HYDROGEN & FUEL CELL PROGRAM

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VENTURE CAPITAL TECHNOLOGY SHOWCASE
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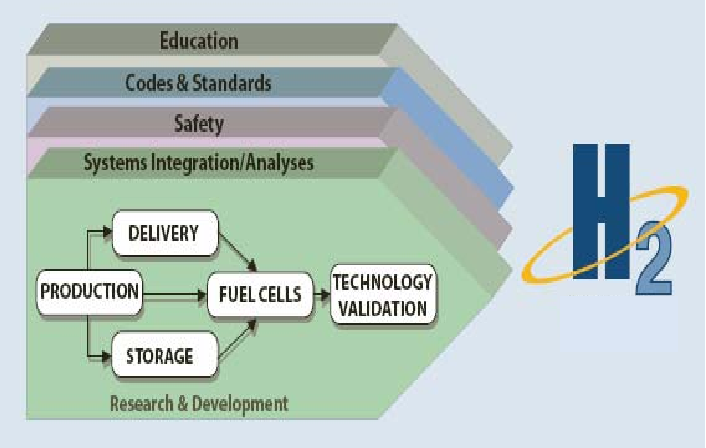
Mission: Reduce oil use and carbon emissions in the transportation sector, and enable clean, reliable energy for stationary and portable power generation

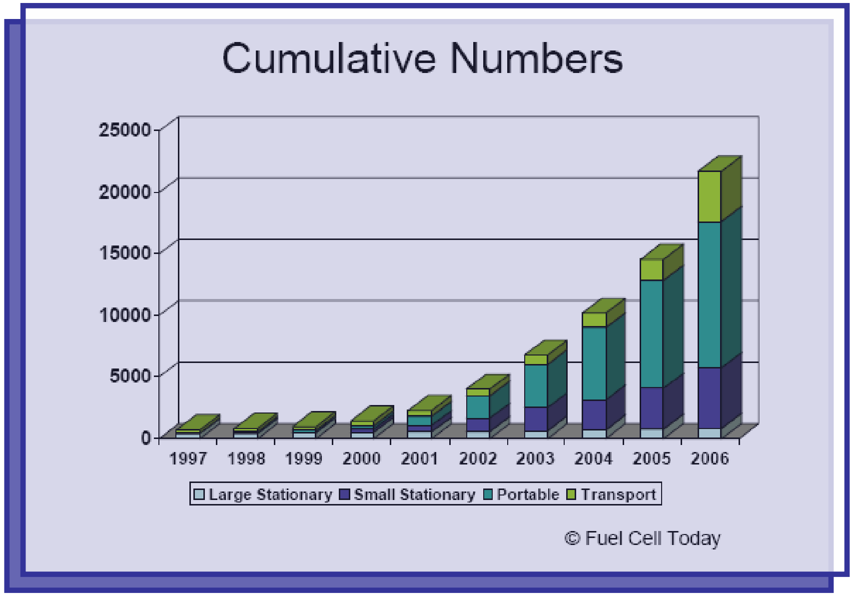
Challenges

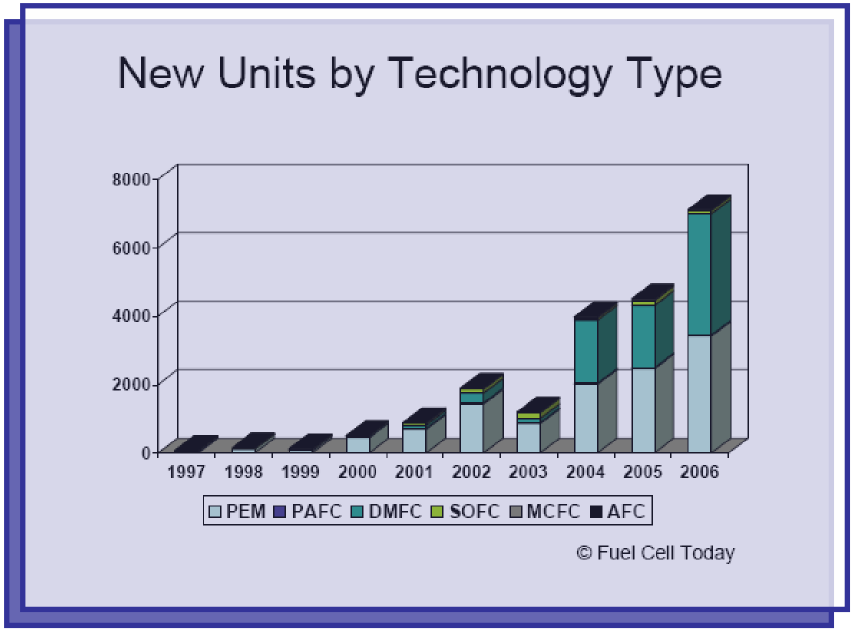
- **Technology Performance and Cost**
  - R&D to achieve cost and performance targets
    - Hydrogen Cost (target: $2.00 - 3.00 per gallon gasoline equiv.)
    - Hydrogen Storage (target: >300-mile range)
    - Fuel Cell Cost and Durability (targets: $30 per kW, 5000 hours)
  - Technology Validation through learning demonstrations

