Systems Analysis

&

Systems Integration

For DOE Hydrogen R & D

Messages from the Academies Hydrogen Study, Personal Experience

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Topics

- Academies findings / recommendations
    - + Systems analysis & integration both needed
- Hydrogen's competition in the marketplace
- Hydrogen options varied / breakthroughs needed
- Academies study wide-ranging but limited
- Differences in systems analysis & system integration

ACADEMIES HYDROGEN STUDY

- COMPREHENSIVE
  - CHALLENGING
    - SUPPORTIVE OF DOE

ACADEMIES FINDINGS

- Pathway to H_2 not straightforward
- Exploratory research is essential
- Extensive R&D needed
- Issues: Economic, social, & public acceptance, especially safety
- Hydrogen program management is far more challenging than any previously undertaken by DOE in civilian energy
    - Systems Analysis essential guidance / perspective
    - System Integration needed for management

PROGRAM MANAGEMENT & SYSTEMS ANALYSIS
Academies Recommendations

- The hydrogen economy may not be the most attractive long-range option for the U.S – all long-term energy options need attention & systems analysis **(Macro Systems Analysis)**

- Making informed tradeoffs between hydrogen systems options, understanding R & D results, and mapping future program directions will be remarkably complex **(Micro Systems Analysis)**

- DOE should identify systems management approaches developed elsewhere in government – adapt and apply them in the hydrogen program **(Systems Integration)**

Consider the complexities

U.S. Energy Options Other Than Hydrogen

- Other options not yet adequately defined by DOE.
- Desirables:
  - Economic
  - Domestic energy-based / No foreign dependence
  - Evolutionary vs revolutionary end-use technologies
  - Minimum of new infrastructure
  - Environmentally clean / Climate robust
  - Sustainable

Possible option include coal liquids, shale oil & biomass.

OPTIONS FOR FUTURE U.S. ENERGY - MY VIEW

Options	Likely Use (Years)	Innovations Needed	Other Issues
Coal Gasification to Liquid Fuels & Electricity	Hundred +	Modest	**Water/Env. (Sequestration?)**
Nuclear	Thousands	Breeders	**Acceptance, $$, Waste**
Renewables	"Forever"	**Major**	**$$, Nature's Variability**
Shale oil	Hundred +	Moderate	**Water/Env.**
Fusion	"Forever"	**Major**	**Start Over?**

Many variables / Issues ⇨ Systems Studies

WHAT ABOUT A BREAKTHROUGH IN ELECTRIC STORAGE?

- **Electric vehicles become practical.**
- **Vehicle operation would be clean.**
- **Electric infrastructure in place, would need expansion.**
- **Pollution reduction then focused on generation.**
- **Safety would be greater than hydrogen.**

Improvements needed ~ 10.

The Current Focus - Light Duty Vehicles

Current Best Hope:

PEM fuel cell with on-board hydrogen storage

Current:	Needed:	Factor:
~$1000s/kW	< $50/kW	~ 20 +
~1000 hour life	~ 5000 hour life	~ 5
~30% efficiency	~ 60% efficiency	~ 2

Improvements needed ~ 100

Requires Exploratory Research / Invention

ACADEMIES ON EXISTING HYDROGEN PRODUCTION OPTIONS

Large = Central station   Medium=Regional   Small = Filling station

OPTIONS	SIZES	ECONOMICS NOW
Natural gas	Small / Large	Best
Coal gasification	Large	Close Second
Coal electric*	Small/Medium/Large	Poor
Wind*	Small/Medium/Large	Fair
Photovoltaics*	Small/Medium/Large	Poor
Nuclear*	Large	Poor
Biomass	Small-Medium	Poor

***Electrolysis - Now expensive**

ACADEMIES ON A H_2 TRANSITION

- Tank trucks ➡ Distributed production ➡ Central station
- Gas reforming or electrolysis?
- Wind or solar energy “onsite”?
- Mature hydrogen economy difficult to imagine – Let it evolve.
- Time allows for
  - Needed inventions & technology development for large scale hydrogen production & infrastructure
  - Market development / overcoming non-technical hurdles

Many variables ➡ Systems Studies

ACADEMIES HYDROGEN STUDY

Wide-ranging but Limited

Academies assumptions:

- + Cut imports
- + Facilitate CO2 reductions
- + Natural gas @ $4.50 Mcf
- + Oil at $30 / bbl

But

- + U.S. LNG is slowed - natural gas supply / cost a problem
- + Sustained oil terrorism a possibility
- + Peaking of world oil production in 5-20 years possible.

Variables to be understood by Systems Studies

ACADEMIES RECOMMENDATIONS
Systems Analysis of U.S. Energy Options

- DOE hydrogen systems analysis
  - Creation, transportation, storage, and end use
  - Short, medium, and long term
  - Context: All U.S. energy options
  - Systems analysis effort should be independent

- All aspects of the conceivable hydrogen pathways must be modeled to understand the complex interactions between components, system costs, & environmental impacts of components and the system as a whole

Independent / "Firewall" separated

Academies Recommendations
Systems Integration

- Hydrogen program management is the <u>biggest challenge yet faced in DOE's civilian energy programs</u>
  + Many paths to a possible hydrogen economy
  + Many inter-related elements

- <u>Systems Integration</u> (NASA/DOD) utilizes tools to
  + Define & validate program <u>requirements</u>
  + Identify and validate <u>interfaces</u>
  + Identify <u>risks</u> & <u>mitigation approaches</u>
  + Support informed <u>decision-making</u>
  + <u>Verify that results meet requirements</u>

- Exploratory research must be treated & managed separately

Systems Integration is an arm of management; Not Independent

Concluding Thoughts

- Systems Analysis & Systems Integration are both critical to an effective DOE H2 R & D program.

  + Systems Analysis - Independent, separate

  + Systems Integration - An arm of management

- Hydrogen R & D challenges require change in DOE.

We wish you well.