Renewable Hydrogen Production: Leveraging Today's Knowledge for Tomorrow's Solutions

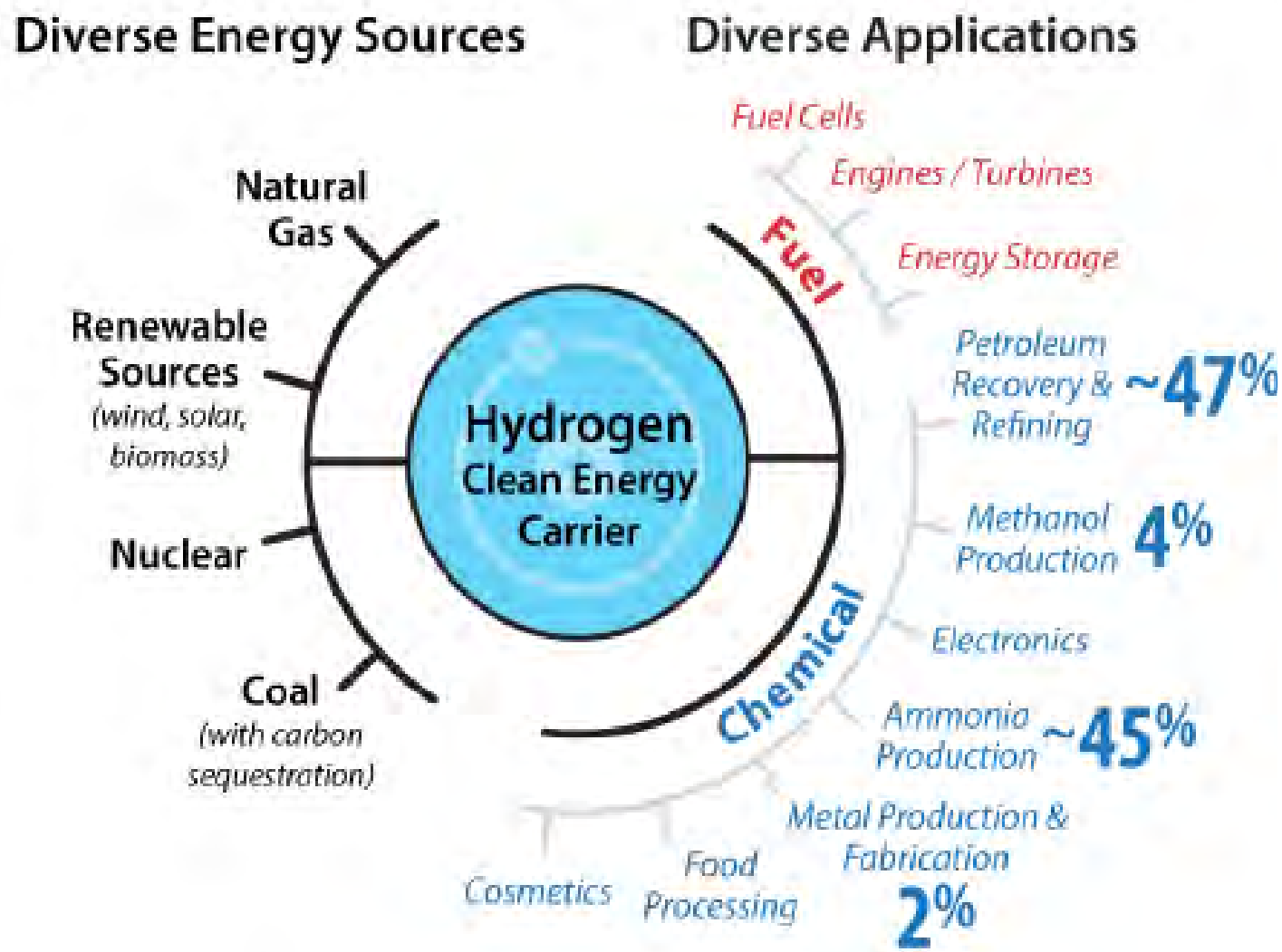
Katherine Ayers,
Vice President, R&D
Proton OnSite, Wallingford, CT

PROTON
THE LEADER IN ON SITE GAS GENERATION.

Outline

- Decarbonization and the role of hydrogen
  - Not just a fueling/transportation question
- Today's water splitting technologies
- Why are we not where we want to be?
- Stepping stones forward

Where is Hydrogen Used?