- **High Volume Manufacturing (FY 2008)**
- **Hydrogen Delivery Infrastructure**
- **Safety, Codes and Standards**
- **Education**

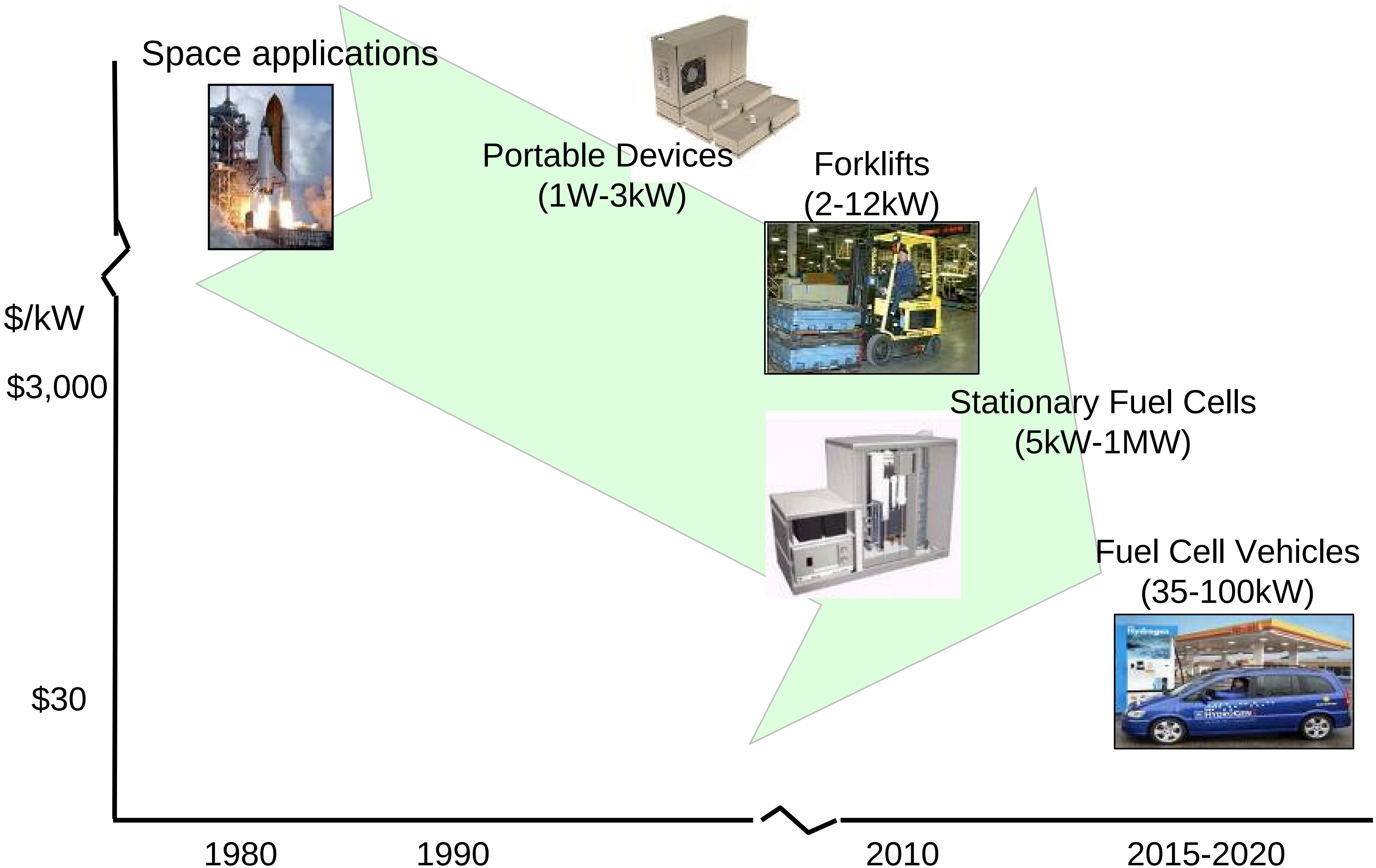


Worldwide Fuel Cell Deployments





Early markets in stationary, portable, and niche applications will ultimately lead to fuel cell cost parity in transportation applications.

