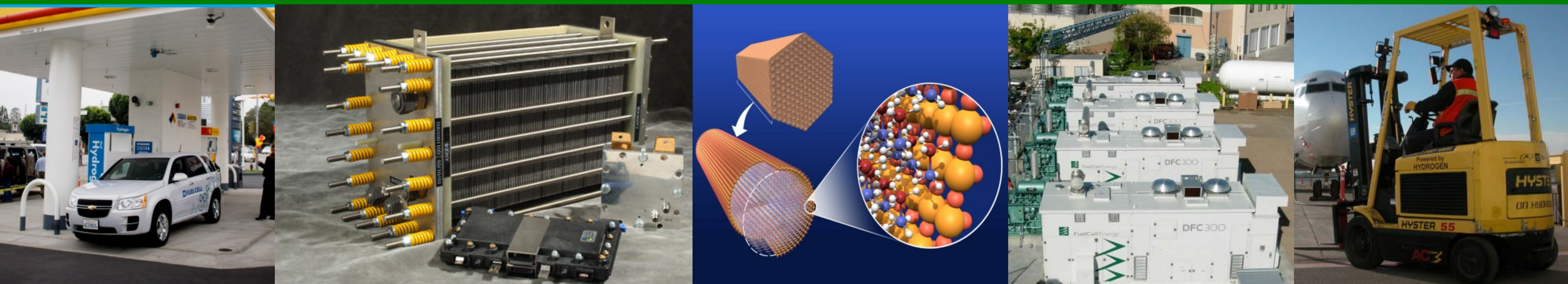
U.S. DEPARTMENT OF
ENERGY

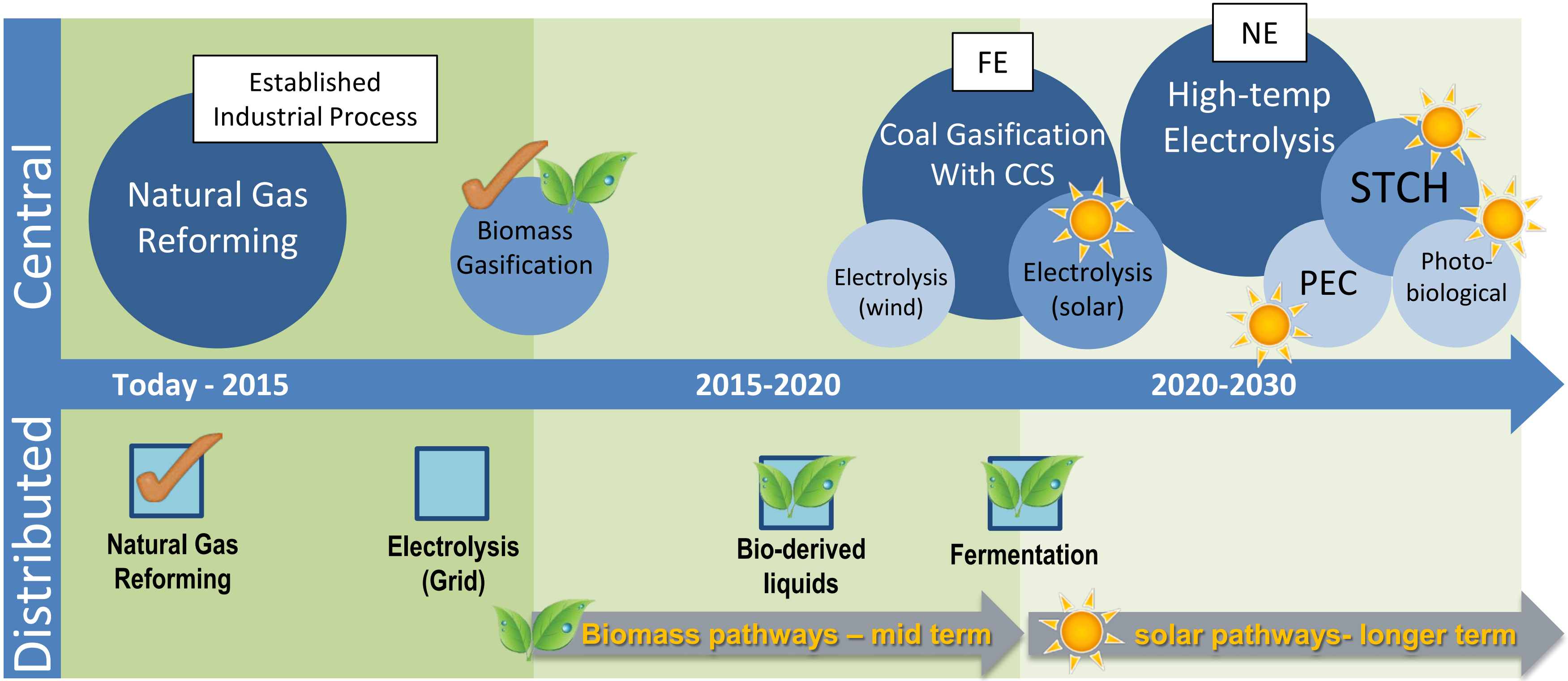


Hydrogen Production and Delivery

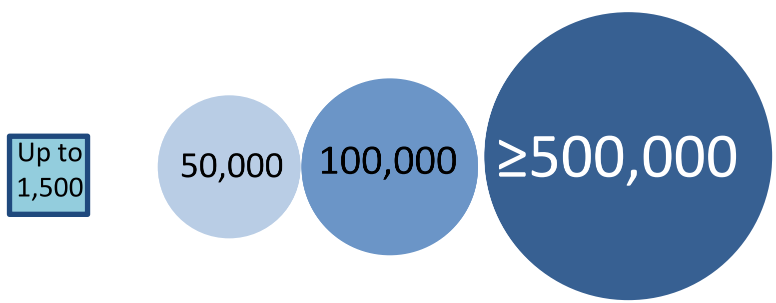
Sara Dillich

2013 Annual Merit Review and Peer Evaluation Meeting
May 13, 2013

Technology Readiness of DOE Funded Production Pathways



Estimated Plant Capacity (kg/day)



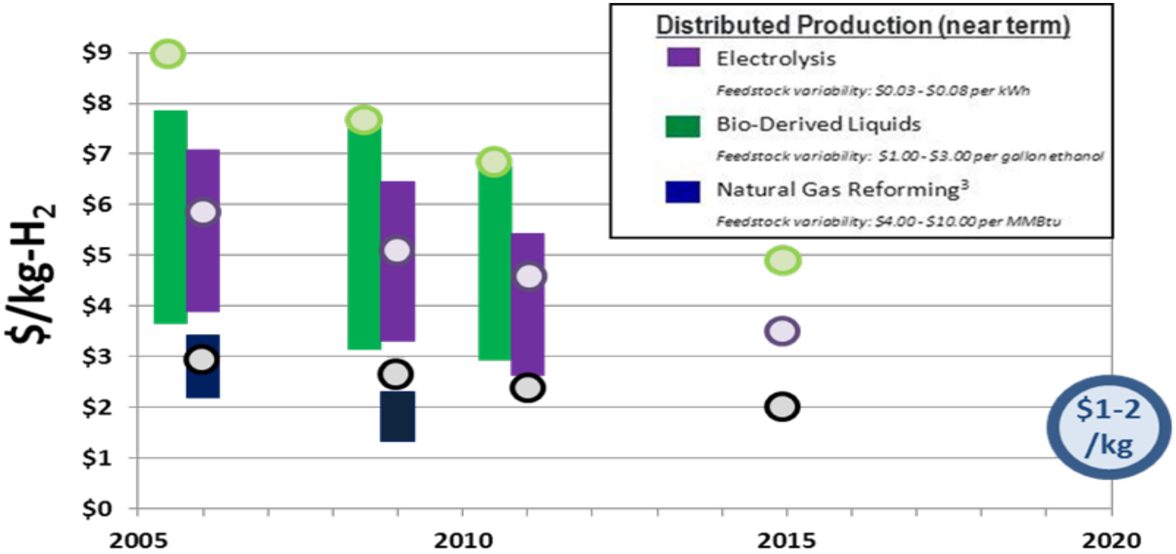
P&D Subprogram R&D efforts successfully concluded

