A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Hydrogen Technology Analysis: H2A Production

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Agenda

- **Hydrogen Overview**
- *H2A Model*
- *H2A Case Studies*

Hydrogen is an Energy Carrier

- Hydrogen is not mined or drilled
- Hydrogen is more like electricity than gasoline
- Both a plus and a minus for hydrogen



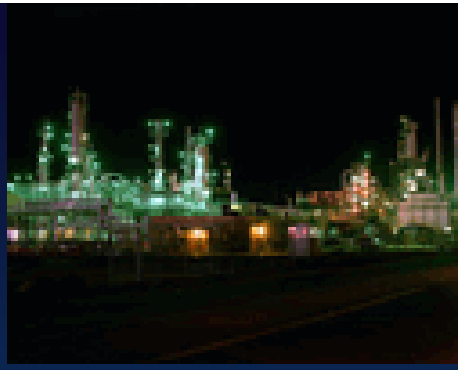









Definition: Gallon of Gasoline vs. Kilogram Hydrogen



- Gasoline
  - ✓ 108,000 – 123,500 BTU/gal
- Hydrogen
  - ✓ 116,000 BTU/kg
- 1 kilogram of hydrogen ≈ 1 gallon of gasoline
- One caveat, if fuel cells are twice as efficient as gasoline internal combustion engines then only half the amount of hydrogen would be needed
  - – Twice the mileage with hydrogen, so double the cost would be accepted

Vocabulary

- H2A = Hydrogen Analysis
- Modeling tool (Model)
- Case studies
  - Short term = today until 2010
  - Mid term = 2010 – 2020
  - Long term = 2020 – 2030 or best case scenario in the future
- Central production
- Forecourt production
  - Forecourt = Filling Station
- GGE – gallon of gasoline equivalent
- Profited Cost

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H2A Mission

Improve the transparency and consistency of analysis, improve the understanding of the differences among analyses, and seek better validation from industry.

With H2A, studies are more likely to be:

- **Consistent**
- **Transparent**
- **Comparable**

H2A Background

- Purpose
  - Analysis portfolio development
  - Provide research direction
- History
  - Began in February 2003, financial support from U.S. DOE
  - Team of analysts from labs, industry, consulting firms, and universities
  - Use of Key Industrial Collaborators (KIC)

Partners, Interactions, Collaboration

- **H2A team:** DOE, NREL, Technology Insights, Parsons Engineering, Directed Technologies, Inc., TIAX, ANL, UC Davis, PNNL
- **Key Industrial Collaborators:** AEP, Air Products, Areva, BOC, BP, ChevronTexaco, Conoco Phillips, Eastman Chemical, Entergy, Exxon Mobil, FERCO, GE, Praxair, Shell, Stuart Energy, Thermochem
- **Feed to and feedback from**: OnLocation, ORNL, ANL, DOE PBA, DOE FE, DOE NE, LLNL Markal, EPA

Model Approach

- Excel spreadsheet
- Discounted cash flow rate of return analysis
- Provides the levelized selling price of hydrogen required to attain a specified internal rate of return
  - i.e., minimum hydrogen price or profited cost (***not*** market price)
- Model is meant to be a means of *reporting* assumptions as well as *calculating* minimum hydrogen selling price
- Transparency is absolute
- Assumptions easy to obtain