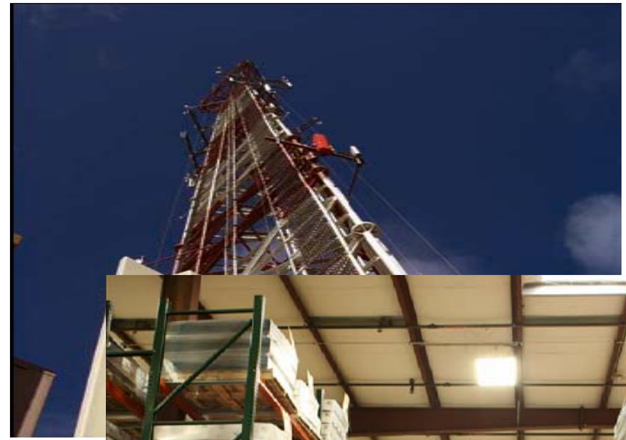


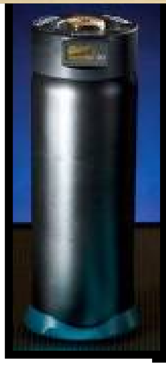
Fuel Cells offer value propositions today.

- **Stationary/Back Up Power**
  - Reliability – no recharging
  - Zero air pollutants
  - Back up power: lower operating and life cycle costs than batteries and gensets

- **Specialty Vehicles**
  - Zero air pollutants
  - Fast refueling (45 seconds for 2 kg)
  - Lower operating and life cycle costs
  - Improved operator productivity - no power loss, no change or recharge time

- **Portable Power**
  - Total energy system is smaller/lighter
  - Extended operating time
  - Recharge/power “in the field”





There are six types of fuel cells.

Polymer Electrolyte Membrane (PEMFC)

- *Pros:* Low temp. operation, quick start, and high power density
- *Cons:* Expensive catalysts
- *Applications:* Transportation and portable power

Direct Methanol Fuel Cell (DMFC)

- *Pros:* Liquid fuel
- *Cons:* Expensive materials, limited durability
- *Applications:* Portable and micro power

Phosphoric Acid Fuel Cell (PAFC)

- *Pros:* Low temperature operation and high efficiency
- *Cons:* Low current and power density
- *Applications:* Distributed generation

Alkaline Fuel Cell (AFC)

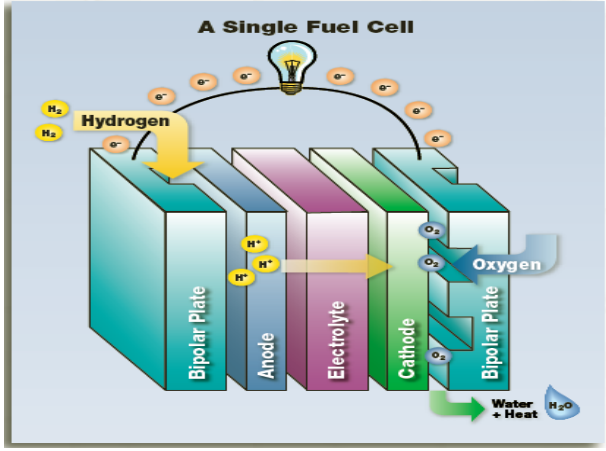
- *Pros:* Low temperature operation and high efficiency
- *Cons:* Expensive impurity removal
- *Applications:* Military and space

Solid Oxide Fuel Cell (SOFC)

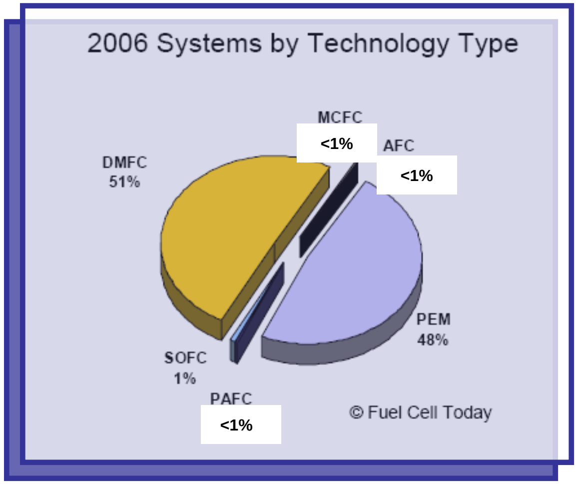
- *Pros:* High efficiency, multiple fuel feedstocks, usable waste heat, and cheap catalysts
- *Cons:* Slow start-up and corrosion issues
- *Applications:* Auxiliary power units (APUs) and distributed generation