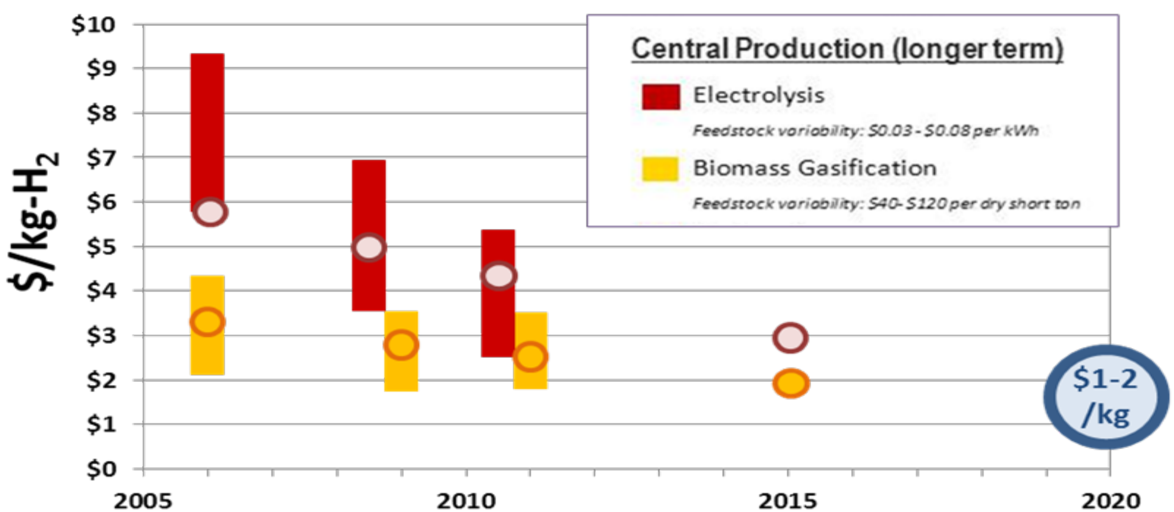
FE, NE: R&D efforts in DOE Offices of Fossil and Nuclear Energy, respectively

Hydrogen Production — Status & Pathways

U.S. DEPARTMENT OF ENERGY

Projected High-Volume Cost of Hydrogen for Near-Term Production Pathways





- **Status of hydrogen cost (production only, does not include delivery or dispensing costs) is shown in vertical bars, reflecting values based on a range of assumptions (feedstock/capital costs).**
- **Targets for hydrogen cost are shown in circles.**
- **Targets shown are normalized for consistency in feedstock assumptions and year-cost basis (2007 dollars)**
- ***Targets prior to 2015 are extrapolated based on 2015 and 2020 targets in the FCT Office's Multi-year RD&D Plan.***
- **Cost ranges are shown in 2007 dollars, based on projections from H2A analyses, and reflect variability in major feedstock pricing and a bounded range for capital cost estimates.**
- **Projections of costs assume Nth-plant construction, distributed station capacities of 1,500 kg/day, and centralized station capacities of ≥50,000 kg/day.**

Cost Status

U.S. DEPARTMENT OF ENERGY

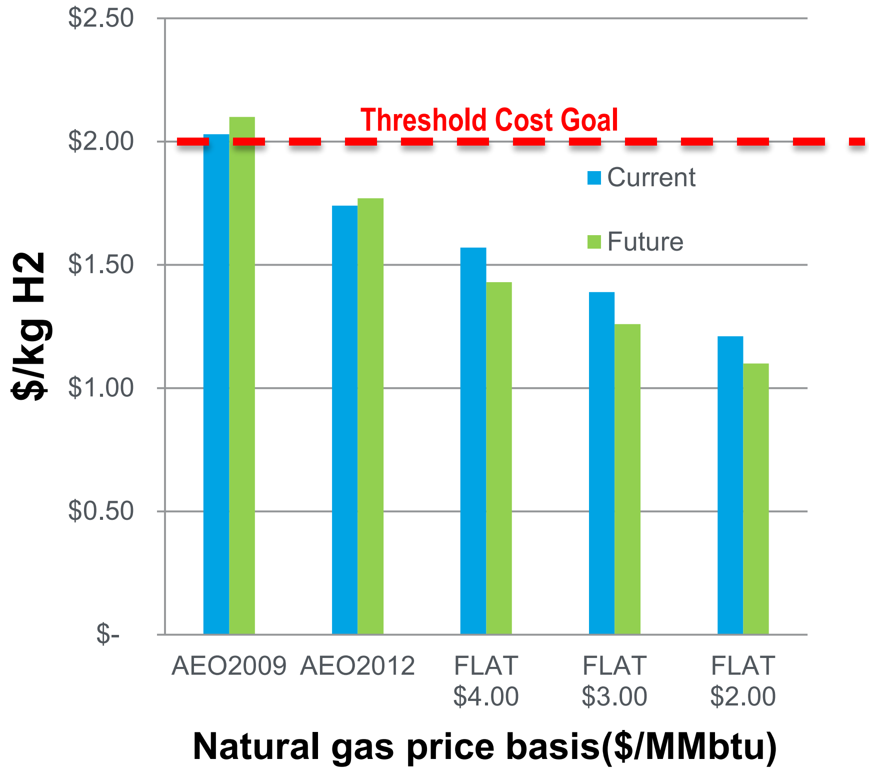
Hydrogen Production from Natural Gas: Bridge to Longer-Term, Low-Carbon Technologies

Distributed H_2 production from natural gas steam methane reforming

(high volume/economies of scale, 1500 kg/day production)

- Cost of H_2 production not limiting factor
- Cost goals can be met by a wide range of NG prices*
- Focus shifting to longer term, early development, renewable pathways

$/kg H_2 (produced & untaxed, today's technology) for Varying Natural Gas Spot Prices



*Production Cost Using Low-Cost Natural Gas, September, 2012, http://hydrogen.energy.gov/pdfs/12024_h2_production_cost_natural_gas.pdf

Based on H2A v3 Case Studies @ http://www.hydrogen.energy.gov/h2a_production.html

AEO2009 avg NG prices (HHV, $/MMbtu): $7.10 (Current, 2010-2030); $8.44 (Future, 2020-2040)

AEO2012 avg NG prices (HHV, $/MMBtu): $5.28 (Current, 2010-2030); $6.48 (Future, 2020-2040)

Defining Our Strategy

U.S. DEPARTMENT OF ENERGY

GOAL: Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of \$2-\$4/gge H_2 by 2020

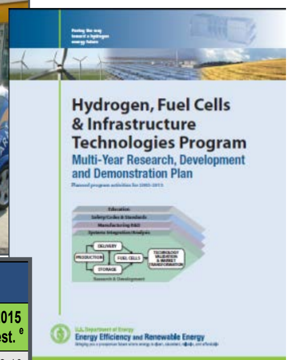


Table 3.1.1 Distributed Forecourt Natural Gas Reforming [a, b, c]

Characteristics	Units	2010 Status [d]	2015 est. [e]
Hydrogen Levelized Cost (Production Only) [f]	\$/kg H_2	\$2.03	\$2.10
Production Equipment Total Capital Investment	\$M	\$1.5	\$1.2
Production Energy Efficiency [g]	%	71.4	74
Production Equipment Availability [c]	%	97	97
Industrial Natural Gas Price [h]	average \$/mmBtu	\$7.78	\$8.81

2011

- **Update of analysis models**
- **Apportionment of cost threshold goal**

2012

H2A Case Studies

&

MYRD&D Updates

2013

FOA for new starts in FY2014

2014

- **Updated MYRD&D Chapters posted online**
- **Updated Production and Delivery Roadmaps submitted to U.S. DRIVE**
- **Analysis FOA & Project Initiation**
- **MOU: FCTO & NSF MOU prepared for joint funding of hydrogen and fuel cells R&D**
- **Hydrogen Production Expert Panel (HPEP) Report prepared**
- **Independent Panel Review of Compression, Storage, and Dispensing (CSD) Costs**
- **Workshop on CSD Cost Reduction March, 2013, ANL**
- **2013 SBIR topic: H_2 Dispensers**

H_2 Production and Delivery Challenges & Strategy

U.S. DEPARTMENT OF ENERGY

Materials durability, efficiency improvements, and capital cost reductions are key challenges for all production and delivery pathways

Barriers

Production and delivery cost of renewable & low-carbon hydrogen

- Feedstock costs
- Capital costs
- O&M costs

Strategy

Near-term

Minimize cost of 700 bar hydrogen at refueling stations

Long-term

Improve performance and durability of materials and systems for production from renewable sources.

