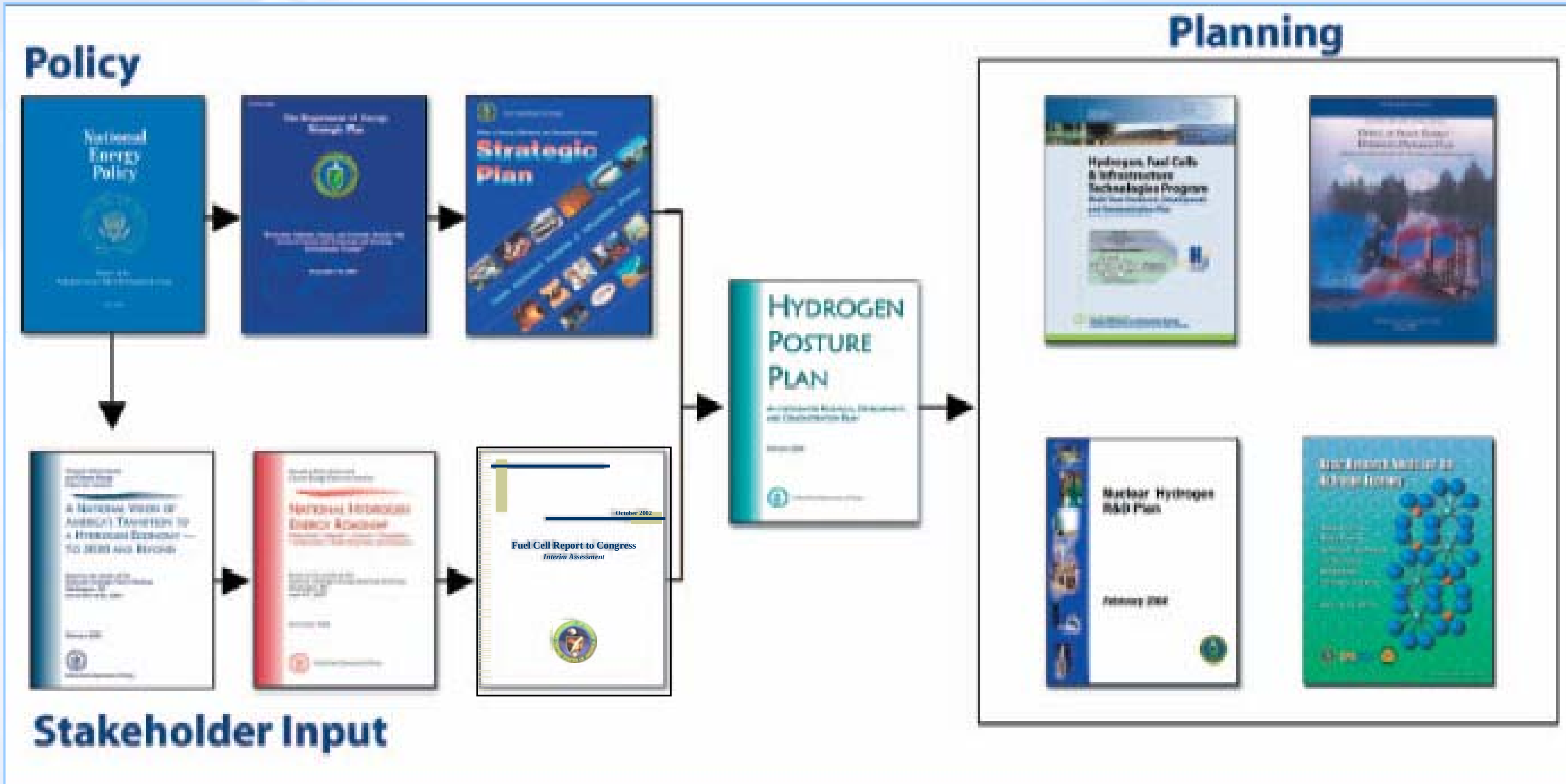
DOE Hydrogen Program Overview

2005 Merit Review and Peer Evaluation Meeting

Steven Chalk
Program Manager

May 23, 2005

Policy and R,D&D Planning



Drivers:
- **Increased energy security**
- **Reduced criteria and greenhouse gas emissions**

Hydrogen Production Strategy

Produce hydrogen from renewable, nuclear, and coal with technologies that will all yield virtually zero criteria and greenhouse gas emissions

Coal

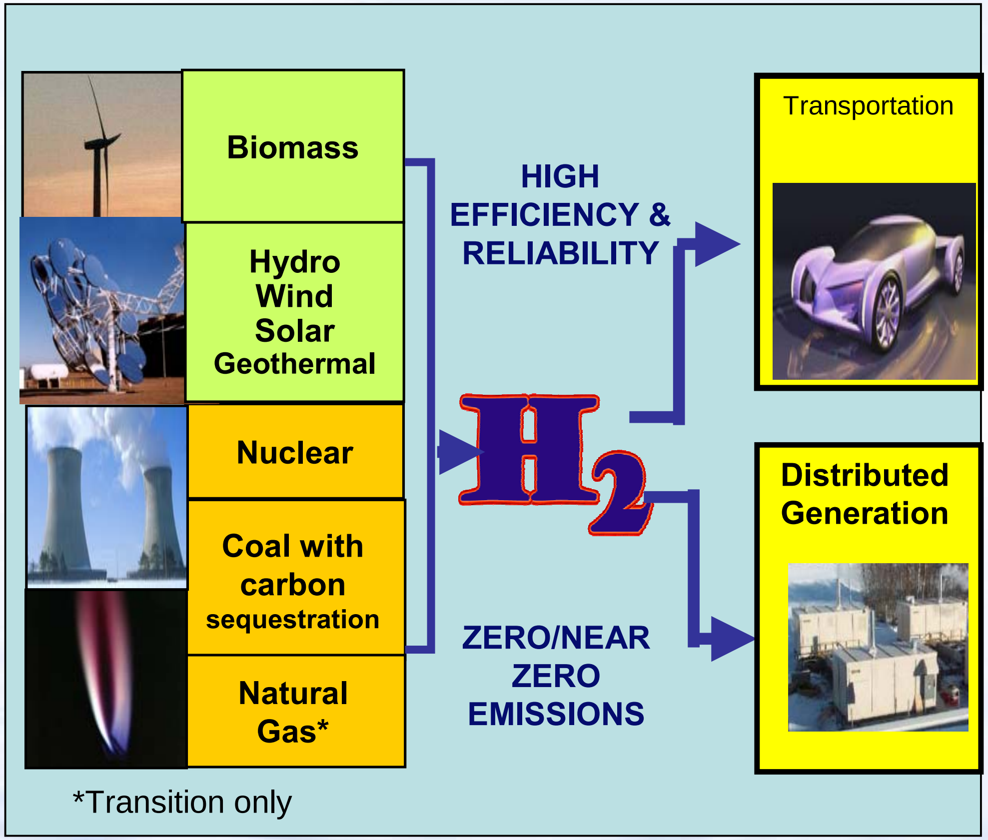
- Only with carbon capture & sequestration
- Gasification process produces hydrogen directly
- Electricity not produced as an intermediary

