VII.16 DOE Hydrogen Program Risk Analysis in Support of EERE's Portfolio Analysis

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Objectives

- **Near Term:** Provide risk analysis methodologies and tools that are useful to staff, team leaders, program managers, and portfolio managers in identifying, quantifying, evaluating, managing, monitoring, documenting, and communicating technology development risks and benefits.
- **Long Term:** Assist project, program, and portfolio decision-making that aligns and balances the DOE Office of Energy Efficiency and Renewable Energy's (EERE's) portfolio with strategic goals.

Technical Barriers

This project addresses the following technical barrier from the Systems Analysis section of the Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program Multi-Year Research, Development and Demonstration Plan:

(E) Unplanned Studies and Analysis

In addition, this project addresses the following technical barriers from the Systems Integration section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(B) Adapting System Integration Functions to an R&D Program

(C) Inherent Uncertainty in R&D

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 7:** Complete an analysis of the hydrogen infrastructure and technical target progress for the hydrogen fuel and vehicles. (2Q, 2011)
- **Milestone 8:** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for technology readiness. (4Q, 2014)
- **Milestone 10:** Complete an analysis of the hydrogen infrastructure and technical target progress for technology readiness. (2Q, 2015)

Accomplishments

- Analyzed uncertainty associated with future technical progress for fuel cells, on-board storage, and several hydrogen production and associated technologies (including compression, storage, and dispensing for distributed hydrogen production).
- Assessed expert opinions on potential technical progress for three funding scenarios: without DOE funding, with planned DOE funding, and with expanded DOE funding.

Aggregated individual expert opinions and projected potential progress for the three funding scenarios including a projection for optimum technology selection between comparable on-board storage technologies.

- Provided projections to be used in EERE's portfolio analysis.

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Introduction

As part of its portfolio analysis, EERE required all of its programs to perform an uncertainty analysis around technical performance measures (TPMs). That uncertainty analysis is commonly referred to as the "Risk Analysis." It involves assessing expert opinions regarding future status of the TPMs in stochastic form (i.e., as a probability density function – pdf) and combining individual projections from multiple experts to generate a single aggregated projection. The aggregated projections are then used in market and economic analysis models to estimate future levels of hydrogen penetration and the resultant effects on emissions (primarily greenhouse gases), oil imports, and economics.

EERE plans to use the results to conduct a more robust portfolio analysis of all its programs and options. The HFCIT program will also use the results to understand potential tradeoffs between objectives and how the overall objective (enabling the hydrogen economy) may be met even though some of the technical targets may not be (other targets may be exceeded). In addition, the HFCIT program gains a better understanding of the probability of reaching the technical targets at different funding levels and can use that information in making decisions on how to adjust funding allocations.

Approach

The following approach was used for all three technology areas (production, on-board storage, and proton exchange membrane [PEM] fuel cells):

- Identify technology improvement opportunities (TIOs). These are research areas where success might improve technology performance (e.g., improved reactor design for production or cryo-compressed on-board storage).
- Select and characterize TPMs. These are measurements of performance (e.g., yield and capital cost).
- Select experts to participate.
- Experts estimate future TPM potential (stochastic estimation):
  - Meeting to explain the process, discuss assumptions, and elicit feedback.
  - Aggregation of initial responses.
  - Present initial responses to experts and allow them to discuss their input.
  - Experts modify responses as desired.
  - Aggregation of final responses.
- Provide TPM potential results as input to additional models for use in EERE's portfolio analysis.

Results

Hydrogen Production and Distribution

The following four TIOs were included in this year's uncertainty analysis:

- central biomass gasification,
- central wind-powered electrolysis,
- distributed ethanol reformation, and
- compression-storage-dispensing (CSD) at the distribution station.

For all three production TIOs, the following TPMs were projected:

- efficiency,
- capital cost, and
- operating and maintenance cost projections.

In addition, capacity factor was projected for central biomass gasification and distributed ethanol reformation, and labor cost was projected for central biomass gasification. For CSD, electricity input (a measure of efficiency) and capital cost were the only TPMs. Seven to eight experts provided input on each of the TIOs.

The experts' distributions were aggregated and the results were provided in vingtile-form to EERE staff for use in their portfolio analysis. Figure 1 shows results of the analysis of central biomass gasification. That figure has the efficiency projections and total capital cost projections for both zero DOE funding (labeled as "Baseline") and flat DOE funding (labeled as "Planned R&D"). The 10^{th} percentile, 50^{th} percentile, mode, and 90^{th} percentile of the aggregated projection are shown on the figure for the selected goal (target) years (current, 2015, and 2025).

On-Board Storage

The following seven TIOs were included in this year's uncertainty analysis:

- 350 bar compressed gas
- 700 bar compressed gas
- Liquid
- Cryo-compressed
- Adsorbents
- Metal hydrides
- Chemical hydrides

For all seven TIOs, the following TPMs were projected:

- Gravimetric capacity
- Volumetric capacity
- Cost

assuming all other necessary technology improvements are achieved.

