escapes from coal. It is vented naturally but also escapes into the atmosphere as a result of mining activity: about 10 percent of anthropogenic methane in the atmosphere is due to coal mining. Harnessing coalbed methane for methanol fuel will help reduce coal mining-related emissions and also reduce the need to extract petroleum.

Worldwide, total coalbed methane recoverable reserves are estimated at 3,000 to 12,000 trillion cubic feet. Used exclusively to make methanol, this would produce enough fuel to power 1 billion passenger vehicles for 75 to 300 years. Coalbed methane is a large resource in the United States and is currently in commercial production.

Methane hydrate is another abundant source of natural gas, although currently not produced. Most of it is offshore. It is a vast resource that defies easy quantification. Total methane gas frozen in methane hydrate reserves for the world has been estimated at 100,000 to 5 million trillion cubic feet, although one analysis calculated as much as 270 million trillion cubic feet. The lower boundary estimate of 100,000 trillion cubic feet would fuel a methanol fuel cell fleet of 1 billion vehicles for 2,500 years. These reserves answer the question of where natural gas can be had if known and future conventional resources, many decades from now, need to be supplemented.

Hydrogen from water is the ultimate renewable methanol feedstock. Hydrogen, oxygen, and carbon are the raw ingredients of methanol. The earth has abundant supplies of carbon, and the only difficulty with obtaining hydrogen is the energy required to split it from the oxygen in a water molecule. Today's exotic technologies for hydrogen production, such as solar-activated catalysts to break down water, or solar heat sources to gasify water at very high temperatures, may become economical in future decades. Water used to provide hydrogen feedstock for methanol would be an infinite resource, since after the fuel is used water is the waste product.

Increased thermal efficiency is also possible for methanol production. Steel manufacture, for example, consumes large quantities of coal. The gases released by the coal can be used to make methanol, in addition to making steel, in a process called COREX. By combining the manufacture of steel with the co-production of methanol fuel, the total contribution to the greenhouse inventory of carbon dioxide is far less than if the production of energy for steel and for transportation is kept separate. Many industrial processes might benefit from such co-production, but their development will be facilitated by the availability of a widespread methanol fuel cell vehicle market.

HOW MUCH WILL I PAY FOR METHANOL FUEL?

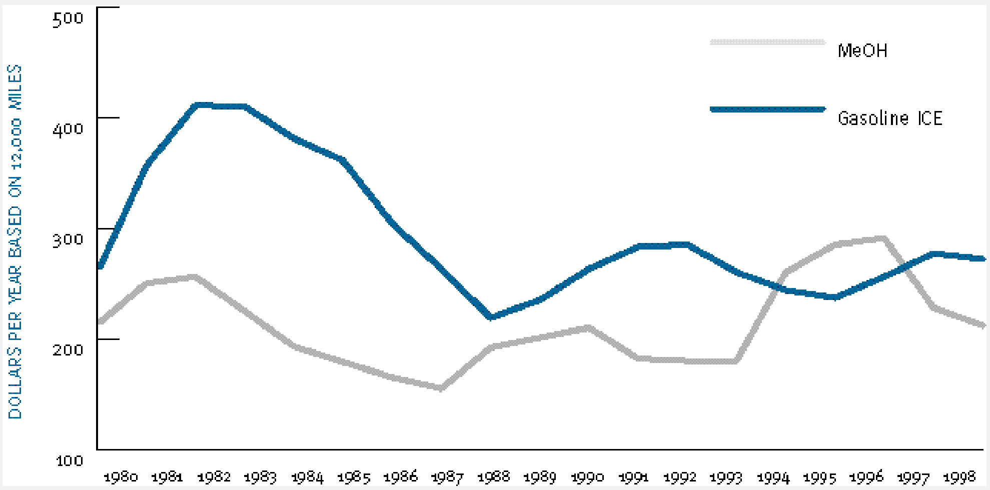
THE FUTURE FUEL COST OF OPERATING A METHANOL fuel cell vehicle cannot be determined precisely, but a relative sense can be inferred from past data. Historical price data can be used to calculate what it would have cost to operate a methanol fuel cell vehicle, in comparison to a standard internal combustion engine vehicle getting 27.5 miles per gallon. Wholesale pricing of gasoline and methanol have both varied significantly over the decades.