Natural Gas

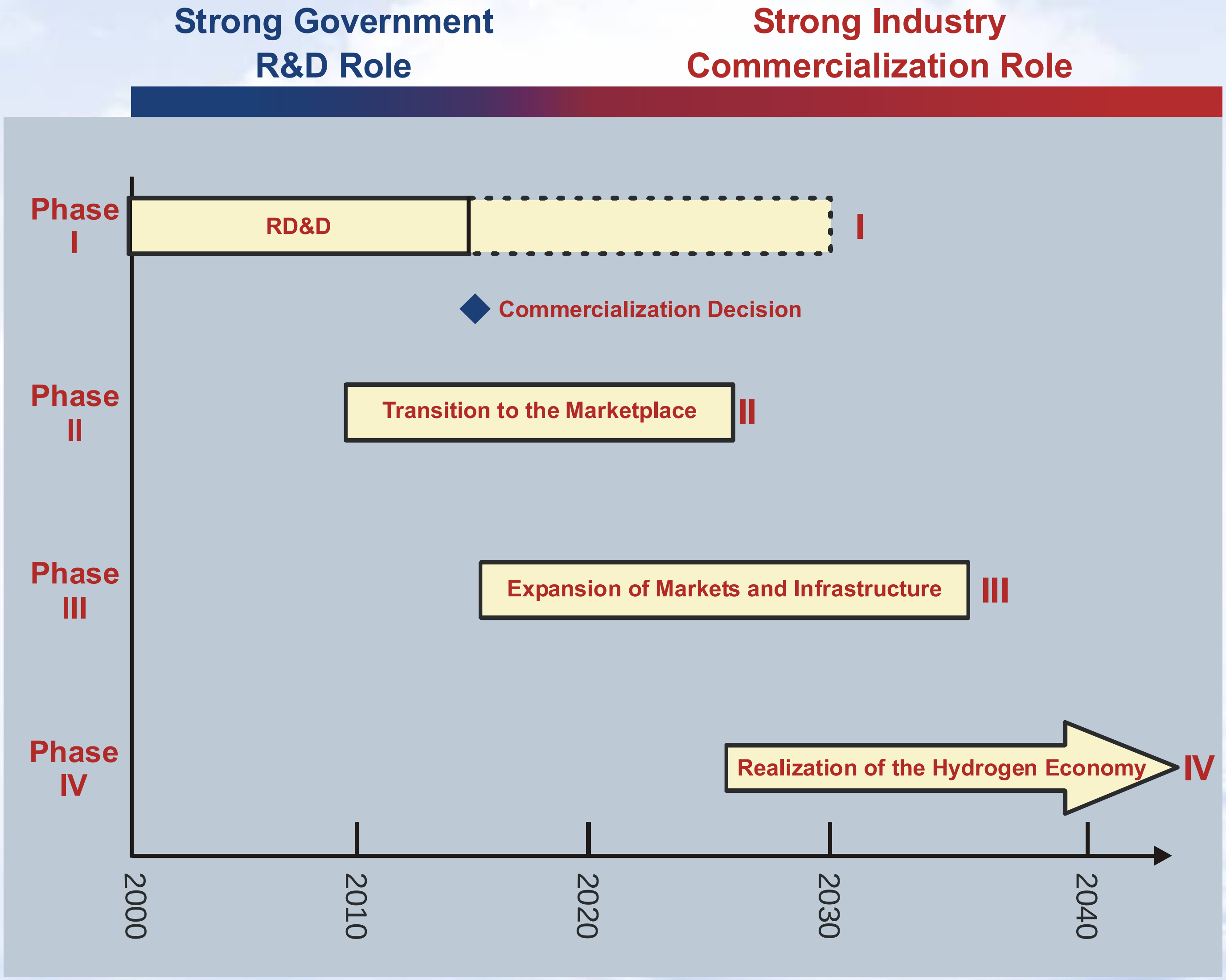
- Transition strategy
- “Well-to-wheels” greenhouse gas emissions substantially less than gasoline hybrid-electric vehicle
- Not a long-term source for hydrogen (imports)

Nuclear/Renewable

- Electrolysis (one option)
- Electricity not necessarily produced as an intermediary, options being pursued include:
  - Gasification of biomass
  - Reforming of renewable liquids
  - Photoelectrochemical
  - Photobiological
  - Thermochemical (solar and nuclear)



Hydrogen Economy Timeline



Transitional Phases

I. Technology Development Phase

II. Initial Market Penetration Phase

III. Infrastructure Investment Phase

IV. Fully Developed Market and Infrastructure Phase

Positive commercialization decision in 2015 leads to beginning of mass-produced hydrogen fuel cell cars by 2020.

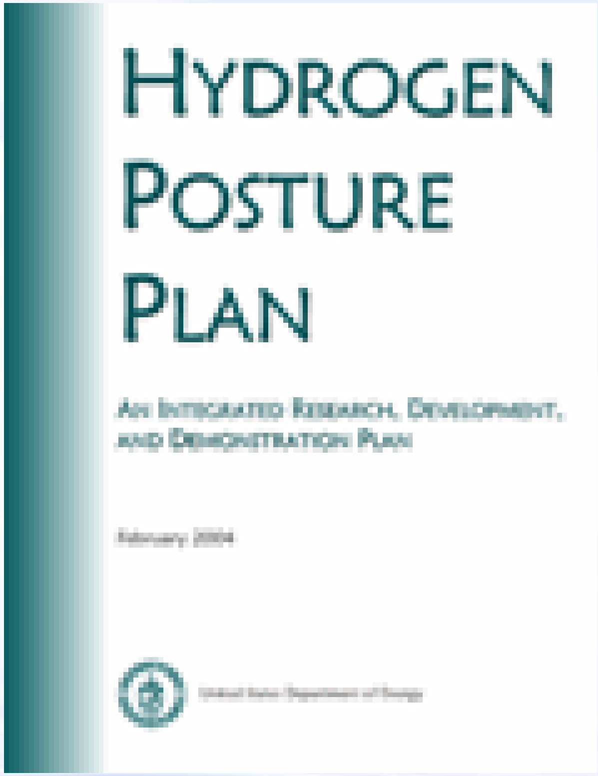
Posture Plan Describes the Research, Development & Demonstration Activities

Critical Path Technology Barriers:

- Hydrogen Storage (>300-mile range)
- Hydrogen Cost ($2.00 - 3.00 per gge)
- Fuel Cell Cost ($30 per kW)

Economic/Institutional Barriers:

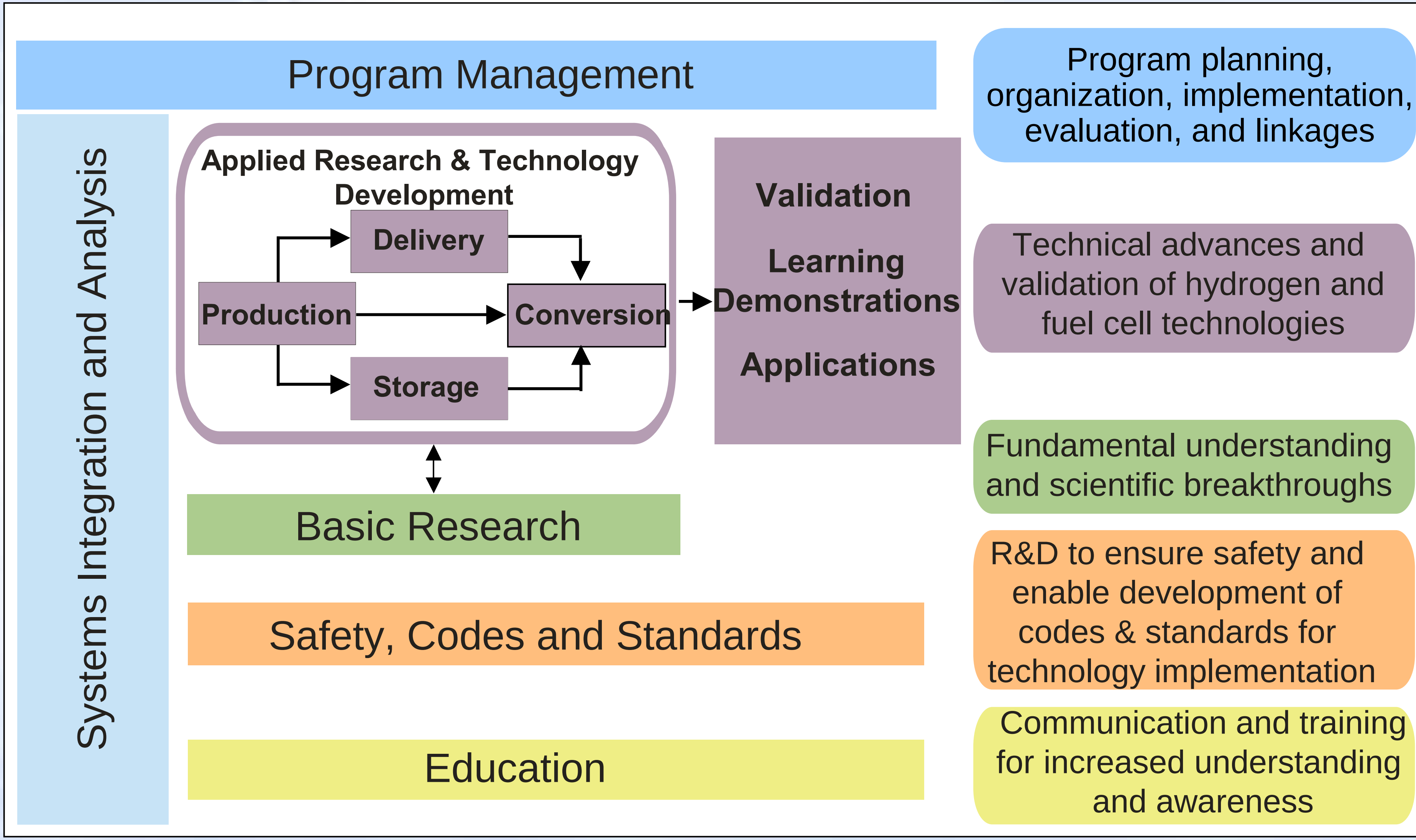
- Codes and Standards (Safety, and Global Competitiveness)
- Hydrogen Delivery (Investment for new Distribution Infrastructure)
- Education