R&D Focus

- Reliability and cost of compression, storage and dispensing
- Renewable integration
- Balance of plant improvements
- Technoeconomic analysis

R&D Focus

- Innovations in materials, devices and reactors for renewable H_2 production
- Advanced materials and systems for H_2 delivery
- Technoeconomic analysis

Key Areas

Production

- Electrolysis
- Bio-Derived Liquids
- Hybrid fossil/renewable approaches
- Solar Water Splitting: PEC, STCH, Biological
- Fermentation

Delivery

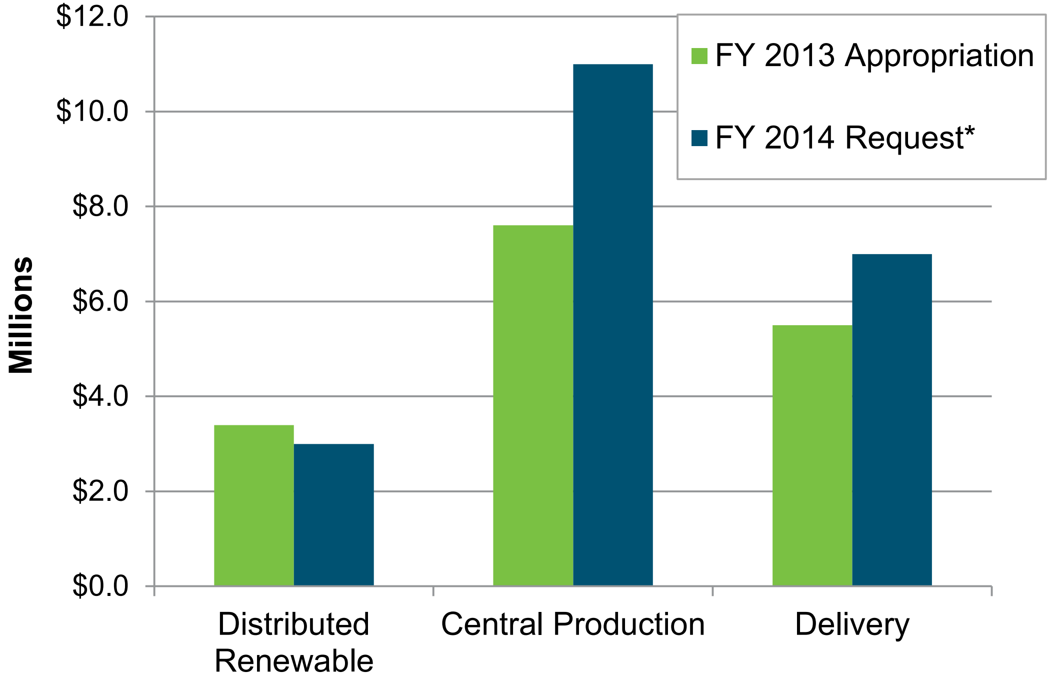
- Polymers & composites for delivery technologies
- Liquefaction technologies
- Compressor reliability
- Low cost onsite storage

H_2 Production and Delivery MYRD&D chapters available at: *http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html*

Budget – P&D subprogram

U.S. DEPARTMENT OF ENERGY

FY 2013 Appropriation: $16.5M ***FY 2014 Request: $21M***



* Subject to appropriations, project go/no go decisions and competitive selections. Exact amounts will be determined based on R&D progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements (FOAs).

2013/14 Emphasis

- FOAs for FY14 new starts: based on updated MYRD&D, Roadmaps and HPEP report

Distributed Production

- Develop production and forecourt CSD technologies for improvements in
  - Cost
  - Balance of plant
  - Reliability

Central

- Innovations in materials, devices and reactors for renewable H_2 production.
- Advanced polymers and composites for H_2 delivery systems

Nuclear Hydrogen Initiative was discontinued at end of FY2009 as a separate program. Funding of high temperature electrolysis continued under the NGNP project through FY2011. After INL demonstration of pressurized stack operation in FY 2012, technology readiness will be sufficiently advanced (TRL5) to allow for further development by industry. Congressional direction to DOE for FY2012 was to focus on conversion of coal and biomass to liquid fuel. No funding for H_2 production from coal was provided.

2013 Progress: Analysis

U.S. DEPARTMENT OF ENERGY

New Project Initiated

Team:

Strategic Analysis, Inc.

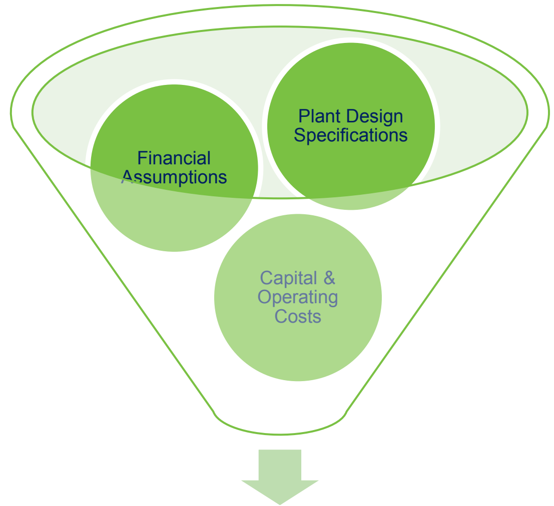
PI: Brian James

Partners: NREL, ANL

Scope:

- Establish cost and performance baselines and track progress for R&D projects (with R&D project teams)
- Update pathway cases and develop new pathway case studies as needed
- Standardize assumptions & metrics for longer term pathways (with DOE and project teams)

Hydrogen Analysis Model



Required Selling Price of H2 ($/kg)

	$/kg (production costs only)	2011 Status	2015 Target	2020 Target	Ultimate Production Target
Distributed	Electrolysis from grid electricity	$4.20	$3.90	$2.30	$1-$2
Distributed	Bio-derived Liquids (based on ethanol reforming case)	$6.60	$5.90	$2.30	
Central	Electrolysis From renewable electricity	$4.10	$3.00	$2.00	
Central	Biomass Gasification	$2.20	$2.10	$2.00	
Central	Solar Thermochemical	NA	$14.80	$3.70	
Central	Photoelectrochemical	NA	$17.30	$5.70	
Central	Biological	NA	NA	$9.20	

2013 Progress: Autothermal Reforming of Bio-Derived Liquids

U.S. DEPARTMENT OF ENERGY

Hydrogen yields depend on composition and properties of bio-oil

Feed-stock	H_2 g/100g bio-oil
Poplar	11.0
Oak	8.5
Pine	10.5
Oak, lignin-free	3.0 (12)*

**hydrogen yield on water-free basis (lignin-free oak bio-oil fraction contained 74.6% water)*

Reforming of poplar and pine bio-oils delivered > 10g H_2 per 100 g bio-oil.

Lower yield from oak bio-oil due to lower carbon and higher oxygen contents, and lower carbon-to-gas conversion

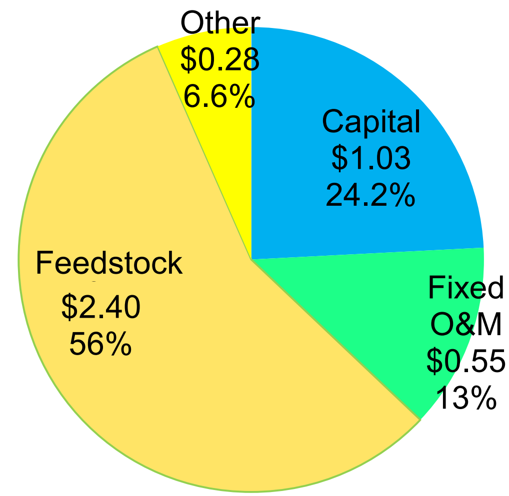
Optimum Process Conditions Identified:

800-850 C, steam-to-carbon ration of 2.5-3.5, Pt/Al_2O_3 catalyst, Space velocity ~ 2000 h-1

H2A v3: $4.26/kg H2

(Production only, CSD not included)

Distributed Production: 1500 kg/day



Production Cost Break-down for Poplar bio-oil: $236/ton

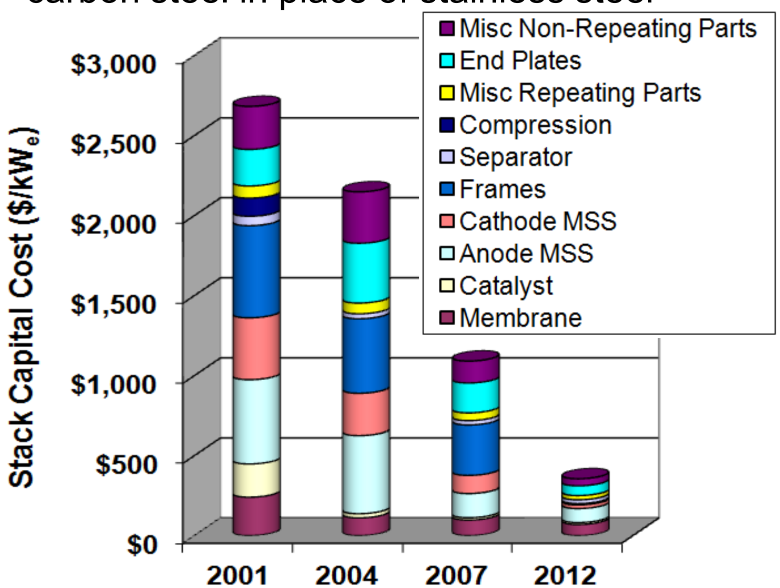
NREL

2013 Progress: Electrolysis

U.S. DEPARTMENT OF ENERGY

Greater than 60% reduction in cost of PEM electrolyzers stacks achieved since 2007 (Giner Inc.)

