FreedomCAR and Fuel Partnership

FUEL PATHWAYS INTEGRATION TECHNICAL TEAM

ROADMAP

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Introduction

The FreedomCAR and Fuel Partnership is a collaborative effort among the Department of Energy (DOE), energy companies (BP America, Chevron Corporation, ConocoPhillips, ExxonMobil Corporation, and Shell Hydrogen LLC) and the U.S. Council for Automotive Research (USCAR) whose members include DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation. The FreedomCAR and Fuel Partnership is an effort to examine and advance the pre-competitive, high-risk research needed to develop the component and infrastructure technologies necessary to enable a full range of affordable cars and light trucks, and the fueling infrastructure for them that will reduce the dependence of the nation's personal transportation system on imported oil and minimize harmful vehicle emissions, without sacrificing freedom of mobility and freedom of vehicle choice.

The Fuel Pathways Integration Technical Team (FPITT):

- ❖ Analyzes hydrogen fuel pathways
- ❖ Provides observations and suggests possible methodologies for setting hydrogen cost targets and component technology targets
- ❖ Suggests priorities and gaps in the systems analysis activity
- ❖ Supports transparency in all areas

This roadmap outlines an approach for identifying and analyzing hydrogen production, distribution, and dispensing pathways.

Technical Approach

The FreedomCAR and Fuel Partnership is pursuing multiple options in each technology area (e.g., hydrogen production, hydrogen delivery, hydrogen storage and fuel cells) required for implementation of a hydrogen economy. Technical teams for each of these technology areas have developed technical targets and identified barriers for their respective subsystems and components. However, lacking a common set of assumptions and parameters, these technical targets cannot readily be combined to describe integrated fuel pathways. The Fuel Pathways Integration Technical Team will address this problem by pursuing activities that achieve the following goals.

Goals

- Analyze issues associated with complete hydrogen production, distribution, and dispensing pathways.
- Provide comments to the Partnership on methodologies for setting targets for full pathways and pathway components.
- Provide observations to the Partnership on needs and gaps in the hydrogen analysis program.
- Suggest approaches for realizing full transparency in all analysis activities.

Technical Challenges

Fuel pathways for a hydrogen economy will need to compete against an existing fuel infrastructure that is well understood, highly efficient, and has widespread consumer acceptance. Though certain components of potential hydrogen fuel pathways are also well understood, complete systems are not. Furthermore, with the continual introduction of new vehicle technologies, the market conditions in which hydrogen must be used are continually evolving. One of the most important technical challenges in the formation of a hydrogen economy, therefore, is estimating the costs, benefits, and risks of potential hydrogen fuel pathways.

The following barriers describe challenges faced in the analysis of hydrogen fuel pathways.

Barriers

A. **Lack of a Prioritized List of Analyses for Appropriate and Timely Recommendations.** Systems analysis and its resulting observations and recommendations are only of value if they address the key issues faced by the Partnership and are tied to the schedules and milestones. Resource constraints, fluid budgets and evolving technologies impact the setting of analysis priorities.

B. **Lack of Consistent Data, Assumptions, and Guidelines.** Analysis results are strongly influenced by the data sets employed, as well as the assumptions and guidelines established to frame the analytical tasks. These elements have been largely uncontrolled in the past, with individual analysts and organizations establishing their own bases. Although this does not necessarily make the results wrong, it does make it more difficult to put the results and resulting recommendations in context with other analyses and the overall objectives of the Partnership, especially as many of the assumptions and much of the data in existing analyses are not explicitly documented. For example, it has been challenging for DOE to establish and endorse a transparent, consistent set of data, assumptions and guidelines due to the large number of stakeholders involved and the breadth of technologies and system requirements.

C. **Lack of Understanding of Hydrogen Quality Requirements.** Hydrogen quality affects the performance, durability, and cost of fuel cells and of hydrogen production, distribution, storage, and dispensing components. The interactions among these components are not well understood. R&D is needed to define hydrogen quality requirements at each component interface in a pathway, and tradeoff studies are needed to optimize the total fuel/vehicle system.