Posture Plan identifies major milestones related to each barrier in an integrated department schedule so that progress can be tracked.

www.hydrogen.energy.gov/pdfs/hydrogen_posture_plan.pdf

Program Implementation



Program Implementation

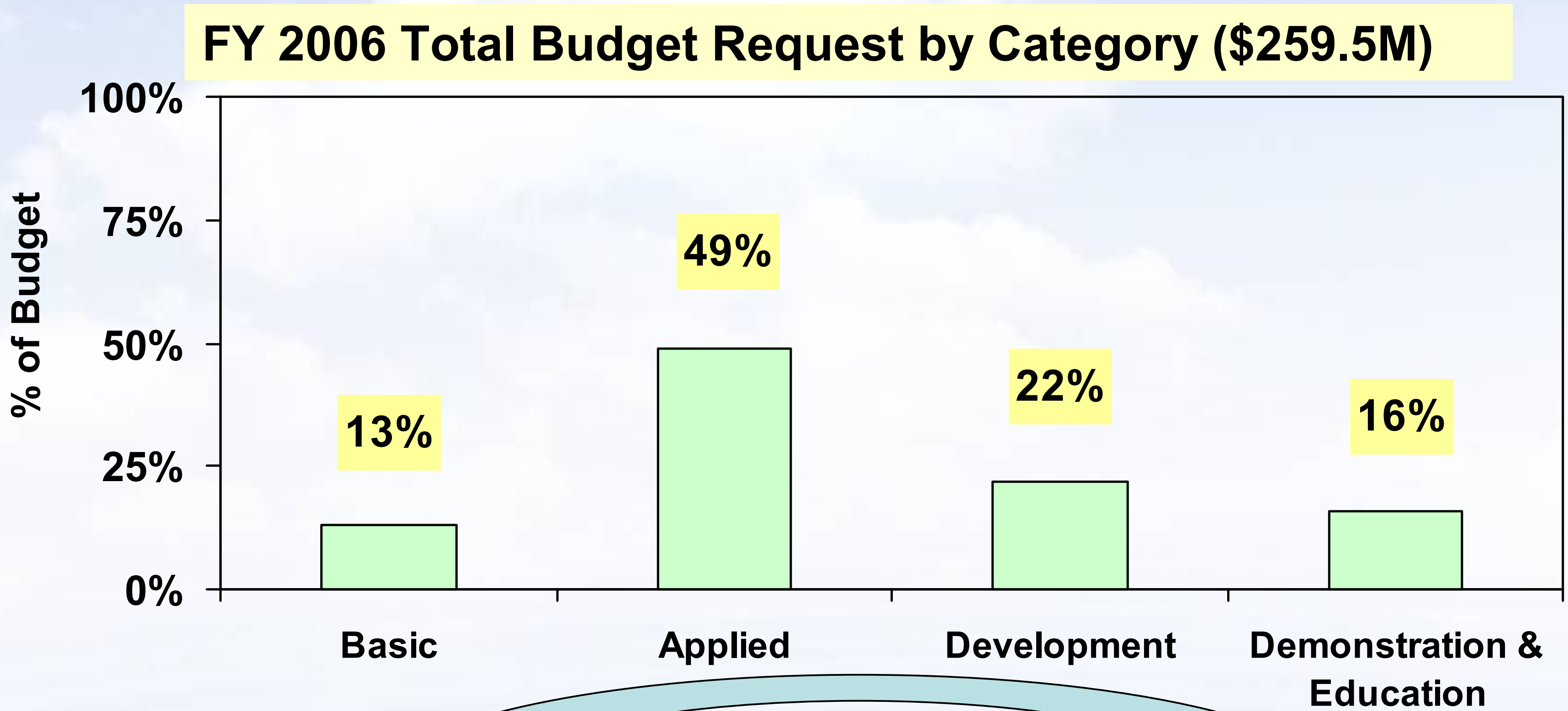
Solicitation	DOE $	No. Awards	Average Cost Share
Basic Research for the Hydrogen Fuel Initiative (FY05)	$21.5M in FY05	To Be Announced Soon	0%
Hydrogen Production and Storage R&D for Coal to Hydrogen (FY05)	$12.7M over 2-3 yrs	11	25%
Hydrogen Utilization for Coal to Hydrogen (FY04)	$1.3M over 2-3 yrs	4	25%
Hydrogen Production for Coal to Hydrogen (FY04)	$2.5M over 5 yrs	5	25%
Nuclear Energy Research Initiative FY05 (Open to Universities Only)	$2.4M over 3 yrs	3	0%
Hydrogen Production & Delivery (FY04)	$77.4M over 3-4 yrs	36	24%

