A RURAL HYDROGEN TRANSPORTATION TEST BED

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ABSTRACT

The University of Missouri-Rolla (UMR), through a hydrogen internal combustion engine vehicle evaluation participation agreement with the Ford Motor Company, will establish a commuter bus service and hydrogen refueling at a station in rural Missouri near Ft. Leonard Wood (FLW). Initiated by a request from the U.S. Army Maneuver Support Center at FLW, UMR is leading the effort to launch the commuter service between FLW and the neighboring towns of Rolla and Lebanon, Missouri each of which are located approximately 40 km from the military base on Interstate-44 highway. The broad research, training, and education agenda for the rural hydrogen transportation test bed is to develop, demonstrate, evaluate, and promote safe hydrogen-based technologies in a real-world environment. With funds provided by the Defense Logistics Agency through the Air Force Research Laboratory, this hydrogen initiative will build and operate a hydrogen fueling facility that includes on-site generation of hydrogen through electrolysis as well as selling a range of other traditional and alternative fuels.

1.0 OBJECTIVES

The Missouri Rural Hydrogen Transportation Test Bed has the following technical objectives:

- To collect and evaluate real-world data to address safety and environmental issues, develop statistically validated codes and standards, formulate policies and regulations, and understand reliability and large-scale deployment of hydrogen technology under diverse operating conditions.

- To develop, validate, and transition to a manufacturing environment, commercially ready, non-destructive testing technologies for hydrogen storage and transport systems;

- To test, demonstrate, and validate hydrogen vehicles, hydrogen transportation infrastructure, and vehicle and infrastructure interfaces for complete system solutions;

- To gain public acceptance to the use of safe alternative energy sources to power the transport system that is independent of the fossil fuel supplies;

- To integrate research results into a comprehensive undergraduate and graduate curriculum to educate the future workforce on hydrogen technologies;

- To develop and implement an outreach program, in collaboration with other national programs, which has a special emphasis on safety training for operators, maintainers, code officials, and first emergency responders at the local and state levels.

2.0 UNIVERSITY TRANSPORTATION CENTER

The recent establishment of the National University Transportation Center (UTC) at the University of Missouri-Rolla (UMR) under the “Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users,” expands the research and education activities to include alternative transportation fuels and other issues that are at the forefront of society and the national agenda. A holistic approach will be taken to address not just the technology but also public perception, permitting, safety standards, and education and training. A key partner already engaged is the

National Association of State Fire Marshals (NASFM) that regards this initiative as an "excellent candidate for the model approach to introducing hydrogen to communities." The tasks identified in five areas, viz., Infrastructure Development and Deployment, High-Pressure Composite Cylinders, Inspection and Monitoring, Statistically Validated Codes and Standards, and Safety, constitute a comprehensive research, development and demonstration program to address some of the challenges described in the U.S. Department of Transportation (DOT) Hydrogen Roadmap 2005 "Research, Development, Demonstration, & Deployment Roadmap for Hydrogen Vehicles & Infrastructure to Support a Transition to a Hydrogen Economy" [1].

This initiative built on previous studies on manufacturing of composites, non-destructive testing and evaluation, expands the current theme of the UTC at UMR. The preliminary activities were aimed at initiating the research related to the development of a rural hydrogen transportation test bed that will demonstrate, evaluate and promote hydrogen-technologies in a real-world environment, including:

- On-site Generation of Hydrogen from Ethanol
- Modeling of Composite Hydrogen Storage Cylinders Using Finite Element Analysis
- Non-Destructive Testing and Evaluation (NDT&E)
- High Voltage Disconnect Systems (HVDS)
- Statistically Validated Codes and Standards - Stationary Fuel Cells
- Hydrogen Flammability Limits and Implications on Fire Safety of Transportation Vehicles
- Blast Wave Modeling

The UTC strategic plans seek to address national needs in the area of transportation infrastructure and safety focusing on the following topical areas:

- Advanced Materials,
- Transition-state Fuel Vehicle Infrastructure, and
- Non-destructive Evaluation (NDE) Technologies and Methods.

