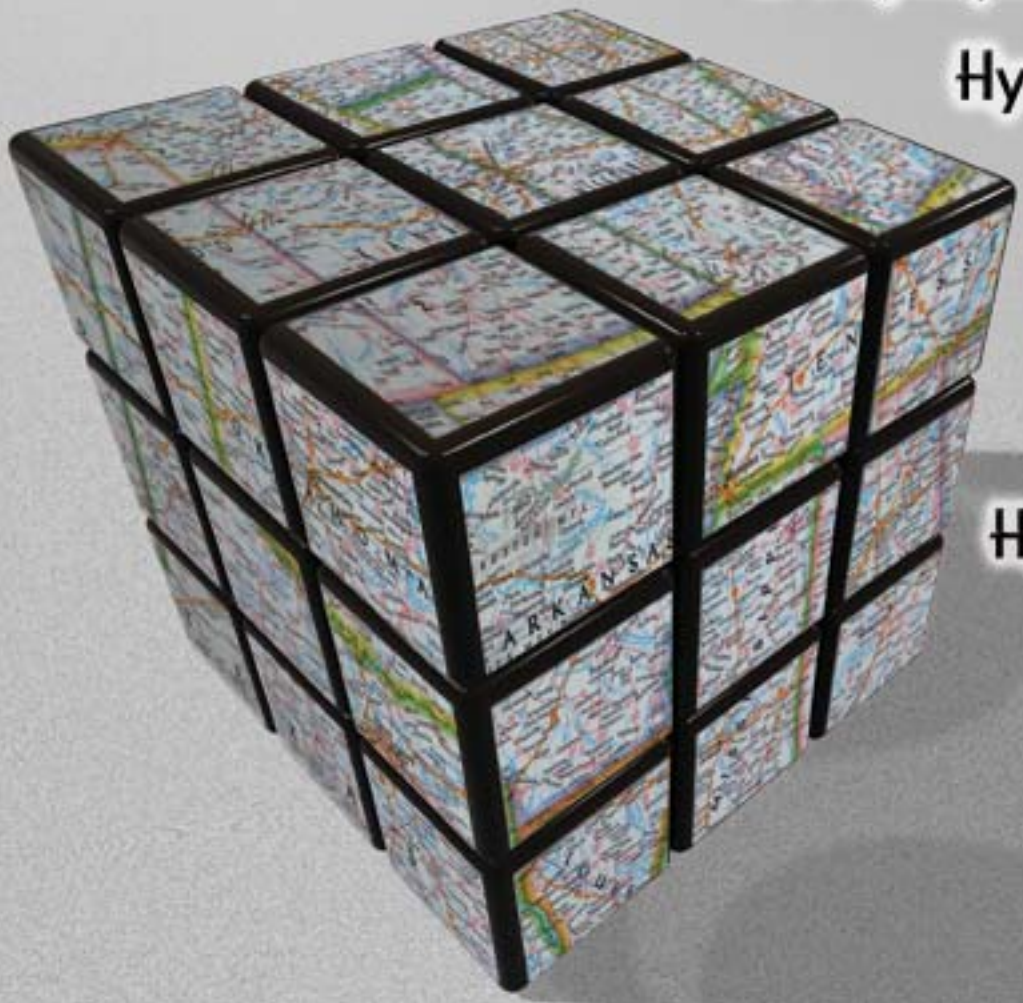
United States Department of Transportation

Research, Development, Demonstration, & Deployment Roadmap for Hydrogen Vehicles & Infrastructure to Support a Transition to a Hydrogen Economy



Foreword

The U.S. Department of Transportation (DOT) Hydrogen Roadmap is the guiding document for the DOT Hydrogen Safety Research, Development, Demonstration, and Deployment (RDD&D) programs. It outlines the roles and activities of each participating operating administration and their parallel efforts within the DOT. The Roadmap also serves as an outreach document for communication, coordination, and collaboration with other Federal agencies, industry, the public, and Congress.

The Roadmap began as an initiative of the DOT Hydrogen Working Group. It was developed with input from senior staff of all the participating DOT operating administrations: the Research and Innovative Technology Administration (RITA), Pipeline and Hazardous Materials Safety Administration (PHMSA), National Highway Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA), Federal Railroad Administration (FRA), Federal Aviation Administration (FAA), Maritime Administration (MARAD) and the Secretary's Policy Office. The Department of Energy's recommendations were also solicited, and are included.

The Roadmap delineates four major topic areas:

- Safety Codes, Standards, and Regulations;
- Infrastructure Development and Deployment;
- Safety Education, Outreach, and Training; and
- Medium- and Heavy-Duty Vehicle Development, Demonstration, and Deployment.

Describing the current and projected DOT activities supporting the President's National Hydrogen Initiative, the Roadmap illustrates the paths and timeframes necessary to enable a successful hydrogen infrastructure for the transportation enterprise. It also responds to the internal need to coordinate and share information among the various DOT operating administrations, and to provide other Federal agencies with an understanding of DOT's hydrogen program roles and funding requirements. Finally, the Roadmap provides a concise and consistent document for future program direction.

As a "living document," this Roadmap will be updated with critical interim addenda as necessary. The solicitation of private sector views is an important part of this process.

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TABLE OF CONTENTS

U.S. Department of Transportation (DOT) Roadmap
For the Safety of Hydrogen Vehicles and Infrastructure
To Support a Hydrogen Economy

Background

In his 2003 State of the Union address, President Bush announced a $1.2 billion Hydrogen Fuel Initiative to reduce America's growing dependence on foreign oil. If successful, the initiative could also reduce environmental pollutants and lessen the greenhouse gas emissions that contribute to global warming. There has been a great deal of activity, not only in the U.S., but throughout the world. Consortia composed of policymakers, safety regulators and inspectors, engineers, scientists, universities, and private industry are focusing on long-term research to understand the implications of a hydrogen economy; and to develop technologies to produce, store, deliver, and use hydrogen safely and cost-effectively.

Hydrogen has been used and transported safely in this country for several decades, almost exclusively for industrial applications in the food, petrochemical, and semiconductor industries. However, using hydrogen as an energy carrier is a relatively new concept. Consequently, there is much to be learned and considered before hydrogen-fueled vehicles, and the supporting infrastructure, can be safely used by the public.

The U.S. Department of Transportation has three principal areas of authority with regard to hydrogen:

1. Ensuring the safety of hydrogen as a fuel and commodity across all modes of transportation;
2. Leading the research, development, demonstration, and deployment (RDD&D) of medium- and heavy-duty vehicles and their accompanying infrastructure, including buses, trucks, rail, marine, and aviation systems; and
3. Guiding the RDD&D of a hydrogen infrastructure, including stationary power, and its integration into DOT-regulated systems.

In early 2003, DOT created a Hydrogen Working Group to coordinate the hydrogen and fuel cell RDD&D activities within the DOT operating administrations. The Working Group also facilitates coordination with other Federal agencies to guide the Department's regulatory policy, as well as vehicle and infrastructure design. The DOT Hydrogen Roadmap outlines each operating administration's responsibilities, the necessary intra- and inter-administration coordination, and DOT's relationship to the activities and responsibilities of other Federal agencies and those of industry.

There are four primary topics in this Roadmap:

Road 1: Safety Codes, Standards, and Regulations;
Road 2: Infrastructure Development and Deployment;
Road 3: Safety Education, Outreach and Training; and
Road 4: Medium- and Heavy-duty Vehicle Development, Demonstration, and Deployment.

Across the broad spectrum of hydrogen and fuel cell-related RDD&D there is a common core of needs and responsibilities shared among the DOT operating administrations, such that each agency has both unique and shared activities within each of the Roads.

The map for each Road includes four areas:

- Anticipated long-term outcomes (11 to 20 years);
- Challenges and requirements;
- Pathways, projects, and products; and
- Timelines.

Each Road includes a flowchart of the interrelation of DOT's major hydrogen activities. Where applicable, the charts also illustrate the pathways to convergence of DOT's RDD&D with the program goals and activities of other Federal agencies. These include the U.S. Department of Energy (DOE), the Department of Defense (DoD), the Environmental Protection Agency (EPA), the Department of Commerce (DOC), and other agencies and industries engaged in the transition to a hydrogen economy.

The connectivity among Roads 1-4 is illustrated in the flow charts for each operating administration (Figures 6-13) located in the Summary section of this document.

Road 1 – Safety Codes, Standards, and Regulations

Ensuring the safety of the transportation system is the principal goal of the U.S. Department of Transportation. Accordingly, DOT has a major role in developing, promulgating, and enforcing regulations in various aspects of transportation operations. These regulations will establish the ground rules and proper operating procedures to provide assurance of the safety of hydrogen as an energy carrier for use by industry and the general public. Road 1 describes the issues and processes that DOT is using to enable the private sector to transition to a hydrogen economy while maintaining the current high standard of safety, reliability, and public confidence in the transportation system. It describes the process for developing and promulgating voluntary and government-imposed codes, standards, and regulations for the use and transport of hydrogen.

Anticipated Long-Term Outcomes

The long-term outcome for Road 1 is the establishment of procedures and standards for the safe use and transport of hydrogen in transportation. It includes the promulgation of performance-based regulations and industry consensus codes and standards. It encompasses DOT-regulated vehicles, containers, and hydrogen transmission through pipelines. New codes and standards should be performance-based and systems-oriented. They should apply to general product applications as opposed to the European method of prescriptive, type-specific regulations for each application. These codes and standards should also be based on sound scientific knowledge of hydrogen effects on material properties and behavior. Finally, they must address both the design and operation of transportation systems, subsystems, components, and consumer devices.

Challenges and Requirements

In order to achieve public acceptance of hydrogen-fueled vehicles, each mode of transportation will require 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 to understand and anticipate the effects of hydrogen on materials. This and other research outcomes will need to be tested in full-scale demonstrations designed to understand 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.