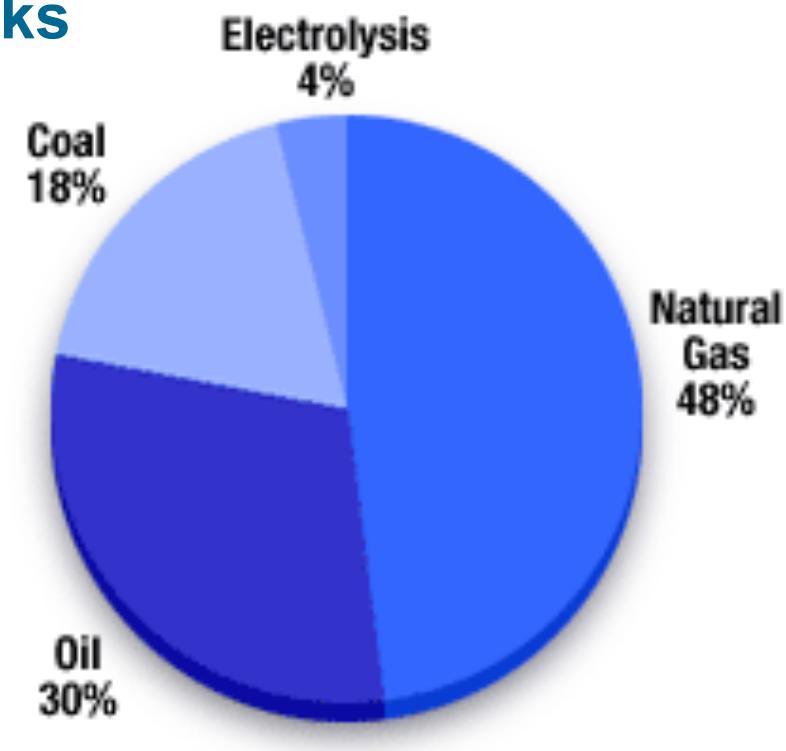


National Renewable Energy Lab, 2016

- ~50 million MT H_2/yr globally
- 2% of US energy goes through H_2

Where Does Hydrogen Come From?

- **Only 4% from non-fossil fuel feedstocks**
- **H_2 is primarily produced via SMR (Steam methane reforming)**



Converting H_2 to renewable sources cuts:

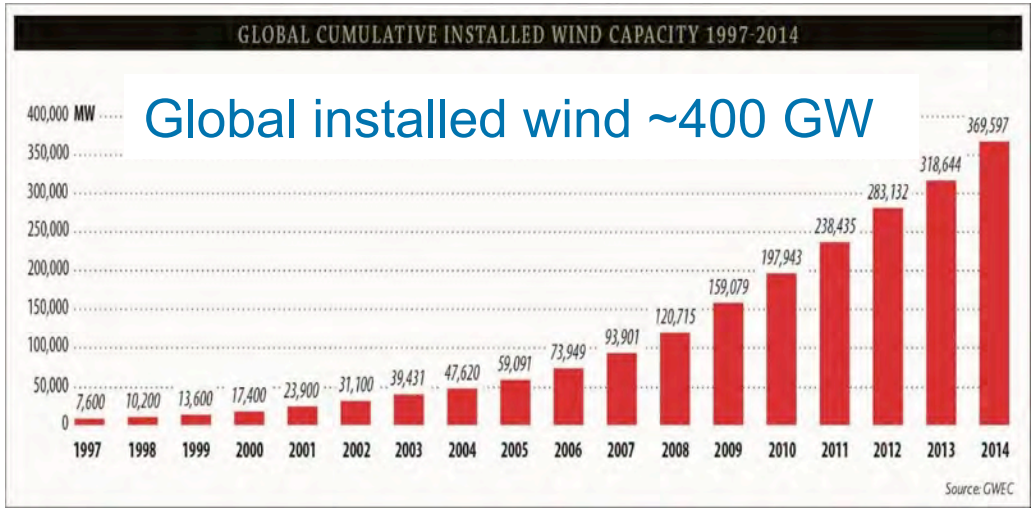
45% of all US carbon emissions

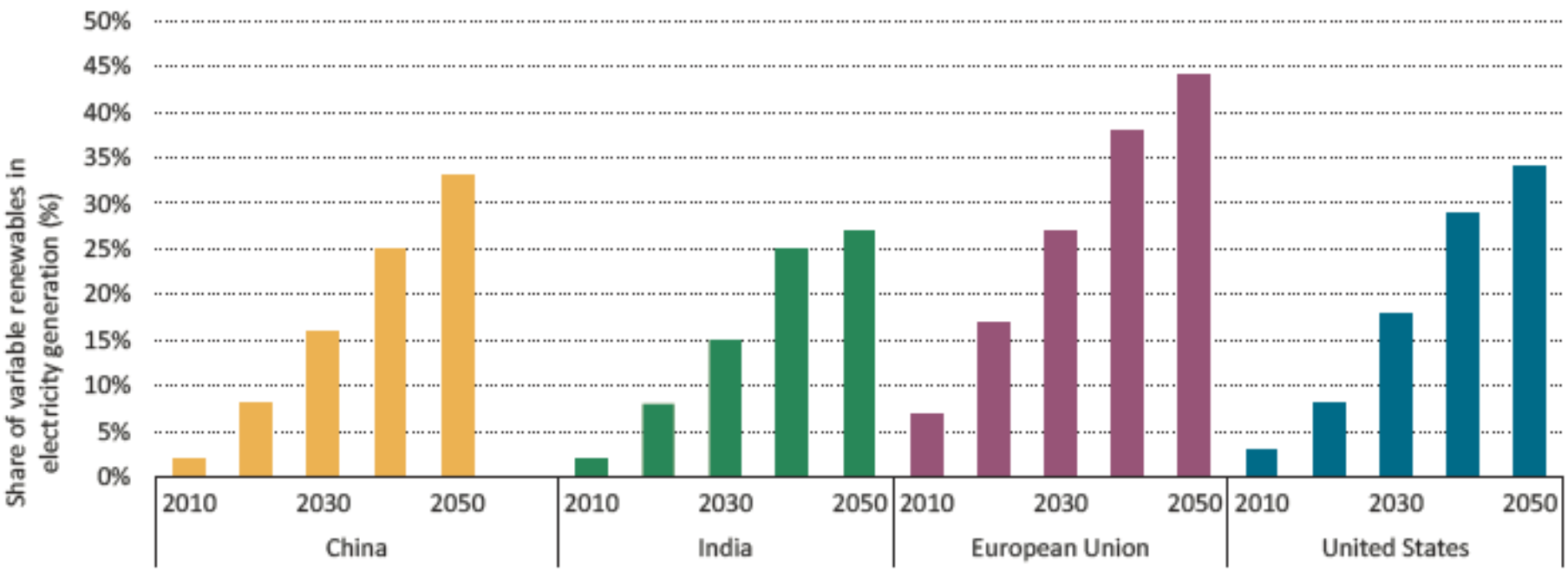
2500 M metric tons of CO_2

- **18 products require 80% of energy and produce 75% of GHGs - Ammonia is largest by far, mainly due to H_2/SMR step**
- **80% decarbonization by 2050 has to involve green hydrogen**