Within the topical area of "Transition-state Fuel Vehicle Infrastructure" which focuses on hydrogen as a transportation fuel, two critical tasks have been identified as follows:

- Development of Safety Codes, Standards, and Regulations
- Infrastructure Development and Deployment

The UTC plans to support proposals in the areas of advanced materials, transition-state fuel vehicle infrastructure, and NDE technologies and methods with the objective of advancing the state-of-the-art of transportation infrastructure and safety. One example is the modeling of composite hydrogen storage cylinders as pressurized hydrogen storage cylinders are a critical component of hydrogen transportation systems (vehicle fuel systems, bulk commodity transport, portable storage, and stationary storage). These cylinders also have pressure/thermal relief devices (P/TRDs) that are activated in case of an emergency. Recent studies [2-3] illustrated the ongoing development of comprehensive finite element analysis tool for the modeling, simulation, and design optimization of composite hydrogen storage cylinders for safe installation and operation. For example, by using of a neural network model, one can effectively predict the burst pressure of these composite hydrogen storage cylinders undergoing thermal loading. To date, the researchers at UMR have applied their two-dimensional, shear deformable, composite shell model for static finite element analysis, thermomechanical analysis, dynamic analysis and failure analysis. Their ongoing tasks include the extension to three-dimensional analysis accounting for hydrogen with fluid-structure interactions; three-dimensional failure analysis/life prediction due to thermomechanical dynamic loading; impact analysis; nonlinear analysis with geometric nonlinearity (large deformation) and material nonlinearity (plasticity for aluminum liner and viscoplasticity for polymer liner); and the design optimization using neural network models.

For nearly half a century, the transportation sector has accounted for 25% of energy consumed in U.S. shown in Fig. 1 [4] and accounted for 28% of energy consumption in 2005 shown in Fig. 2 [4].

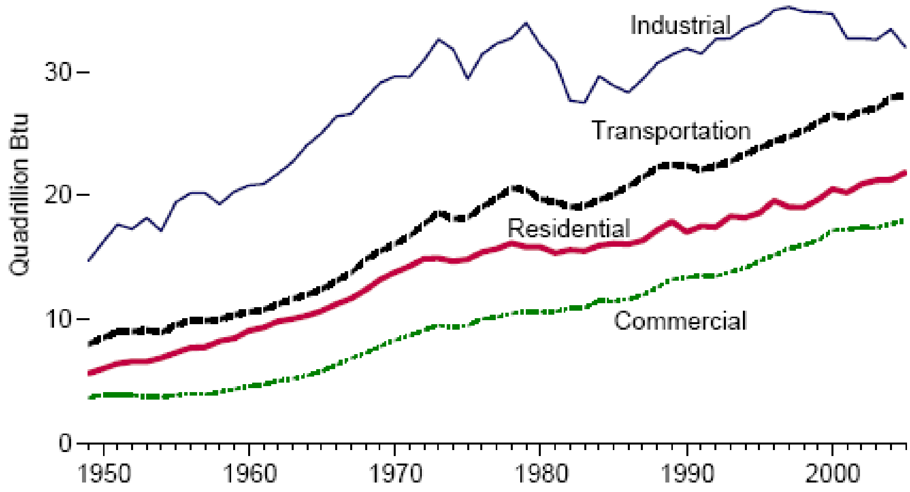

Figure 1. Total U.S. Energy Consumption by End-Use Sector, 1949-2005.
(Annual Energy Review 2005: Report No. DOE/EIA-0384)

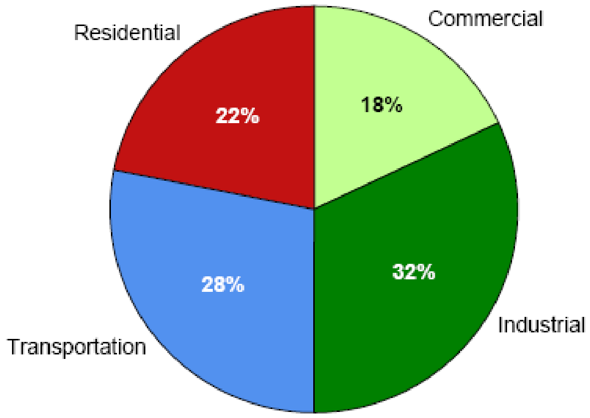

Figure 2. U.S. End-Use Energy Shares of Total Consumption, 2005.
(Annual Energy Review 2005: Report No. DOE/EIA-0384)

It is recognized that the development of a marketable hydrogen vehicle has the potential to greatly reduce the growing dependence on foreign oil in U.S. shown in Fig. 3 [4].