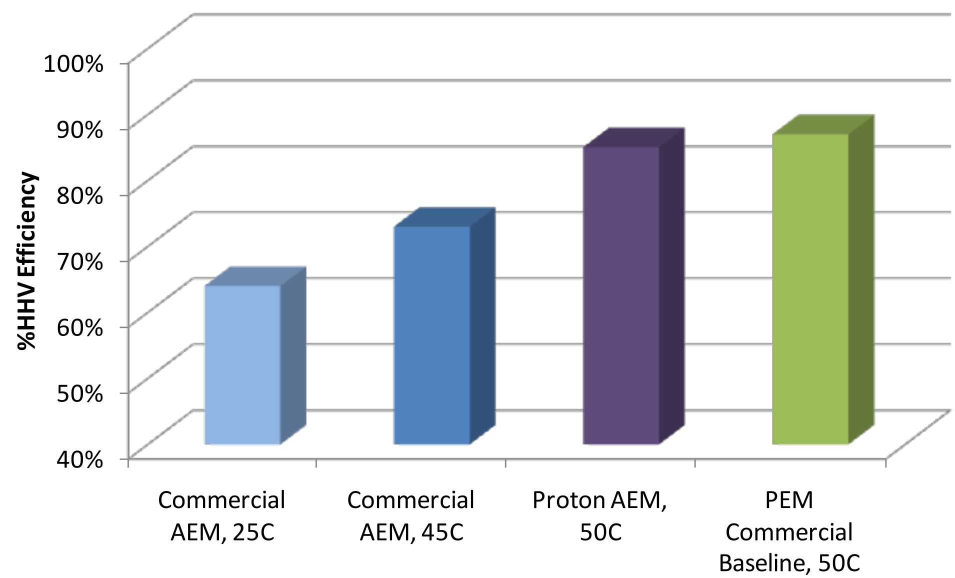
- ✓ 75% reduction in part count leading to a 50% reduction in manufacturing labor
- ✓ 30% thinner frame reduce cathode and anode support material
- ✓ 90% cost reduction of DSM MEA's through fabrication with chemically etched supports
- ✓ 66% end plate material cost reduction by using carbon steel in place of stainless steel



Alkaline exchange membrane (AEM) technology offers potential for efficiency & small footprint of PEM stacks, but at lower cost ***(Proton OnSite)***

- ✓ Developed OER catalysts for AEM electrolysis
- ✓ Demonstrated performance over >100 h of operation
- ✓ > 80% HHV AEM efficiency shown at bench scale
- ✓ Material cost savings potential of > 80% using AEM technology are projected
- ✓ Leveraging ARPA-e project on AEM technology for regenerative fuel cell systems

Electrolyzer Performance, 400 mA/cm^2



2013 Progress: Solar-Thermochemical

U.S. DEPARTMENT OF ENERGY

Innovative chemical reaction materials and reactor designs used to produce hydrogen from sunlight and water through thermochemical processes

R&D Focus

- Materials efficiency and durability *(SNL, U of CO)*
- Reactor design *(SNL, Univ. of Colorado)*
- Membranes and electrocatalysts *(ANL, SAIC, SRNL)*
- Technoeconomic analysis to establish efficiency and durability requirements for meeting DOE cost goal

High Temp 2-Step cycles

- Metal oxides, Perovskite compounds *(SNL)*
- Nanostructured hercynite *(Univ. of Colorado)*

Hybrid Cycles wt Electrolysis Step

- Cu-Cl cycles (*ANL/GTI/Penn State)*
- Sulfur-ammonia (*SAIC)*
- Hybrid sulfur *(SRNL)*

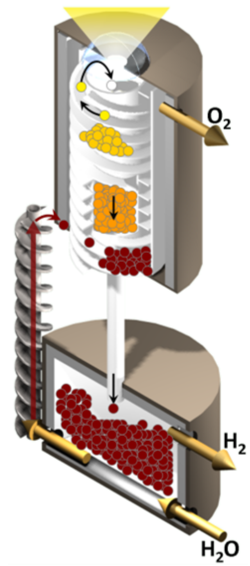
Reactor Designs

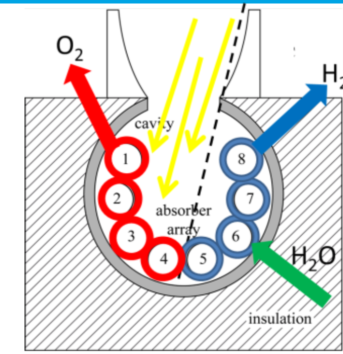
- Particle receiver-reactor *(SNL)*
- Absorbing cavity w/ multi-tubular fixed beds *(Univ. of Colorado)*
- Bayonet-type reactor *(SAIC)*

Field Concepts

- Central tower/Heliostat field
- Central tower/Heliostat with molten salt storage *(SAIC)*
- Dish field -- one reactor/dish *(SNL)*

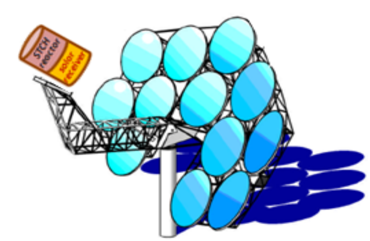
SNL reactor design



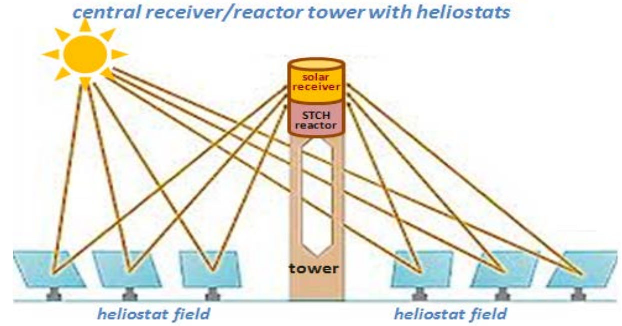


Univ. of Colorado reactor design

modular dish-mounted receiver/reactor



central receiver/reactor tower with heliostats

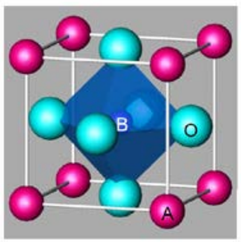


2013 Progress: Solar-Thermochemical

U.S. DEPARTMENT OF ENERGY

Novel perovskite compounds, nanostructured hercynite, split H_2O in 2-step thermochemical cycles

- Synthesized 45 perovskite compounds from 9 elements (Al, Cr, Ce, Fe, La, O, Sr, Ti, Zr) using Sol-gel or Solid State Reactive Sintering *(SNL)*

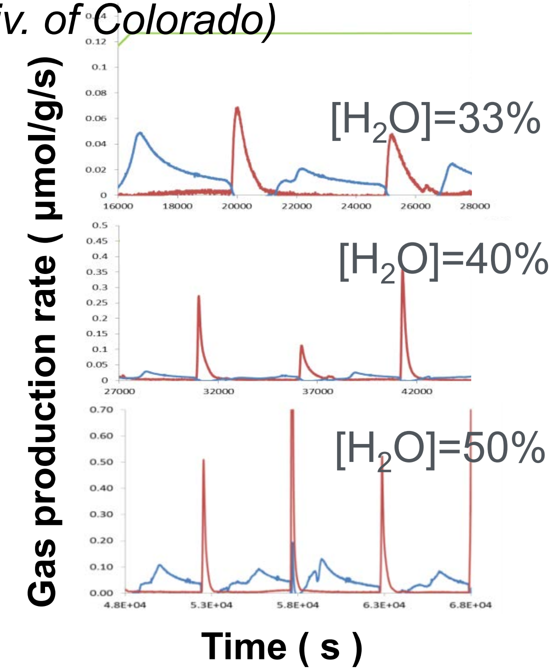


Perovskite structure ABO_3

property	ceria (CeO_2)	perovskite (ABO_3)	ideal
redox kinetics	**FAST**	**TBD**	**FAST**
redox capacity	**LOW**	**HIGH**	**HIGH**
reduction T_H	**HIGH**	**LOW**	**LOW**
durability	**HIGH**	**TBD**	**HIGH**
earth abundance	**LOW/MED**	**HIGH**	**HIGH**

Patent filed on a perovskite family of Sr - and Mn- substituted $LaAlO_3$.

