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Ford's Vision for a Hydrogen Transportation Future

Ford Motor Company

Summary
Ford Motor Company believes that hydrogen offers the promise of reducing mobile and stationary emissions, as well as the potential to improve our nation's energy independence. We are investing significant resources to advance and demonstrate hydrogen vehicle technologies, such as fuel cells and hydrogen internal combustion engines. Given the enormity of the challenge, no one can do it alone, and we believe that industry, energy providers, and government partnerships and long-term vision will be required to undertake this critical endeavor.

Benefits of Hydrogen

Hydrogen offers many attributes as a transportation fuel. It can be derived from various sources. This diversity means that different geographic regions can obtain hydrogen from whatever feedstock is available which would tend to reduce concerns over regional energy security. Hydrogen is a "clean burning" fuel, contributing to significantly reduced local emissions where it is used. If hydrogen is derived from renewable resources, if carbon is successfully sequestered, or if environmentally benign nuclear power sources can be developed, the total environmental impact of hydrogen as a fuel would be minimal.

- For the transportation sector, much of the discussion of hydrogen as a fuel has been centered on the fuel cell. While this is the most likely "end game" for sustainable transportation, in the shorter term hydrogen is attractive since it can be efficiently burned in conventional internal combustion engines. Hydrogen has a wide combustion range which means that hydrogen fueled engines can operate on a wider range of air-fuel mixtures than gasoline engines, and can run lean for more efficiency with minimal pre-ignition or knock. The maximum brake thermal efficiency[1] of a hydrogen ICE is approximately 38%, about 25% better than a gasoline engine.
- Converting existing engines to run on hydrogen requires modifications to the engine such as new fuel injectors designed to handle hydrogen gas, revised ignition system, new high compression pistons, modifications to the engine controls software and adding a supercharger. These engine changes would leverage the large manufacturing infrastructure already in place to produce gasoline- and diesel-fueled engines which can affordably be converted to run on hydrogen. In addition, key vehicle subsystems needed for fuel cell vehicles, such as on-board hydrogen storage, fuel handling, instrumentation and sensors, could be developed first on a hydrogen ICE vehicle.
- Taking the hydrogen ICE vehicle one step further along the evolutionary path by adding a hybrid electric powertrain provides further efficiency improvements. Here again, technologies such as durable and efficient batteries, electric motors, electronic inverters/converters and controls developed for H_2 ICE HEVs would also support development of fuel cell vehicles.
- Thus, a H_2 ICE could serve as a bridging action -- providing significantly lower tailpipe emissions and better fuel efficiency, while helping to provide an economically viable path towards hydrogen fuel cell vehicles. H_2 ICEs could also help develop vehicular demand for the installation and expansion of a hydrogen refueling infrastructure – the lower cost of a H_2 ICE means that for the same cost, more ICEs than fuel cell vehicles could be produced and put into the market.

Hydrogen Challenges

Many issues must be resolved before hydrogen can become a viable fuel alternative:

Vehicle:

In general, for any new hydrogen fueled vehicle to be viable for high volume sales, it will need to provide equal or better function than a conventional vehicle at comparable cost very soon after public introduction. (Or public policy incentives would have to exist that temporarily cover the gap between the cost of the vehicle and what the customer is willing to pay for it. This is discussed in somewhat more detail in the policy section below.) Although there will be a few "early implementers" who are willing to pay a premium price for new technologies, the automobile is becoming a commodity to customers who are uncompromising in their demand for performance, function, quality and affordability. The hydrogen vehicle is faced with many challenges, many of which will require technical breakthroughs rather than simply further development of existing technology:

- Low cost, high density, on board hydrogen storage systems that do not add significant weight to the vehicle or reduce its cargo or passenger carrying capacity. H_2 storage provides the largest vehicular challenge to the viability of a hydrogen fueled vehicle. A minimum of a 300 mile range is required which results in storage goals of
    - 2010: 2.0 kWh/kg (6 weight percent), 1.5 kWh/liter, $4/kWh
    - 2015+: 3.0 kWh/kg (9 weight percent), 2.7 kWh/liter, $2/kWh