An objective function was developed to weigh tradeoffs among weight, volume, and cost assuming that the upstream (off-board) costs for those technologies are similar. Five of the technologies were optimized stochastically to develop a best or optimum scenario – a selection of best technologies based on distributions

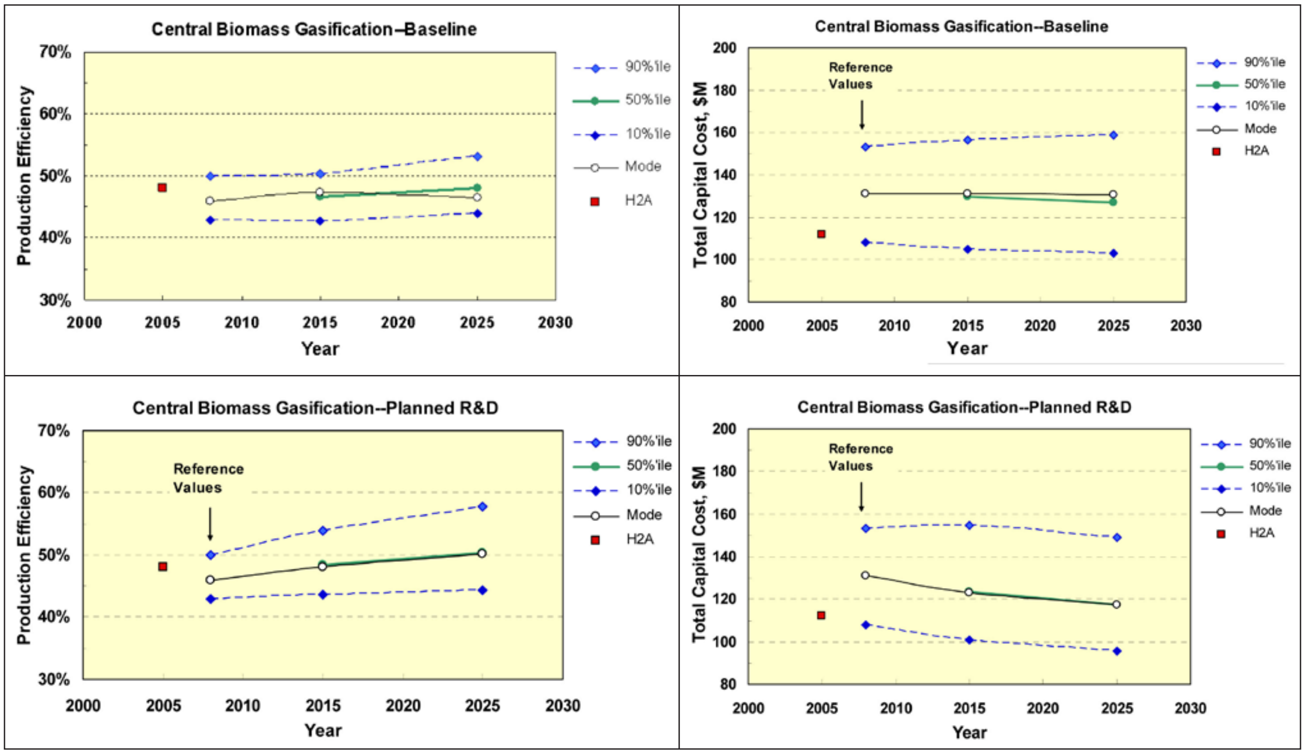

FIGURE 1. Central Biomass Gasification Efficiency and Total Capital Cost Projections

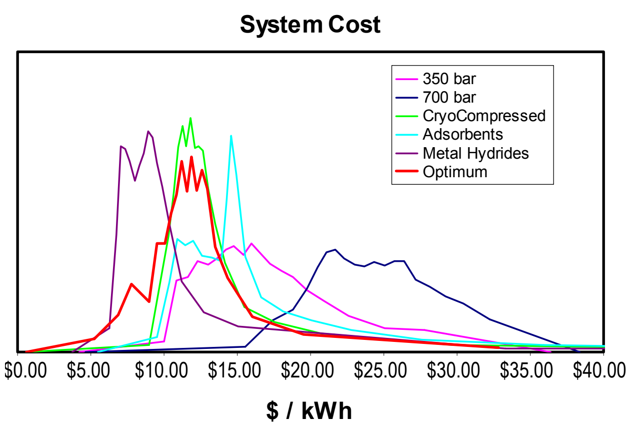

FIGURE 2. 2015 System Cost pdfs Showing the Optimum Cost as Calculated Using the Objective Function

(i.e., no single winner). The resulting cost pdf for 2015 with a flat DOE budget is shown in Figure 2 with the corresponding pdfs for the five individual technologies. Note that the "Optimum" pdf has a higher percentage of low-cost results (less than $5/kWh than any of the individual technologies). That is the case because the best technology was chosen for each of the many potential futures that were simulated in the stochastic analysis. Gravimetric capacity and volumetric capacity results are available upon request. The optimum results for each budget scenario and year were provided to the Powertrain Systems Analysis Toolkit team.