Molten Carbonate Fuel Cell (MCFC)

- *Pros:* High efficiency, multiple fuel feedstocks, and usable waste heat
- *Cons:* Slow start-up and corrosion issues
- *Applications:* Electric utility



Fuel Cells use hydrogen, and oxygen from air, to generate electricity through an electrochemical reaction. The only by-products are water and heat.



Emerging Technologies

Fuel Cells

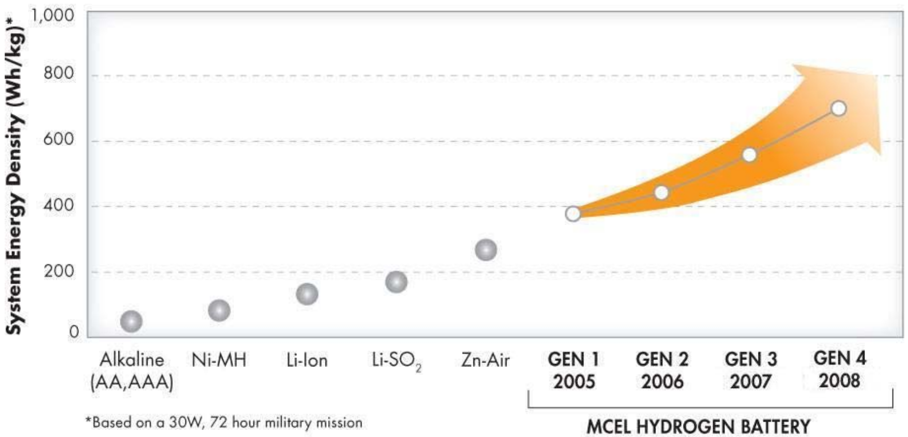
- Compact, inexpensive hydrogen fuel cartridges for portable power
- Metallic bipolar plates for fuel cells

Hydrogen Generation

- Distributed hydrogen production from natural gas
- Renewable hydrogen production using bio-oils
- Renewable hydrogen production using sugars and alcohols
- Low cost, high pressure water electrolyzer
- Compressor-free, high pressure electrolyzer

Compact, Inexpensive Hydrogen Fuel Cartridges for Portable Power

- **Problem:** Traditional batteries are sealed systems so the volume limits the amount of energy that can be supplied. Once that energy is consumed, the entire battery must either be recharged or replaced.
- **Description:** Millennium Cell produces hydrogen storage cartridges for fuel cells. Gaseous hydrogen is produced only when needed. The fuel is non-flammable at ambient pressure and temperature and generates hydrogen at a relatively low reaction temperature (60 - 80°C).
- **Impact:** A combination of a Protonex fuel cell and 3 Millennium fuel cartridges replaces 13 BA5590 batteries and results in a solution that is 66% lighter, 20% cheaper, and 50% smaller for 72 hour missions.
- **IP Position:** 32 patents granted, 74 patents pending (Patent No. 7,214,439, Patent No. 6,706,909, Patent No. 7,105,033)
- **Status:**
  - Reduction to practice: First prototype tested; beta test units (special operations radio) to DOD delivered for field tests
  - Special needs to implement: Customization may be necessary depending upon the application of interest.
  - Capital Needs: Application dependent



Rex Luzader - Business Contact	Millennium Cell
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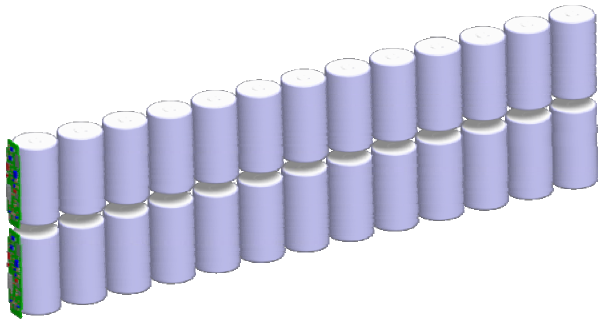
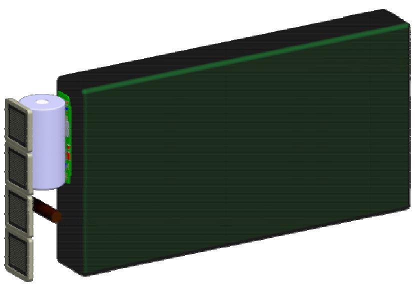
Portable Power Fuel Cells - *Example*