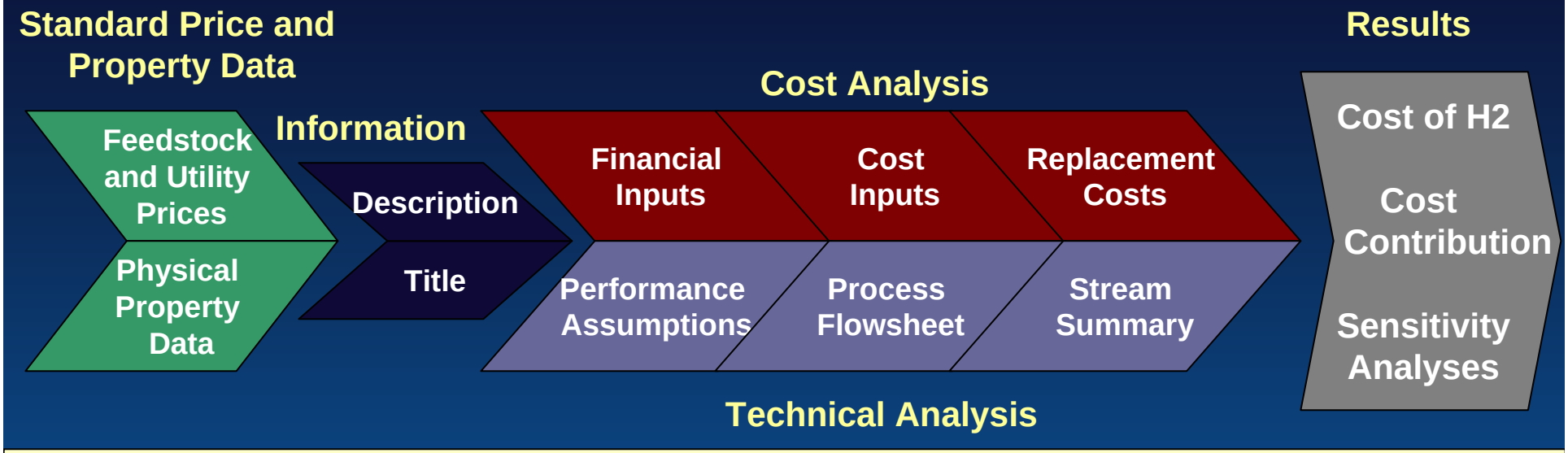
H2A Tool Features

- Color-coded to facilitate user input

	Calculated Cells
	User Input Required
	Optional Input
	Information

- Yes/no toggle switches to allow for user input or H2A standard input
  - Inputs turn on/off based on yes/no toggle switch
- Error messages included to alert user when input errors are made
- Documentation is provided on website for model support

H2A Cash Flow Modeling Tool



Spreadsheet Examples

Table A. Feedstock an
Spreadsheet Calculatio
2000 $)

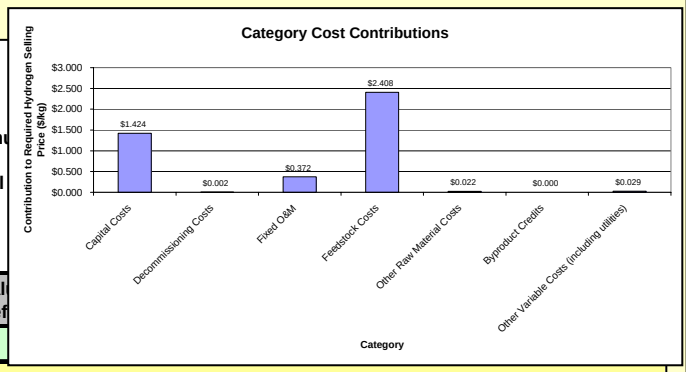
Fuels, Feedstocks, Other Inputs and Byproducts
Commercial Natural Gas
Industrial Natural Gas
Electric Utility Natural Gas
Commercial Electricity
Industrial Electricity
Electric Utility Steam Coal
Diesel Fuel

Financing Inputs

COLOR CODING

= Calculated Cells (do not change formu
= Input Required
= Optional Input; To Provide Additional
= Information Cells

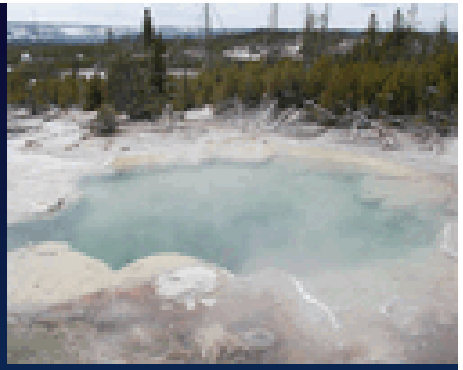
	Base Case	H2A Guidelines	Val Ref
Reference $ Year (in half-decade increments)	2000	2000	
Assumed Start-up Y			
After-Tax Real IRR			
Depreciation Type (MACRS, Straight L			
Depreciation Schedule Length (No. of Ye			
Analysis Period (ye			
Plant Life (ye			
Assumed Inflation Rate			
State Income Taxes			