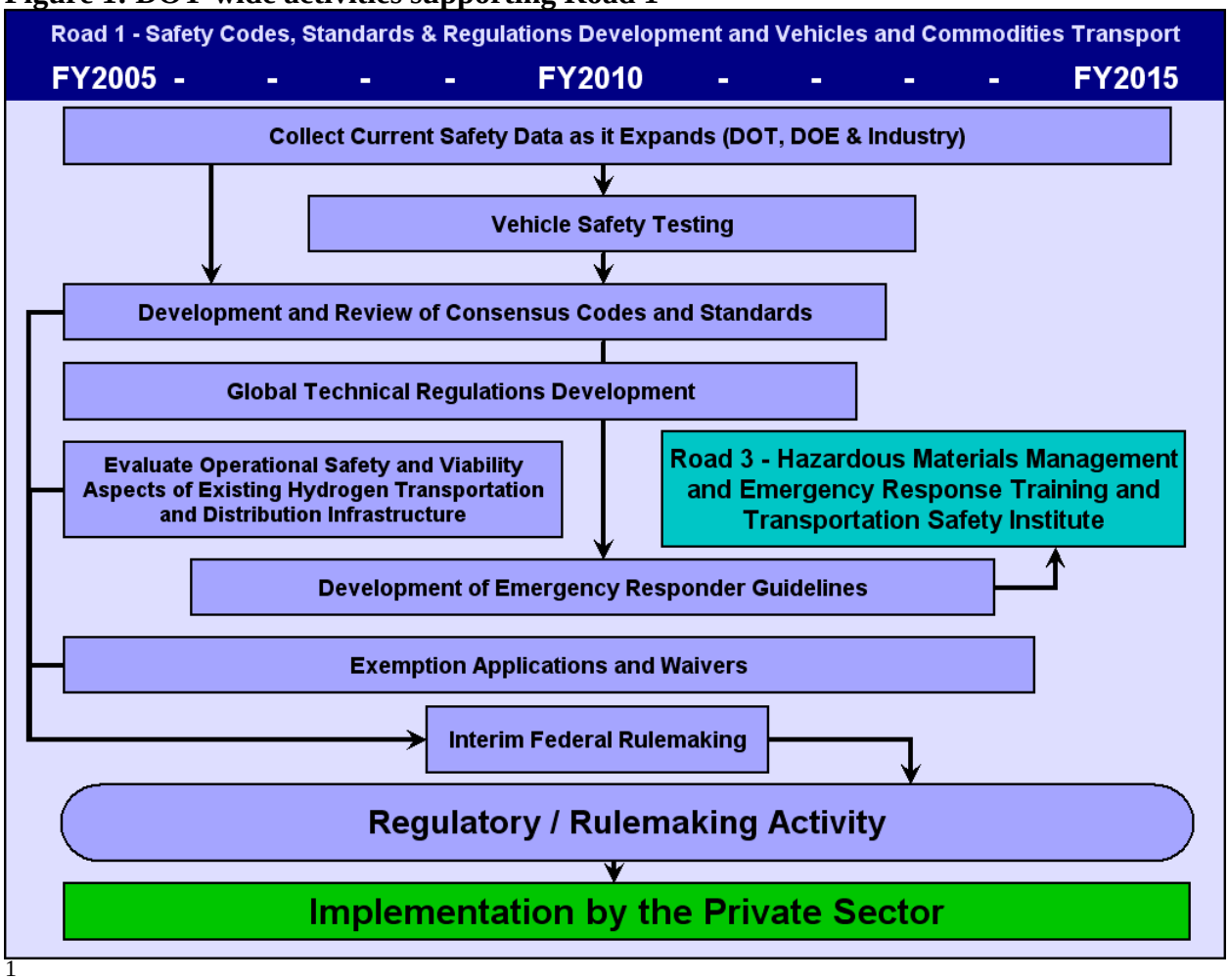
Inspection technologies must be developed to detect and maintain the integrity of hydrogen fuel and commodity transport systems. The DOT's standards and regulations actions will rely on data collected from a diverse set of research and demonstration projects, including those conducted or funded by DOE, EPA, DoD and others. Although basic knowledge and early research and development (R&D) on materials behavior can be shared across the modes and used for many purposes, regulations are specific to the application and will be developed

independently by the appropriate DOT operating administration(s), in collaboration with relevant standards organizations.

Pathways, Projects, and Products

An activities flow chart for Road 1 (Figure 1) illustrates the major DOT-wide projects and products and how they are related. The three major independent activities in this roadmap are the collection of safety data, the evaluation of the operational safety and viability of existing hydrogen transportation and distribution infrastructure, and exemption applications and waivers. All other activities either support or complement these three primary activities. For example, safety data collection will be a continuing effort; it will feed into the development and review of consensus codes and standards, as well as DOT regulations. Similarly, the consensus codes will lead to the development of emergency responder guidelines, Global Technical Regulation (GTR) development, and Interim Federal Rulemaking.

Figure 1: DOT-wide activities supporting Road 1



[1]

National Highway Traffic Safety Administration (NHTSA)

NHTSA is responsible for promulgating the necessary Federal Motor Vehicle Safety Standards (FMVSS) based on test and evaluation procedures. In order to facilitate the RDD&D of hydrogen-fueled vehicles from a safety perspective, NHTSA will conduct tests to evaluate the performance of safety systems such as pressure and thermal relief devices for fuel tanks, and thermal and electrical management systems for fuel cells, batteries, and ultracapacitors. NHTSA will also conduct testing to monitor leakage, leakage mitigation systems, and evaluate static electricity and spark suppression mechanisms during fueling. Additionally, NHTSA will conduct crash tests to determine obstacles to compliance with existing FMVSS, and to identify comparable areas of fuel system integrity not covered under existing FMVSS. As vehicle design concepts mature, NHTSA anticipates an increase in vehicles presented for safety performance testing.

[1] An Interim Federal Rulemaking occurs where a great need for regulation exists – it is published without a Notice of Proposed Rulemaking and goes into effect immediately. It fills the void until a formal rulemaking is completed. See Table 1 for additional background on the rulemaking process.

NHTSA is also responsible for anticipating the potential increases in fuel economy resulting from hydrogen use in fuel cell vehicles. As the agency responsible for determining the corporate average fuel economy (CAFE), a gasoline gallon equivalent (GGE) for hydrogen is needed to control the energy use and carbon dioxide impact of passenger vehicles. Within that authority, NHTSA will coordinate with the EPA to develop the appropriate GGE value. In 1996, by statutory requirement, NHTSA issued a final rule establishing a GGE value for hydrogen internal combustion engine vehicles. Currently, NHTSA is determining the applicability of the established GGE value to fuel cell technologies.

Through its participation in the United Nations Economic Commission for Europe Working Party 29, NHTSA leads the U.S. delegation on international efforts to harmonize standards and regulations, and to develop a GTR for hydrogen fuel cell vehicles. The DOT's role in this forum will help ensure the development of comprehensive performance-based regulations that will aid the development, commercialization, adoption, and export of U.S.-developed technologies.

Details of these efforts are described in NHTSA's Four-Year Plan for Hydrogen, Fuel Cell and Alternative Fuel Vehicle Research.[2] The NHTSA flow chart in Figure 6 (pg. 24) illustrates the relationship among RDD&D tasks, vehicle development, demonstrations, and regulatory activity.

Pipeline and Hazardous Materials Safety Administration (PHMSA)

PHMSA is responsible, through its Offices of Pipeline Safety (OPS) and Hazardous Materials Safety (OHMS), for ensuring the safety of the U.S. hazardous materials commodity transportation system. This is accomplished, in part, through the enforcement of regulations under the Code of Federal Regulations Title 49 parts 171-180 and parts 190- 199 (49 CFR). On occasion, the granting of exemptions and modifications to these regulations is advisable. Industry requests exemptions when a new technology or application is not permitted under the current 49 CFR. The 49 CFR regulations are based on the general properties of a specific commodity, such as flammability or toxicity and the risks implied in their transport. This may lead to unintended restrictions on new technologies or applications not anticipated during the rulemaking. In instances where the safety intent of 49 CFR is demonstrated, exemptions that are product-, application-, and/or time-specific may be issued. A few examples to date include those granted to metal hydride storage and high pressure composite cylinders.

PHMSA will continue to support new technologies for the entire hydrogen pipeline infrastructure, hydrogen commodity transport, and storage containers for personal and commercial hydrogen use. Research will be conducted to evaluate exemption requests as they occur, and assess the need and timing for modifications of existing 49 CFR regulations.

In parallel with Infrastructure Development and Deployment (Road 2), these regulations will reflect the best available design, inspection, and maintenance technologies. The PHMSA flow charts (Figures 7 and 8) illustrate the relationship between identified projects, Research and Innovative Technology Administration's (RITA) and other crosscutting R&D, and their support of safety-focused regulatory decision-making.

[2] This and other hydrogen-related information is available on the DOT Hydrogen Portal at http://hydrogen.dot.gov

Federal Motor Carrier Safety Administration (FMCSA)
FMCSA is responsible for the operational safety of commercial motor vehicles used in interstate commerce. These include:

- vehicles of gross vehicle weight rating, gross combination weight rating, gross vehicle weight, and gross combination weight of 10,001 pounds or more;
- vehicles designed or used to transport more than 8 passengers, including the driver, for compensation;
- vehicles designed or used to transport more than 15 passengers, including the driver, not for compensation; and
- hazardous materials in quantities requiring placarding.

FMCSA promulgates and enforces the Federal Motor Carrier Safety Regulations that typically are based on the NHTSA FMVSS and developed in coordination with NHTSA. FMCSA will develop requirements and guidelines for the safe operation, fueling procedures, inspection, and maintenance of hydrogen fuel systems used in commercial vehicles. The FMCSA RDD&D efforts will focus on operational safety of medium- and heavy-duty buses and trucks, including their fuel systems. When hydrogen technology matures to the point where adoption by commercial fleets is feasible, results from this effort could contribute to FMCSA regulations governing fuel system use, as well as developing the information needed by fleet operators to use hydrogen technology safely. The FMCSA Flow Chart (Figure 9) enumerates these projects and pathways.

Research and Innovative Technology Administration (RITA)
RITA will conduct research to develop, evaluate, and deploy advanced enabling technologies, including those for inspection, monitoring, and storage. RITA is currently commissioning a study to identify emerging safety technologies, near-term regulatory needs, and existing regulatory and technology gaps.

In conjunction with DOE, RITA RDD&D will concentrate on filling these technology gaps, the results of which will inform regulatory development and enable the increased transport and use of hydrogen. The program areas are enumerated in Figure 13. Specific component and system level risk assessments will be conducted for hydrogen pipelines and storage technologies, including high-pressure composite cylinders. Other specific tasks include assessing the viability of utilizing existing natural gas pipelines for hydrogen transport. RDD&D for exemptions and demonstration evaluation will complement RDD&D specifically conducted for rulemaking. These efforts will be closely coordinated with PHMSA.

Other Operating Administrations
The Federal Railroad Administration (FRA), Maritime Administration (MARAD), and Federal Aviation Administration (FAA) have their own set of propulsion system requirements. They also enforce PHMSA's regulations in commodity transport regulations and responsibilities. Each of these transportation modes will need to develop safety codes and standards for hydrogen use and transport within the structure of their individual operating environment. For example, MARAD is interested in shore-based hydrogen fueling infrastructure for vessels that may be outside the scope of U.S. Coast Guard regulations. MARAD endeavors to ensure appropriate

codes and standards for this portion of its marine hydrogen projects. These same model codes typically apply to other transit modes, such as bus fleets, and are also supported by the Federal Transit Administration (FTA).

Timelines

The regulatory process is highly structured and serial in nature, often requiring more than a decade to fully implement new or modified regulations. The following chart (Table 1) reflects a general timeline for completing a significant rulemaking. It incorporates the specific tasks necessary to promulgate a rulemaking for any operating administration. While not all of the steps indicated are always necessary and some of the steps could be shortened, the chart is a good indicator of the lengthy time it takes from the beginning of the rulemaking process to the issuance of a final rule.

The DOT recognizes that this is a lengthy process. To be fully supportive of the President's Hydrogen Initiative, opportunities to compress the timeline without compromising safety should be utilized.

Table 1: General Timeline for Significant Rulemaking

STEP	YEAR	ACTIVITY	RESPONSIBLE PARTIES
1	0	Identify need	Industry (petition) Government (identified problem) Congressional directive Government / Industry (new technology)
2	1-3	Review available consensus standards	Government (DOT)
3	1-5	Research phase (usually 3-5 years required to collect, evaluate, and validate data for a major rulemaking)	Government (DOT) and industry
4	4	Advanced Notice of Proposed Rulemaking (ANPRM)	Government (DOT)
5	4	Comment period	Industry / Public
6	4	Receive and analyze ANPRM comments	Government (DOT)
7	5	Notice of Proposed Rulemaking (NPRM), Preliminary Regulatory Evaluation (PRE), & Office of Management & Budget (OMB) review	Government (DOT, OMB)
8	5	Comment period	Industry / Public
9	6	Receive and analyze NPRM comments	Government (DOT)
10	7	Draft Final Rule and Final Regulatory Evaluation (FRE)	Government (all)
11	8	OMB review	Government (OMB)
12	8-9	Reject/ accept/ modify; publish Final Rule	Government (DOT)
13	10+	Second Notice of Proposed Rulemaking if substantially different from proposed (repeat steps 7 - 12)	Government (DOT)

In order to meet the industry-targeted commercial integration of hydrogen vehicles by 2010, or the DOE Hydrogen Fuel Initiative commercialization decision target of 2015, steps 2 and 3 need to be initiated no later than 2005. This will produce appropriate regulations in step with the transition from demonstration to deployment in the 2015 - 2020 timeframe.