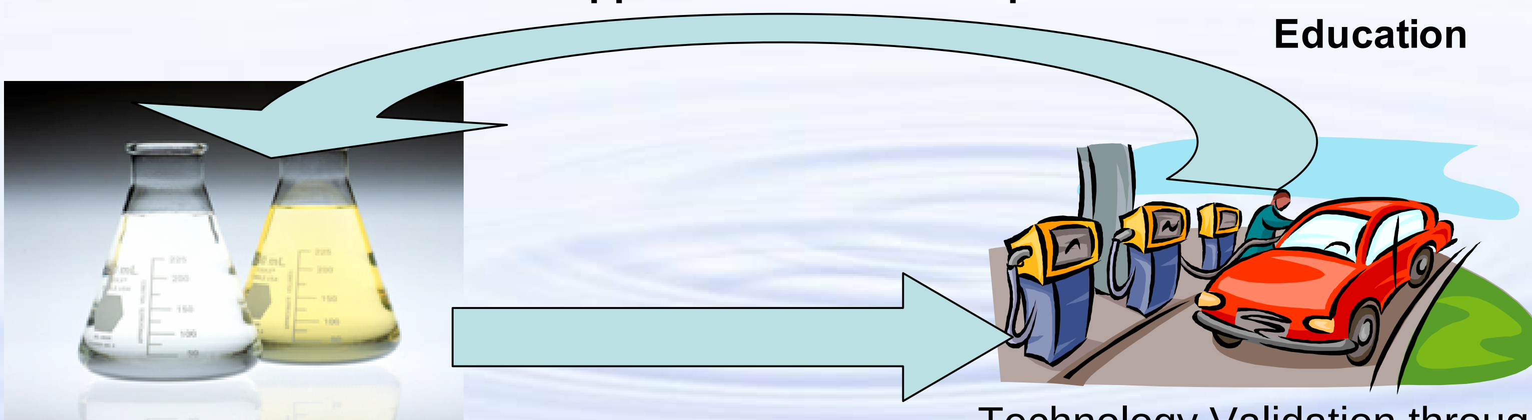
Program Implementation

Solicitation	DOE $	No. Awards	Average Cost Share
National Hydrogen Vehicle/ Infrastructure "Learning Demonstration" (FY04)	$190M over 5 yrs	5 Teams Selected (4 Signed)	50%
Hydrogen Storage Grand Challenge (FY04)	$150M over 5 yrs	3 centers of excellence & 15 independent projects	20%
R&D for Portable Power, APUs & Off-Road Fuel Cell Applications (FY04)	$13M over 3-4 yrs	5	42%
Education (FY04)	$7M over 5 yrs	8 planned	40%

R&D of PEM Fuel Cells for the Hydrogen Economy: FY07 awards	$70M over 3 yrs	**May 26 Meeting Open to Public**	20%
High-Temperature, Low-Humidity Membrane R&D: FY06 awards	$7.5M over 5 yrs	11	20%

Balanced Program Being Implemented

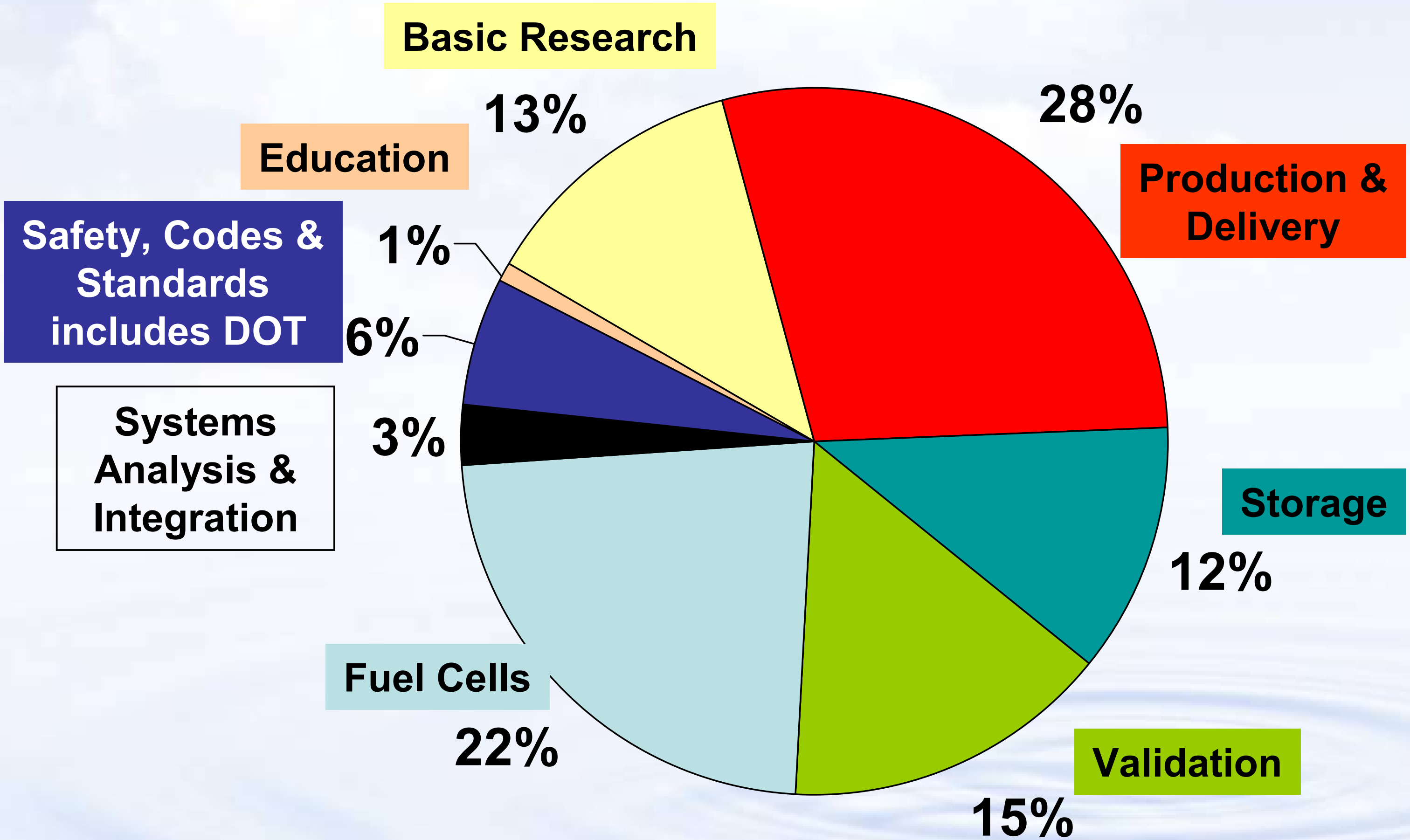




Research & Development

Technology Validation through "Learning Demonstrations"

FY2006 Hydrogen Fuel Initiative Budget Request



DOE FY06 Request
$259.5M

Partnering with Industry for Success

FreedomCAR and Fuel Partnership Accomplishments

- Partnership plan
- New roadmaps
  - Hydrogen Production
  - Delivery
  - Fuel Pathways
- Evaluation
- Goal Changes
  - No-go decision on on-board fuel processing
  - Hydrogen cost goal

Program Changes
Hydrogen Cost Goal Revision

Background: Current Program Hydrogen Cost Target

- The current target is $1.50/gge (untaxed, 2001$) for 2010 (Developed in 2002)
- $1.50/gge is based only on the Distributed Natural Gas Reforming pathway

Principles of the Program New Cost Goal

- The consumer fueling costs are equivalent or less on a cents per mile basis
- The New Cost Goal will be pathway independent
- The Goal was determined through a defined, transparent process
- Gasoline ICE and Gasoline Hybrid Electric vehicles are the benchmarks for comparison to the Fuel Cell Vehicle
- The New Cost Goal will be a “yardstick” for assessing technology and pathway performance

Hydrogen Cost Goal Revision Methodology

$$\text{H2 Cost} \; (\$ / \text{gge}) \leq (\text{EIA Gasoline Price in 2015}) \left[\frac{\text{Fuel Economy H2FCV}}{\text{Fuel Economy Competitive Vehicle}} \right]^{1}$$

Input	Value	Source
Gasoline price projection for 2015	$1.26 / gal (untaxed, 2005 $)	Gasoline price from Hi A Case of EIA Annual Energy Outlook, 2005
Ratio of FCV fuel economy to evolved gasoline ICE	2.40	NRC H2 Economy Report
Ratio of FCV fuel economy to gasoline hybrid	1.66	NRC H2 Economy Report

Results:

- **Hydrogen Cost Goal upper bound = $3.00 / gge**
- **Hydrogen Cost Goal lower bound = $2.00 / gge**

[1] Ratio of FCV fuel economy to competitive vehicle
Hi A-case uses oil price of $34/B