Press this button to determine the minimum hydrogen selling price

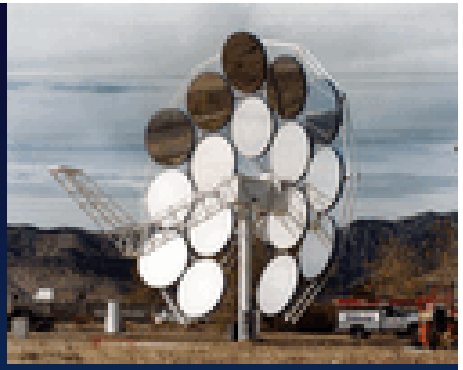
Solve Cash Flow for Desired IRR

Key Financial Parameters Forecourt and Central



- Reference year (2005 $)
- Debt versus equity financing (100% equity)
- After-tax internal rate of return (10% real)
- Inflation rate (1.9%)
- Effective total tax rate (38.9%)
- Design capacity (varies)
- Capacity factor (90% for central (exc. wind); 70% for forecourt)
- Length of construction period (0.5 – 3 years for central; 0 for forecourt)
- Production ramp up schedule (varies according to case)
- Depreciation period and schedule (MACRS -- 20 yrs for central; 7 yrs for forecourt)
- Plant life and economic analysis period (40 yrs for central; 20 yrs for forecourt)
- Cost of land ($5,000/acre for central; land is rented in forecourt)
- Burdened labor cost ($50/hour central; $15/hour forecourt)
- G&A rate as % of labor (20%)

Cash Flow Calculation



- Selling price of hydrogen varied until IRR = that which is specified (10% is H2A base case)
- IRR function calculates the interest rate at which the NPV=0
  - i.e., the present value of the sum of the cash flows = 0
- After-tax, post-depreciation cash flow
- Items in cash flow calculation:
  - Debt payments, taxes, depreciation, construction, working capital, capital replacement costs, equity capital, H2 revenue, byproduct revenue, operating costs, inflation
- Important functionality: Inputs can be changed by user

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Case Studies: Central Technologies

	Coal Gasification	Coal Gasification w/CO2 Sequestration	Coal Gasif w/CO2 Seq & Power Co-production	Biomass Gasification
Current	Conventional	Conventional	Conventional	Distinct
Mid term		+Membrane Separation	+Membrane Separation	Advanced Distinct
Long term		+Adv Materials	+Adv Separation	Integrated

	Natural Gas Reforming	Nat Gas Reforming w/CO2 Sequestration	Current Nuclear Electrolysis	Advanced Nuclear
Current	Conventional	Conventional		
Mid term		+ Autothermal OTM	High Pressure	
Long term		+Advanced Separation	Steam Electrolysis	SI Thermo-chemical