Fuel Cells

Only PEM fuel cells were considered for this analysis. The following TPMs were projected by as many as eight experts:

- System specific power (W/kg)
- System power density (W/L)
- Total fuel cell system cost ($/kW)
  - 80 kW stack cost ($/kW)
    - Power density (mW/cm^2)
    - Platinum loading (mg/cm^2)
    - Membrane cost ($/m^2)
    - Gas diffusion layer cost ($/m^2)
    - Gaskets ($/kW)
    - Bipolar plate stamping ($/kW)
  - Balance-of-plant costs ($/kW)
    - Mounting frames ($/kW)
    - Air loop ($/kW)
    - Humidifier and water recovery loop ($/kW)
    - Coolant loop ($/kW)
    - Fuel loop ($/kW)
    - System controller and sensors ($/kW)
    - Other ($/kW)

Aggregated system total cost results are shown in Figure 3.

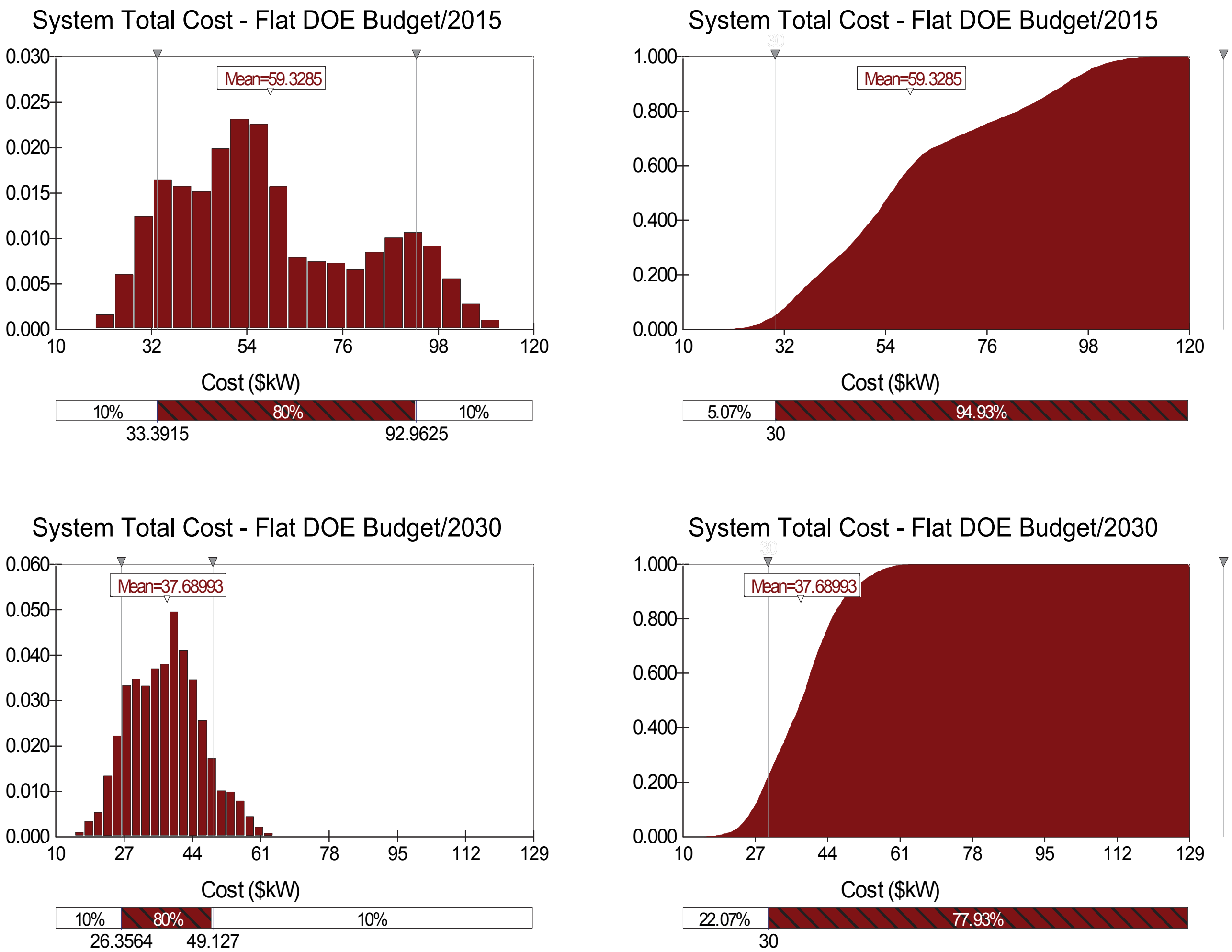

FIGURE 3. PEM Fuel Cell System Cost Projections

Conclusions and Future Directions

Projections of potential technical improvement are important in helping the program prioritize research funding and in helping EERE manage its portfolio. Data generated by this project will be used for both purposes.

Risk analysis will probably be requested by EERE on a biennial basis. In the future, the focus may be on subsystem-level TPMs to improve understanding of each system's drivers and uncertainty to help focus research funding.