Energy Storage

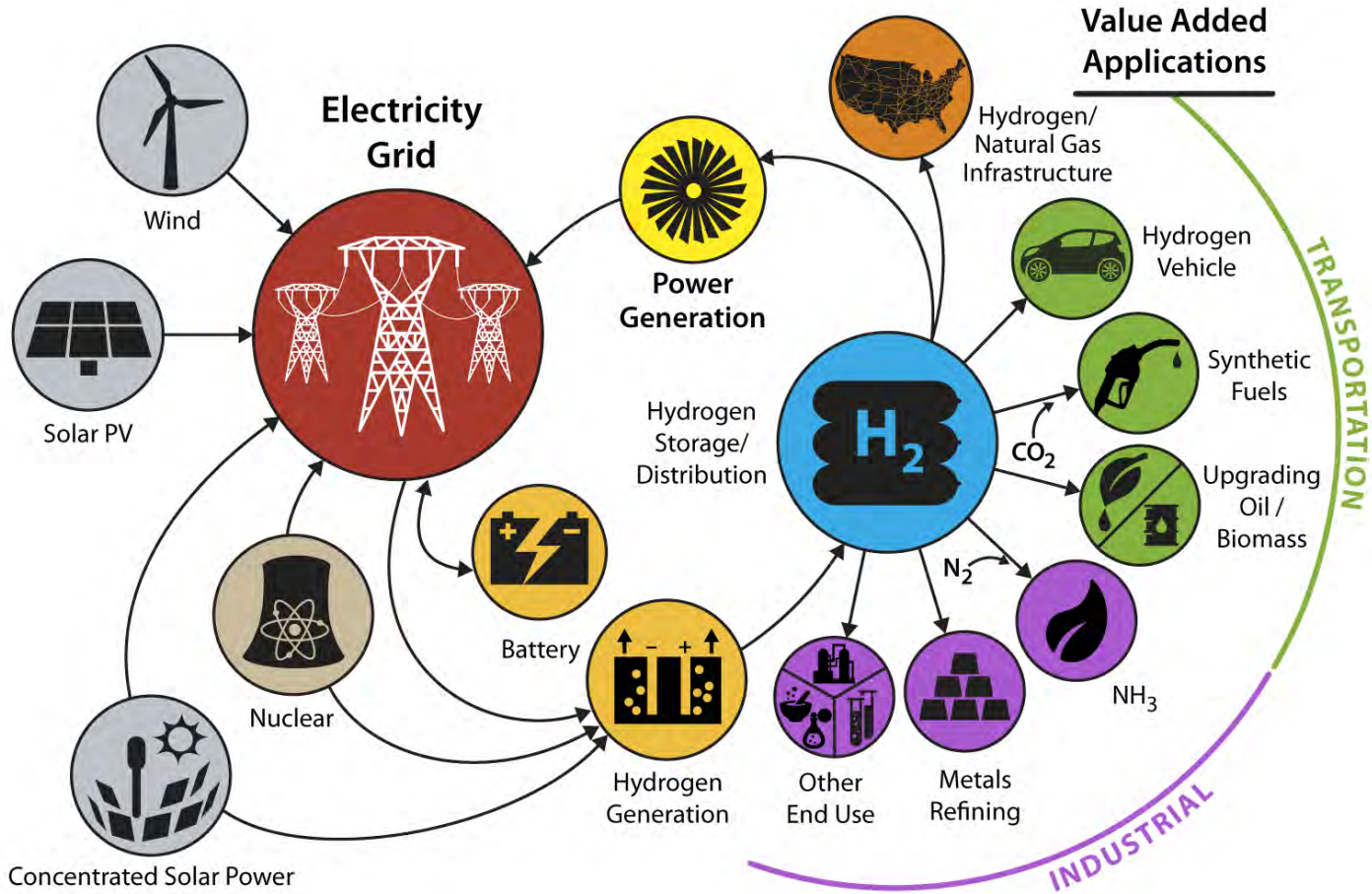
- Adding more renewables to grid requires storage
- Already have overcapacity in some areas
- Further growth expected in all geographies





“H2@Scale”

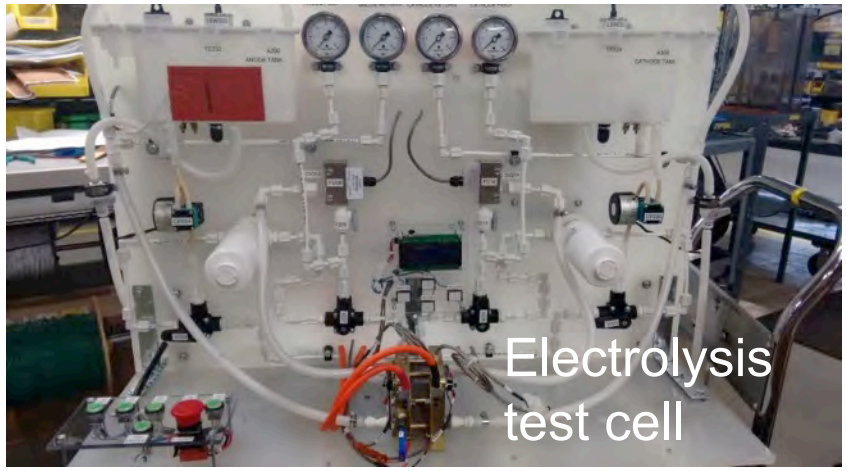
Linked solution for renewable hydrogen and energy storage



National Renewable Energy Lab, 2016

- Diversity of applications provides flexibility
- Low cost electricity makes economic case