- Verified stability of Hercynite redox activity via Raman analysis and >150 cycles testing
- Increased H_2O pressure increases total H_2 produced and peak rates of H_2 production *(Univ. of Colorado)*



U.S. Patent Issued on Coated Redox Materials for Chemical and Thermochemical Reduction

2013 Progress: Solar -Thermochemical

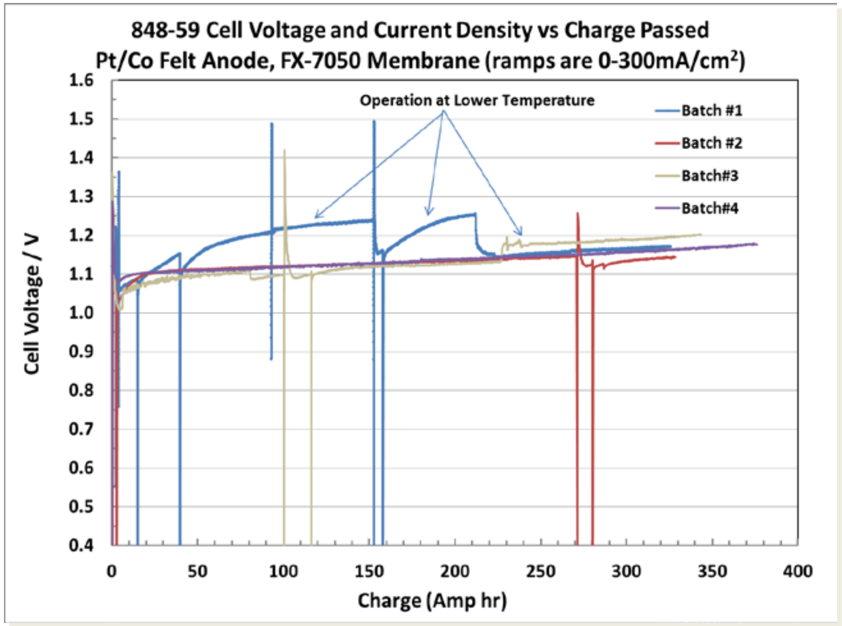
U.S. DEPARTMENT OF ENERGY

High performance membranes and electrocatalysts are key for hybrid cycles

Sulfur Ammonia Cycle

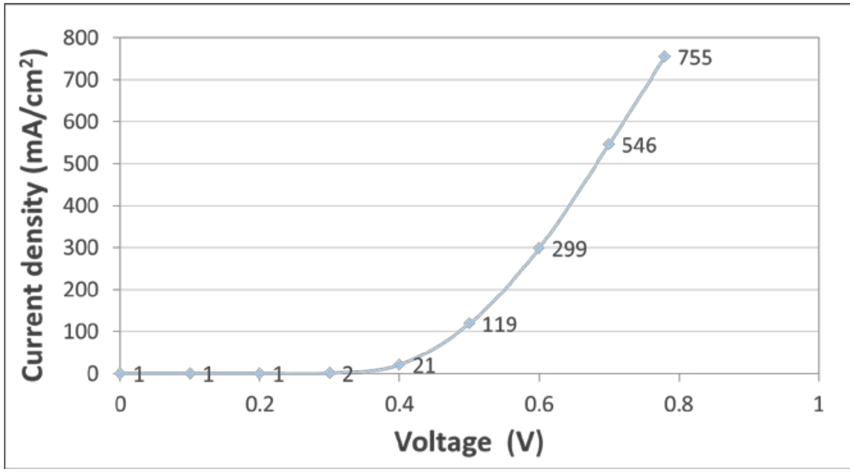
(SAIC)

- Demonstrated long term voltage stability of complete electrochemical system (500+ hour extended run)
- Identified new membranes with up to 2 orders of magnitude lower sulfite crossover fluxes



Cu-Cl Cycle

(ANL /GTI/Penn State)



- $5 cm^2$ electrolyzer ran successfully for 168 h at milestone value of 300 mA/cm^2 at 0.7V
- One cell, 300 cm^2, electrolyzer ran at >500 mA/cm^2 at 0.7V (exceeding 2015 design target)

2013 Progress: Photoelectrochemical

U.S. DEPARTMENT OF ENERGY

Innovative wide band gap semiconductor material systems to produce hydrogen from sunlight and water through low-temperature photoelectrochemical processes

R&D Approach and Focus

- Innovative crystalline, thin-film and nano-structured material systems to meet efficiency, durability and cost requirements
- Technoeconomic analysis to establish efficiency and durability requirements for meeting DOE cost goal

Efficient Crystalline Systems

- III-V materials and integrated tandem devices *(NREL)*
- Stabilization of III-V PEC interfaces *(NREL, LANL)*

Durable, low-Cost Thin-Film systems

- Novel metal oxide, copper chalcopyrite and silicon carbide thin-film materials and devices *(MVSystems, UH)*
- Large-scale integrated thin-film PEC electrode device fabrication *(MWOE)*

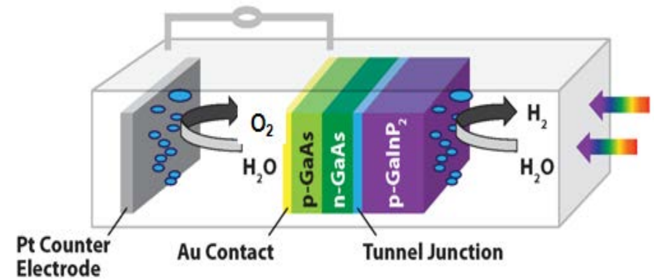
Innovative Nano-structured Systems

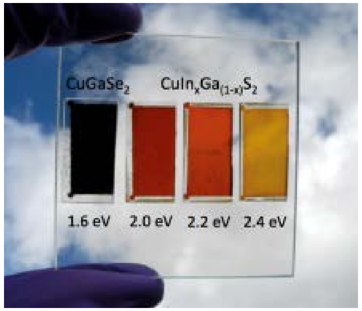
- Quantum-confined MoS_2 photocatalysts on nano-structured support scaffold *(Stanford, LBNL)*
- Mixed oxide photocatalyst particles *(UH)*

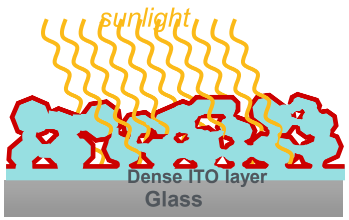
Cross-Cutting PEC Materials R&D Efforts

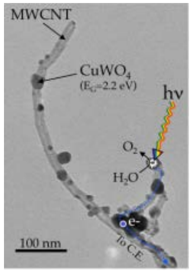
- Theoretical modeling of PEC interfaces and bulk bandgaps *(LLNL, UTA)*
- Advanced spectroscopic characterization *(UNLV)*
- Standardized PEC protocols *(PEC WG)*

III-V material systems R&D utilizing advanced theory, synthesis and characterization capabilities









Thin-film and nano-structured materials R&D leveraging theory, synthesis and characterization tools

2013 Progress: Photoelectrochemical

U.S. DEPARTMENT OF ENERGY

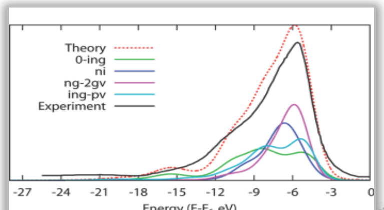
Significant new PEC progress this year in stabilizing high-efficiency crystalline materials and in developing new lower-cost thin films

Developed reproducible process to extend III-V durability at high production rates

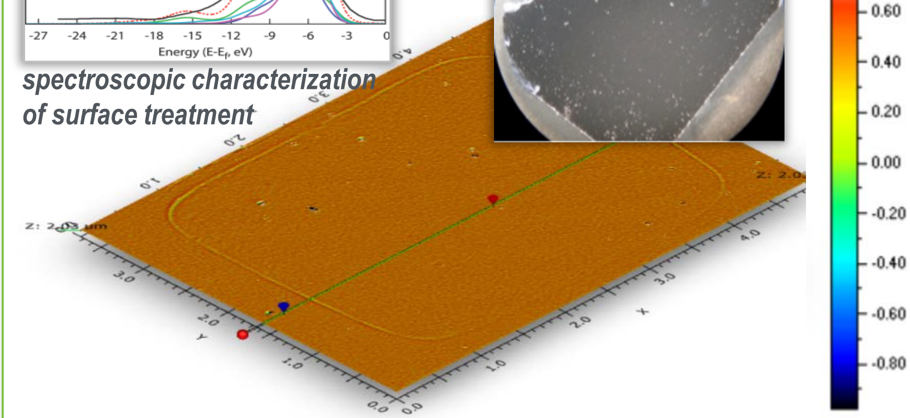
(NREL / UNLV / LLNL)

Reproducible N_2^+ ion treatment to protect high-efficiency $GaInP_2/GaAs$ tandem PEC devices from corrosion achieved. Durability demonstrated under operating conditions comparable to 25% STH

No detectable etching in treated tandem photoelectrodes after 24 hours at high current density of ~20mA/cm²



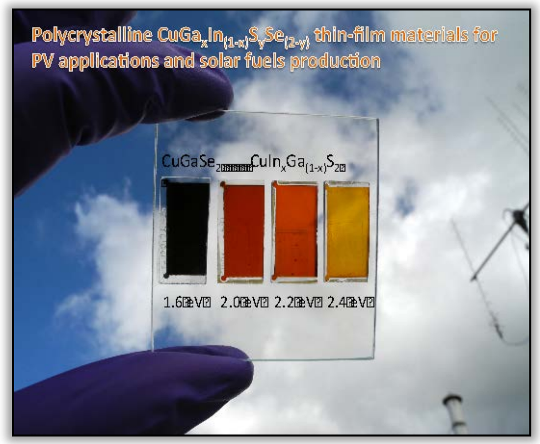
spectroscopic characterization of surface treatment