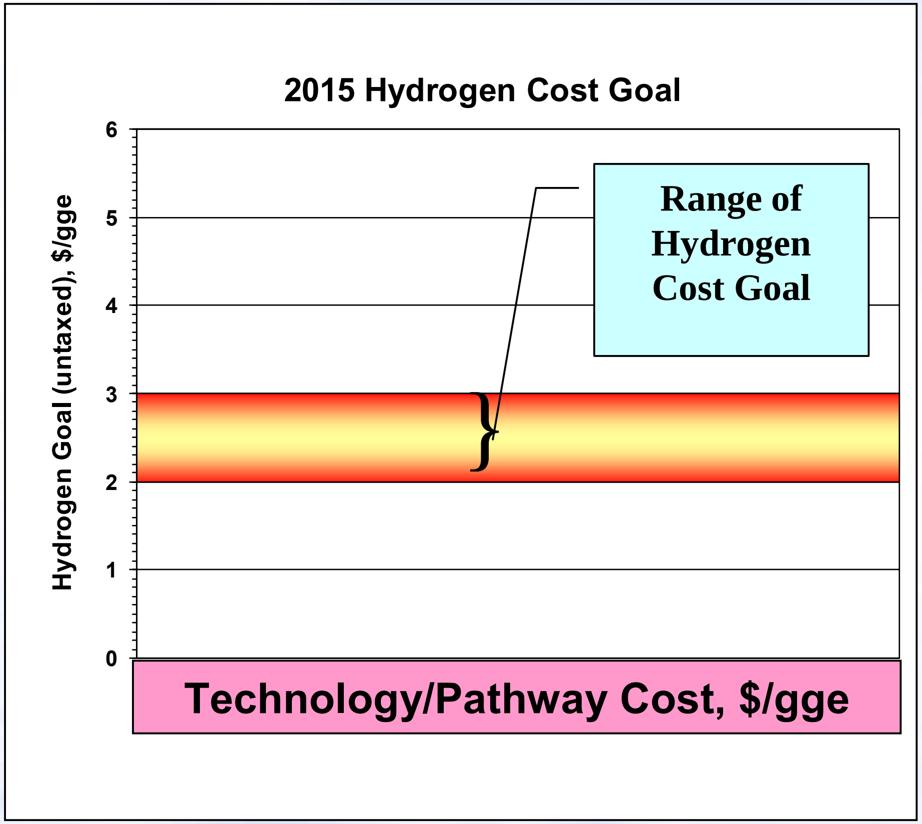
Hydrogen Cost Goal Revision

The new Hydrogen Cost Goal is a range of $2.00 to $3.00/gge (untaxed, 2005$) for 2015

- The upper bound will be $3.00/gge and will be used to assess pathways and technologies for R&D funding
- The lower bound will be $2.00/gge and will be used to guide the R&D to reduce the technology and pathway costs

Key Point is the Methodology

- Competitive with vehicle technologies in 2015
- Competitive with gasoline prices in 2015
- Provides a transparent process for all pathways



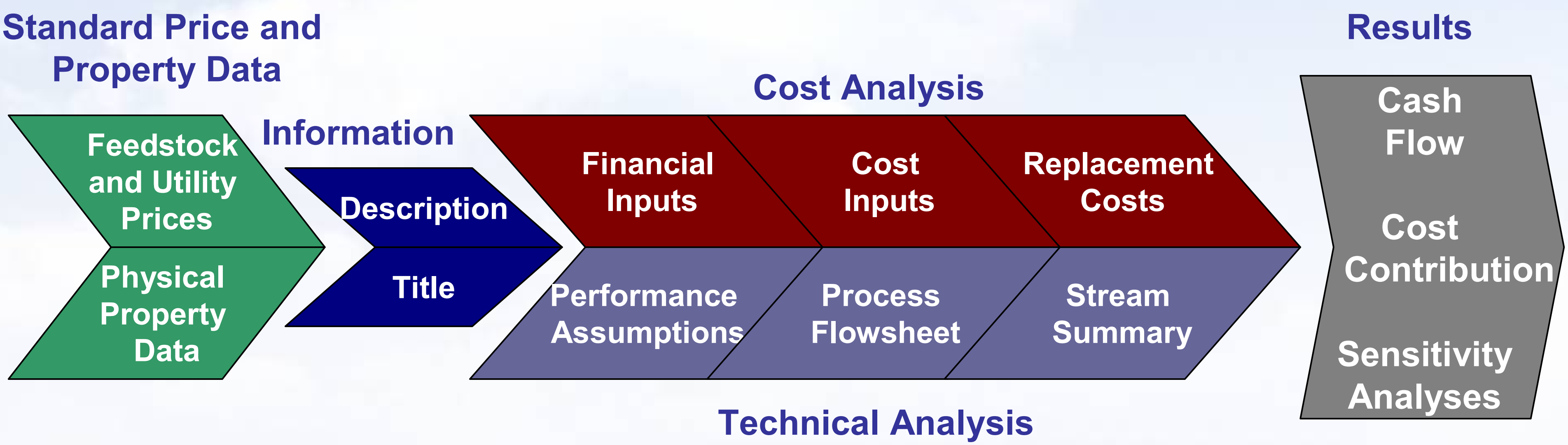
Hydrogen Cost Analysis "H2A" Tool

- Mission
  - Improve the transparency and consistency of analysis
  - Improve the understanding of the differences among analyses
  - Seek better validation from industry
- Purpose
  - R&D portfolio development
  - Provide research direction (Not to be used to pick winners)
- History
  - Began in February 2003
  - Team of twelve analysts from national labs, industry, consulting firms
  - Activities to-date
    - H_2 production cash flow model & case studies
    - H_2 delivery model & scenarios
  - Use of Key Industrial Collaborators

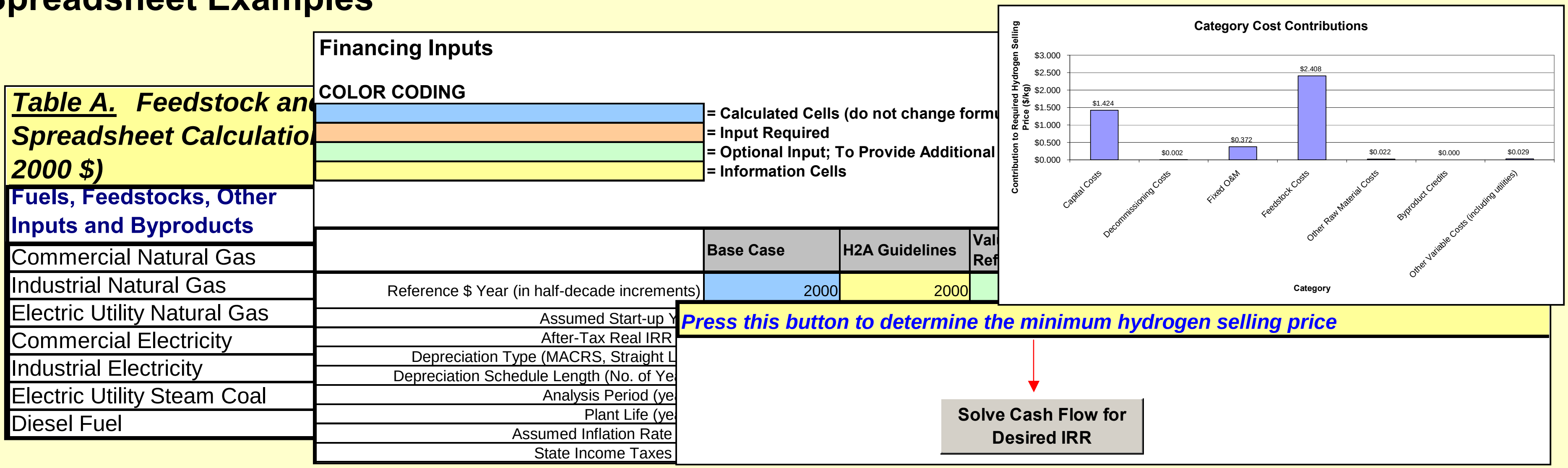
Approach for Production Analysis

- Cash flow analysis tool for Central & Forecourt production
  - Estimates levelized price of hydrogen for desired internal rate of return
  - Takes into account capital cost, construction time, taxes, depreciation, O&M, inflation, and projected feedstock prices
- Production and delivery costs estimated
  - Timeframe definitions: Current, mid- (~2015), and long-term (~2030) for production technologies
    - Natural gas, coal, biomass, nuclear, electrolysis
  - Current delivery components
  - Data from published studies and industry designs
- Refined inputs and results based on peer review, Beta test and input from key industrial collaborators
- Identified key cost drivers using sensitivity analyses