Figure 15 shows how the wholesale prices of gasoline and methanol would translate into average wholesale fuel costs per vehicle per year using three-year lagged average pricing. This kind of data presentation "smoothes out" the year-to-year variations in commodity prices for both fuels, and allows us to examine "the big picture" that is

THE GASOLINE-EQUIVALENT GALLON

The term "gasoline-equivalent gallon" is commonly used to ensure that vehicle fuel economy figures are presented on a common energy basis. In other words, a miles per gasoline gallon equivalent (mpge) figure is the distance that a vehicle would travel with use of an alternative fuel with the same total energy content as one gallon of gasoline. In the case of methanol, its energy content is 1/2.02, or 49.5%, the energy content of gasoline on a lower heating value basis. This means that 2.02 gallons of methanol have the same energy content as one gallon of conventional gasoline. Given that the average price of methanol from 1978 to 1998 was 48 cents per gallon, and the average pretax wholesale gasoline price over the same period was 66 cents per gallon, the price of methanol has been 47% higher than gasoline per unit of energy. However, when taking into consideration that a methanol fuel cell vehicle is expected to be twice as efficient as a gasoline-powered internal combustion engine, and have twice the fuel economy, the price of fuel per mile driven would have been 26% lower for a methanol fuel cell vehicle than for a conventional gasoline vehicle.

WHOLESALE YEARLY FUEL COST, GASOLINE VERSUS FUEL CELL VEHICLE



Lagged three-year moving averages. 1998 data for 1st quarter only.

Source: "Zeroing Out Pollution," Jason Mark, Union of Concerned Scientists, May 1996

Figure 15

evolving over time. Methanol, like gasoline, has had its hills and valleys in pricing, but it is clear from the data analysis that the fuel cell vehicle using methanol fuel, if deployed on a large scale over this period, would have saved the economies of the world hundreds of billions of dollars in fuel costs. The methanol fuel cell vehicle historically underprices the gasoline internal combustion engine in terms of transportation delivered per dollar of fuel.

More concretely put, if two average drivers, one driving a gasoline-powered vehicle averaging 27.5 miles per gallon and the other driving a methanol fuel cell vehicle averaging 55 miles per gallon equivalent, had each procured gasoline and methanol at wholesale prices, the driver of the gasoline vehicle would have paid $288 a year while the driver of the methanol fuel cell vehicle would have paid $213. These prices exclude taxes, which vary significantly from state to state, as well as distribution and retailer margins, which we can expect in the long term to be similar for methanol and gasoline with comparable volumetric demands. Therefore, it shows the decisive economic advantage that would have been available to the operator of a methanol fuel cell vehicle over the indicated period.

WHAT ARE THE STRATEGIC IMPLICATIONS OF A WORLD METHANOL MARKET?

THE GLOBAL RELIANCE ON OIL AS A MOTOR VEHICLE fuel brings energy security risks that can have serious economic implications. The United States continues to spend $30 billion per year to protect its interests in the Persian Gulf. The oil price shocks of the 1970s led to major global economic recessions.

The early period of fuel cell introduction will begin a shift in world energy dependency away from major oil producers to major natural gas producers. The overlap with current oil supplies will not be complete, and energy diversification will result. Soon the development of the fuel market will spur more interest in nonconventional methanol feedstocks, which will bring about intense interest in the resources discussed in the preceding sections. Finally, geographic diversification of methanol supplies will intensify once fuel cell vehicles gain momentum. The benefits may be summarized as follows:

Greater dispersion of energy resources ■ The gasoline-powered automobile will be with us for decades. The energy-importing countries of the world will benefit because there will be a larger number of suppliers of transportation fuels, and less energy will be required due to higher vehicle efficiencies.