  Technologies being investigated include compressed gaseous hydrogen tanks, chemical hydrides, metallic hydrides, and carbon nanotubes, but none can meet these aggressive targets yet. Because H_2 ICEs are less efficient than fuel cells, their range will be somewhat less. This, however, was considered when the FreedomCAR Hydrogen Storage goals were set with the expectation that a storage system meeting the 2015 goals, in particular, will provide acceptable range to either customer.
- Lower cost fuel cell systems with total costs an order of magnitude or more lower than the cost of today's developmental fuel cell systems. 2010/2015 targets of $45/$35/kW are necessary to be cost competitive with conventional gasoline or diesel ICE technologies. (Costs much higher than this are unlikely to encourage customers to make the switch from known technology.) Improvements needed to contribute to the achievement of this goal include:
    - Lower cost fuel cell components such as cathodes and anodes which require less (or no) precious metal.
    - Fuel cell stack design improvements addressing present reliability, durability, and manufacturability issues.
    - Improved, lower cost, smaller size and more durable and reliable power electronics and batteries.
- Fuel cell enabling technologies such as:
    - Fuel cell systems that are tolerant of broad ranges of operating temperatures and variations in hydrogen purity
    - Compressor/expanders which are smaller, more efficient and quieter
    - Drive motors which are more efficient and lower cost
    - Sensors which are smaller, lower cost and more effective

- A "given" for any new vehicle technology is that it meets the same safety, quality/durability (10 years/150,000 miles) and functional requirements as other vehicles on the road.

Infrastructure:

Establishing the required hydrogen retail infrastructure will be an immense and expensive proposition. From an auto manufacturer's perspective, the existence of an expansive refueling infrastructure is critical to management commitment to high volume vehicle production. Some have estimated that hydrogen fuel will need to be available at 25-50% of urban and 50-70% of rural filling stations before consumers will feel confident enough to purchase a hydrogen vehicle. The estimated costs of creating this infrastructure exceed tens of billions of U.S. dollars.

- Means for hydrogen transportation and delivery need to progress to the same extent as the gasoline distribution system today. Today's usual transport of compressed gaseous or liquid hydrogen by tube tanker trucks will have to be replaced by significantly higher capacity transportation systems that may require a mix of local, regional and central hydrogen production facilities feeding the transportation and delivery system.
- Today in the United States, local, regional and state governmental agencies are responsible for setting codes and standards. Thus, it is not unusual to find different requirements for the operation, storage and maintenance of hydrogen-fueled vehicles in different locales. This makes the production of vehicles that can be widely sold and operated very difficult. Significant changes in Codes and Standards (C&S) are required to:
    - Develop and provide uniform C&S throughout the United States and developed world to permit the deployment and operation of hydrogen-fueled vehicles and a hydrogen infrastructure.
    - Develop a common C&S permitting template that can be used by local, regional and state permitting authorities.
    - Modernize existing C&S based on future research data on hydrogen characteristics and safety.
    - Develop industry standard C&S that can be universally applied to vehicles regardless of where they will be sold.
- Similarly international harmonization or homologation of hydrogen codes and standards is needed. The DOE and U.S. code and standard setting bodies can assist with this.

Timing

Although it is very difficult to predict the advent of technology, the U.S. DOE has suggested a broad timeline to determine the practicability of fuel cell commercialization. In its fuel cell report to Congress,[2] DOE suggested (and Ford concurs with):

- **2004-2009**: controlled fleet test and evaluations to evaluate use of fuel cell vehicles in real world conditions
- **2009-2015**: commercial readiness demonstrations to demonstrate viability of fuel cell vehicles in higher volume fleet usage, and the expansion of hydrogen refueling stations to provide convenience
- **2015 and beyond**: determine whether there has been sufficient technical progress with the fuel cell and vehicle technology to permit auto manufacturers to make decisions regarding

commercialization, and sufficient demand for energy providers to make H_2 available at substantial numbers of fueling stations.