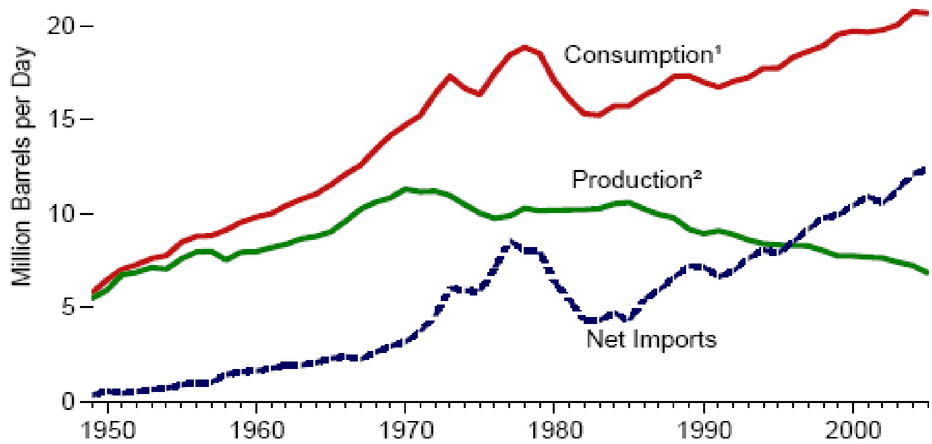

Figure 3. U.S. Petroleum Overview, 1949-2005.
(Annual Energy Review 2005: Report No. DOE/EIA-0384)

Petroleum remains the primary energy source in the U.S. transportation sector shown in Fig. 4 [4].

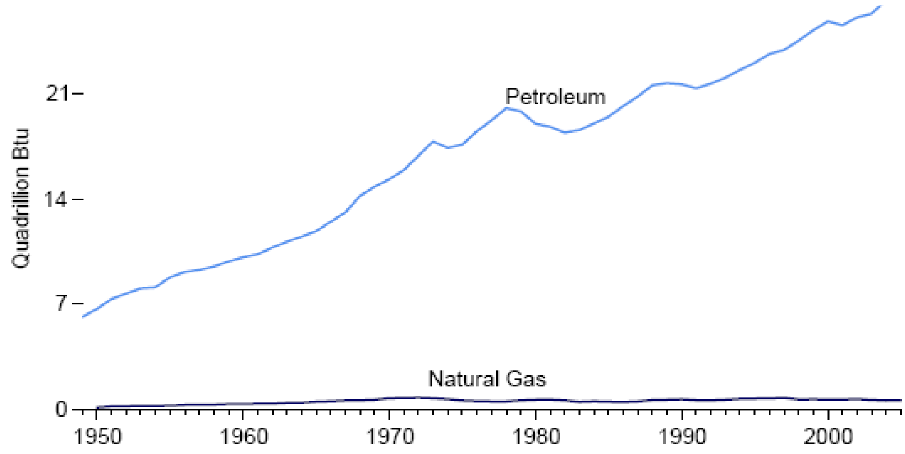

Figure 4. U.S. Energy Consumption in Transportation Sector by Major Source, 1949-2005. (Annual Energy Review 2005: Report No. DOE/EIA-0384)

Within the transportation sector in U.S., gasoline has remained the primary petroleum-based fuel for more than fifty years, followed by distillated fuel oils and jet fuel shown in Fig. 5 [4].