Stable energy pricing ■ Price-regulating entities will find it increasingly difficult to control prices as the number of energy producers increases.

Fewer strategic crises ■ The more production there is, the less chance there is that “tight markets” will turn a local crisis in one country into an international energy shortage.

Greater capacity for domestic self-reliance ■ The development of renewable methanol feedstocks will offer many countries far more opportunities for self-reliance than can be discerned from current maps of the geographic distribution of natural gas resources.

For the first several years of the methanol fuel cell vehicle market, it is likely that a relatively modest methanol demand increase is likely to result in an intensification of current patterns of methanol production and distribution. As can be seen from Figure 16, it is quite possible that Latin American and Caribbean production will play a growing role, proportionately, in the developing methanol fuel market.

2000 WORLD METHANOL TRADE FLOW (1,000 METRIC TONS)

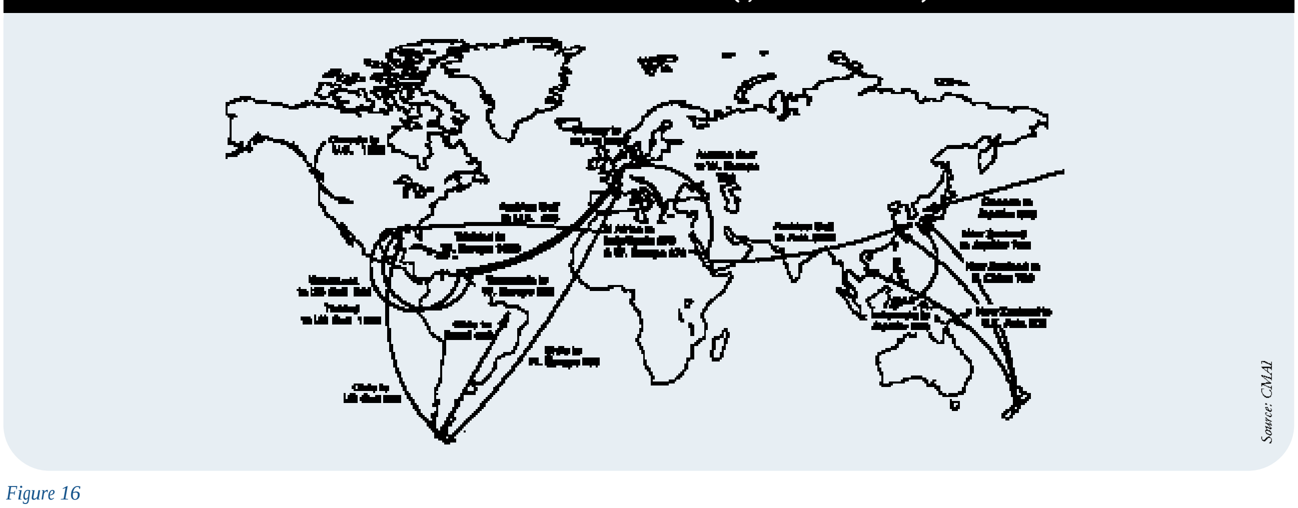


Figure 16

WOULDN'T GASOLINE FUEL CELLS AND GASOLINE/BATTERY HYBRIDS BE BETTER?

"Gasoline is not the fuel of choice for fuel cells. It makes them both dirtier and more complex. In effect, you have a 21st-century technology running on a 20th-century fuel."

Jason Mark, Union of Concerned Scientists, San Francisco Examiner, November 14, 1997

METHANOL FUEL CELL VEHICLES ARE ONE OF THE great environmental bargains in history. For less than $2 per person, a state or nation the size of California, with 30 million people, could put methanol fueling pumps into one out of 10 gasoline stations. From there, further development of the fuel system would cost even less. The principal obstacle to fuel cell vehicle deployment is adequate refueling infrastructure.