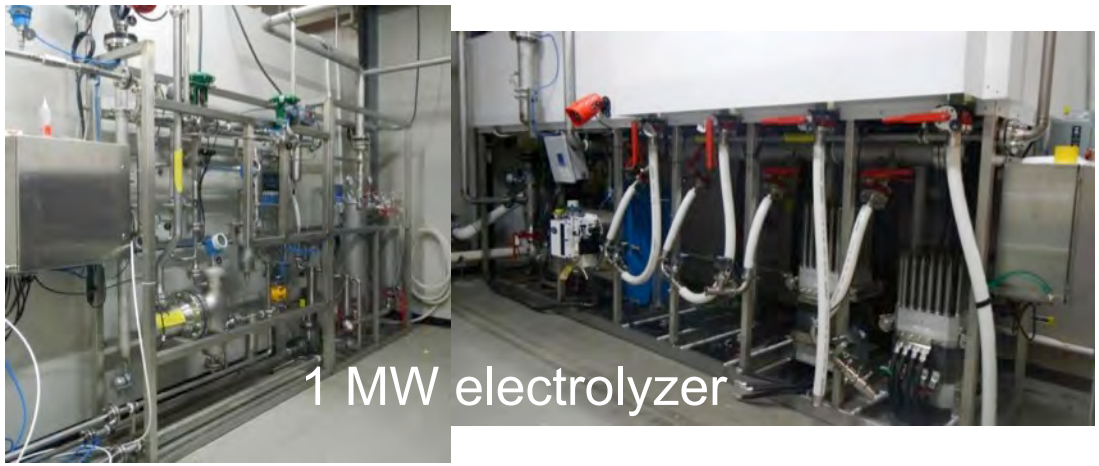
Relative Technology Maturity

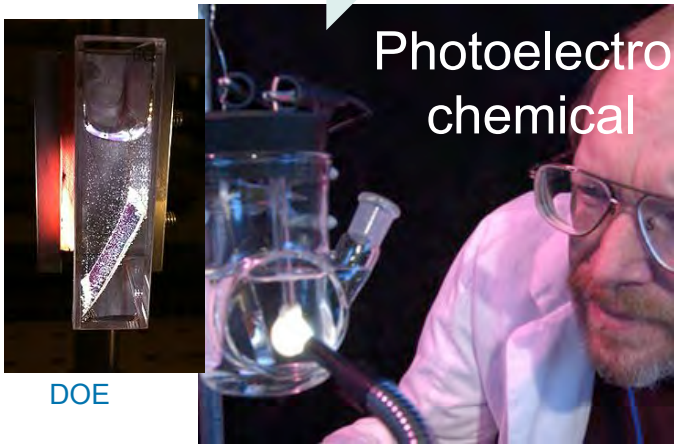


DOE

http://www.fgcsic.es/lychnos/en_EN/articles/hydrogen_production_methods

Natural Gas	Commercial Electrolysis	Advanced Electrolysis	New Technology
10,000+ kg/day	100-1000 kg/day	g-kg/day	mg-g/day