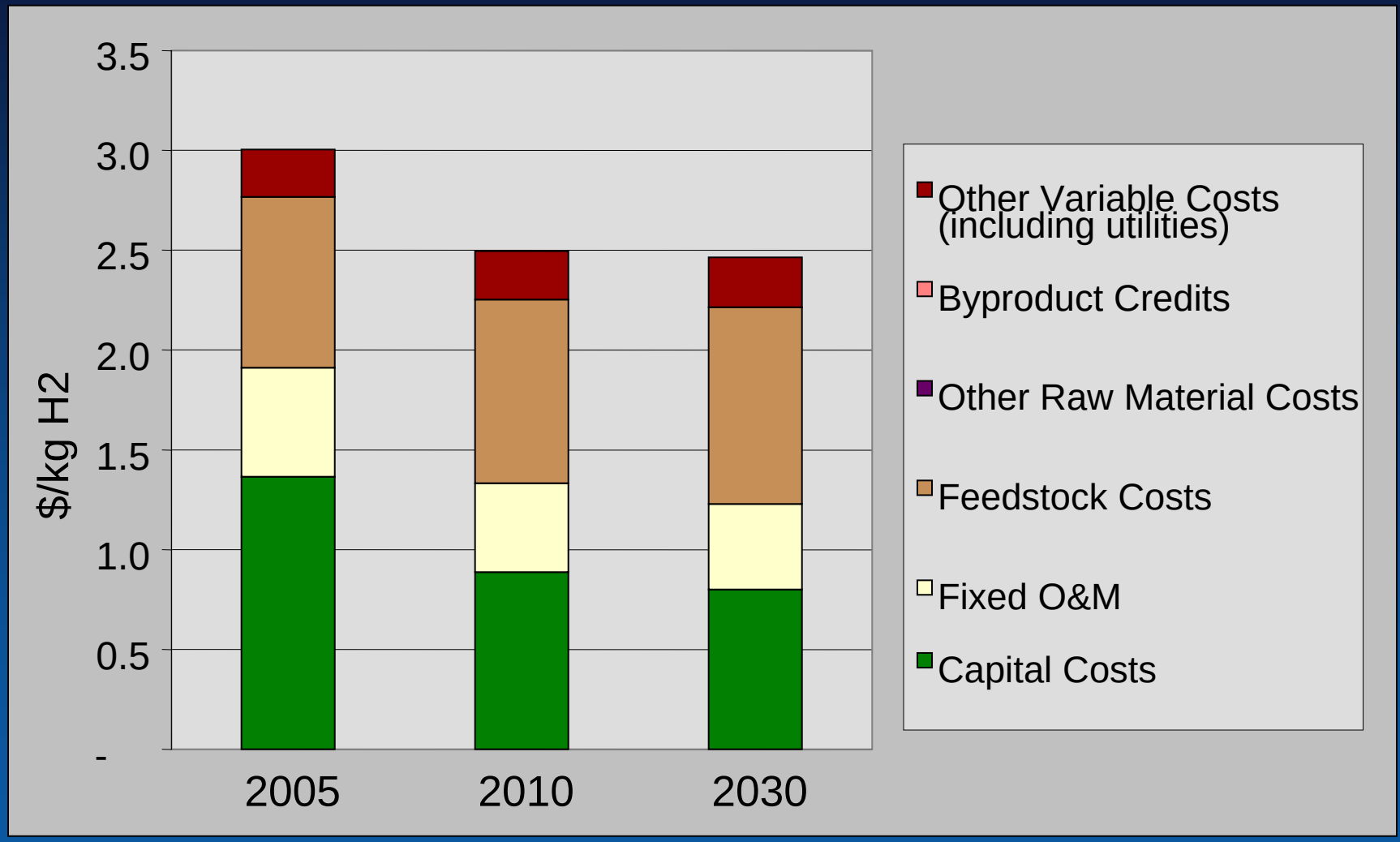
	Stand-alone Wind Electrolysis	Wind Electrolysis w Power Co-production
Current	Atmospheric	Atmospheric
Mid term	High Pressure	High Pressure
Long term	High Pressure	High Pressure