Convergence

The DOT is responsible for Federal regulations related to the safe operation of the transportation system. However, the research required to develop these performance-based regulations is conducted and shared by a number of other organizations. Cooperation between DOT, DOE, and EPA focuses on providing collaborative opportunities across the spectrum of research needs, from basic to applied research, demonstration, and deployment. The DOT's efforts, beginning in FY05, will incorporate the end-user (public) perspective as it relates to the deployment of safe systems into the RDD&D model, including participation in identifying data gaps. This approach complements ongoing efforts currently led by DOE.

Road 2 – Infrastructure Development and Deployment

Infrastructure is the backbone of the Nation's transportation system. It includes the highways used by automobiles, trucks, and buses; the rail lines used by passenger and freight trains; the inland and coastal waterways; as well as long-haul and local distribution pipelines. It also includes the National Airspace System (NAS) used by private and commercial airplanes. Essential components of the Nation's transportation system include the collection of maintenance and refueling facilities used by individual vehicles, and the pipeline and energy transportation and distribution infrastructure.

For the hydrogen economy, there are several major infrastructure issues. First is the consideration of sufficient capacity of the appropriate type to move the hydrogen fuel from source to destination. The second issue is the feasibility and logistics of transitioning approximately 200,000 gasoline and diesel fueling stations to stations that dispense hydrogen fuel; particularly those that support DOT-funded operations such as public transit facilities. Finally, DOT will ensure that certain elements of DOT operations can transition to the use of hydrogen. In particular, DOT intends to work toward using hydrogen for the FAA's power requirements for NAS.

Anticipated Long-Term Outcomes

The long-term outcome for Road 2 is the deployment of the infrastructure needed for hydrogen use by the Nation's transportation and power generation system. This includes the network of hydrogen refueling stations and the entire pipeline infrastructure to support them: the transmission pipelines outside production facilities to the pumping and storage facilities, from there to the distribution system, and finally to the point of delivery. It also includes other types of transportation to move the raw materials for hydrogen production, and hydrogen itself. It additionally includes the integration of fuel cell power into NAS facilities.

Challenges and Requirements

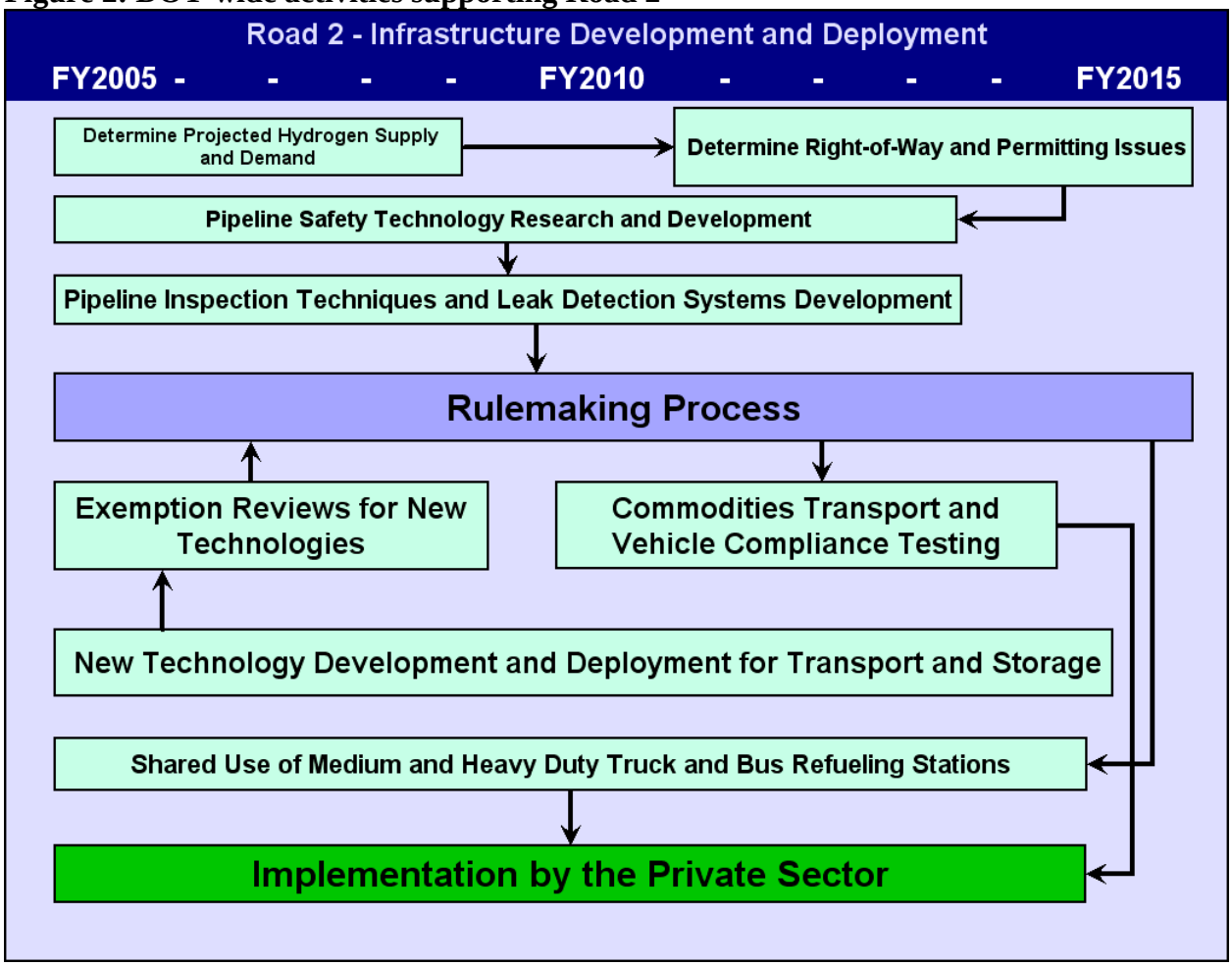
Comprehensive research and other activities will be conducted by all operating administrations to integrate hydrogen infrastructure into their respective transportation modes. Once this occurs, these operating administrations will incorporate hydrogen, including the enforcement of regulations, into the transportation modes under their jurisdiction. The major challenge in developing the infrastructure for hydrogen is to accomplish this transition in a seamless, cost-effective manner so that all sectors of the transportation system function without interruption and adverse impact to the economy.

A major concern for the use of hydrogen as a fuel is the need for new operating procedures for the refueling and maintenance of vehicles. Hydrogen fuel systems pose new challenges for leak detection and mitigation, damage prevention, and safety. New technologies and procedures culminating in "best practices" need to be established. All DOT hydrogen activity will focus on risk mitigation, as well as the integrity of the delivery and infrastructure systems. This focus promotes safety, security, operability, and public confidence.

Pathways, Projects, and Products

An activities flow chart for Road 2 (Figure 2) illustrates the major DOT-wide projects and products, and how they relate to each other and the other Roads. The major activities in Road 2 are the deployment and operation of hydrogen pipelines, hydrogen transport systems, and the deployment of hydrogen refueling and maintenance infrastructure for medium- and heavy-duty fleet vehicles.

Figure 2: DOT-wide activities supporting Road 2



The safety and physical security of the system, including vehicles and pipelines, is an integral aspect of deployment that must be included from the beginning research stages through the development and demonstration phases, and on into deployment. Each of the operating administrations needs to evaluate the risks to, and methods for, achieving security. Finally, these methods and technologies will need integration into the systems for which DOT is responsible.

Specific areas of concern include the communication equipment and protocols at the interface between transport and storage systems; systems integrity, particularly with seal materials degradation; and the efficacy and reliability of detection and containment materials. Ongoing

RDD&D is seeking to address identified gaps in these infrastructure safety technologies. The end results will support codes, standards, and regulatory development (Road 1) and provide the foundation for full-scale, long-term deployment of a hydrogen infrastructure using test-proven technologies and protocols.

Research and Innovative Technology Administration (RITA)
To support expanded hydrogen use for vehicles, RITA will analyze various delivery concepts to assess their ability to deliver large quantities of hydrogen consistently and reliably. Research and data analyses will be conducted, with support from DOE's National Laboratories, to evaluate advanced container designs and develop in-service inspection technologies for quality assurance.

Pipeline and Hazardous Materials Safety Administration (PHMSA)
PHMSA is responsible for the safety and security of hazardous materials in commercial transport by all modes, including pipelines. For hydrogen transmission and distribution pipelines, this is accomplished through the implementation of risk management and integrity plans. PHMSA coordinates this effort with infrastructure owners (e.g., pipeline and merchant hydrogen bulk transport), operators, and non-Federal agencies.

PHMSA will also develop safety and inspection criteria for the interface between fuel delivery and bulk storage systems. The existing pipeline system undergoes frequent in-field inspections and repairs. This is because unscheduled system maintenance and failures pose a risk to the safety and operability of the transport network. The challenge for effective management is to incorporate known operational factors and shortcomings into up-front RDD&D.

Other DOT Administrations
DOT's operating administrations have a responsibility to make sure that taxpayer funded investments in the Nation's transportation infrastructure are protected. This includes the need to make sure infrastructure is safe and secure. To this end, DOT's hydrogen-fueled transportation strategy highlights coordination with DOE, EPA, DoD, and other public and private entities conducting demonstrations to reflect DOT's safety perspective. These efforts will develop data to support Road 1 activities.

For example, NHTSA will evaluate the safe interface between the fuel dispenser and road vehicle. Although DOT does not regulate fuel dispensers, the interface between the dispenser and vehicle must have an appropriate level of safety and reliability. The design for this interface needs to be based on accurate knowledge of the independent behavior of each of the two systems, as well as how they work together.

As another example, FTA and MARAD invest in fueling and maintenance infrastructure for transit and marine fleets, respectively. These DOT-funded modes can be effective early adopters of advanced and emerging propulsion system technologies, and serve as a foundation for potential widespread deployment and use by the public. Indeed, much of the near-term infrastructure is integrated into Road 4: Medium- and Heavy-duty Vehicle Development, Demonstration, and Deployment. This integration is illustrated in Figures 10 and 11.

Timelines

The timeframe for infrastructure demonstration and deployment begins in FY 2005 and extends to FY 2020 and beyond. Early infrastructure is needed to support demonstrations and validate technology for public deployment. Initial RDD&D that supports safety codes and standards (Road 1) will also support infrastructure development and deployment (Road 2) by approximately FY 2010.

Convergence

Close coordination between the regulatory agencies, operators, and manufacturers is necessary at the physical interfaces among production, transport, and storage segments. In particular, there are many possible delivery, storage, and distribution options. Some of these are illustrated in Figures 3a-c which outline three different approaches to this part of the hydrogen infrastructure. For each of these, there is a different primary production and transportation pathway. In each figure, the DOT regulated components are highlighted.