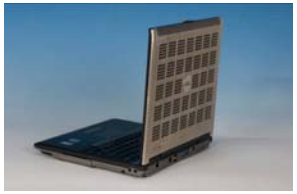


26 Lithium Primary D Cells

Dimensions (cm):	48.5 x 14 x 3.7
Volume (liter):	2.5
Approximate weight (kg):	2.6
Energy Density (Wh/l):	343
Specific Energy (Wh/kg):	330
Price	$260

Gecko Power System

Dimensions (cm):	31 x 14 x 3.7
Volume (liter):	1.6
Approximate weight (kg):	2.0
Energy Density (Wh/l):	550
Specific Energy (Wh/kg):	425
Price	$100

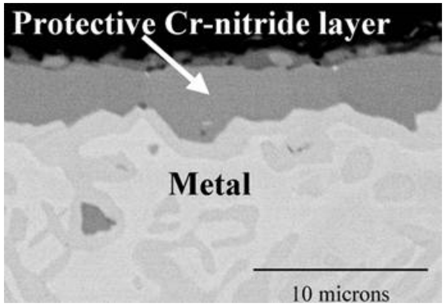


Focus on portable applications < 500W

Military	Medical	Industrial	Consumer
• Soldier Power	• Portable & Wearable Diagnostics	• Portable Video Equipment	• Notebook Computers
• UAVs	• Backup Power	• Industrial Power Tools	• Portable DVD Players
• Sensors	• Remote Patient Monitors, Wheelchairs	• Wireless Sensors & Data Collection Equipment	• Wireless chargers

Metallic Bipolar Plates for Fuel Cells

- **Problem:** Bulk manufacture of thin, low-cost, corrosion resistant bipolar plates is needed for high power density in fuel cells for various applications.
- **Description:** Thin, stamped metallic bipolar plates are protected by applying a Cr-nitride layer (i.e. nitride reacts with metal) to produce defect-free surface layers. Ni-Cr plates meet DOE fuel cell performance targets for corrosion resistance, and contact resistance.
- **Impact:** Metal plates are thinner than conventional composite plates, leading to increased stack energy density and reduced product weight and volume by 25-30%. The plates can be used in fuel cell applications for transportation and distributed power.
- **IP Position:** 2 patents and 1 patent pending; currently available for licensing.
- **Status:** Currently developing low-cost Fe-Cr base steels for the stamped bipolar plate to meet DOE cost targets.
  - Reduction to Practice: The Ni-Cr bipolar plates have been demonstrated in single cells no voltage loss after 1160 hrs of testing. Testing conducted on Fe-Cr-V bipolar plates in single cells with good preliminary results.
  - Special Needs to Implement: No special needs.
  - Capital Required: 2 staff for 2 years to develop specific application; capital requirements based upon product design



Cross section of plate showing nitride treated surface of Ni-50Cr

Stamped metallic bipolar plate (courtesy of GenCell Corp.)

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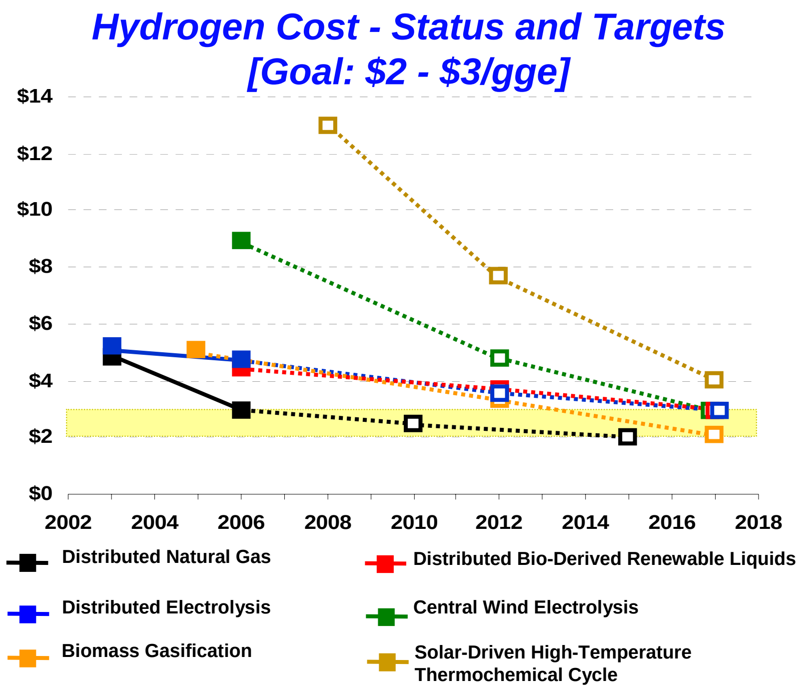
Distributed hydrogen production will enable a low cost infrastructure in the near-term. A diverse, domestic supply base is the end goal.