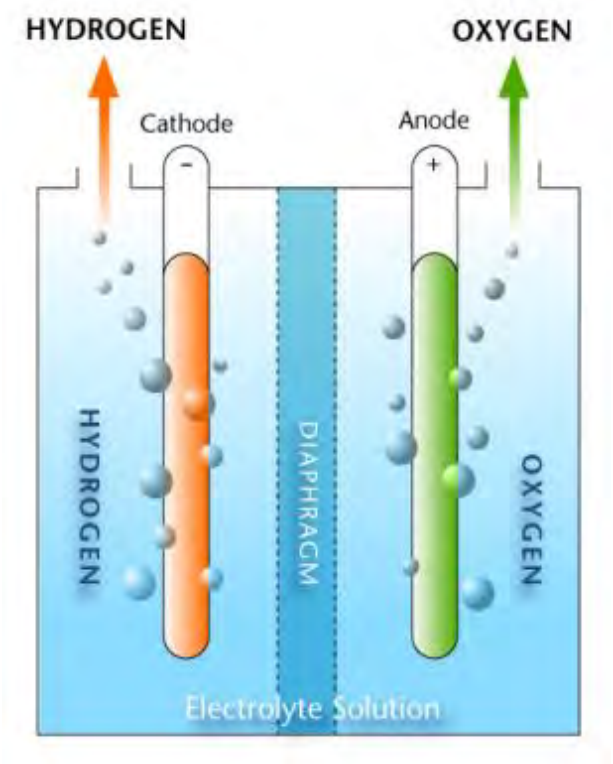


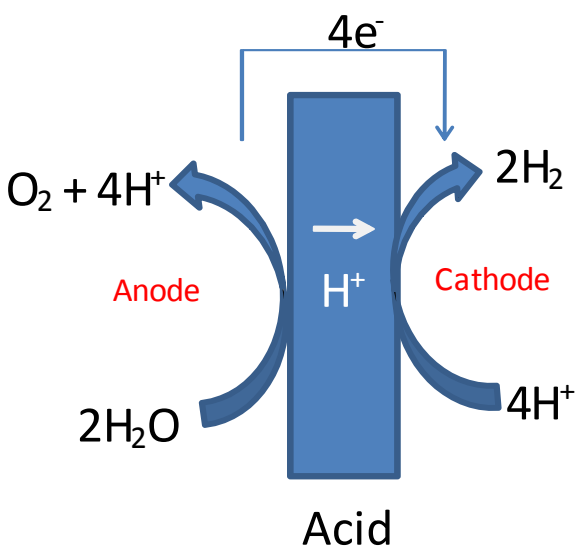


DOE

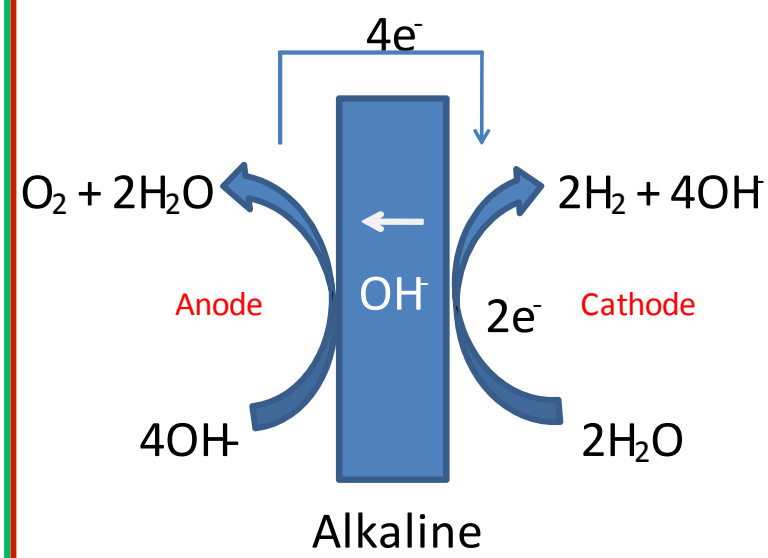
Low Temperature Electrolysis Options

- Liquid KOH:
  - Corrosive electrolyte
  - Enables non-noble metals
  - Lower current density
- Membrane-based:
  - Solid electrolyte
  - Enables differential pressure
  - Room for development