Case Studies: Forecourt Technologies

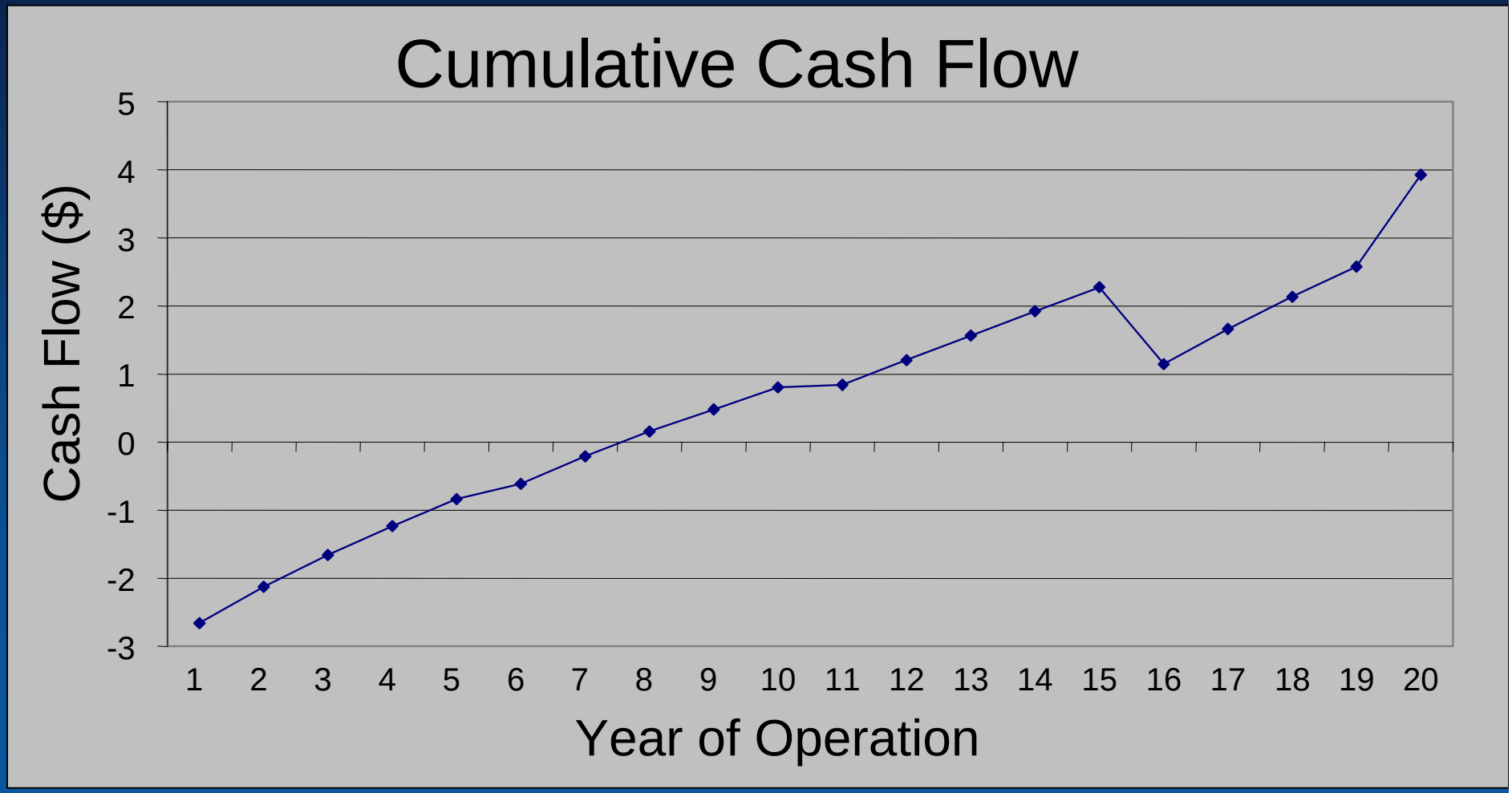
Type of Station	Small (100 kg/day)	Large (1,500 kg/day)	Current Technology / Design Assumptions
Natural Gas Reformer	X	X	SMR with PSA cleanup, 6250 psi piston compressors, cascade dispensing
Methanol Reformer	X	X	Comparable to SMR design, low temperature
Ethanol Reformer	X	X	Comparable to SMR design
Electrolysis	X	X	Electrolyzer, 6250 psi piston compressors, cascade storage and dispensing

Note: All cases include assessment of current, mid-term, and long-term technologies.

Example Case Study

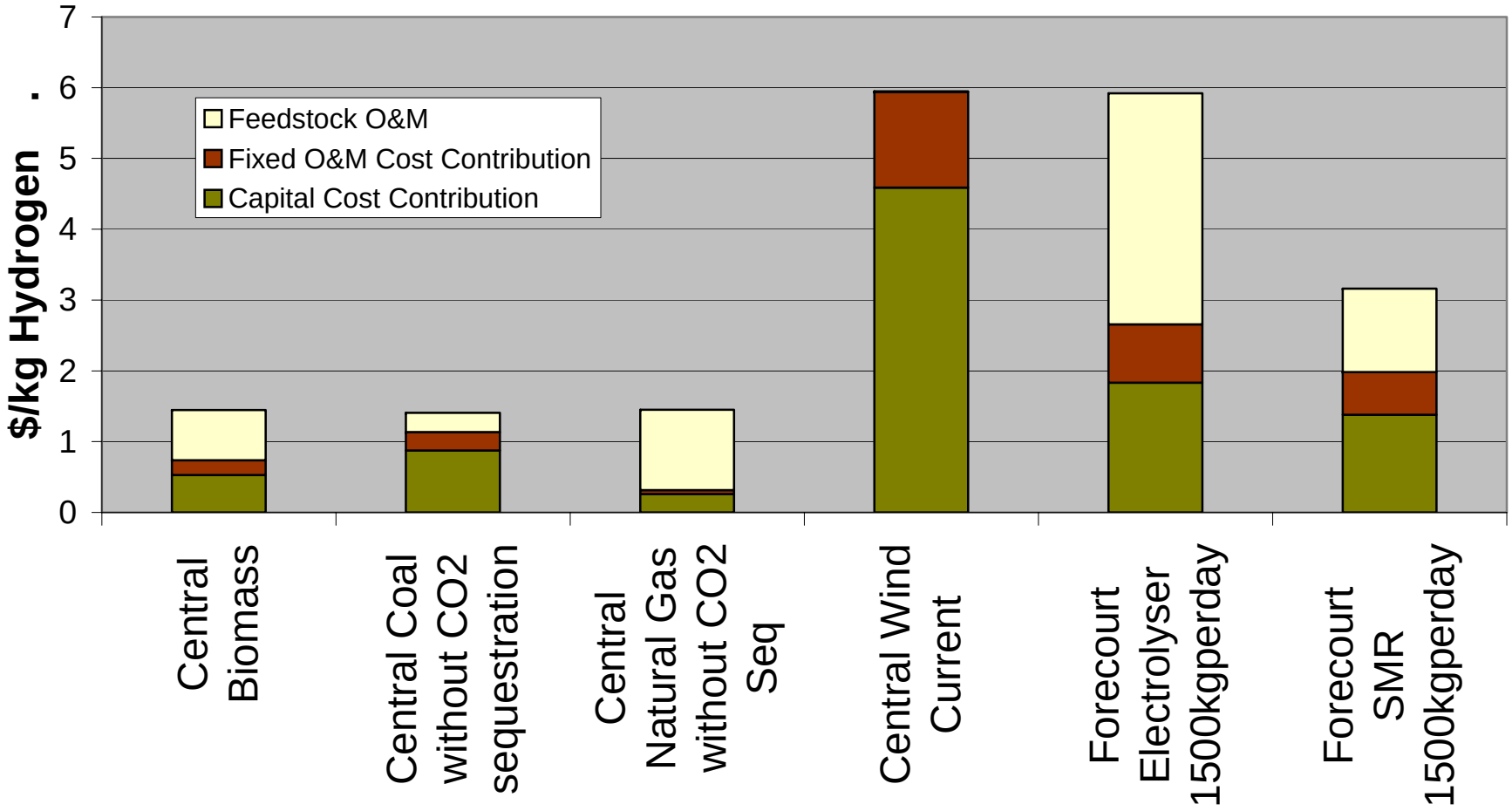


Sample Project Cash Flow



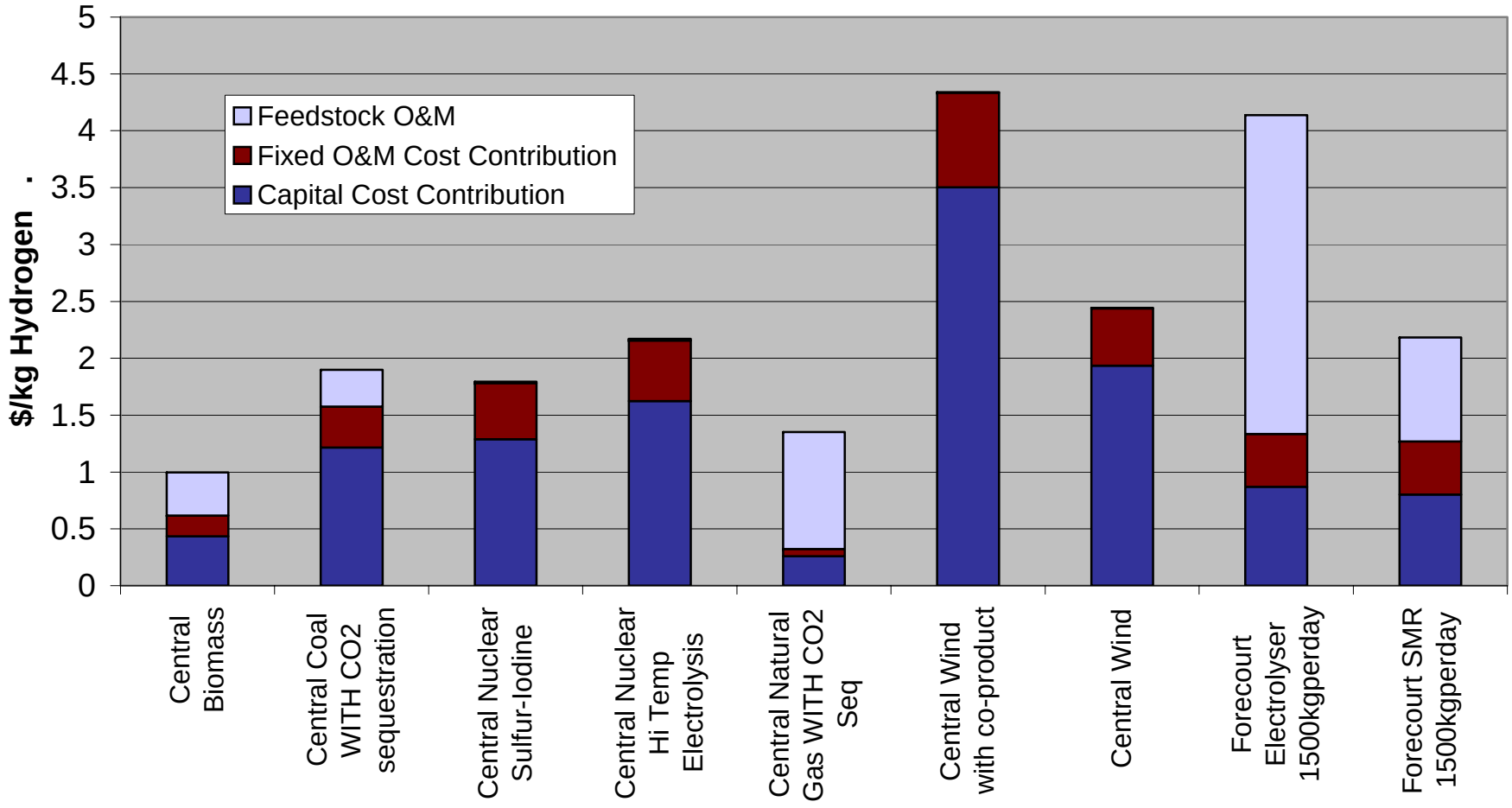
H2A Current Technology Results

Profited Cost Contributions, Current Technology Status, 10% IRR



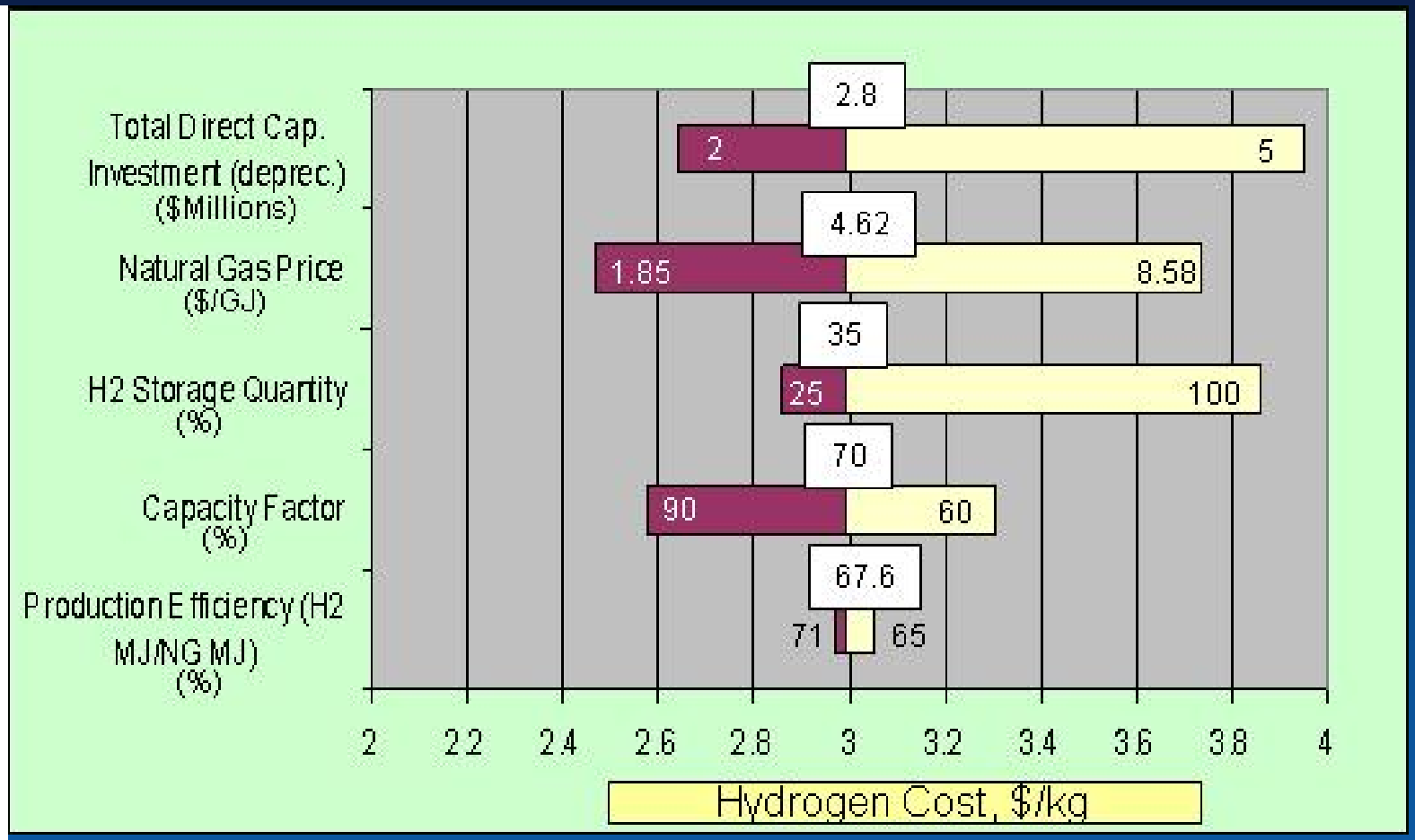
H2A Longer-Term Technology Results

Profited Cost Contributions, Longer Term Technologies, 10% IRR



Sample Sensitivity Analysis

Distributed Steam Methane Reforming



"Tornado" Chart: Single-parameter sensitivity

H2A Model Evolution

- Production capacity scaling function
- Update production cases with new R&D data
  - Reconvene H2A group
- Automate sensitivity analysis calculations & graphing
- Yearly-variable demand, plant availability, operating costs, performance, fuel switching
- Perform Monte Carlo sensitivity analyses on existing cases
- Examine feedstock and utility costs on a regional basis

H2A Model Availability

www.hydrogen.energy.gov/h2a_analysis.html

- H2A production cash flow model
- Current (2005) cases
- Delivery components model
- Delivery scenario model

H2A Production Questions:

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