H2A Cash Flow Analysis Modeling Tool



Spreadsheet Examples

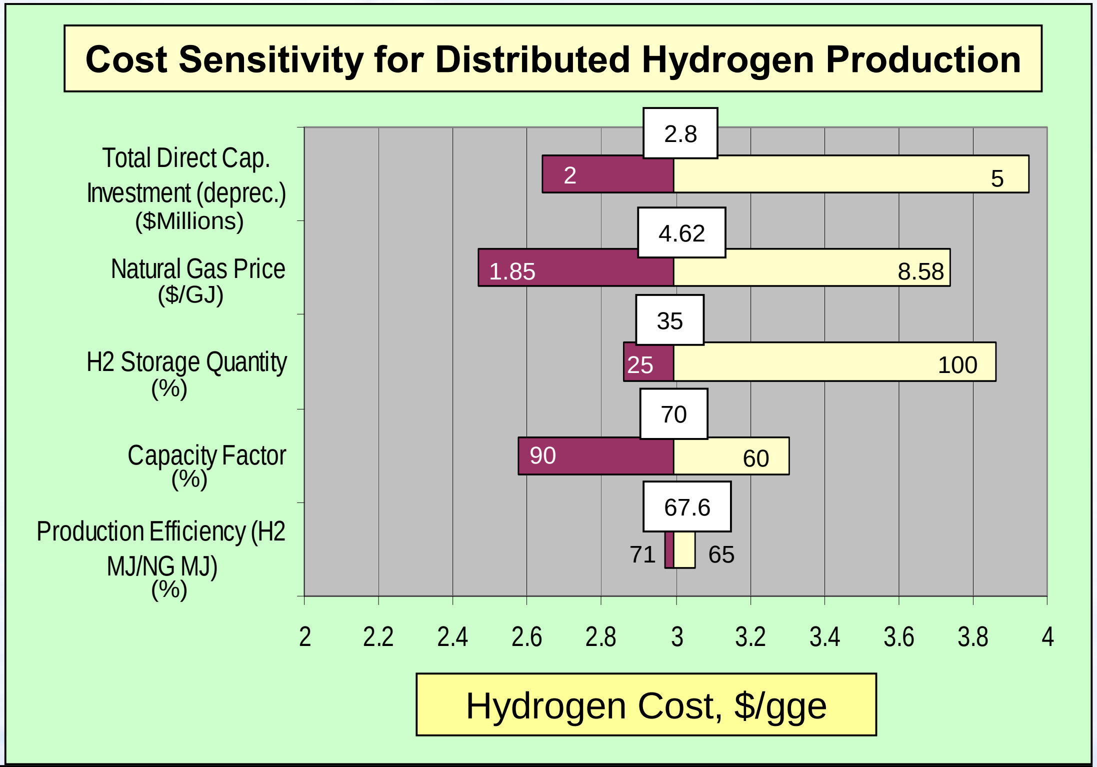


How H2A Tool is to be Used

H2 Cost Model Tool, H2A applications*

- Cost analysis for production technologies (includes "distributed" applications)
- Sensitivity analysis for production technologies
- Generates a "tornado" chart of cost sensitivities
- Research data and "Learning Demonstrations" data will be used to validate model

Tornado Chart of Sensitivity Analysis



Note: Numbers displayed on the chart correspond with the y-axis and the values in the white boxes indicate the baseline value corresponding with the $3/gge hydrogen cost

*H2A cost model, (not a price model) includes feedstock price, fixed and variable operating cost, internal rate of return, capital equipment, depreciation, etc.

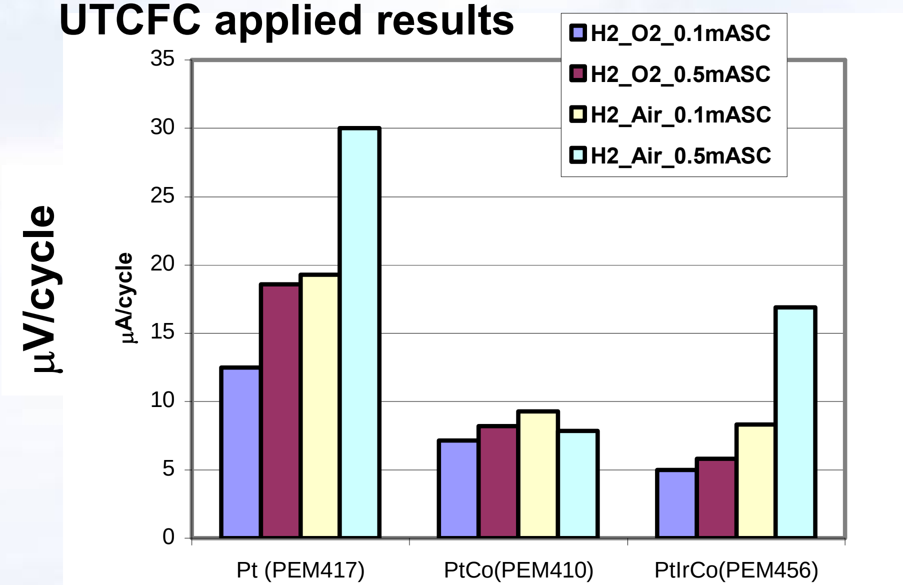
H2A Summary

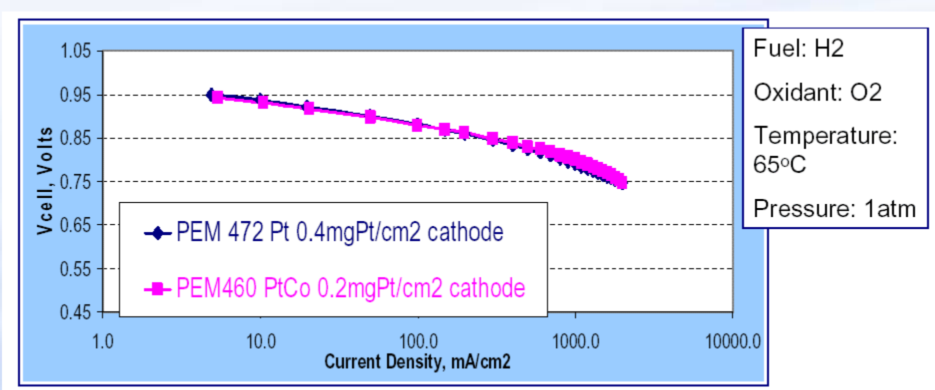
- Primary goal is consistency: Useful for developing consistent assumptions and approach
- Modeling tools:
  - Available for production analysis (after beta testing)
  - Delivery scenario analysis (by end of FY05)
  - Provides capability to evaluate sensitivity cases for production and delivery
- Beta test for several central and forecourt cases completed
- Delivery H2A models under development
- H2A is a tool to evaluate whether cost target can be met

Fuel Cell Improvements: Pt Alloy Catalysts

United Technologies has solidified durable 2x activity gain vs. Pt in membrane-electrode assemblies

UTCFC applied results





Alloy catalysts give smaller activity losses and Pt area losses than pure Pt in accelerated testing

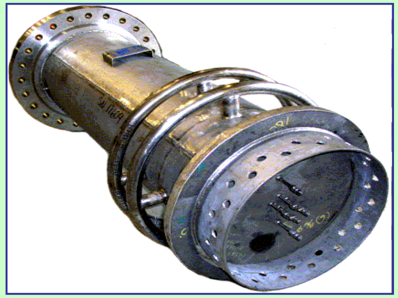
- Square wave cycling 0.87 – 1.2V emulates shutdown/startup & local fuel starvation

½ of Pt loading without sacrifice in performance is allowed with $Pt_{.75}Co_{.25}/C$ system

Recent Technical Accomplishments in Production Technologies

Distributed Natural Gas Reforming

Approaching R & D target of $3/gge for distributed natural gas reforming at 5000 psi.