Hydrogen produced at the point of use does not require hydrogen delivery via truck or pipelines. Distributed pathways under development:

- Natural gas reforming
- Renewable liquid reforming (bio-oils, alcohols, sugars)
- Water electrolysis



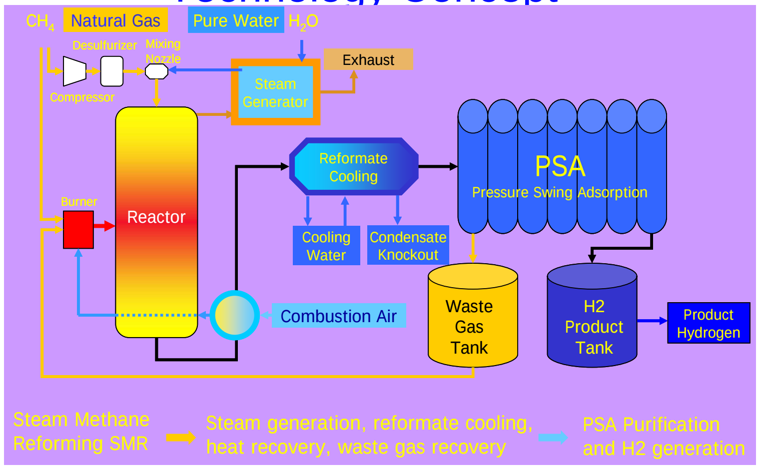
About 9 million tons of hydrogen are produced annually in the U.S. today for industrial purposes, and there are about 700 miles of hydrogen pipelines.

- **Demand for hydrogen will increase as all major automakers are developing fuel cell vehicles (FCVs).**
- **Specialty hydrogen markets such as semiconductor manufacturing and oil refining are also increasing demand.**

Distributed Hydrogen Production from Natural Gas

- **Problem:** Steam Methane Reforming (SMR) technology needs to be lower cost and scaled to an "appliance" size for current and future applications
- **Description:** A skid-mounted SMR system that is easily installed and operated
- **Impact:** Enable low cost hydrogen (<$3/gge) using the existing natural gas infrastructure.
- **IP Position:** 13 patents granted; 14 applied for
- **Status:**
  - Low-cost SMR unit now being sold commercially at 115 gge/day scale primarily to specialty users, e.g. semiconductor manufacturers
  - First prototype of 565 gge/day version with cost-reduction attributes developed under DOE contract started field testing August 2007; expect initial field testing completion by Q1 2008
  - $16 million cash on hand from investors

Technology Concept



H2Gen HGM 2000

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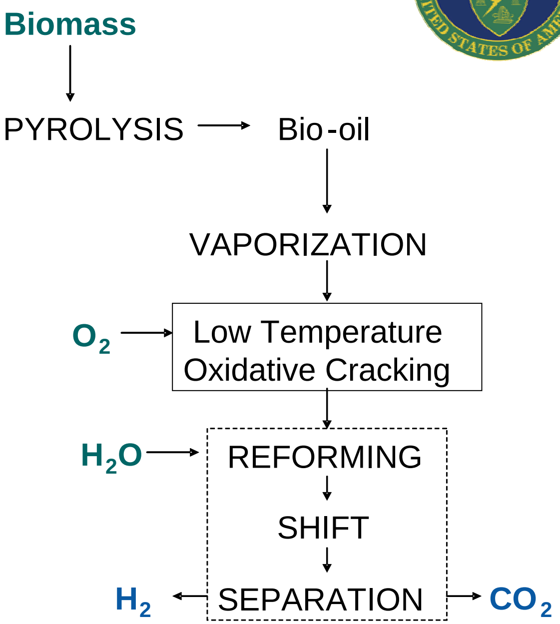
Renewable Hydrogen Production Using Bio-Oils