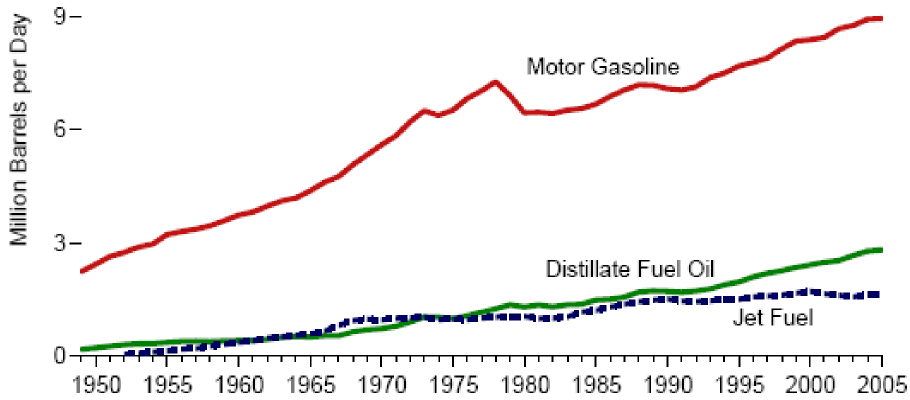

Figure 5. U.S. Energy Consumption in Transportation by Selected Product, 1949-2005. (Annual Energy Review 2005: Report No. DOE/EIA-0384)

In the U.S., it should be noted that DOT has authorities, regulatory responsibilities and expertise for vehicle safety and fuel economy, and for pipeline and hazardous material safety, including the safety of hydrogen fueled vehicles and hydrogen storage in vehicles, as well as the safe transportation and distribution of hydrogen. While the U.S. Department of Energy (DOE) is the federal government agency responsible for light-duty vehicles in U.S., it is the DOT which is responsible for heavy-duty vehicle research and provides capital funds to support, and to maintain the safety of the Nation's transportation infrastructure including the development of the hydrogen distribution and delivery system. Because DOT has primary responsibility for pipeline safety and transportation of hazardous materials, it must also coordinate the concurrent development of the infrastructure to support the pace of commercially available vehicles, and the pact of local production, storage and protection of energy using hydrogen.

The safety of the entire transportation system will be essential for the success of hydrogen as an emerging alternative transportation fuel. Accordingly, DOT has a vital role in developing, promulgating, and enforcing regulations in various aspects of transportation operations. In a small way, the rural hydrogen transportation test bed in Missouri will be addressing the issues and processes important for the transition to a hydrogen economy while maintaining the current high standard of safety, reliability, and public confidence in this rural transportation system. The project seeks to confirm the validity of the procedures and standards for the safe use and transport of hydrogen in transportation vehicles. Many believe that hydrogen safety codes and standards should be performance-based and systems-oriented and that the hydrogen safety codes and standards be designed to apply to general product applications as opposed to prescriptive, type-specific regulations for each application. Thus these new hydrogen codes and standards are being developed based on sound scientific knowledge of hydrogen effects on material properties and behavior. Finally, these new hydrogen codes and standards must address both the design and operation of transportation systems, subsystems, components, and consumer devices.

Public acceptance of hydrogen fueled vehicles will dictate fuel system integrity, vehicle safety, and crashworthiness performance equal or superior to the existing petroleum fuel currently in use. The challenges for developing safety codes, standards, and regulations for hydrogen fuel systems include the need for substantial research in understanding and anticipating the effects of hydrogen on various materials. The full-scale demonstration projects must be designed to research the complex systems operations, performance, reliability, and costs. Cross-cutting research is also required to examine the effects of hydrogen on conventional and composite materials (i.e., stainless steel alloys and carbon composites, respectively) including the effects of temperature, pressure ranges, and fluctuations. In addition, the effects of atmospheric and vehicle environmental stressors such as humidity, temperature, airborne and waterborne contaminants (acids, salt compounds, etc.), dirt, vibration, and shock on material integrity need to be fully understood before the standards for hydrogen use and transport can be promulgated. Inspection technologies must also be developed to detect and maintain the integrity of hydrogen fuel and commodity transport systems. The standards and regulations actions will rely on data collected from a diverse set of research and demonstration projects, including those conducted or funded by DOE, Environmental Protection Agency (EPA), Department of Defense (DOD), and DOT in U.S. as well as others international sources. Although basic knowledge and early research and development on materials behavior can be shared across the modes and used for many purposes, regulations should be specific to the application and will be developed independently by the appropriate operating organizations, in collaboration with relevant standards organizations.