D. **Lack of a Macro-System Model.** Although numerous models exist to analyze components and subsystems of an eventual hydrogen economy, a modeling architecture does not exist that addresses the overarching hydrogen fuel infrastructure as a "system." Such a macro-system model is critical to assessing the transition from the existing energy infrastructure to one including hydrogen. Individual models spanning a wide range of modeling platforms (operating systems, software, inputs, outputs, boundary conditions, etc.) must be integrated into a common modeling framework.
E. **Stove-Piped/Siloed Analytical Capabilities.** Analytical capabilities and resources have been largely segmented, both functionally by technology (production, storage, fuel cells, etc.) and organizationally (laboratories, specialized teams, industry/academia, etc.). Successful systems analysis requires the integration of analysis resources across all facets of the issue.
F. **Lack of Understanding of the Transition of a Hydrocarbon-Based Economy to a Hydrogen-Based Economy.** The long-term hydrogen fuel infrastructure is little understood and numerous economic, social, political and technical influences will be involved in the transition to the hydrogen economy. In addition, the overall energy infrastructure and economy into which hydrogen must fit is an ever-changing domain.
G. **Segregation of Fuel and Vehicle Issues.** If hydrogen fuel cell vehicles and the associated fueling infrastructure are to be developed, they will need to deliver well-to-wheels advantages over competing technologies. System integration and optimization will identify additional areas of R&D and analysis that are required for understanding full well-to-wheels impacts.

Strategic Framework

The following sections outline strategies for achieving the goals of the Fuels Pathway Integration Technical Team.

Section 1: Analyzing Hydrogen Fuel Pathways

Goal: Analyze issues associated with complete hydrogen production, distribution, and dispensing pathways.

Objectives:

- **Identify, and where possible quantify, the challenges associated with using a pathway on a large scale, e.g., primary energy input, land and water use, other infrastructures, scalability, well-to-wheel CO_2 emissions, etc.**

  Each pathway will have feedstock, supply, emissions, utility, land and infrastructure issues that must be addressed and quantified. As the hydrogen production, distribution and dispensing pathways are evaluated, these attributes will require definition to understand supply, peripheral infrastructure and environmental impacts. These elements may increase the capital cost, impact timing and require detailed technical and environmental assessment.

- **Identify related technologies (e.g., carbon capture and sequestration) not addressed in the Partnership's Research Goals that will be needed to successfully implement pathways.**

  Related requirements will be identified as part of the evaluation of pathways and pathway technologies. This will enable related issues such as specific emissions and utility components to be identified and quantified. Based on the results of this assessment, the FPITT will identify any additional research and/or analysis projects that should be explored and developed by the responsible DOE program or other entity to provide the technical solutions for the identified issue.

- **Develop approach to integrating hydrogen quality requirements into individual technical team roadmaps and analyses. Facilitate discussion.**

  Hydrogen quality requirements have the potential to impact all fuel pathway components as well as fuel cells. To date, however, little work has been done to quantify those impacts or to assess tradeoffs among performance requirements for individual pathway components or fuel cells. The FPITT will suggest a process whereby these issues are integrated into the relevant technology roadmaps.

- **Periodic update for selected pathways.**

The issues associated with a pathway technology will be assessed periodically based on technology evolution or changes in external factors. The evaluation will provide direction for component research in a given pathway.

Barriers:

- B. Lack of Consistent Data, Assumptions, and Guidelines
- D. Lack of a Macro-System Model
- E. Stove-Piped/Siloed Analytical Capabilities
- F. Lack of Understanding of the Transition of a Hydrocarbon-Based Economy to a Hydrogen-Based Economy.

Current Activities:

- Identification of the challenges to pathway implementation that should be evaluated and the approach for conducting the evaluation.
- Monitoring of H2A work on central and distributed production, distribution, storage, and dispensing to provide transparent, baseline data and assumptions for use in analysis.

Integration with Other Technical Team Roadmaps:

- Dialogue with the production, distribution, and storage technical teams, as well as the Fuel Cells Technical Team, will be required to establish requirements for technologies needed to meet the pathway-independent hydrogen cost goal.
- Integration with Vehicle Systems Analysis Technical Team is required to assess WTW implications of hydrogen pathways and compare them to the WTW performance of evolving internal combustion engine and hybrid electric systems.

Section 2: Setting Targets

Goal: Provide input to the Partnership on setting goals for full pathways and pathway components.

Objectives:

- **Establish a full pathway hydrogen cost goal.**

Goals aimed at enabling commercialization must ensure that the resulting pathways are at least economically equivalent to competing technologies expected to be available. The hydrogen cost goal will be based on anticipated future market conditions and will be pathway independent. The goal will be expressed as a range, in dollars per gasoline gallon equivalent, untaxed at the pump. The upper boundary will be based on the expected ratio between fuel cell vehicle fuel economy and evolved gasoline internal combustion engine fuel economy in 2015, and will represent a threshold cost to be used to screen or eliminate pathway options that cannot demonstrate an ability to meet the goal. The lower boundary will be based on the expected ratio between fuel cell vehicle fuel economy and gasoline-electric hybrid vehicle fuel economy in 2015, and will define a lower hydrogen cost to be used to prioritize projects for resource allocation. Both boundaries will be calculated using projected gasoline costs in 2015, expressed in 2005 U.S. dollars. The hydrogen cost goal may be changed in the future if warranted by changes in vehicle system energy efficiency characteristics and gasoline price projections.

- **Develop "pathway component" goals that are consistent with the high-level goal and can be used to identify those components that should be the primary focus of R&D. Provide the results of that analysis to the production, storage, and delivery technical teams as input to their goal setting processes.**

Operating from the high-level, pathway-independent hydrogen cost goal, individual pathways must be sub-divided into components. The development of component goals will consider the contribution of the component within and across pathways. An integrated hydrogen fuel pathway will include some or all of the following components depending on location of the production facility:

- Feedstock
- Production: Processes that convert an energy source to hydrogen
- Delivery
  - Purification
  - Production storage: For central production processes, storage necessary to ensure uninterrupted flow of hydrogen to the distribution system
  - Distribution preparation: Process for preparing hydrogen from the production process and/or storage for introduction to the distribution system, e.g., compression, liquefaction, charging solid carrier
  - Terminals: Facilities that buffer capacity between production and retail and have the capability to change the state of the hydrogen (e.g., liquid to gas, liquid to solid)
  - Distribution: Facilities used to transport hydrogen between production, terminals, and retail locations (e.g., pipeline, compressed tank truck, liquid tank truck)
- Local storage: Storage capacity needed at the retail site to handle peak demand periods and ensure an uninterrupted flow of hydrogen to consumers
- Compression: Includes vaporization and compression if needed to interface between local storage and the vehicle
- Dispensing: Facilities needed to transfer hydrogen from local storage to vehicle tanks

- **Ensure consistency between pathways.**

The establishment of consistent goals requires commonality in the bases and assumptions used to develop component goals. In particular, all pathways must assume that hydrogen is delivered to the vehicle at the same level of purity. Likewise, all central plant cases will be evaluated on a common scale, as will all distributed production cases; furthermore, the central plant and distributed cases will be based on a common scenario to the extent possible.

- **Identify pinch points.**

Barriers that make attainment of a component goal difficult will be identified, including possible mitigation via trade-offs with other goals. An example is hydrogen quality: in addition to understanding the impact that it has on the hydrogen pathway component cost, it will be necessary to coordinate with the Fuel Cell Technical Team to evaluate the impact of a lower / different quality on fuel cell operation.

- **Periodic update to capture improvements in technology outlooks and future fossil fuel costs.**

Due to the uncertainty involved in the development of future fuel costs and technology projections, the hydrogen cost goal will be reviewed when there are significant changes in the outlook for vehicle technologies (either ICE or fuel cell based) or the outlook for gasoline prices. The cost review will be used to determine whether the magnitude and certainty of the change require an update of the component goals. Note that such changes should be infrequent, since R&D activity requires a reasonable level of certainty in the goals.

Barriers:

- B. Lack of Consistent Data, Assumptions, and Guidelines.
- C. Lack of Understanding of Hydrogen Quality Requirements

Current Activities:

- Development of a methodology for the calculation of goals that recognizes the uncertainty associated with the predictions of future trends for both fossil fuel costs and vehicle capabilities.
- Development of a methodology to "allocate" full pathway hydrogen costs among key pathway components.

Integration with Other Technical Team Roadmaps:

- The “top down” goals developed by the Fuel Pathway Integration Technical Team will be communicated to the Production and Delivery Technical Teams for evaluation of their feasibility and comparison with “bottom up” goals. Feedback from these other Technical Teams will be used to refine the full pathway analysis.

Section 3: Identifying Analysis Needs and Gaps

Goal: Provide input to the Partnership on priorities and gaps in the hydrogen analysis program, especially with regards to pathway analysis.

Objectives:

- **Review the DOE portfolio of non-policy related hydrogen analysis programs to identify current pathway analysis capabilities.**

In order to adequately provide hydrogen pathway analysis input to the Partnership, the current DOE analysis portfolio needs to be better understood. After reviewing the current portfolio, gaps in analysis capabilities will be identified, and observations on the breadth and depth of existing analyses will be developed. In addition, the ongoing analysis tasks that need to be modified to better integrate with other DOE analysis tasks will be identified.

- **Identify and prioritize pathway analysis needs for long term and transitional analysis.**

Upon the completion of the analysis portfolio review, gaps in analysis capabilities will be identified. These gaps will need to be prioritized with regards to analyses focusing on the long-term hydrogen economy, along with analyses for the transition economy. The prioritization of these gaps will provide input to DOE for their planning of future analysis activities.

- **Use industry expertise to provide input on individuals / groups that could develop analyses to fill gaps.**

With the identification of the long-term and transitional analysis gaps, industry members of the group will help to identify what groups or individuals may have the knowledge and skills needed to fill these gaps.

- **Integrate technical team activities with DOE System Integration Macro Model planning. Provide reviews of Macro Model activities.**

An activity within the DOE hydrogen analysis program is to develop an overarching hydrogen pathway model: the DOE Systems Integration Macro System Model. FPITT will serve as a potential user and reviewer of this model, as the charter of the team mirrors the requirements of the model. The technical team will be involved in the requirements gathering, provide input during development, and test this model.

Current Activities:

- Identify pathway analysis programs to be reviewed.
- Participate in DOE Annual Review process.
- Provide input to the DOE System Integration Macro System Model.
- Hold discussions with principal investigators of DOE projects to better understand existing analysis programs, program goals and planned outcomes.

Barriers:

- A. Lack of Prioritized List of Analyses for Appropriate and Timely Recommendations
- D. Lack of a Macro System Model
- E. Stove-Piped/Siloed Analytical Capabilities
- F. Lack of Understanding of the Transition of a Hydrocarbon-Based Economy to a Hydrogen-Based Economy.
- G. Segregation of Fuel and Vehicle Issues

Integration with Other Technical Team Roadmaps:

- To be determined.

Section 4: Achieving Transparency
Goal: Work towards full transparency of all analysis activities.

Objectives:

- **On an ongoing basis, provide input and resource support to the Hydrogen Program Hydrogen Analysis Resource Center (HyARC).** DOE's Hydrogen Program is developing standard and consistent analysis data, assumptions, guidelines, and scenarios to comprise a data resource center for use by all DOE-sponsored hydrogen analysis projects. FPITT will provide input to this resource center to ensure that it supports FPITT's goals of enabling analysis of complete fuel pathways and achieving transparency of analysis activities. FPITT will peer-review and provide input to the resource center, as the resource center is maintained and updated.

Current Activities:

- Participate in beta-testing of H2A model.
- Provide observations for the Hydrogen Analysis Resource Center.

Barriers:

- B. Lack of Consistent Data, Assumptions, and Guidelines

Integration with Other Technical Team Roadmaps:

- To be determined