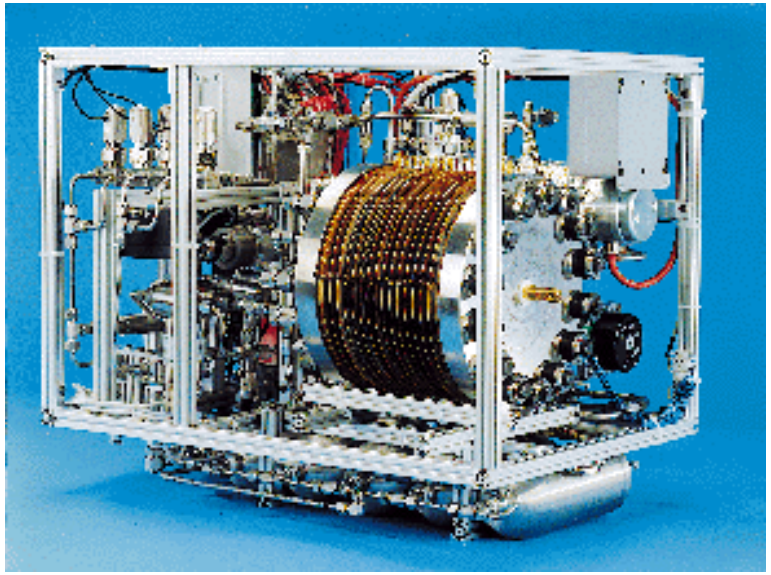
Commercial



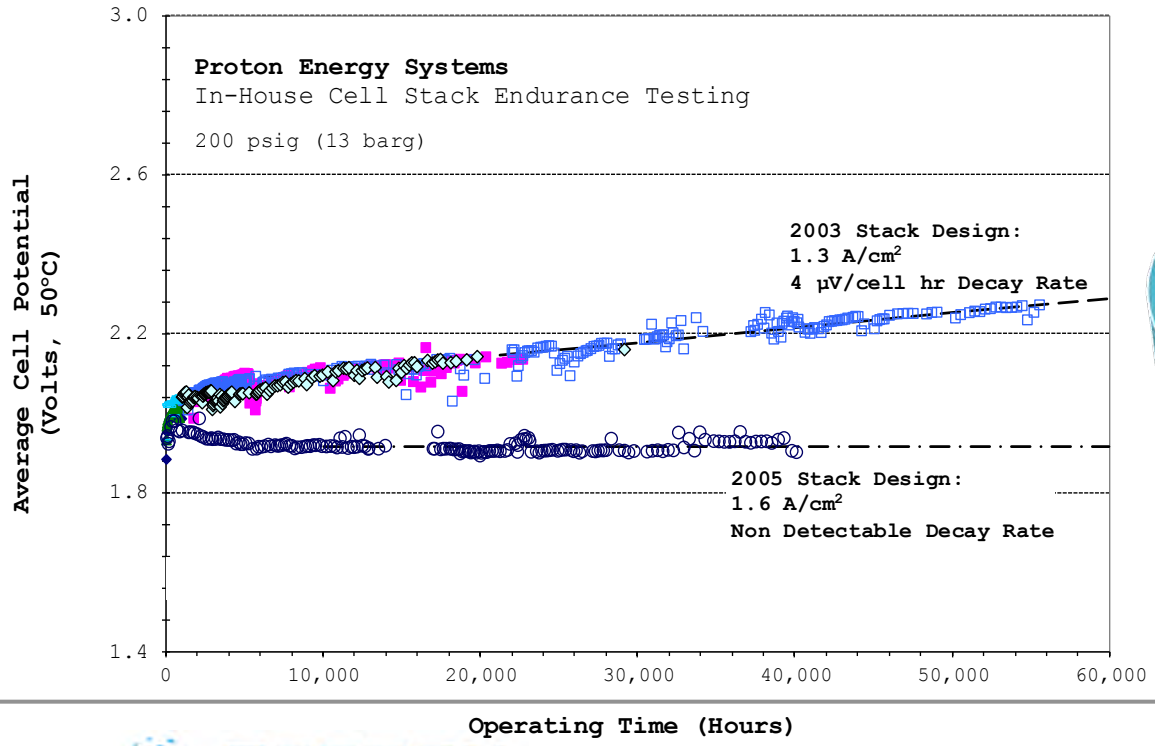
Emerging

PEM Commercial Status

- Designed for life support (O_2)
- Basis for H_2 products
- High reliability demonstrated
- Overdesigned; behind vs. fuel cell investment/status