Figures 3a-c: Possible hydrogen delivery pathways illustrate the interface between transport and distribution modes and PHMSA regulatory interfaces

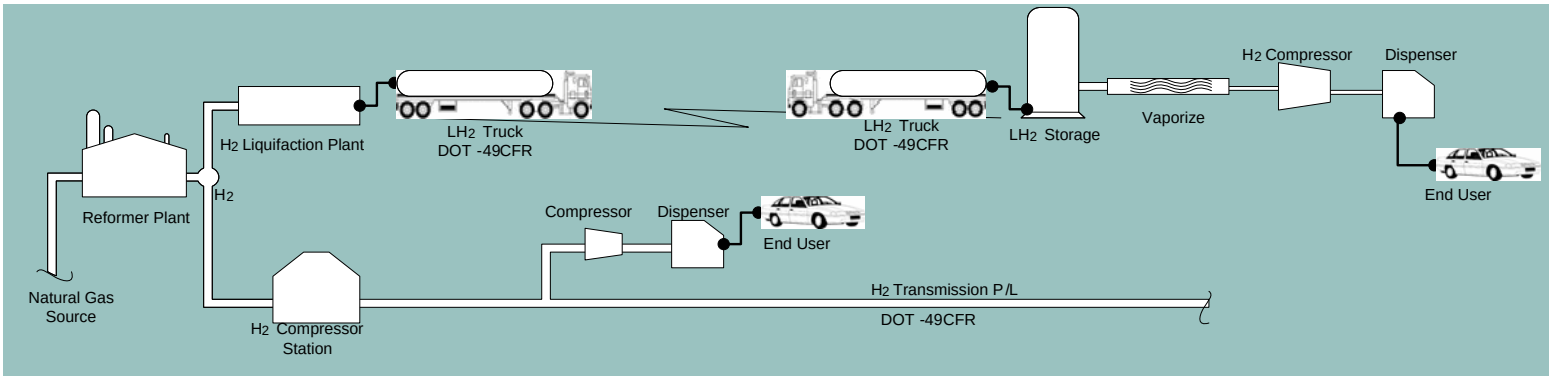


Figure 3a: Centralized production and hydrogen transport and distribution via pipeline and bulk commodity transport

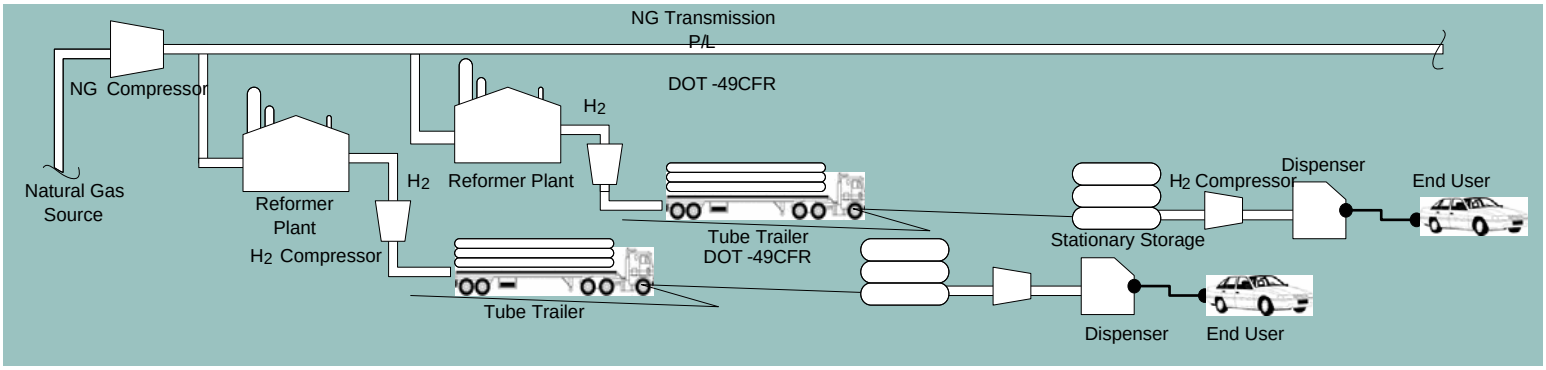


Figure 3b: Natural gas transport via pipeline supporting distributed hydrogen production and distribution via bulk commodity transport

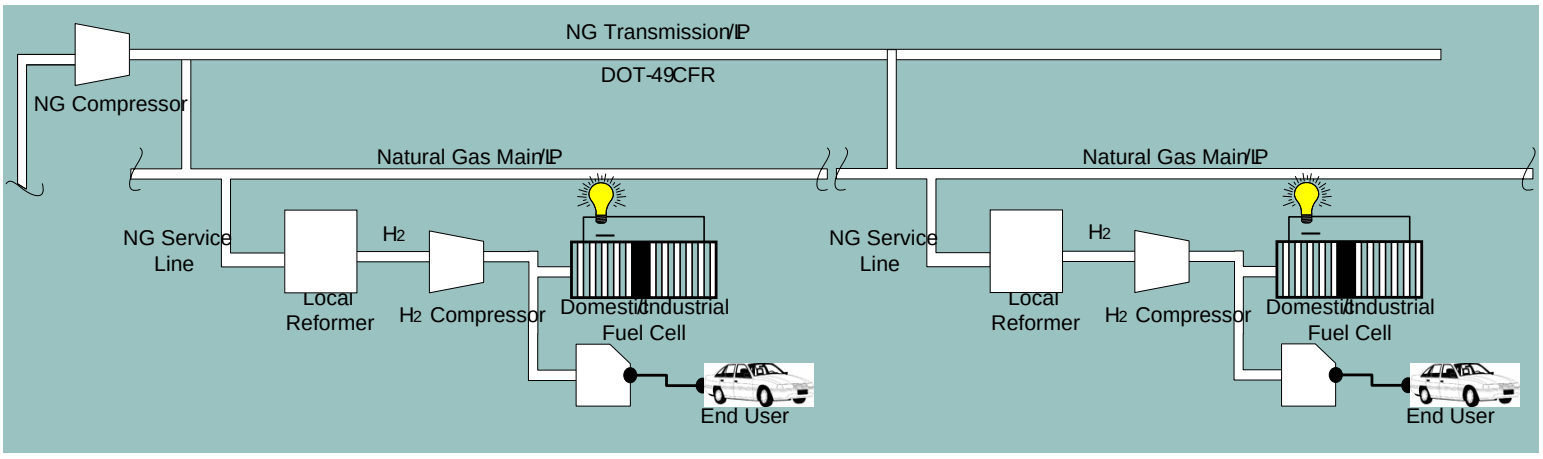


Figure 3c: Natural gas transport via pipeline supporting localized hydrogen production and use

Road 3 - Safety Education, Outreach, and Training

In addition to promulgating safety standards, it is necessary to provide education on the application of DOT standards and regulations as well as outreach and training on best practices. As a part of this education, outreach, and training function, DOT maintains a strong relationship with the Nation's safety and first responder communities, i.e., police, fire, emergency medical services, etc. These communities have daily contact with the public and will have a strong influence on advising which technologies will be integrated into society.

Prior to mass deployment of hydrogen vehicles and the supporting transportation infrastructure, effective hydrogen safety education must be rigorously provided. First responders must have the proper knowledge and training to best respond to an accident. The long-term operation and safety of the transportation system also depends on having an appropriately trained workforce to conduct the inspections and execute the maintenance and repairs to meet the public's safety needs.

Anticipated Long-Term Outcomes

The long-term outcome for safety outreach and education is strong public confidence in the safety of hydrogen vehicle systems and infrastructure. This also will be reinforced by the comfort level among first responders who are confident that they have the knowledge and ability to effectively respond to incidents. The approach taken to foster these outcomes is program outreach and education to develop well-trained first responders and inspection and maintenance forces, as well as efforts to educate state and local regulatory authorities, operators, and the general public.

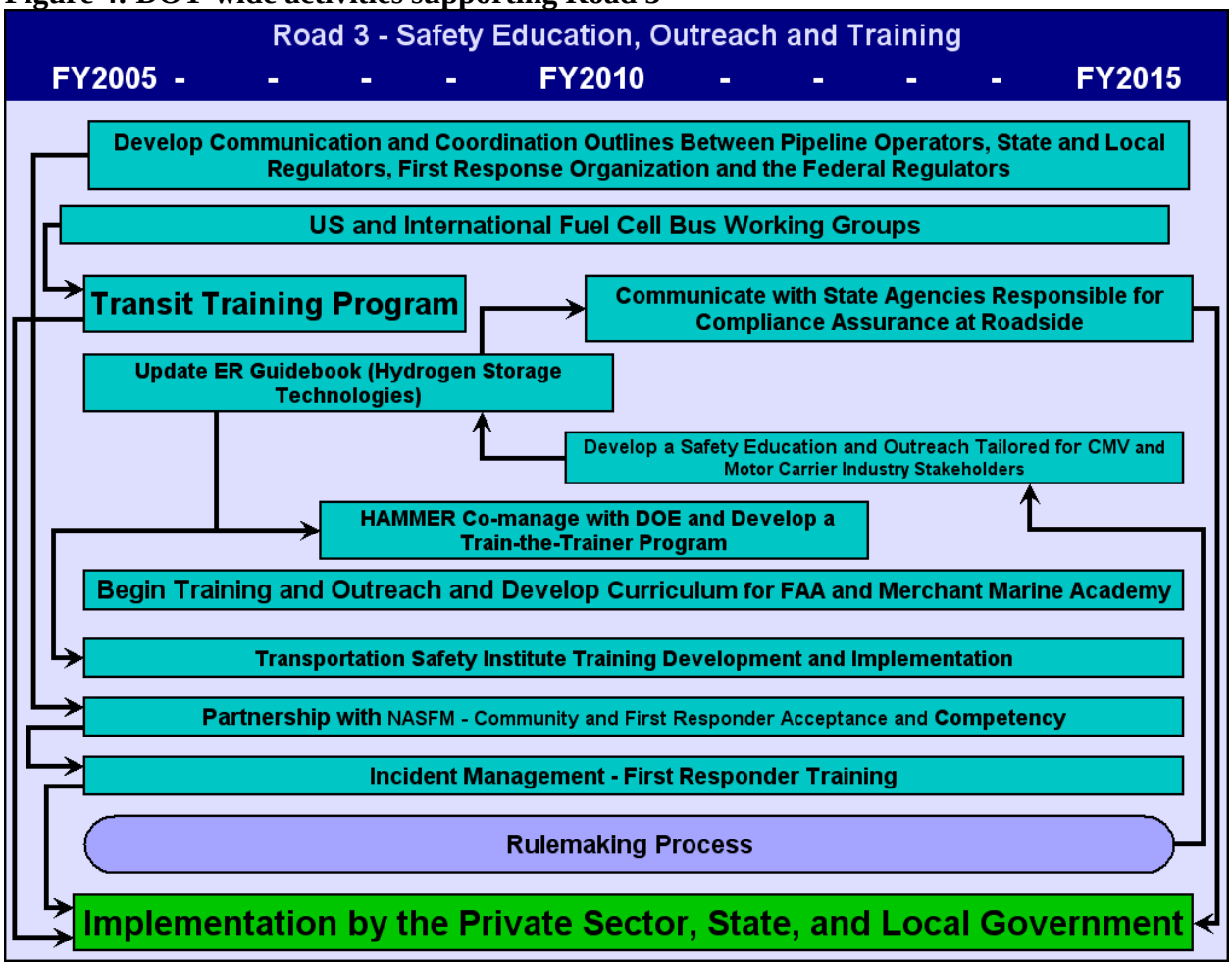
Challenges and Requirements

As hydrogen use expands from an industrial commodity to consumer and commercial applications, it will be necessary to train a variety of individuals, groups, and communities in the operation, maintenance, use, and handling of hydrogen systems. Proper techniques for avoiding and managing unintended releases, spills, and accidents must also be taught.

Pathways, Projects, and Products

An organizational flow chart for Road 3 (Figure 4) illustrates the major DOT-wide pathways, projects, and products, and their interrelationship with the other Roads. The primary activity is the development of first responder, maintenance, and end-user educational and training materials. These materials will be integrated into the existing training and outreach programs for the responsible handling of hazardous materials.