If the 2015 decision point results in a commitment to go forward with hydrogen vehicles and widespread availability of hydrogen refueling stations, Ford can envision a scenario where auto companies would begin to shift production from gasoline ICEs to hydrogen at the same time energy providers begin to add significant numbers of hydrogen pumps. It is likely that the new vehicles and expanded infrastructure would arrive in the market together a few years later. Because of their lower costs and similar environmental benefits relative to fuel cells, H_2 ICEs may initially dominate the hydrogen powered vehicle market. But, over the next ten to fifteen years there may be a shift toward increasing numbers of fuel cell vehicles as they become more refined, more publicly accepted and as costs are reduced. Successful fleet testing of H_2 ICEs during the 2005-2015 timeframe could play a key role as a bridging strategy to this vision.

Policies Needed

- Ford strongly supports cooperative partnerships among the auto industry, fuel providers, and government, like the California Fuel Cell Partnership (CaFCP), FreedomCAR Program and Hydrogen Fuel Initiative to help speed hydrogen research to lower the cost of fuel cells and hydrogen fuel, storing hydrogen on vehicles, and developing infrastructure.
- Continued R&D programs to address the technological issues with fuel cells and hydrogen storage and infrastructure
    - Develop and promulgate uniform Codes and Standards
    - World-wide homologation of Codes and Standards
    - Identify sustainable hydrogen production alternatives
    - Carbon sequestration research
    - The CaFCP has brought key stakeholders to promote discussion of critical issues and identify key activities that are necessary to advance the commercialization of fuel cell vehicles. Through the demonstration of fuel cell vehicles and fueling technology, the partnership has developed a substantial experience base that is constantly growing. By communicating lessons learned to other organizations that wish to accomplish similar objectives, the CaFCP is making a contribution to fuel cell vehicle commercialization.
- Once the technologies (both vehicle and hydrogen fuel and delivery) have advanced beyond the research stage, the industries involved will need some form of incentive to increase volume to achieve the economies of scale that will help start driving the costs down. Policy actions such as the following can help to do this:
    - Encouraging or mandating government fleet purchase of hydrogen fueled (H_2 ICE and FCEV) vehicles and hydrogen fuel.
    - Providing financial incentives to purchasers of hydrogen fueled vehicles and to the use of hydrogen fuel.
    - Ford and many others like the broad based CLEAR Act Coalition and U.S. Energy Futures Coalition believe that temporary incentives in the form of customer tax credits will be required to accelerate the purchase and acceptance of these advanced vehicles in the marketplace, as well as to encourage the development of the required hydrogen retail fueling infrastructure. Generally speaking customer incentives should

be performance-based, scaled relative to the incremental costs of the advanced technology, and in place long enough to generate sustainable volumes and manufacturing economies of scale.

- The financial community, government and industry need to find a way to sustain the interest of investors in emerging technologies that support the vision of a hydrogen transportation future, but cannot promise a quick pay back of investment funds. It will likely be years before many of the emerging, high-tech companies needed to launch the hydrogen economy achieve ongoing profitability; yet, preservation of those companies over the long term is critical to the success of a hydrogen economy.
- Education and outreach are needed to train government officials, permitting agencies and officials, emergency personnel and the general public about the safety and potential benefits of hydrogen.

Definitions:

- Lean Operation: *Engine management that delivers more air (and less fuel) than necessary to burn the air/fuel mixture for improved engine efficiency.*
- Pre-Ignition: *The tendency of fuel to ignite spontaneously due to local high temperatures (hot spots) in an engine's cylinder.*
- Knock: *The sound made by the engine when the fuel ignites prematurely due to poor engine timing or use of low octane fuel. The ability to maximize power and fuel economy by optimizing spark timing for a given air/fuel ratio is limited by engine knock. Detecting knock and controlling ignition timing to allow an engine to run at the knock threshold provides the best power and fuel economy. Damage to pistons, rings, and exhaust valves can result if sustained heavy knock occurs. Additionally, most automotive customers find the sound of heavy engine knock objectionable.*

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[1] Brake Thermal Efficiency: The ratio of work done by an internal combustion engine to the amount of energy contained in fuel as measured on a dynamometer (sometimes called a "brake").

[2] U.S. Department of Energy. 2003. *Fuel Cell Report to Congress*. February 2003. Available at: http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf.