Production Pathways & Targets (EERE)

- Dist. Natural Gas
- Dist. Electrolysis
- Dist. Bio-Derived Renewable Liquids
- Central Wind Electrolysis
- Solar-Driven High-Temp. Thermochemical Cycle
- Biomass Gasification

The graph shows the cost changes over the years from 2003 to 2017 for different production pathways and targets. The costs are indicated in dollars, with a range from $0.00 to $14.00.
Delivery Goals and Objectives

By 2017, develop technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/kg of hydrogen

• By 2007, define the criteria for a cost-effective and energy-efficient hydrogen delivery infrastructure.
• By 2010, develop technologies to reduce the cost of compression, storage, and dispensing at refueling stations and stationary power sites to <$0.80/kg of hydrogen. By 2015, reduce this cost to <$0.40/kg.
• By 2012, develop technologies to reduce the cost of hydrogen delivery from central and semi-central production facilities to the gate of refueling stations and other end users to <$0.90/kg of hydrogen. By 2017, reduce this cost to <$0.60/kg.

Timing has been delayed by 2 years due to Congressional Earmarks and limited appropriations (except refueling site delivery).
Distributed Reforming Hydrogen Production Pathway Projects

**Natural Gas**
- Low Cost Hydrogen Production Platform
  - Praxair
- Low-Cost Hydrogen Distributed Production System
  - H2Gen
- Integrated Hydrogen Production, Purification & Compression
  - Linde (BOC)
- Integrated Short Contact Time Hydrogen Generator
  - GE Global Research

**Bio-Derived Liquids**
- Bio-Derived Liquids Reforming
  - PNNL
- Biomass-Derived Carbohydrates via Aqueous-Phase Reforming
  - Virent
- Investigation of Bio-Ethanol Steam Reforming Over Cobalt
  - Ohio State
- Distributed Bio-Oil Reforming
  - NREL
- High-Pressure Ethanol Reforming
  - ANL

**Separation and Purification**
- Zeolite Membrane Reactor for Water-Gas-Shift
  - Arizona State
- Carbon Molecular Sieve Membrane Reactor
  - Media & Process
- High-Performance, Durable, Pd-Alloy Membrane
  - Pall Corporation
- Integrated Ceramic Membrane System
  - Praxair
- Low-Temperature Ion Transport Membrane
  - ORNL
Electrolysis and Biomass Gasification Projects

Electrolysis

- Renewable Electrolysis Integrated System Development and Testing
  - NREL
- Low-Cost, High-Pressure Hydrogen Generator
  - Giner Electrochemical
- Cost Reduction of High-Pressure Hydrogen Generation
  - Distributed Energy Systems
- Solid-Oxide Hybrid for Co-generation of Hydrogen and Electricity
  - Materials and Systems Research
- Advanced Alkaline Electrolysis
  - GE
- High Performance Flexible Reversible Solid Oxide Fuel Cell
  - GE
- Renewable Hydrogen Production and Transportation Fueling System
  - EVermont

Biomass Gasification

- Biomass Gasification and Process Intensification
  - GTI, et al
- Novel Slurry-Based Biomass Reforming
  - UTRC
- Fully Integrated Pilot Scale Biomass to Hydrogen Unit
  - NREL

Alkaline, High Pressure Electrolysis
  - Teledyne

Legend:
- Oral Presentation
- Poster Presentation
- Not Presented
Longer Term Pathway Projects

**Solar Driven HT Thermochemical**
- Development of Solar-powered Thermochemical Production of Hydrogen from Water
  - UNLV, et al
- Solar-thermal Mn2O3/MnO Thermochemical Cycle to Split Water
  - U of Colorado
- Solar Driven HT Thermochemical Water Splitting with Photo Assist
  - SAIC, FSEC

**Biological**
- Biological Systems for Hydrogen Photoproduction
  - NREL
- Hydrogen from Water in a Novel Recombinant Oxygen Tolerant Cyanobacteria System
  - Venter Institute
- Montana Palladium Research Initiative/Biological Production and Separations
  - Montana State
- Maximizing Light Utilization Efficiency & Hydrogen Production in Microalgal Cultures
  - UC Berkeley

**Photoelectrochemical**
- Photoelectrochemical Water Systems for H2 Production
  - NREL
- Cost-effective Photoelectrochemical Production of Hydrogen
  - Midwest Optoelectronics
- Water Splitting Catalysts Based on the Oxygen Evolving Complex of Photosystem II
  - Arizona State
- Photoelectrochemical Generation of Hydrogen Using Sonicated Hybrid Titania Nanotube Arrays
  - UN - Reno
- Photoelectrochemical Hydrogen Production: UNLV-SHGR
  - UNLV, et al
- Solar Water Splitting: Photocatalyst Materials Discovery and Systems Development
  - GE Global Research

Legend:
- Oral Presentation
- Poster Presentation
- Not Presented
Coal Hydrogen Pathway Related Projects

**Synthetic Natural Gas (SNG)**
- Hydrogasification for Co-production of SNG and Power
  - Arizona Public Service
- Co-produce Electricity and SNG Via Catalytic Coal Gasification
  - Research Triangle Institute

**Reforming**
- H₂ from Reforming of Coal-derived Methanol
  - UC-Davis
- Co-produce Power and FT Liquids CCPI Project
  - WMPI/Gilberton

**Liquid Fuels**
- Iron-based FT Synthesis
  - Headwaters Technology Innovation Group
- Cobalt-based FT Synthesis
  - ICRC/Syntroleum
- Catalytic Conversion of Syngas Into Ethanol
  - Abengoa
- Conversion of Syngas to Ethanol and Higher Alcohols
  - LSU, Clemson, ORNL
- Conversion of Syngas into Ethanol and Transformation of Ethanol Into Hydrogen
  - Iowa State U
- Production and Storage of Hydrogen Using C1 Chemistry
  - U of Kentucky

**Polygeneration**
- Binder Pitch for Carbon Electrodes
  - WVU/Graftech
- Anode Grade Coke
  - CPCPC

**Aviation Systems**
- FT-Derived Jet Fuels In Aviation Systems
  - AF Wright Lab

**Condensed Table**
- Oral Presentation
- Poster Presentation
- Not Presented
Nuclear Hydrogen Production Pathway Projects

**High Temperature Thermochemical**
- Sulfur-Iodine Thermochemical Cycle Laboratory-Scale Experiment
  - SNL/GA/CEA
- Hybrid Sulfur Thermochemical Process Development
  - SRNL
- Evaluation of Alternative Thermochemical Cycles
  - ANL
- Catalyst and Membrane Studies for Thermochemical Cycles
  - INL
- Corrosion Studies of Metallic Materials for Thermochemical Cycles
  - General Atomics

**High Temperature Electrolysis**
- Laboratory-Scale High-Temperature Electrolysis System
  - INL/ANL/Ceramatec
- Test of High Temperature Electrolysis ILS Half Module
  - Ceramatec
- Modeling and Diagnostics of HTE Components
  - ANL
- Materials Issues and Experiments for HTE and SO3 Electrolysis
  - ANL
- Membrane Development for Hybrid Sulfur Electrolysis and Oxygen Separation
  - SNL

**System Interfaces Supporting Systems**
- Nuclear Reactor/Hydrogen Process Interface
  - INL
- HyPEP Model Development
  - INL
- UNLV High Temperature Heat Exchanger Development
  - UNLV
- Membrane Applications for Nuclear Hydrogen Production Processes
  - ORNL

**Supporting Systems**
- Oral Presentation
- Poster Presentation
- Not Presented
Hydrogen Delivery Projects

**Delivery Analysis**
- Hydrogen Delivery Infrastructure Options Analysis and H2A Delivery Models
  - **Nexant**

**Compression**
- DG Integrated Hydride Compression Linde (BOC)/HERA
- Centrifugal Compressor MITI

**Pipelines**
- Fundamentals and Modelling of Pipeline Hydrogen Embrittlement
  - **University of Illinois**
- FRP Hydrogen Pipeline
  - **ORNL/SRNL**
- Materials Solutions for Hydrogen Delivery in Steel Pipelines
  - **SECAT Collaboration**
- H2 Permeability and Embrittlement of Welds/HAZ
  - **ORNL/SRNL**

**Liquefaction**
- Advanced Liquid H2 Production Techniques
  - **GEECo**

Legend:
- Oral Presentation
- Poster Presentation
- Not Presented
Hydrogen Delivery Projects

- Carriers
  - Liquid hydrocarbon
    - APCI, UTRC, Penn State

- Off-Board Storage
  - Composites for High Pressure Storage and Tube Trailers
    - LLNL

- Cross-Cut
  - Regional Analysis, Pipelines, Storage, Separations, and Sensors
    - Concurrent Technology, et al

Legend:
- Oral Presentation
- Poster Presentation
- Not Presented
Additional Projects/Crosscutting

• Photobiological Hydrogen Research, FIU
• Developing Improved Materials to Support the Hydrogen Economy, Edison Materials Tech Center
• Production of Hydrogen for Clean and Renewable Sources of Energy for Fuel Cell Vehicles, University of Toledo
• Adapting Planar Solid Oxide Fuel Cells for Distributed Power Generation, Ohio University
• Production, Fuel Cell, and Delivery Research, University of South Florida
• Ohio Distributed Hydrogen Project, Ohio University
• Generation and Solid Oxide Fuel Cell Carbon Source Sequestration in Northwest Indiana, NiSource