- **Problem:** Need to develop renewable hydrogen production technologies from diverse feedstocks. Biomass feed stocks are bulky and difficult to transport; bio-oils from biomass are difficult to reform.
- **Description:** NREL is investigating an approach based on oxidative cracking (adding oxygen) prior to catalytic conversion that could allow complex bio-oil mixtures to be reformed like simple alcohols such as ethanol.
- **Impact:** Diverse biomass feed stocks can be pyrolyzed locally, bio-oils are then transported and reformed at the point of use.
- **IP Position:** NREL has established a pre-competitive proof of concept and developed experimental techniques that will allow IP to be established as the process is further refined.
- **Status:** With industry partnering, build a pilot scale system; anticipated capital investment ~$500K to $1 million



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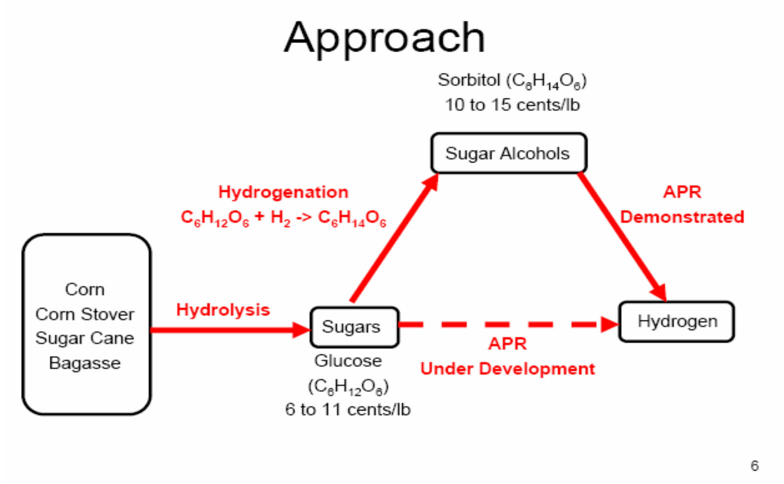
Renewable Hydrogen Production Using Sugars and Alcohols

- **Problem:** Need to develop renewable hydrogen production technologies using diverse feedstocks
- **Description:** The BioForming™ process uses aqueous phase reforming to cost effectively produce hydrogen from a range of feedstocks, including glycerol and sugars. The key breakthrough is a proprietary catalyst that operates in the aqueous phase and has high hydrogen selectivity at low temperature.
- **Impact:** Sugars and alcohols are capable of producing hydrogen for $2 to $4/gge.
- **IP Position:** Exclusive worldwide licenses have been granted, multiple new patent applications placed, and solid trade secret position established.
- **Status:** A pilot plant for hydrogen production from glycerol is in operation and one using sugar is being developed as part of a DOE funded program.



10 kg/day Hydrogen Pilot Plant

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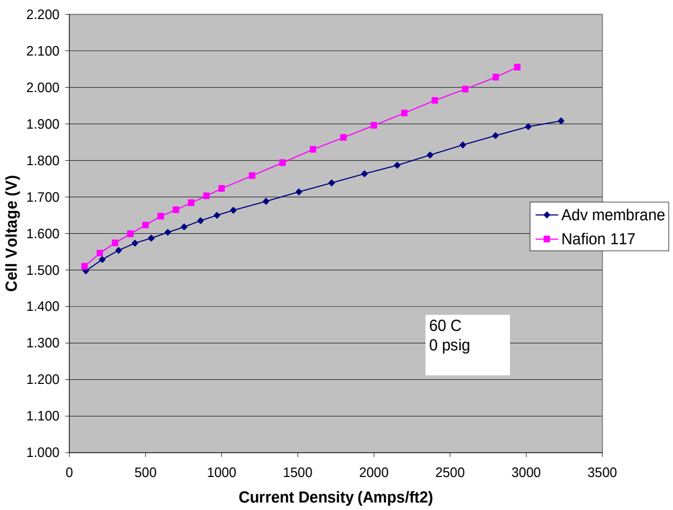
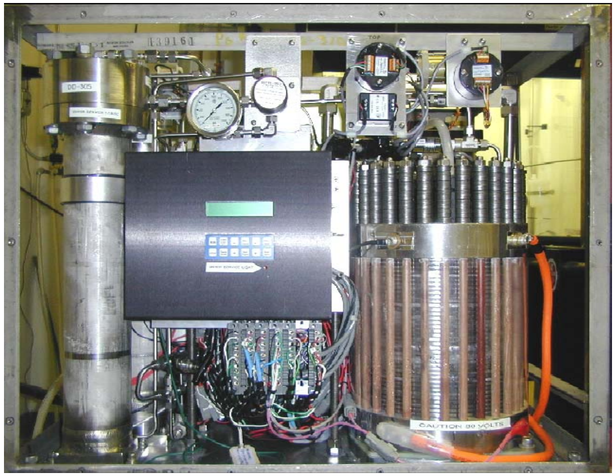
Low Cost, High Pressure Water Electrolyzer