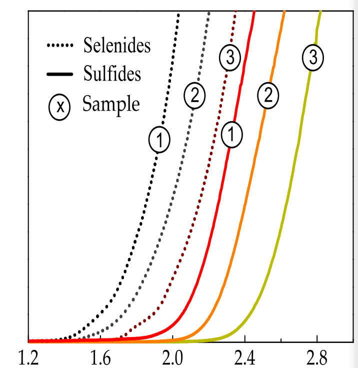


Demonstrated bandgap tuning to optimize a promising thin-film material class

(MVSystems / U. Hawaii)

Reproducible control over bandgap achieved in copper chalcopyrite material systems is critical to the design and development of efficient PEC tandem devices based on lower cost thin-films





- *Chalcopyrites with bandgap ranging from 1.1eV (selenides) to 2.5eV (sulfides) successfully fabricated,*
- *In/Ga ratio in sulfides adjusted to match 2.0eV Eg target*
- *PEC tests show significant charge carriers generation.*

2013 Progress: Biological

Innovative reactor configurations and genetic engineering used to improve microbial hydrogen production

R&D Approach and Focus

- Development of strains with improved hydrogen production capacity
- Technoeconomic analysis to establish efficiency and production duration requirements for meeting DOE cost goal

Develop O_2-tolerant photolytic organisms

- Engineered cyanobacterial strains with non-native, oxygen-tolerant hydrogenases *(NREL, JCVI)*
- Algae with modified or replaced hydrogenases to reduce oxygen sensitivity *(NREL)*

Improved photo-biological activity

- Increase light utilization by reducing collection of excess photons *(UC-Berkeley)*
- Improved energy flow from photosynthesis to hydrogen production pathways *(NREL, JCVI)*

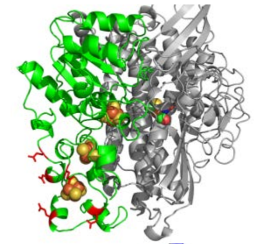
Feedstocks

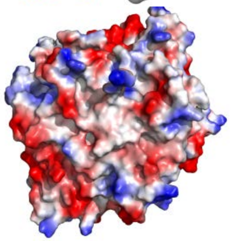
- Improved utilization of less refined biomass feedstocks (cellulose, corn stover) through genetic engineering, optimized mixtures of strains *(NREL)*
- Optimized Microbial Electrolysis Cells (MEC) to produce hydrogen from fermentation wastewater *(Penn State)*

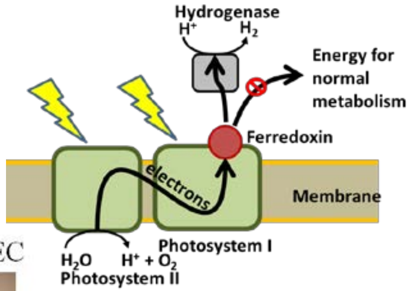
Reactor designs

- Improved sequence-batch bioreactor systems *(NREL)*
- Innovative MEC designs to reduce or eliminate external power requirements *(Penn State)*

Genetic engineering to improve strain's hydrogen production capacity







Improved reactor designs for better feedstock utilization, hydrogen production rates

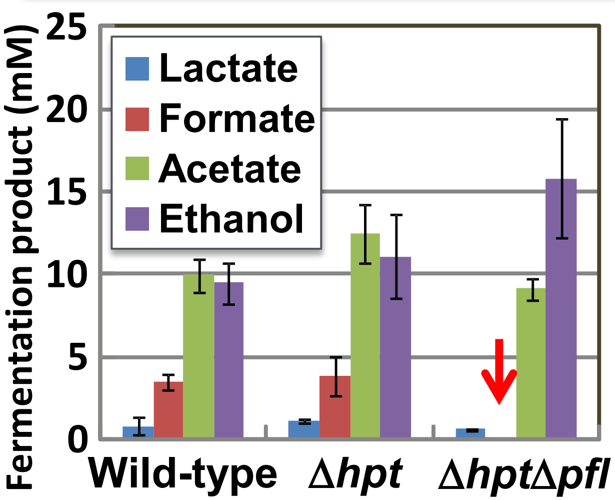
2013 Progress: Biological

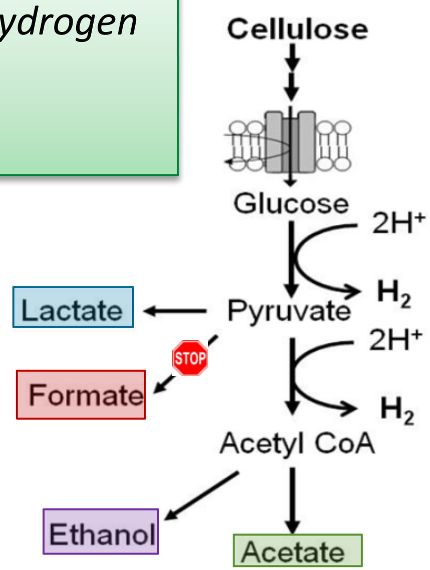
Genetic engineering to improve biological hydrogen production

Eliminating competing metabolic pathways *(NREL)*

- Developed *Clostridium thermocellum* strain (Δ*hpt)* for improved mutant generation method
- Generated strain missing the pyruvate-to-formate pathway (Δ*hpt*Δ*pfl)*, which consumes pyruvate that could be used for hydrogen production

Next steps: determine effect on hydrogen production, and knock-out other competing pathways

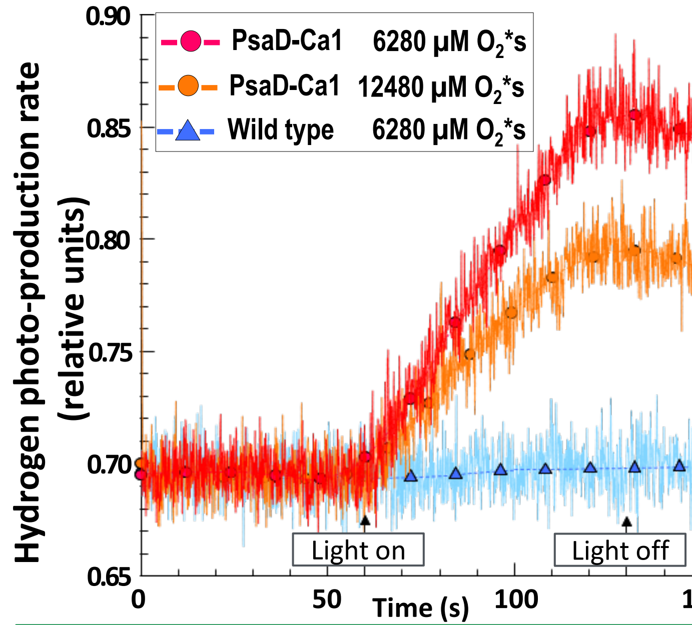




Bacterial cellulose metabolism pathway

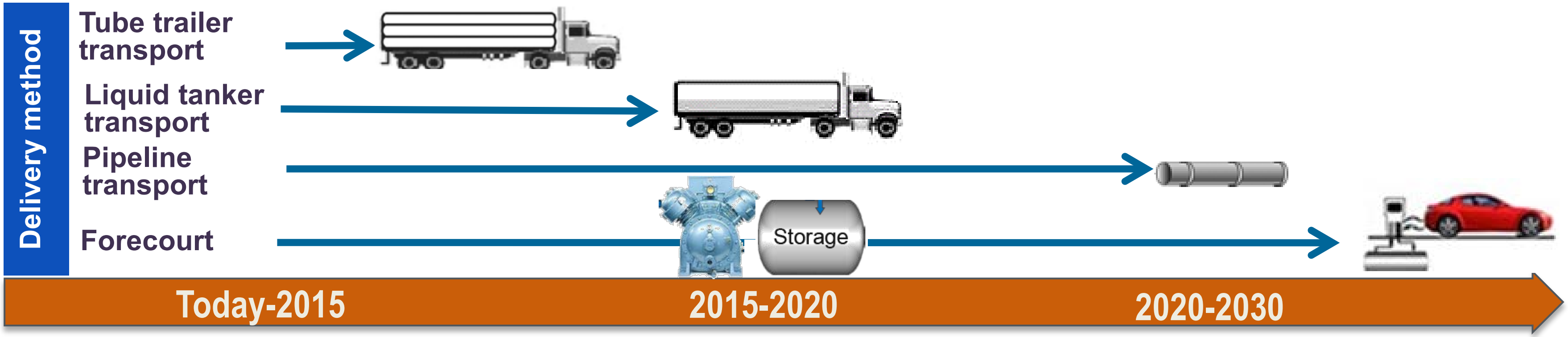
Improving oxygen tolerance *(NREL)*

- Demonstrated light-induced hydrogen production in algae with bacterial Ca1 hydrogenase at oxygen concentrations equivalent to 80% of air, more than double the oxygen that wild-type algae can tolerate