While this distribution hurdle should be manageable, it has been assumed by some that future vehicle designs should be based on petroleum products with existing retail presence such as gasoline and diesel. The two leading developments in this area are the "gasoline" fuel cell vehicle and the gasoline/diesel-battery hybrid vehicle.

The "gasoline" fuel cell vehicle is in its infancy in terms of development, several years behind the efforts to commercialize steam-reformed methanol fuel cell vehicles. Today's gasoline has several components that make it more difficult to reform into a hydrogen stream. Aromatic and sulfur levels make reforming gasoline a daunting engineering challenge. Researchers have been experimenting with the partial oxidation of gasoline in the laboratory. This technology is being designed with a multi-fuel capability, able to run on methanol, ethanol, gasoline, or natural gas. At this time, there are no fuel cell vehicles operating on gasoline, and the complexity of the gasoline reformer is likely to add to the cost and weight of the vehicle.

For these reasons, it is likely that a specially designed fuel from the refinery will be preferred for use in a gasoline fuel cell vehicle. This means that additional infrastructure costs would have to be incurred to accommodate this "designer gasoline." Specifically, it is likely that a light fraction of straight chain hydrocarbons with little or no sulfur will be desired for fuel cell vehicles. This specially engineered fuel would require separate storage at the retail stations.

If today's gasoline were to be used, at the very least sulfur levels would need to be controlled to much lower levels, and this would have associated refinery upgrade costs. In the United States, automakers and environmentalists have been pushing the oil industry to reduce the sulfur content of gasoline from an average of 300 parts per million today down to 40 ppm or less. Estimates on the cost to produce this cleaner gasoline range from two to nine cents per gallon more at the pump.

Even if gasoline fuel cell vehicle technology is developed, there are still a number of reasons why methanol is the fuel of choice for fuel cells:

- Gasoline reforming requires much higher temperatures than methanol steam reforming: 800° C vs. 250–300° C. The higher temperature may mean longer start-up times. The gasoline partial oxidation reaction is also inherently less efficient than steam reforming methanol.

- Gasoline reformer technology requires greater carbon monoxide clean-up (which is required for efficient performance of the fuel cell); levels of approximately 10 parts per million will remain, compared with 1 or 2 ppm for a methanol reformer. Higher levels of carbon monoxide adversely affect fuel cell performance.

- The gasoline reformer process yields a lower concentration of hydrogen than methanol, which also impedes fuel cell efficiency.

- Gasoline reformer development — because of its complexity — could delay the commercialization of fuel cell vehicles.

All of these reasons combined give ample justification for pursuing methanol, and it is not surprising that most leading fuel cell developers and automobile manufacturers are actively promoting methanol for use in fuel cells.

Another technological development is the hybrid vehicle. The gasoline/diesel-battery hybrid vehicle is a direct development borne out of the limitations of battery technology. Battery-powered electric vehicles are heavy, due to the weight of the battery pack, and have severe range limitations, reaching at most 100 miles in real-world range per charge, but more typically 75 miles.

On the hybrid vehicle, a small gasoline or diesel engine is provided to give extra power. The vehicle can recharge in use. There are a variety of designs, but they all have the common feature of allowing a battery pack to be recharged while the vehicle is in use. Moreover, they allow the gasoline engine to be optimized to control emissions to very low levels. For example, Toyota's hybrid battery-gasoline vehicle will reduce emissions of NOx and VOCs significantly. Mileage per gallon may double if vehicle weight penalties are not too high, so that the carbon dioxide reduction may reach 50%.

Methanol fuel cell vehicles should achieve even lower levels of emissions for "criteria pollutants," especially in the longer term when the direct methanol fuel cell is likely to take the very low levels of the steam reformer fuel cell to zero in most emission categories.

All in all, a $2 per capita one-time cost in developed countries for methanol infrastructure development seems a sensible investment when compared to these alternatives. It seems unreasonable to advocate continued reliance on petroleum products that are likely to cost the consumer more in annual fuel costs (based on historical pricing) and have higher environmental impacts. The wisest investment for the public in its various roles as environmentalists, citizens worried about energy security and consumers — is the methanol fuel cell vehicle.