- **Problem:** Significant reductions in the capital and operating costs of electrolysis systems are required to make the technology competitive.
- **Description:** Improved electrolyzer design, manufacturing techniques, and materials have resulted in part count reductions from 40 to 16 components and assembly labor reduction by 60%. Pressurizing the product gas inside the electrolyzer unit has reduced capital cost and electricity needed. An improved membrane has increased stack energy efficiency from 66% to 74% and increased power density, thus reducing equipment size and cost. Overall capital cost was reduced from $800/kW to $600/kW.
- **Impact:** Optimizing design and increasing energy efficiency could enable a potential hydrogen cost of <$3/gge.
- **IP Position:** 4 issued, 5 patents pending
- **Status:** Prototype unit is being tested at NREL
  - Capital needed: $1.2 - $1.8 million needed to further develop a high-strength, highly efficient membrane, demonstrate reproducibility and durability of stack components as well as decrease fabrication costs.





Prototype electrolyzer system

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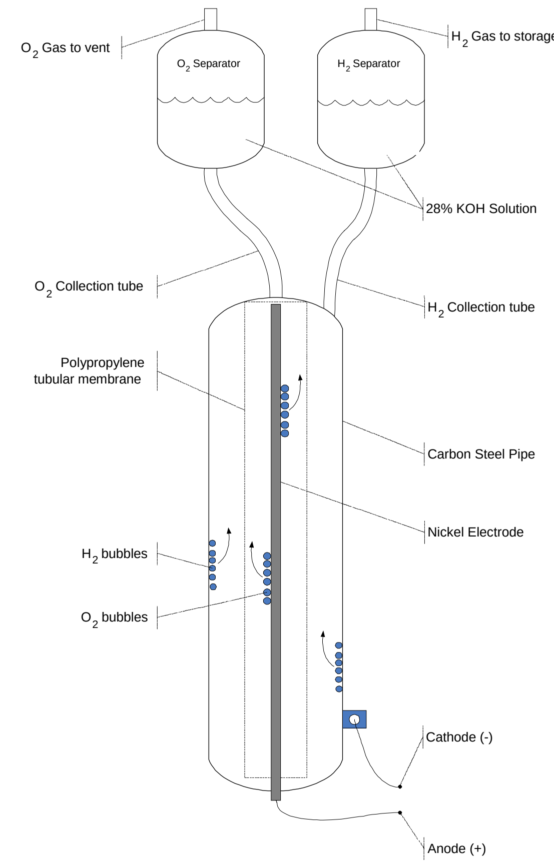
Compressor-Free, High Pressure Electrolyzer

- **Problem:** Significant reductions in the capital and operating costs of electrolysis systems are required to make the technology competitive.
- **Description:** *Avalence Hydrofiller's Electrolyzer Design -*
  - *Unique configuration:* direct high pressure hydrogen (6500 psi+) production eliminates costly and unreliable compressor systems and hydrogen driers.
- **Impact:** Potential to achieve hydrogen cost of <$3/kg in 3-5 years.
- **IP position:** Core technology patent pending in 6 countries/regions
- **Status:**
  - Reduction to practice: 4 units in field, + 6 under fabrication.
  - Availability: 1 to 30 kg/day models available now in pre-commercial status; 300 kg/day model requires development.
  - Next steps: Reduce component count, obtain certifications for 1 - 10 kg/day models, design and build a 300 kg/day unit.
  - Capital Needs: $5 million to meet capital equipment needs, staff expansion, and above listed special needs.



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Coming Attractions – Hydricity or Integrated Renewable Hydrogen

Wind/PV Power→ Electrolysis → Hydrogen

- **Example: DOE/NREL and Xcel Energy Wind/Hydrogen Project**
  - Project integrates electrolyzers and wind turbines to:
    - Identify and overcome the challenges of integrating wind and hydrogen systems
    - Determine and understand the benefits and impacts of adding hydrogen production facilities to the electrical grid