Next steps: genetic engineering for high, stable Ca1 hydrogenase expression

Delivery: Compression, Storage and Dispensing (CSD) Cost Reduction

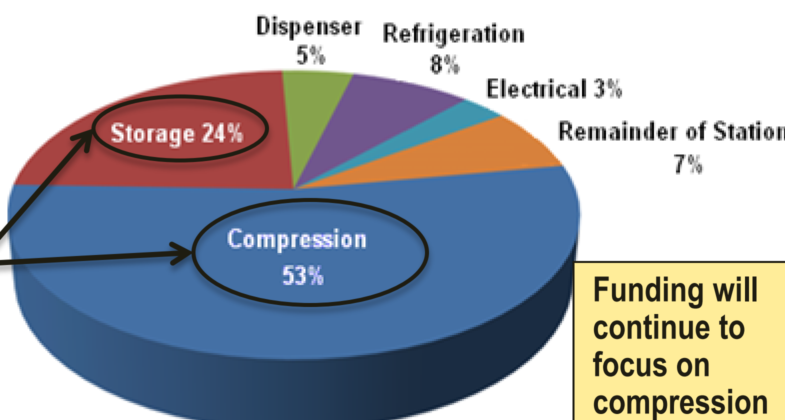


- Advanced tube trailer GH_2 transport
- Conventional LH_2 transport
- Mobile re-fuelers
- Forecourt GH_2 production

- Improved liquefaction
- Cold GH_2 transport
- Improved, low-cost forecourt technology (compression & storage)

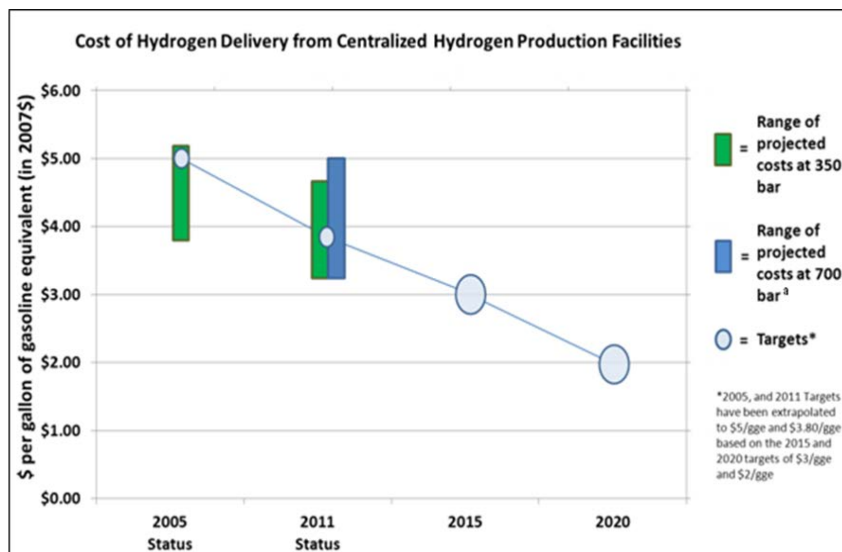
- Pipeline GH_2 transport
- Advanced energy efficient liquefaction
- Dedicated forecourts with advanced compression/ storage/dispensing technology

Station CSD costs adds >$2.00 to the cost of hydrogen Delivery. Compression and Storage accounts for 77% of the cost of CSD[1]



Delivery Costs

Funding will continue to focus on compression and storage



*Based on 2011 advances projected to high volume

1.) Record 12021, Cost Projections for Delivery Operations at a Distributed H_2 Production/Refueling Site, may 2012, http://www.hydrogen.energy.gov/program_records.html

Delivery Challenges and Priorities

U.S. DEPARTMENT OF ENERGY

Lowering the Cost of Forecourt CSD is a top priority for FY13/14

Near-term

- **Improve forecourt compressor cost, reliability & efficiency through improved seals and other R&D advancements**
- **Address dispenser cost and reliability through SBIR projects and investigation of existing failure modes**
- **Decrease the footprint and cost of storage at the forecourt through advanced composite designs**

Longer-term

- **Focus on materials research to enable high volume hydrogen delivery (FRP pipelines, High-pressure composite tube trailers, Carrier technologies…)**
- **Research and develop advanced compression technologies for high reliability and through-put**

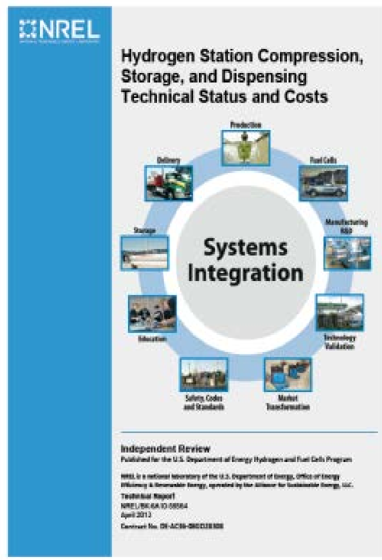
CSD Workshop Proceedings posted on FCTO website!

2013 Progress: Analysis

U.S. DEPARTMENT OF ENERGY

Direct fills from high pressure tube trailers can reduce capital at the forecourt by ~40%

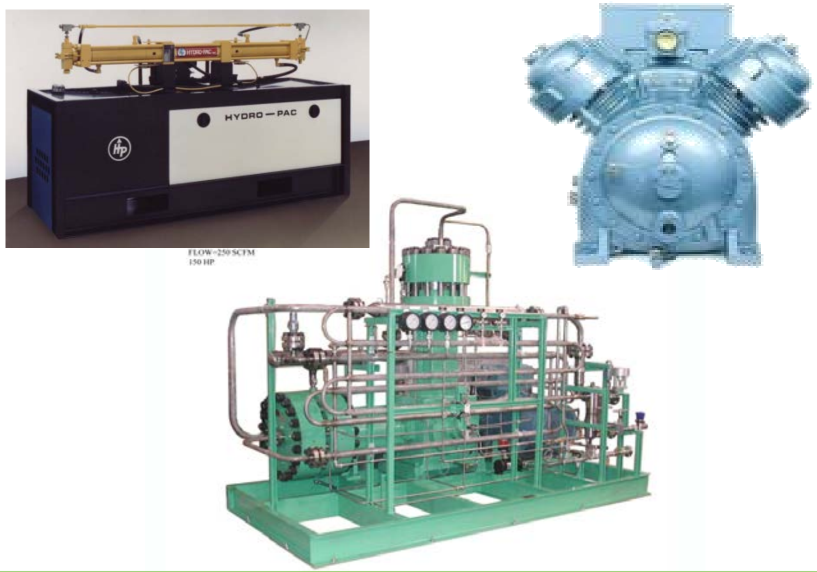
Compression, Storage, and Dispensing (CSD) Independent Panel review of the assumptions used by the hydrogen delivery scenario analysis model (HDSAM) V2.32. Report finalized Q3 FY13


NREL

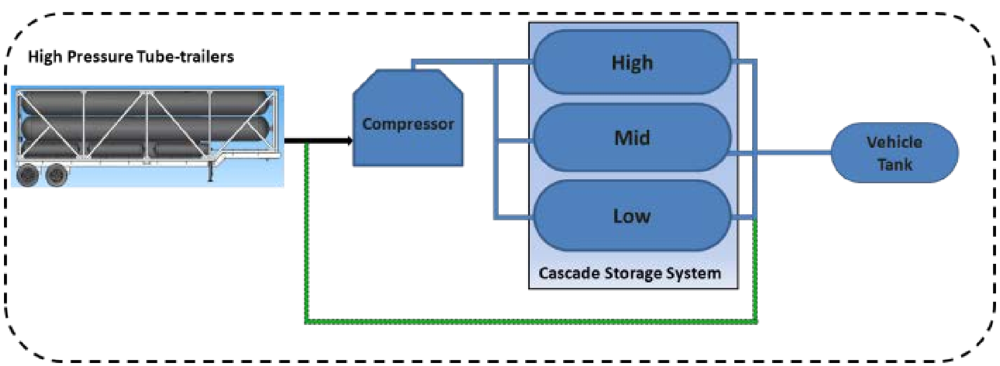
Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs

Systems Integration

Independent Review



ANL



CSD cost minimized by:

- ✓ ***Optimized compression to storage capacity***
- ✓ ***4-5 cascade storage banks***
- ✓ ***Direct fills from high-pressure tube trailers***

2013 Progress: Forecourt CSD

U.S. DEPARTMENT OF ENERGY

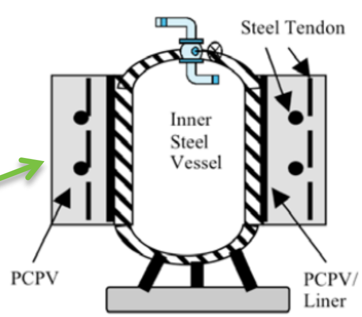
Demonstrated that high pressure steel-concrete composite vessels (SCCV) for hydrogen storage can exceed the relevant cost targets (ORNL)