GE High-Pressure Autothermal Cyclic Reforming Reactor

Electrolysis

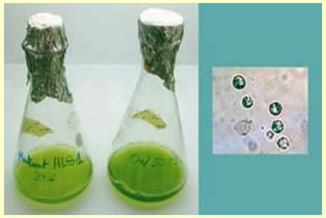
Developed new system designs with 40-50% part count reduction

Novel stack design for alkaline system on track for achieving a hydrogen production cost $2.85/gge by 2010

Teledyne HP TITAN™ HP generator

Biological

40-50% increase in oxygen tolerance achieved



Measuring photosynthetic productivity of micro-algae (NREL)

Lab scale testing of semiconductors (NREL)

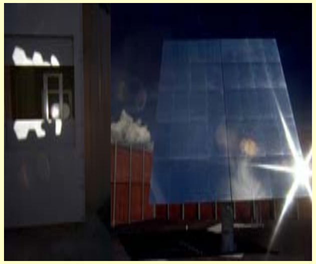
PEC

Projected 1000 hours durability with new gallium phosphide nitride material based on accelerated testing

Solar HT Thermochemical

Demonstrated lab feasibility of zinc & manganese cycles

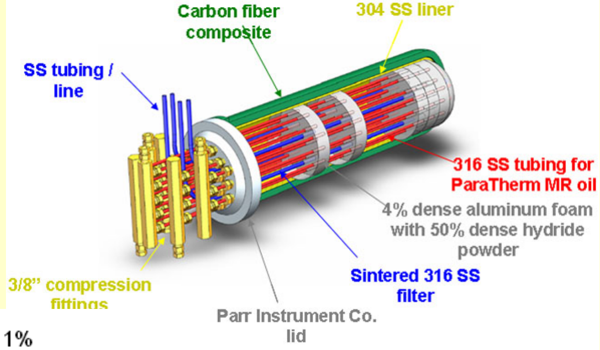
Selected 4 groups of cycles (Volatile metal, metal oxide, sulfate, sulfuric acid)

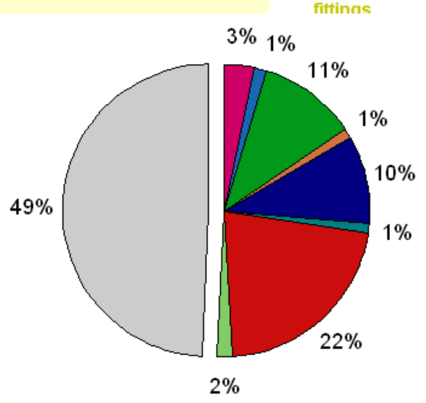


Recent Technical Accomplishments
Hydrogen Storage

1st Gen System Prototype

- Preliminary 1-kg hydrogen system prototype developed based on sodium alanate
- With composite vessel, ~50% of system is balance of plant





- Prototype gravimetric & volumetric capacity reinforce need for high-capacity materials
- Thermal management, and reaction kinetics strongly impact weight & volume

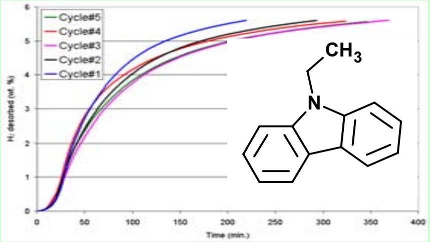
660 Wh / kg **530 Wh / L**

Anton, Moser et al, UTRC

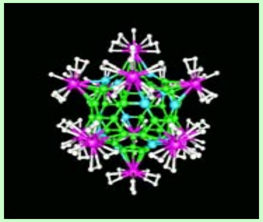
High Capacity Materials > 5 wt%

- Mg modified Li-amides: 5 wt% reversible (material) capacity, with potential to 10 wt%. Absorption demonstrated down to 180C, >100 cycles demonstrated ***(Luo, Wang, Gross et al, SNL)***

- Identified chemical hydride with 5.5 - 7 wt% materials storage capacity **(Cooper, Pez et al, APCi)**



- Optimum compounds predicted for potential storage materials ~ 6 to 8 wt% material **(Heben, Dillon et al NREL)**



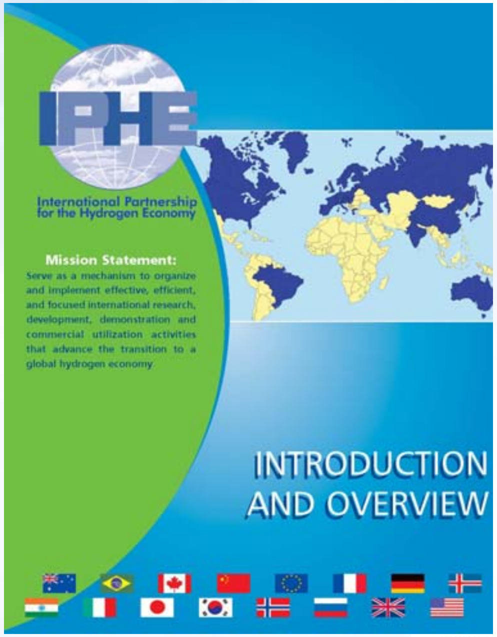
Future R&D Opportunities
Manufacturing R&D for the Hydrogen Economy

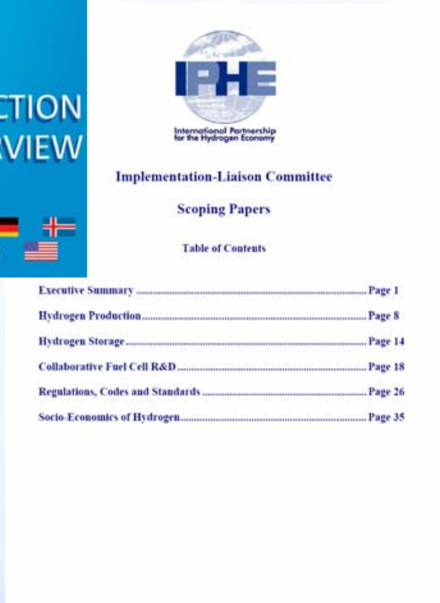
Manufacturing challenges:

- Develop low-cost, high-volume fabrication methods for new materials & components
  - ✓ Adapt laboratory fabrication to low-cost, high-volume production
  - ✓ Establish and refine cost-effective manufacturing techniques while hydrogen products are still evolving
- Meet customer requirements for hydrogen systems
- Address the diversity and size of industries in both the manufacturing and energy sectors
- Enable development of supplier networks

Manufacturing Roadmap Workshop
July 13-14, 2005
Washington, DC
Points of Contact:
J. Milliken
P. Devlin
G. Sverdrup

International Partnership for the Hydrogen Economy (IPHE)





IPHE

International Partnership for the Hydrogen Economy

Implementation-Liaison Committee

Scoping Papers

Table of Contents

Vision:

"… consumers will have the practical option of purchasing a competitively priced hydrogen powered vehicle, and be able to refuel it near their homes and places of work, by 2020."

- Secretary Abraham, April 2003

Partners' Economy:

> $35 Trillion, 85% of world GDP

~ 3.5 billion people

> 75% of worldwide electricity used

> 2/3 of energy consumption and CO2 emissions

Current Status: Evaluating 30 projects for IPHE cooperation.