HOW DO WE ENCOURAGE THE INTRODUCTION OF METHANOL FUEL CELL VEHICLES?

TO FACILITATE THE INTRODUCTION OF METHANOL fuel cell vehicles, the American Methanol Institute proposes:

Encourage the development of strategic alliances ▪ A number of strategic alliances have already been formed to support the introduction of fuel cell and alternative fuel vehicles. Methanex is working with the Daimler/Ford/Ballard partnership, Ford is working with Mobil, and General Motors is partnering with Amoco. Broad-based strategic partnerships that involve the automotive, methanol, natural gas, and oil industries, along with government, should be encouraged. These strategic partnerships can help overcome many of the initial hurdles to the introduction of methanol fuel cell vehicles, particularly the establishment of a retail fueling infrastructure.

AMI Board ofDirectors Chairman Roger Seward (r) of the Lyondell Methanol Company meets with Johannes W. Ebner (l), Daimler-Benz Vice President for Infrastructure and Communications

Establish fuel tax incentives ▪ Tax incentives that encourage both gasoline retailers to provide methanol pumps and consumers to purchase methanol fuel should be established. Permanent subsidies are not necessary or wanted. What is needed are short-term incentives to help overcome initial obstacles and jump-start the market. Legislation has been introduced in the U.S. Congress to provide a 50¢ per gasoline-equivalent gallon tax credit for the use of methanol and other natural gas-based fuels. The methanol industry supports such legislative initiatives.

Support vehicle purchase incentives ▪ The existing $4,000 federal tax credit for purchases of electric vehicles should be used to assist methanol fuel cell vehicle buyers.

STATE TAXES ON GASOLINE AND METHANOL FUELS

In Cents Per Gasoline-Equivalent Gallon

STATE	GASOLINE	METHANOL
Alabama	16	32
Alaska	8	16
Arizona	18	36
Arkansas	18.5	37
California	18	18
Colorado	22	41
Connecticut	39	74
Delaware	23	44
D.C.	20	40
Florida	4	8
Georgia	7.5	15
Hawaii	32.5	65
Idaho	25	50
Illinois	19	38
Indiana	15	30
Iowa	20	38
Kansas	18	40
Kentucky	15	30
Louisiana	20	40
Maine	19	36
Maryland	23.5	47
Massachusetts	21	42
Michigan	15	30
Minnesota	20	40
Mississippi	18	36
Missouri	17	34
Montana	27	54
Nebraska	25.3	50.6
Nevada	23	46
New Hampshire	18	36
New Jersey	10.5	21
New Mexico	22	44
New York	8	16
North Carolina	21.7	43.4
North Dakota	20	40
Ohio	22	44
Oklahoma	16	32
Oregon	24	48
Pennsylvania	12	24
Rhode Island	28	56
South Carolina	16	32
South Dakota	18	12
Tennessee	20	34
Texas	20	40
Utah	19	38
Vermont	16	32
Virginia	17.5	35
Washington	23	46
West Virginia	20.5	41
Wisconsin	23.7	47.4
Wyoming	8	16

Source: The Clean Fuels Report, November 1997

Figure 17

This tax credit also should be extended from its current expiration date of 2004 to the year 2010.

Support also should be given to President Clinton's proposed tax credits for buyers of ultra-fuel efficient cars ▪ Under the proposal, purchasers of cars that achieve double the fuel economy of today's cars by 2000, would be eligible for a $3,000 tax credit, and buyers of cars getting triple the fuel economy by 2004, would receive $4,000.

Encouragement of necessary infrastructure ▪ Making methanol fuel available to the public at 10% of all fueling stations would cost only $1 billion nationwide, and only $60 million in a state the size of California, with 30 million people. The gasoline industry spent $6 billion to offer reformulated gasoline to the public in order to comply with the 1990 Clean Air Act amendments in the United States. Some combination of incentives may be necessary to make sure that an adequate distribution facility for methanol will be available to service the fuel cell cars as they hit the market in 2004. Current tax deductions for the cost of capital equipment for installing alternative fuel stations should be expanded to include non-equipment installation costs, such as site preparation.