Near Term Forecourt Storage
(ORNL)

- ✓ Validated ability to meet 2020 target of $1000/kg of hydrogen stored at 860 bar using optimized design (target exceeded).
- ✓ Successfully demonstrated ability to use Friction Stir Welding (FSW) to lower manufacturing cost
- ✓ Completed a manufacturing study – posted on OSTI: *ORNL/TM-2013/113*

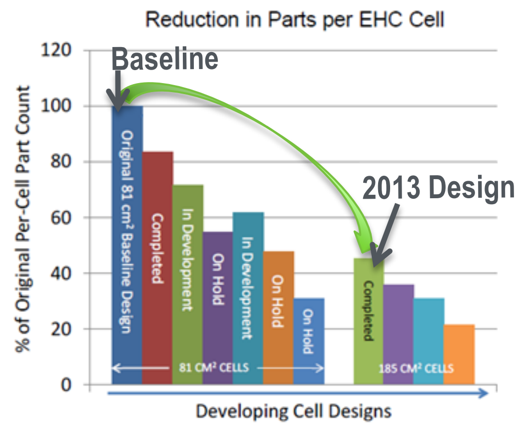
50/50 split between steel and concrete was selected as the optimal design for cost and strength.

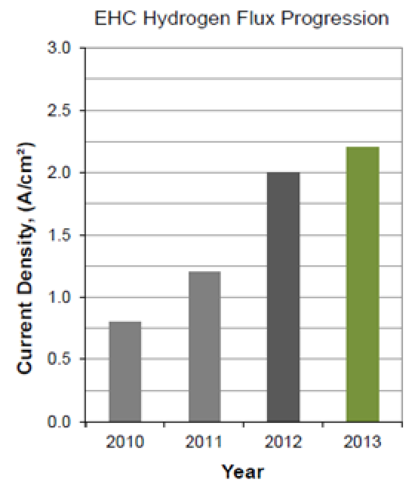
SCCV



Long Term Forecourt Compression
(FCE)

- ✓ Reduced electrochemical compressor cell part count through design innovations by >50%
- ✓ Increased operating current density by ~3X over the 2010 baseline
- ✓ Combined, this results in a greater than 50% cost reduction over the 2010 baseline





2013 Progress: Pipelines for H_2(g) Delivery

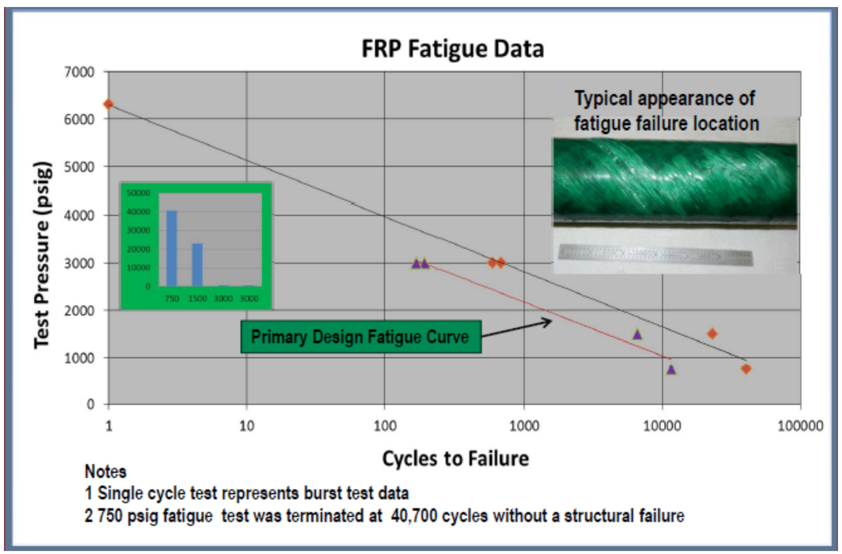
U.S. DEPARTMENT OF ENERGY

Fiber reinforced polymer (FRP) pipelines and new compressor technology can reduce cost

FRP pipeline testing
(SRNL)

Can reduce installation costs by 20– 40%

- ✓ Fatigue testing completed over the range of 750 to 3000 psig
- ✓ Calculated FRP fatigue design curve from data
- ✓ Report submitted to ASME for inclusion in B31.12



Detailed designs for high speed centrifugal H_2 compressors
(Mohawk)

Potential to reduce capital cost by 20% and O/M costs by 30%

- ✓ Selected double-entry design over single-entry
- ✓ Completed single stage prototype fabrication and verified achievement of performance goals through testing in air and He at 55,000 RPM

Single Stage Compressor and Motor Drive

2013 Progress: Gaseous and Liquid Delivery

U.S. DEPARTMENT OF ENERGY

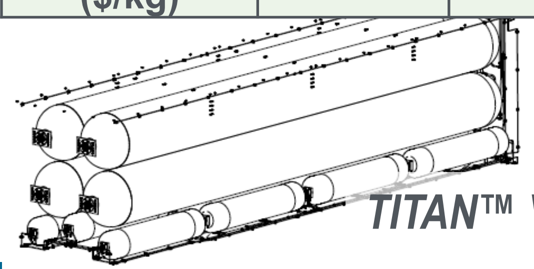
High pressure composite tube trailers show significant potential to meet the 2020 tube trailer delivery targets

Tube Trailer Delivery

(Hexagon Lincoln)

- ✓ Exceeded DOE 2015 delivery capacity target using Hexagon Lincoln's TITAN™ V Magnum Trailer System (originally designed for the 2010 targets)
- ✓ 350 bar design shows promise toward the 2020 targets.

	250 Bar (Available)	350 bar (Designed)	DOE 2015 Target	DOE 2020 Target
Delivery Capacity (Kg)	720	907	700	940
Capital Cost ($/kg)	744	710	730	575



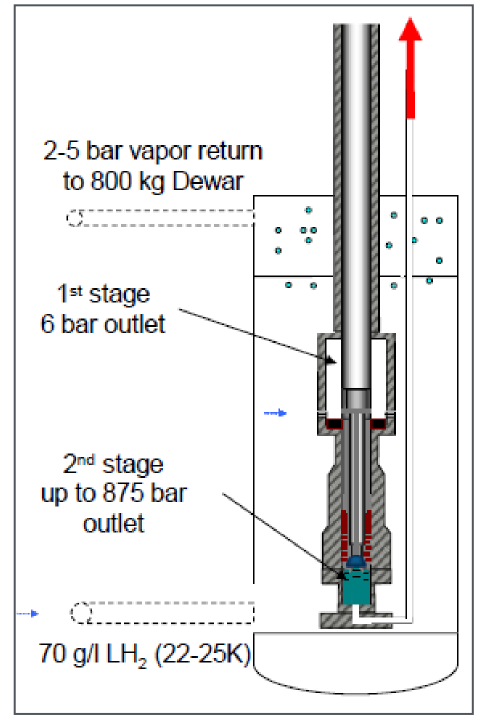
TITAN™ V Magnum Trailer

Liquid Delivery

(LLNL)

Cryogenic liquid pumps have the potential to reduce energy consumption and capital cost at the forecourt

- ✓ Pump installation in progress, efficiency validation to follow
- ✓ Successful test of high pressure cryogenic 3 ft. hose segment
- ✓ Completed electrical and civil work necessary for pump installation



Pump rated at 900 bar

Hydrogen P&D Collaborations

U.S. DEPARTMENT OF ENERGY

DOE/EERE

H_2 Production and Delivery Applied R&D

- **> 30 projects**
- **14 SBIR projects:**
  - **Home Refueling**
  - **Electrochemical Process Intensification**
  - **Large Scale PEM Electrolysis**
  - **Sorbents for Biofueled SOFCs**
  - **Hydrogen Fueling Station Cost Reduction**

INTERNATIONAL ACTIVITIES

Examples:

- IEA HIA Tasks 21, 23-28
- Infrastructure Workshop
- IPHE

INDUSTRY

- **U.S. DRIVE Partnership**
  ***Tech teams*:**
  - H_2 Production
  - H_2 Delivery
- **Codes & Standards Organizations**

I²CNER - Japan

Director: Dr. Petros Sofronis

Focus on H_2 production, delivery, and FC technologies

TECHNOLOGY VALIDATION (DOE EERE)

>180 vehicles & 25 hydrogen stations

National Collaboration *(inter- and intra-agency efforts)*

- **DOE Basic Energy Sciences** — **Over 25 Projects**
- **DOT/NIST**
- **DOE Bioenergy Technologies Office**
- **National Science Foundation**
- **DOE Fossil Energy**
- **DOE Nuclear Energy**
- **ARPA-E**

For More Information

U.S. DEPARTMENT OF ENERGY

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