3.0 HYDROGEN DEMONSTRATION PROJECT

Why Missouri? Although significant demonstration projects are on-going with hydrogen highways in California, Florida and urban locations such as Washington DC, there is still much to do to address issues related to the real-world and practical applications of standards, safety, and public acceptance of these new systems in rural applications. The state of Missouri is ideally suited to develop and demonstrate the proper operation of hydrogen highways in a rural setting which represents over 25% of the nation's transportation needs and which is not well-represented in the current major national projects in the U.S. UMR is especially well positioned to focus on rural applications. Based on the interest and encouragement from DOT, the UTC at UMR redirect significant resources toward initiating this important task. Other key partners include the National Association of State Fire Marshals, the Missouri State Fire Marshall, the Missouri Department of Transportation (MoDOT) and the Missouri Transportation Institute (MTI).

A new rural commuter bus service was established in May 2007 serving a large military installation (FLW) from two neighboring towns of Rolla and Lebanon each located about 25 miles away on U.S. Interstate-44 highway. The need for this commuter bus service has resulted from a significant growth in the FLW population, which has almost doubled to around 40,000 people at FLW. The increase in commuter traffic, coupled with the U.S. Army's interest in reducing single-occupant auto trips to FLW and its willingness to provide each federal employee with a monthly tax-free benefit, make the long-term operation of this commuter bus service viable. The shuttle buses will pick up passengers at locations in Rolla and/or Lebanon, and drop them off at locations at Waynesville/St Robert/Fort Leonard Wood. Passengers will be returned to their original pick-up point (Fig. 6).

Figure 6. Missouri Rural Hydrogen Test Bed.

A hydrogen fueling station will be built in St. Robert, Missouri with an on-site hydrogen generation via electrolysis at a rate of 1 kg per hour. The hydrogen internal combustion engine (H2ICE) vehicle participation agreement with the Ford Motor Company provides this rural hydrogen test bed with two Ford E450 H2ICE shuttle buses with the following specifications:

1.	Vehicle description	E450 Cutaway Shuttle Bus
2.	Configuration	Shuttle Bus (Body by Corbeil Enterprises)
3.	Wheelbase	176" WB
4.	Body style	Shuttle Bus Body on E450 Chassis
5.	Passenger capacity	12 passengers or 8 plus wheelchair lift
6.	Chair lift capacity	Yes
7.	Vehicle length	301.5 inches
8.	Vehicle width	96 inches
9.	Vehicle height	112.5 inches
10.	Frontal overhang	30 inches
11.	Rear overhang	95.5 inches
12.	Fueling location	Left rear side
13.	Power steering	Yes
14.	Engine displacement	6.8L V10 Engine , Supercharged
15.	Engine horsepower	235 HP
16.	Engine torque	310 ft.-lbs.
17.	Transmission	Automatic, 5R110W
18.	Final drive ratio	4.56:1
19.	GVW	14,050 lbs./ 6375 kg
20.	Emission level	0.2 gm / BHP-hr NOx (target)
21.	OBD compliant	Partially compliant
22.	Warranty	Property of Ford Motor Company
23.	Fuel system	5000 psi storage
24.	Fuel capacity	30 kg of gaseous hydrogen
25.	Vehicle range	150 miles
26.	Tank configuration	Rear of vehicle above frame
27.	Fuel tanks	Dynetek W205 Type 3 (carbon fiber wrapped, metal liner)

In order to achieve public acceptance of hydrogen-fueled vehicles, an outreach program is being developed and implemented that promotes production, distribution, and use of hydrogen as a transportation fuel, integrates with existing structure, regulatory processes, public understanding, and emergency response systems, and has a special emphasis on safety training for local and state officials, first responders, general public, and operators/maintainers in collaboration with other national programs. A broad range of safety education and training activities on best practices is in progress for effectively supporting the deployment of hydrogen vehicles and related infrastructure.

CONCLUSIONS

This Missouri Rural Hydrogen Transportation Test Bed builds on previous studies on manufacturing of composites, non-destructive testing and evaluation, and expands the current theme. This initiative is aimed at initiating the research related to the development of a rural hydrogen transportation test bed that will demonstrate, evaluate and promote safe hydrogen-based technologies in a real-world environment. Lessons learned and technologies developed will be transferred to support larger efforts, and critical links will be maintained with other hydrogen centers.

ACKNOWLEDGEMENTS

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