Figure 4: DOT-wide activities supporting Road 3



Research and Innovative Technologies Administration (RITA)

RITA, through various partnerships and initiatives, will expand its already extensive training and outreach activities on hazardous materials transportation, including pipeline safety, to encompass the new risks and responsibilities associated with a hydrogen economy. For example, RITA is working with the National Association of State Fire Marshals (NASFM) in communities where hydrogen pipelines and infrastructure may be located. The partnership outreach programs will also improve the fire services' capabilities to respond to accidents and incidents involving hydrogen and fuel cell vehicles. This activity is an extension of the existing partnership between PHMSA and NASFM in regards to natural gas pipelines outreach and education. This expanded partnership will complement the broader DOE Education Subprogram, and will focus on the environmental, technical, economic and social aspects of the hydrogen economy.

The Transportation Safety Institute[3] (TSI) in Oklahoma City, will also offer related safety and security education. TSI is RITA's premier training organization for transit, aviation, pipeline,

[3] The Transportation Safety Institute is an office within RITA that develops and conducts safety, security, and environmental training, products and services for all DOT agencies, other government agencies, and the private sector: http://www.tsi.dot.gov

motor carrier, highway safety, hazardous materials, and risk management both nationally and internationally

Pipeline and Hazardous Materials Safety Administration (PHMSA)
PHMSA, NHTSA, and RITA will develop and advise on "Train the Trainer" materials for first responders and hazardous material cleanup crews. DOT will work with DOE to identify additional hydrogen-specific safety concerns and to develop methods for mitigating and responding to these potential events. These concerns and response methods will be shared with communities for broad outreach and education through DOT-DOE partnerships.

The regularly revised Emergency Response Guidebook (ERG) will include expanded material on container systems developed for hydrogen storage and transport. In addition, PHMSA, in conjunction with RITA, will evaluate data generated under the auspices of the DOE program and conduct research (if warranted) on plume modeling to update and expand the ERG. Novel storage materials and systems used for hydrogen may pose unique or different first responder risks than conventional fuels. DOT will regularly assess the need for expanded and improved first responder training programs to address these new technologies. In many instances, DOT may be able to leverage the development of these new programs with the ongoing RDD&D efforts of DOE and industry.

Maritime Administration (MARAD)
MARAD plans to develop a hydrogen and fuel cell transportation laboratory at the federally-owned United States Merchant Marine Academy. Although approximately half of the students are trained as marine engineers, the intermodal aspects of the maritime industry result in many graduates entering related transportation fields. The fuel cell transportation laboratory will train students in state-of-the-art hydrogen technologies and serve as a venue for community and professional outreach.

Federal Transit Administration (FTA)
FTA is developing training manuals and educational programs for transit agencies operating fuel cell buses. These programs will address the safe operations and maintenance of all fuel options, including compressed and liquid hydrogen, methanol, ethanol, metal and chemical hydride storage, and other advanced storage technologies. Similarly, training manuals and programs will be developed to ensure the safe operations and maintenance of the high voltage systems of fuel cell buses. This effort builds upon earlier efforts conducted by FTA with SunLine Transit in Coachella Valley, CA, and the College of the Desert in Palm Desert, CA.

Other DOT Administrations
Consistent with decades of effective communication and outreach activity, the DOT operating administrations will continue coordination with other "authorities having jurisdiction." In addition to training early adopters, operators, repair and maintenance personnel, and consumers, there needs to be a systematic documentation of safety-related incidents in a manner that supports the efforts outlined in Roads 1, 2 and 4. One approach to accomplish the reporting of incidents in each transportation mode is through NHTSA's ARTEMIS[4] database system. Another complementary approach is to use the One DOT reporting center to document hydrogen incidents.

Timelines

Trained professionals will be required as deployment proceeds. Consequently, training and outreach programs on hydrogen fuel need to be implemented ahead of large-scale commercial deployment of hydrogen-fueled vehicles. The development of these training programs, beginning with the review of available information and identification of knowledge and program gaps, will begin in FY05. Effective education and outreach programs are anticipated to be in place during the 2010-2015 timeframe.

Convergence

DOE has an extensive program focused on all aspects of hydrogen education. It currently supports the development of curricula for all grade levels, the general public, policymakers, and local officials. Specific audiences, such as first responders, require specialized safety-related training, the development of which will benefit from close collaboration with DOE. In addition, MARAD will develop university programs and curricula specific to marine applications based in part on materials developed in cooperation with DOE.

[4] The Early Warning Reporting System (EWRS) identifies vehicle defects. The database that houses this information is called ARTEMIS: Advanced Retrieval (Tires, Equipment, Motor Vehicles) Information System.

Road 4 – Medium and Heavy-Duty Vehicle RDD&D

In conjunction with our Federal partners conducting light-duty vehicle research, DOT is the designated lead agency for medium and heavy- duty vehicle RDD&D. Based on DOT's positive experience with other alternative fuels, these vehicles may be the first to be effectively deployed and anchor the success of the hydrogen economy. In particular, DOT is interested in exploring the use of hydrogen for public transit buses and for certain types of waterborne vessels. This includes shuttles, ferries, and deepwater passenger and freight vessels. Hydrogen may be appropriate for primary propulsion and/or on-board auxiliary electrical generation.

Anticipated Long-Term Outcomes

The long-term outcome for Road 4 is the commercial deployment of hydrogen fueled medium and heavy-duty vehicles. The fleet operation of these vehicles, especially transit buses, is conducive to early commercial introduction of new technologies. This will be accomplished through continued RDD&D efforts in buses, medium and heavy-duty trucks, rail vehicles, and marine vessels.

Challenges and Requirements

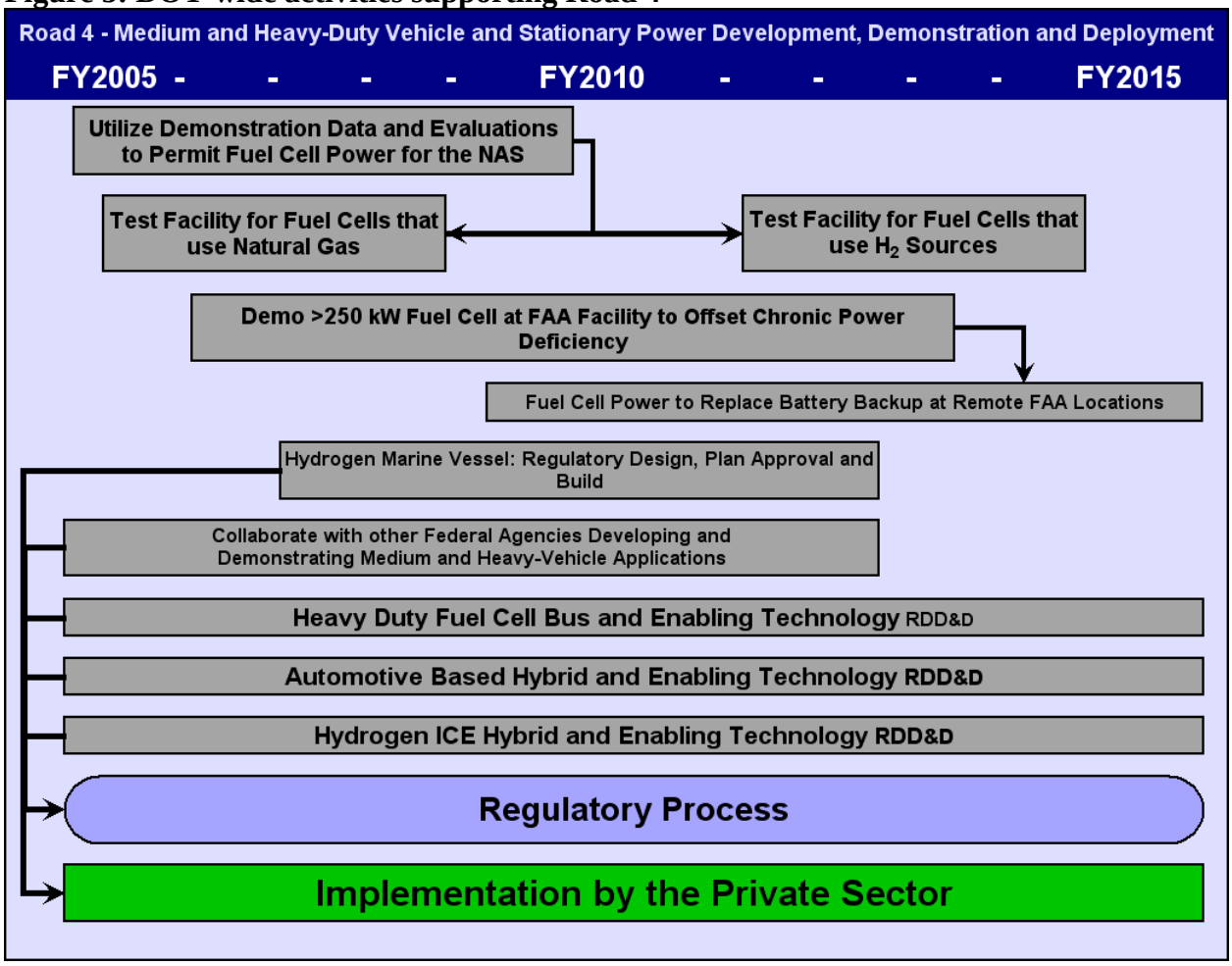
The operating and market characteristics of medium- and heavy-duty vehicles are substantially different from the light-duty vehicles operated by the general public. The performance and cost aspects of the heavier vehicles make them more conducive to early use of hydrogen fuel technology. The activities of Roads 1 through 3 can be leveraged to support the development and demonstration activities of DOT operating administrations.

These operating and market characteristics present new opportunities and challenges for the hydrogen program. For the most part, medium- and heavy-duty vehicles operate in a tighter integrated and regulated system than light-duty vehicles. Development and demonstration activities need to address the challenges of these demanding environments in order to ensure that these new technologies do not compromise operational and safety requirements and functionality. There are severe requirements for a successful demonstration. First, the technology needs to work. Second, the demonstrations need to prove the financial and environmental benefits of the technology. Finally, the tests must also demonstrate the durability, reliability, and safety of the technology to end-users and regulators.

Pathways, Projects and Products

An organizational flow chart for Road 4 (Figure 5) illustrates the major DOT-wide pathways, projects and products, and their interrelationship to the other three Roads.

Figure 5: DOT-wide activities supporting Road 4



Federal Transit Administration (FTA)

The FTA is in the forefront of the research, development, and demonstration of fuel cell buses. Transit buses have been in the vanguard for demonstration of alternative fuels and hybrid electric systems for a variety of practical reasons. Weight and volume packaging constraints are less rigorous for buses than for light-duty vehicles. Buses can take longer to start and get running than is acceptable for personal automobiles. Transit buses are centrally fueled and stored at discrete locations, while the public expects personal vehicle fueling and storage options to be ubiquitous. Additionally, buses are driven and maintained by trained professionals, facilitating the safe introduction of this new fuel and propulsion system.

Perhaps most importantly, the success of transit buses in major population centers provides an opportunity to accustom the public to the safe operation of zero-emission hydrogen fuel cell vehicles. The operational and maintenance experience obtained through the introduction of fuel cell vehicle technologies in buses will significantly enhance successful applications in light-duty vehicles. Synergistically, the success of the FreedomCAR Partnership and Hydrogen Fuel Initiative will enable transit to take advantage of the economies of scale from the volume production of cars and light-duty trucks.

To accomplish this mission, FTA in partnership with key stakeholders, developed the Hydrogen and Fuel Cell Bus Initiative. This initiative is a broad-based, national effort to coordinate and consolidate the diverse efforts inherent in the development of hydrogen and fuel cell buses. This coordination will accelerate hydrogen's commercial viability and also encourage the successful commercialization of hydrogen fuel cells into other transportation applications. This initiative focuses on three vehicle technology development pathways: heavy-duty fuel cell bus, automotive-based fuel cell hybrid bus, and hydrogen internal combustion engine hybrid bus. Research, development, and demonstration efforts are underway for each of these efforts.

The FTA is also spearheading an effort to enhance international coordination and collaboration in fuel cell bus research, development and demonstration. The FTA conducted the First International Fuel Cell Bus Workshop in November 2003, in Long Beach, California, and the second workshop in Oporto, Portugal in November 2004. Representatives from fuel cell bus programs in Europe, China, Brazil, Canada, Japan, and Mexico participated. At the meeting, there was agreement on the benefits of greater information sharing, harmonization of data collection and evaluation, and enhanced coordination of future research, development and demonstration efforts. Participants also agreed on the benefits of establishing an International Fuel Cell Bus Working Group to foster greater coordination and collaboration. Additional workshops are being planned to build upon the groundwork of the first two workshops.

Federal Motor Carrier Safety Administration (FMCSA)
The FMCSA is not currently engaged in demonstration activities but will collaborate with other Federal partners to conduct demonstrations for hydrogen and fuel cell powered medium- and heavy-duty vehicles.

Maritime Administration (MARAD)
MARAD foresees slow-speed ferries and passenger water shuttles as being well-suited vehicles for the deployment of hydrogen and fuel cell technologies. The weight and volumetric flexibilities of these craft allow for ease of system design. The single point fueling characteristics require minimal infrastructure development. The vessels often operate in pristine environments, creating a premium need for low-emission technologies. Initial demonstrations will involve these types of vessels. Long-term efforts will seek to fully integrate hydrogen power and fuel cell technology across all marine craft platforms and in stationary port power applications.

Federal Aviation Administration (FAA)
The FAA is currently engaged in collaborative demonstration efforts with DoD and DOE's Solid-State Energy Conversion Alliance program to install, test, and evaluate high temperature stationary fuel cells. Current regulations prohibit the use of fuel cell power in National Airspace System (NAS) facilities. However, power that is purchased can be generated by fuel cells. Moreover, non-critical infrastructure and redundant back-up systems can be powered directly by fuel cells. This creates a pathway for validating the technology and demonstrating improved environmental results and energy security while providing greater power reliability to the NAS infrastructure. Once confidence in fuel cell power is established, FAA efforts will focus on fully deploying and integrating these technologies into NAS facilities.

Federal Railroad Administration (FRA)
The FRA has outlined a multi-year program beginning in FY07 to develop and demonstrate a fuel cell powered mainline locomotive. The rail system's fleet-centralized fueling infrastructure reduces infrastructure demands, and hydrogen and its feedstock commodities are already being handled by the rail industry. Demonstrations will target line-haul operations that operate in non-attainment areas or have diesel use restrictions where the need and ability to utilize new technologies are critical. The FRA demonstration projects will ultimately prove the viability and benefits of fuel cell locomotives to industry, and create an avenue for a long-term fleet turnover. This work will build on current research being conducted by DoD for fuel cell locomotives.

Timelines

Research, development, and demonstration activities will continue through the FY 2010-2015 timeframe. The operating characteristics of medium- and heavy-duty fleet vehicles result in a deployment schedule that will likely precede that for light-duty vehicles. Based on the success of the demonstrations with medium- and heavy-duty vehicles and the continued technology improvements resulting from industry and DOE research, initial heavy-duty deployment could occur prior to 2015.

Convergence

DOT's activity is consistent with DOE's Hydrogen Road Map. DOT has primary responsibility for the development, demonstration, and deployment of medium- and heavy-duty hydrogen vehicles, while DOE's transportation-related hydrogen efforts focus on light-duty vehicle applications. Basic research in hydrogen storage and use as a fuel will integrate into DOT's development and demonstration activities. Lessons learned from this activity will be shared with DOE to help guide future research. Infrastructure built for DOT demonstrations can serve as a foundation for the expansion of infrastructure to the light-duty market. Ultimately, DOE's RDD&D program on light-duty vehicles will parallel DOT's activities on medium- and heavy-duty vehicles. DOT and DOE are actively coordinating and collaborating in data collection and evaluation efforts for fuel cell bus demonstrations already underway and those planned for both national and international markets.

SUMMARY

The Department's Hydrogen Roadmap outlines the critical roles and activities for the next 15 years. By implementing this Roadmap, DOT's three primary responsibilities – safety, RDD&D for medium- and heavy-duty vehicles, and infrastructure deployment – are fully integrated in a coordinated effort with industry and other Federal agencies.

Implementation of the Roadmap is coordinated through DOT's Hydrogen Working Group, chaired by RITA. This body is working cross-modally with the individual operating administrations to exchange information on progress, share expertise, and to realize DOT's top priority – safety – as the hydrogen economy develops. This working group also fosters interaction, technically and programmatically, with DOT's Federal partners: Department of Energy, Department of Defense, Environmental Protection Agency, National Institute of Standards and Technology, and other partners who have reviewed and provided input to this coordinated Roadmap.

The pathways to hydrogen commercialization begin in FY05 with the initial regulatory work and RDD&D and support for existing vehicle and infrastructure demonstrations. However, the road is just beginning and the final outcome is not yet clear. The ultimate commercialization and technology decisions will be made by the private sector for economic and technical feasibility reasons. The DOT needs to provide the regulatory and safety framework within which these choices can be made. The Roadmap clearly demonstrates the need for DOT's near-term and ongoing planned activities to support a safe and technically viable transition to the Hydrogen Economy. The Roadmap presents clear rationales for conducting the mapped activities in accordance with the timeframes outlined. The timely execution of the DOT Roadmap will be a critical component for the successful execution of the hydrogen initiative within DOE and industry-defined timeframes.

The main goals for DOT in supporting these initiatives, as outlined in the Roadmap, include:

- ensuring the safety of hydrogen in transportation;
- defining a regulatory framework for hydrogen through voluntary consensus codes and standards;
- leading the RDD&D of medium- and heavy-duty vehicles, components, and supporting infrastructure across all modes of transportation;
- guiding the safe integration of hydrogen infrastructure into DOT-regulated systems;
- accomplishing system integration of hydrogen infrastructure without compromising the safety, security and operability of the current and transition-state fuels infrastructure; and
- providing training and outreach activities to support these goals.

Roads by Each Applicable Operating Administration

Figure 6: NHTSA Flow Chart

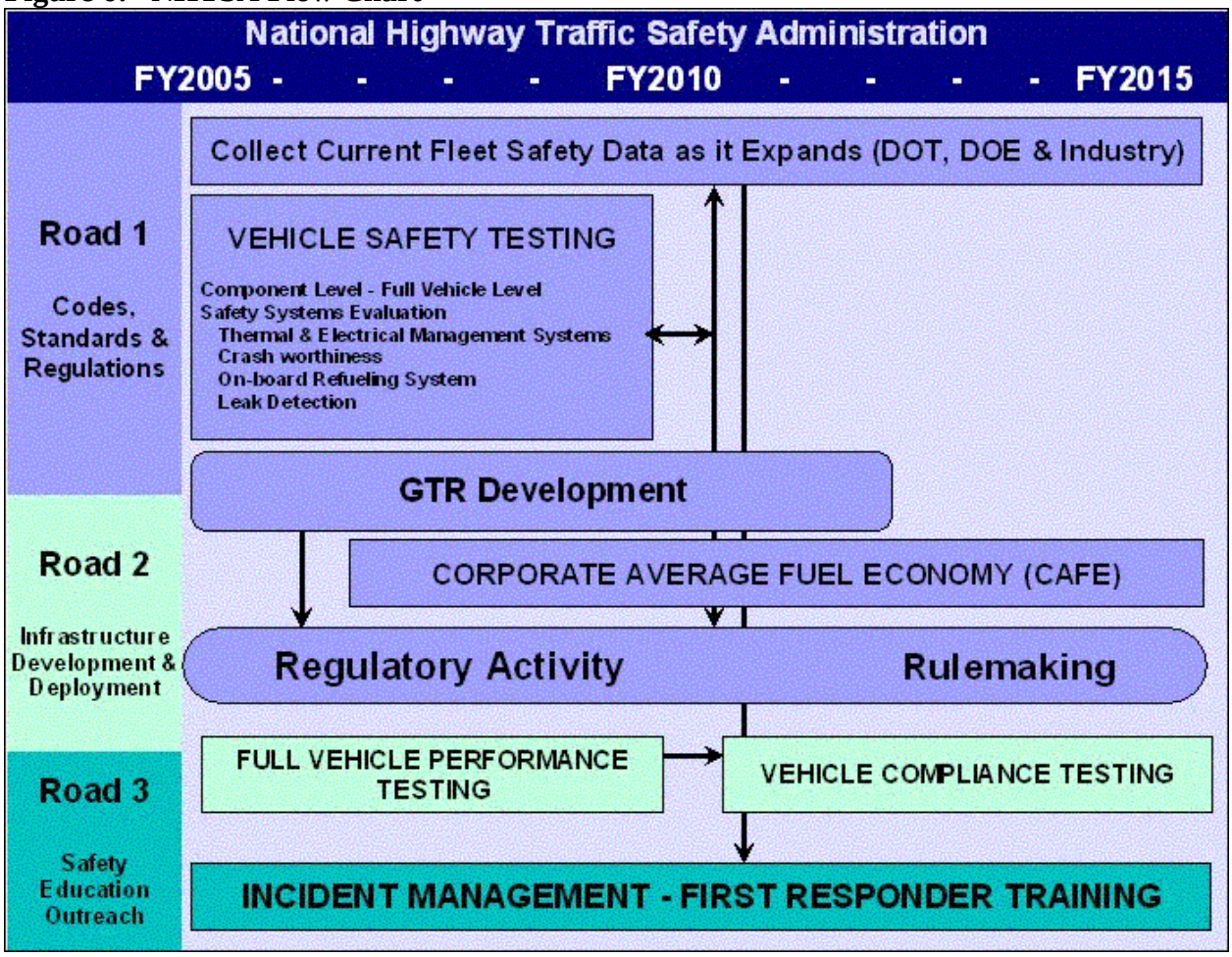


Figure 7: PHMSA OPS Flow Chart

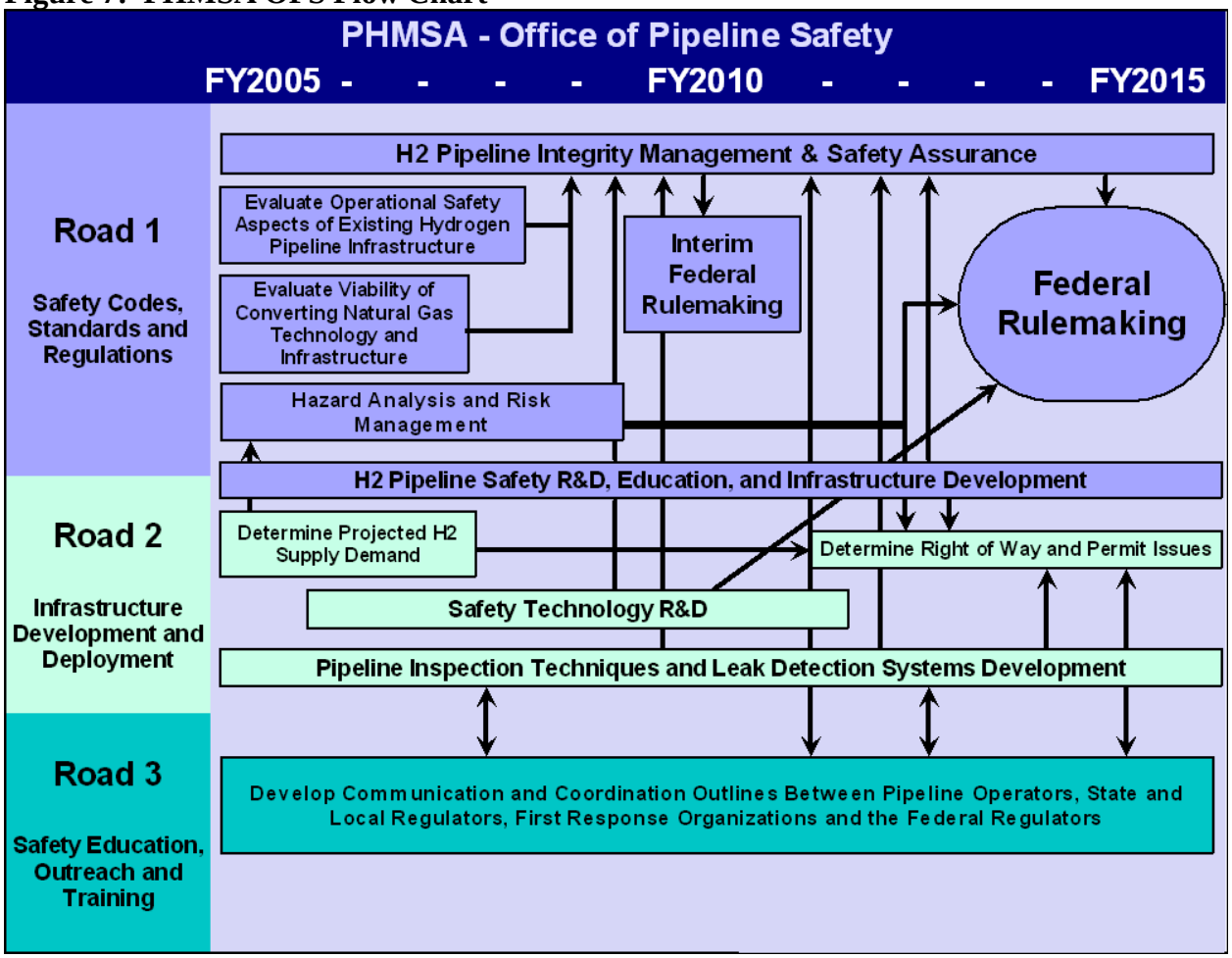


Figure 8: PHMSA OHMS Flow Chart

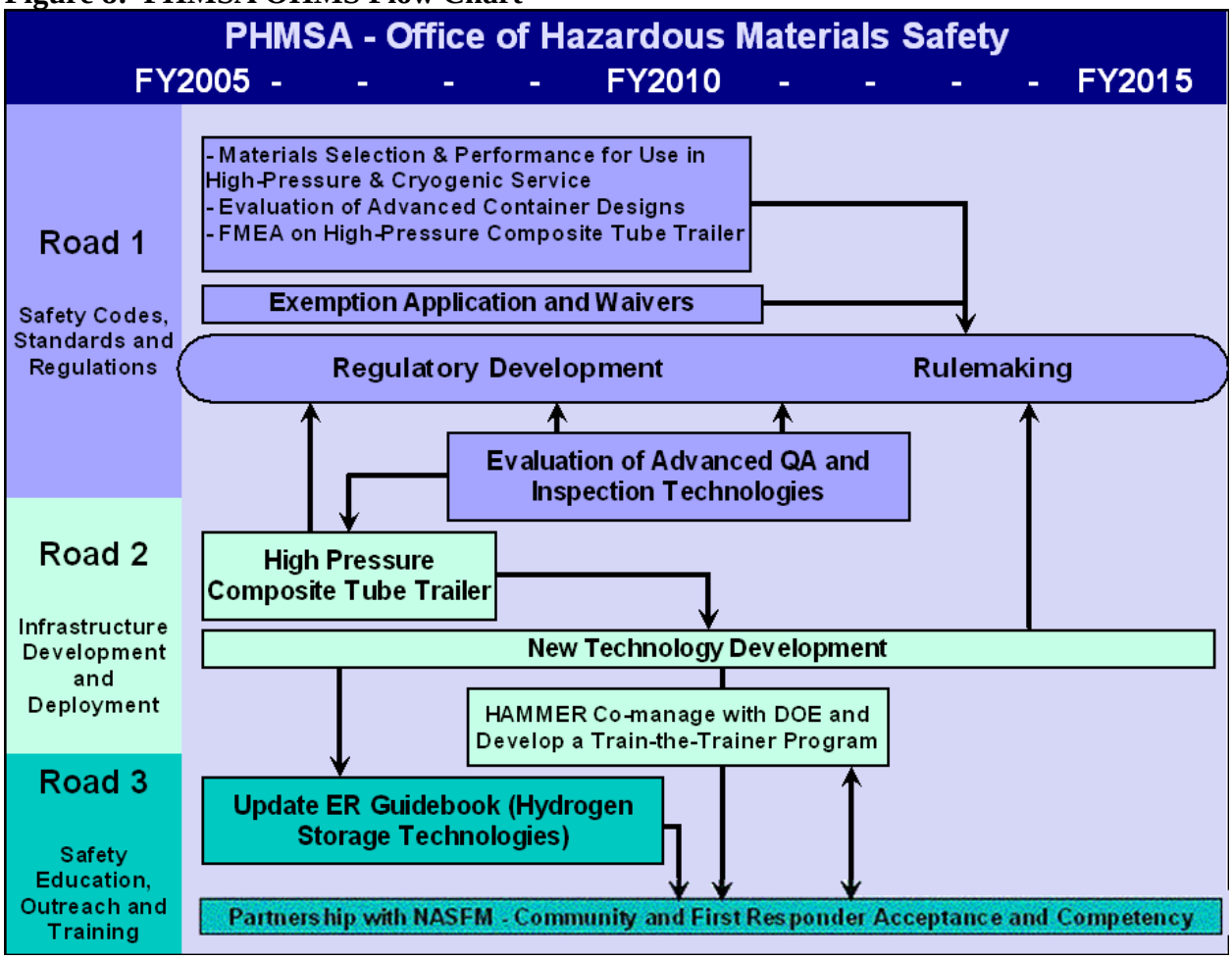


Figure 9: FMCSA Flow Chart

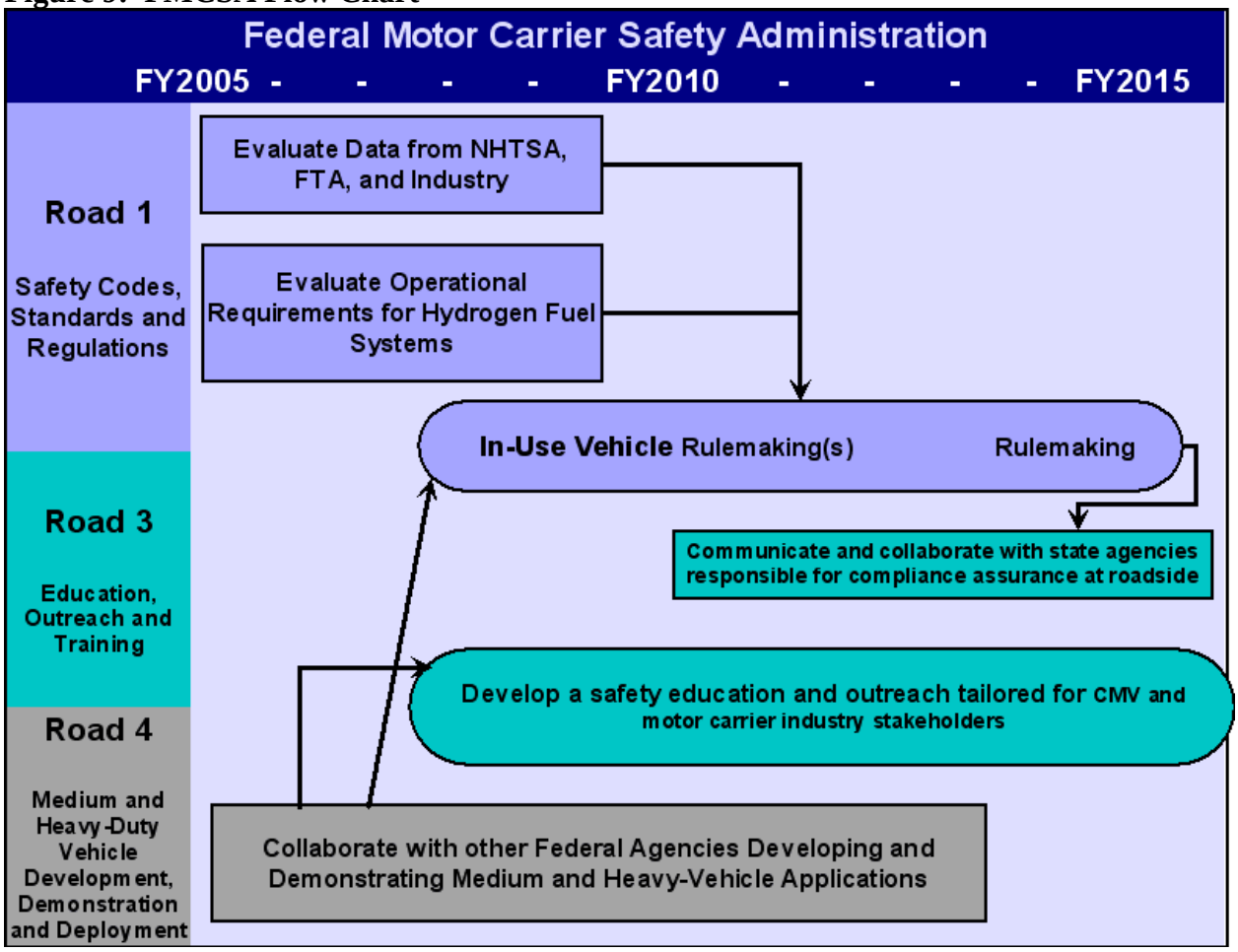


Figure 10: MARAD Flow Chart

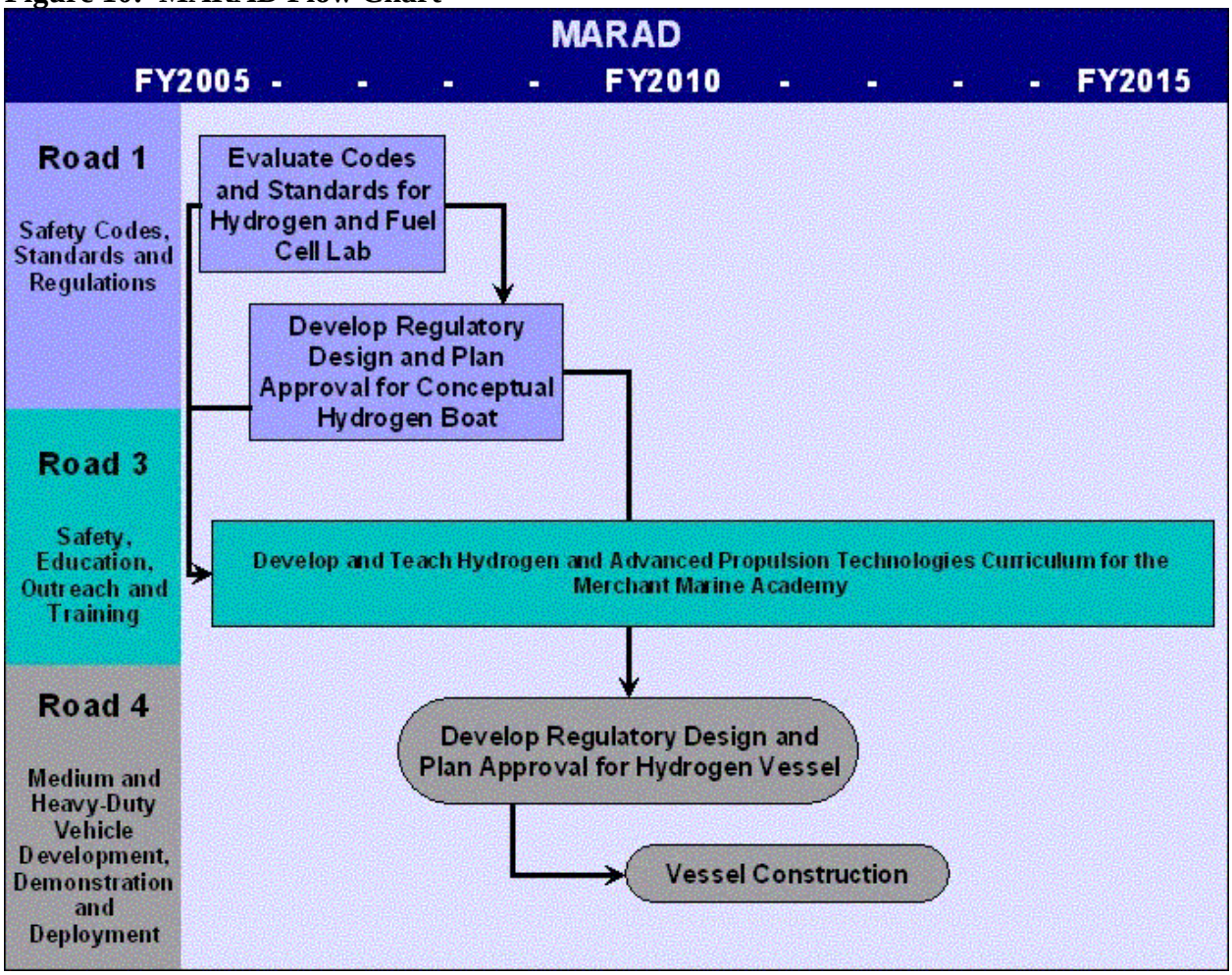


Figure 11: FTA Flow Chart

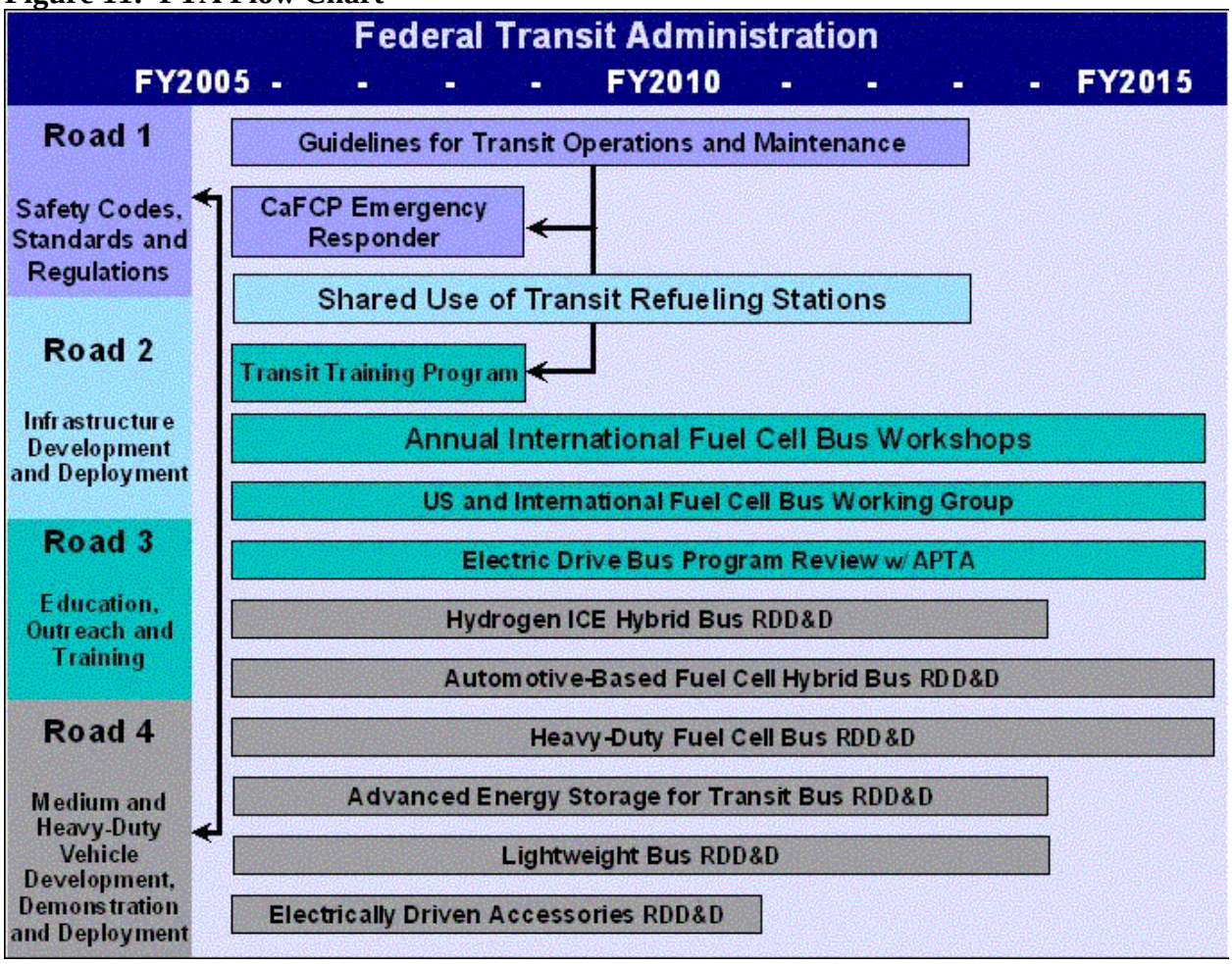


Figure 12: FAA Flow Chart

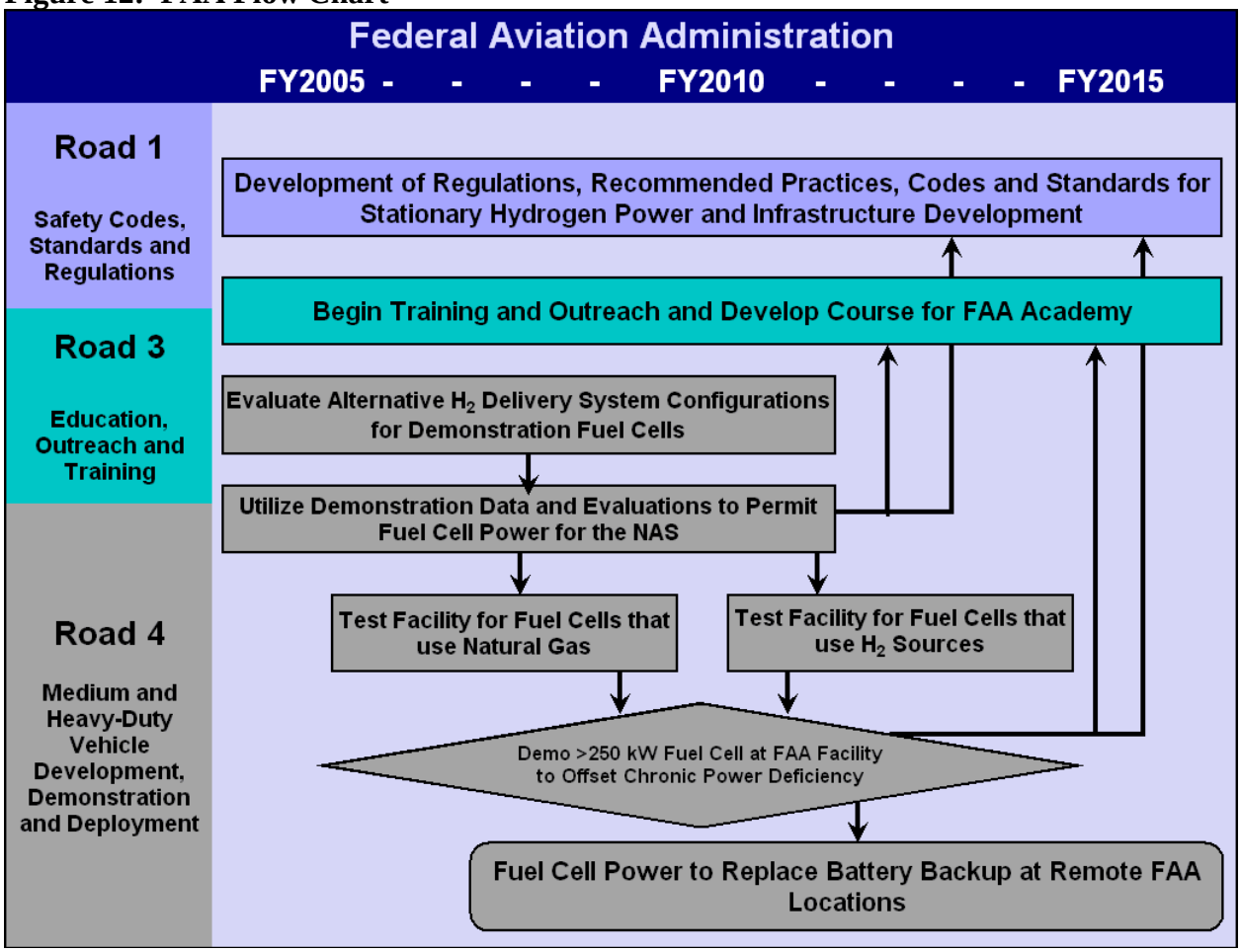


Figure 13: Research and Innovative Technology Administration --Activities by Road

Road 1 **Safety Codes Standards and Regulations**	• **Multimodal Consensus Codes and Standards Development** • **Hydrogen Materials Interaction and Compatibility** • **Fuel Quality** • **Coordinated RD&D with other Federal Agencies**
Road 2 **Infrastructure Development and Deployment**	• **Safety Technology R&D** • **State H_2 Highway Support** • **H_2 Supply and Demand Analysis**
Road 3 **Education Outreach and Training**	• **Hydrogen Executive Leadership Panel Education and Training Development with the National Association of State Fire Marshals**
Road 4 **Medium and Heavy-duty Vehicle Development Demonstration and Deployment**	• **Infrastructure and Vehicle Technology Support and Collaboration with DOT Operating Administrations and Government Agencies**

APPENDIX A: DOT's Strategic Plan Overview

Vision:

"Safer, Simpler, Smarter Transportation Solutions"

Mission:

To develop and administer policies and programs that contribute to providing fast, safe, efficient, and convenient transportation at the lowest cost consistent with the national objectives of general welfare, economic growth and stability, the security of the United States and the efficient use and conservation of the resources of the United States.

Strategic Objectives:

Safety: *Enhance public health and safety by working toward the elimination of transportation-related deaths and injuries.*

Mobility: *Advance accessible, efficient, intermodal transportation for the movement of people and goods.*

Global Connectivity: *Facilitate a more efficient domestic and global transportation system that enables economic growth and development.*

Environmental Stewardship: *Promote transportation solutions that enhance communities and protect the natural and built environment.*

Security: *Balance homeland and national security transportation requirements with the mobility needs of the Nation for personal travel and commerce.*

Organizational Excellence: *Advance the Department's ability to manage results and achieve the goals of the President's Management Agenda.*