Upcoming IPHE events

May	Jun	Jul	Aug	Sept	Oct

IPHE/IEA PEM Fuel Cell Workshop
Jun 1-3
Mol, Belgium

IPHE Socio-Economic Task Force
Jun 39
Paris

IPHE Hydrogen Storage International Conference
Jun 20-22
Italy

International Conference on Hydrogen Safety
Sept 8-10
Pisa, Italy

Hydrogen from Renewable Sources IPHE Conference
Oct 24-26
Seville, Spain

www.iphe.net

Purpose of Merit Review & Peer Evaluation

- A peer review panel will evaluate the results of Fiscal Year ‘05 DOE-funded research projects
- The strengths and weaknesses identified by the panel will be used by DOE to make FY06 funding decisions
- End of year progress will be documented in FY05 DOE Hydrogen Program Annual Progress Report

Merit review findings and the annual progress report will be published in the Fall ’05.

Structure of Meeting

2005 Hydrogen Program Annual Review Block Schedule — **Monday, May 16, 2005**

Monday Session A (Salons V&VI)	Monday Session B (Salons B&C)	Monday Session C (Salons I&II)	Tuesday Session A (Salons V&VI)	Tuesday Session B (Salons B&C)	Tuesday Session C (Salons I&II)	Wednesday Session A (Salons V&VI)	Wednesday Session B (Salons B&C)	Wednesday Session C (Salons I&II)	Thursday Session A (Salons V&VI)	Thursday Session B (Salons B&C)	Thursday Session C (Salons I&II)
Plenary Session			P&D	ST	FC	P&D	ST	FC	ED	S,C&S	FC
			P&D	ST	FC	P&D	ST	FC	ED	S,C&S	FC
			P&D	ST	FC	P&D	ST	FC	AN	S,C&S	FC
			P&D	ST	FC	P&D	TV	FC	AN	S,C&S	FC
			Break	Break	Break	Break	Break	Break	Break	Break	Break
			P&D	ST	FC	P&D	TV	FC	AN	S,C&S	FC
			P&D	ST	FC	P&D	TV	FC	AN	S,C&S	FC
			P&D	ST	FC	P&D	TV	FC	AN	S,C&S	FC
			P&D	ST	FC	P&D	TV	FC	AN	S,C&S	FC
Lunch (12:00-1:45)			Lunch (12:00-1:15)			Lunch (12:00-1:15)					
P&D	ST	FC	P&D	ST	FC	P&D	TV	FC			Fuel Cell R&D Workshop
P&D	ST	FC	P&D	ST	FC	P&D	TV	FC			
P&D	ST	FC	P&D	ST	FC	P&D	TV	FC			
P&D	ST	FC	P&D	ST	FC	P&D	TV	FC			
Break	Break	Break	Break	Break	Break	Break	Break	Break			
P&D	ST	FC	P&D	ST	FC	P&D	TV	FC			
P&D	ST	FC	P&D	ST	FC	P&D	TV	FC			
P&D	ST	FC	P&D	ST	FC	ED	TV	FC			
P&D	ST	FC	P&D	ST	FC	ED	TV	FC			
P&D	ST	FC	P&D	ST	FC	ED	TV	FC			

Storage Center of Excellence Posters (4:00 to 7:00 in Salon K)	Reception/Poster Session at the DAR (6:00-8:30)

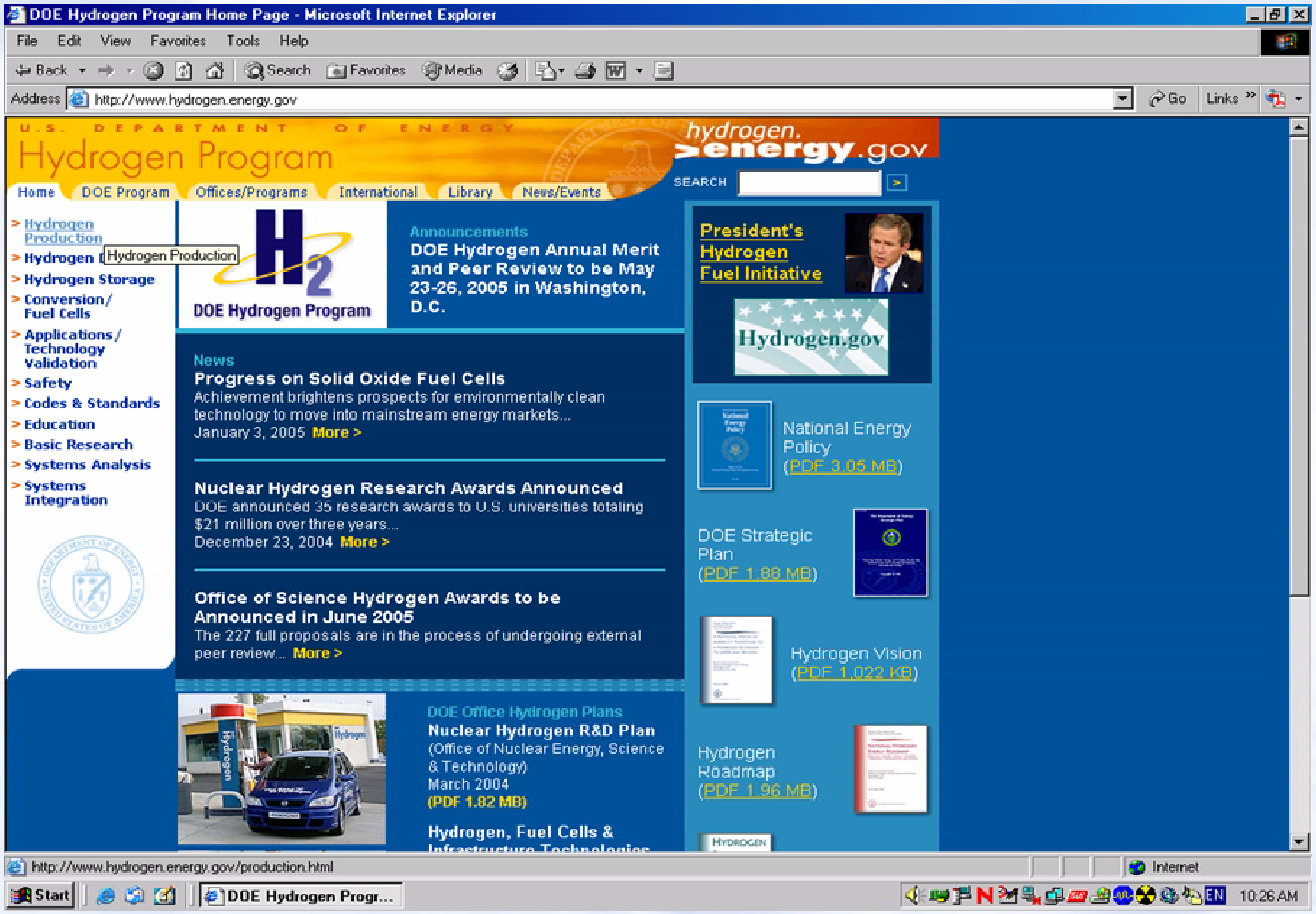
Note: Additional posters will be on display in the Hotel all during the Review

P&D	Production and Delivery
ST	Storage
FC	Fuel Cells
TV	Technology Validation
ED	Education
S,C&S	Safety, Codes and Standards
AN	Analysis

- Program requirements presentation (DOE EE/FE/NE)
- Basic R&D needs (DOE-Sc)
- Project Presentations
- Projects evaluated by peer panel using 5 criteria:
  - Relevance to overall DOE objectives
  - Approach to performing the R&D
  - Technical accomplishments and progress towards DOE goals
  - Technology transfer/collaborations
  - Approach & relevance of proposed future work

For More Information

www.hydrogen.energy.gov



Interagency Information:

www.hydrogen.gov