Elimination of discriminatory fuel taxation ▪ Fuels should be taxed on their energy content, not by volume. Currently taxation policies in many jurisdictions discriminate against alternative fuels by taxing clean fuels with relatively lower energy content on a simple volume basis, which encourages the use of gasoline. Figure 17 shows that many state governments penalize methanol fuel by taxing it as if it were gasoline. The graph also shows that California is truly a "fuel neutral" state, with very little differential in taxation on an energy-equivalent basis, while policies in South Dakota favor the development of a methanol market.

Provide credit for methanol fuel cell vehicles in regulatory policies encouraging the use of electric vehicles ▪ California, New York and Massachusetts require that 10% of the vehicles sold in these states in Model Year 2003 must be Zero Emission Vehicles (New York's ZEV program began with the 1998 Model Year). ZEVs have been assumed to be battery-powered electric vehicles, however, the performance limitations of battery EVs do not make them attractive to many consumers. Regulatory officials have begun to look at emissions from battery EVs beyond the vehicle, tracing emissions to the local generating plants that provide electricity to recharge the batteries. The emissions from methanol steam reformer fuel cell vehicles will be a fraction of the most stringent requirements for internal combustion engine vehicles (Ultra Low Emission Vehicles or Super Ultra Low Emission Vehicles — "ULEVs" or "SULEVs"). Further, the methanol fuel cell vehicle will come close to or meet the emissions levels attributed to the electric generating stations powering ZEVs. Regulatory policies and programs should encourage the use of methanol fuel cell vehicles by providing full or partial ZEV credits for these vehicles.

Provide additional incentives for fuel cell vehicle consumers ▪ Provide states with the authority to allow single-occupant drivers of methanol fuel cell vehicles to use high-occupancy vehicle (HOV) lanes. Also, encourage the designation of preferential parking for operators of methanol fuel cell vehicles in public facilities, including ride-and-drive lots and transit facilities.

Encourage the use of CMAQ funds for methanol fueling station construction ▪ With funding levels expected to exceed $1 billion per year for the federal Congestion Mitigation and Air Quality Improvement Program, municipalities should be encouraged to use this funding to help install methanol fueling stations. The installation of fueling facilities serving government fleets is a logical first step.

Support the fuel cell work of the Partnership for a New Generation of Vehicles ▪ This public/private partnership has identified fuel cell vehicles as one of its technology options for developing highly efficient vehicles. Given the strong support for methanol fuel cell vehicle development evidenced by the world's automakers, this technology should be given a higher priority.

Increase funding for research in direct methanol fuel cell technologies ▪ The direct methanol fuel cell holds the greatest promise of reducing emissions and improving energy efficiency for a broad array of applications. Federal funding for DMFC development has been minimal and fragmented. The efforts of national laboratory, university, and private researchers should be directed to accelerating the pace of development of this technology.

U.S. Energy Secretary Frederico Peña (l) discusses fuel cell technology development with AMI Senior Consultant Raymond Lewis (r).

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This report summarizes information gathered from a wide variety of sources: interviews with, and critical review comments from, industry and government officials; academic journals; academic and industrial conference papers; news articles in major print media sources; the business press; government publications; industry reports and news releases; and a variety of Internet materials made available by government, industry, environmental organizations, and other entities. The following materials are an extensive, but not exhaustive, list of resources used in compiling this report. Internet web sites are included.

Special Note on Web Sites: Many "URL" (Universal Resource Locators, or web addresses) listings that point to a specific document cannot be accessed directly after typing the address into a browser. Some web sites do not permit access directly to documents without first passing through a higher directory. Where this is so, we have divided the URL into two parts, the highest directory at which access can be gained to the web site and then the subsequent subdirectory information, which usually will require the researcher to select and click on the correct options.

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