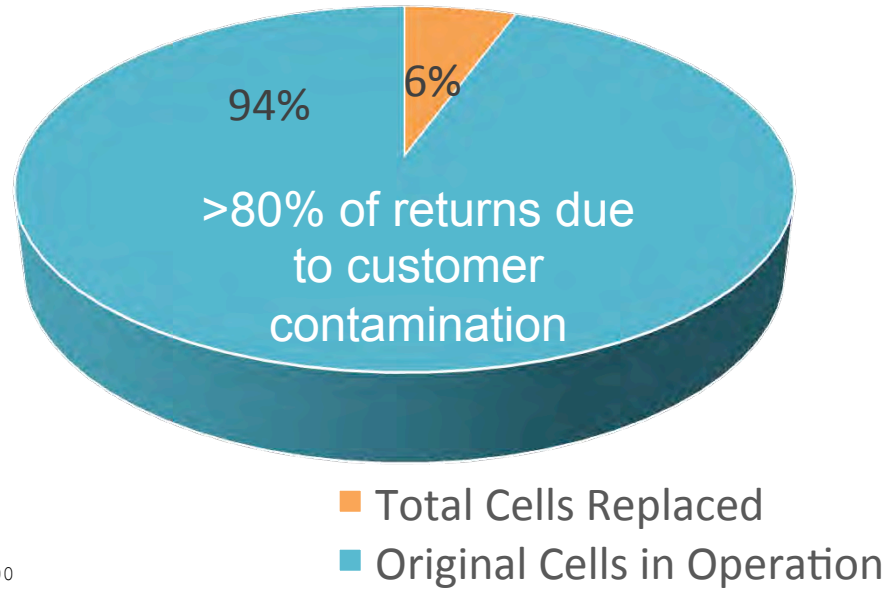


NASA OGA system: ISS



Proton Testing and Field History

Cell Rework Summary, 2006 - 2015



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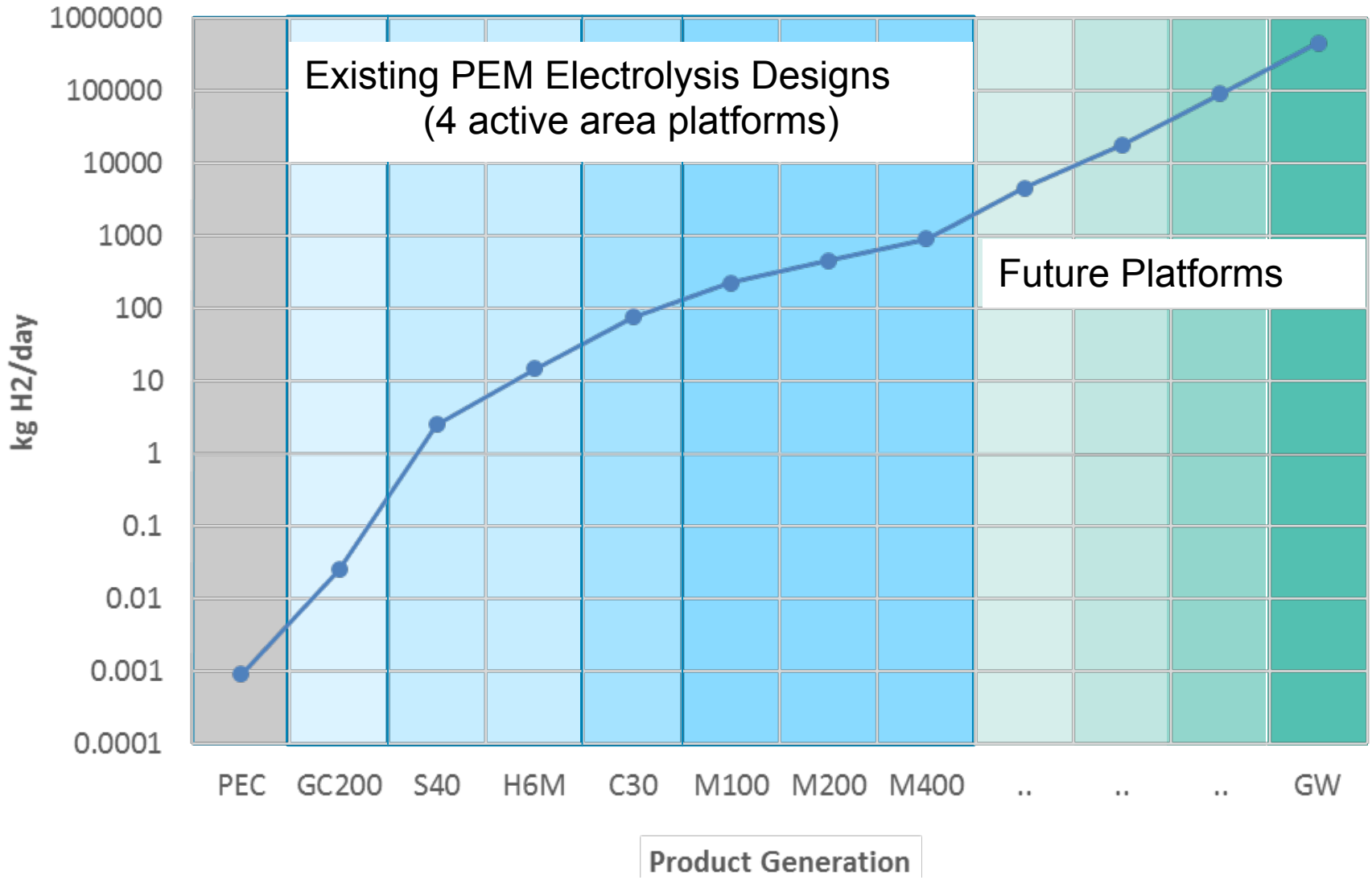
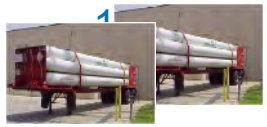
Platform Iterations



- Potential to get to GW scale in 4 product generations
- Likely ~12 for PEC (based on 10 mA/cm^2, 100 cm^2)

From Science to Product; a 20 year timeline

Starting from a well-established technology in 1996

$/kW vs. S-Series	100%	43%	28%	13%
Input Power	6 kW	36 kW	180 kW	1 - 2 MW
Product Type				
Year Introduced	2000	2004	2010	2014
Units Sold	450+	200+	40+	NA
H2 output (Nm^3/hr)	1	6	30	200–400
Generates	1 [	1 		
Replaces	 Six Pack	 Tube Trailer	 Jumbo Tube Trailer	 Jumbo Tube Trailers

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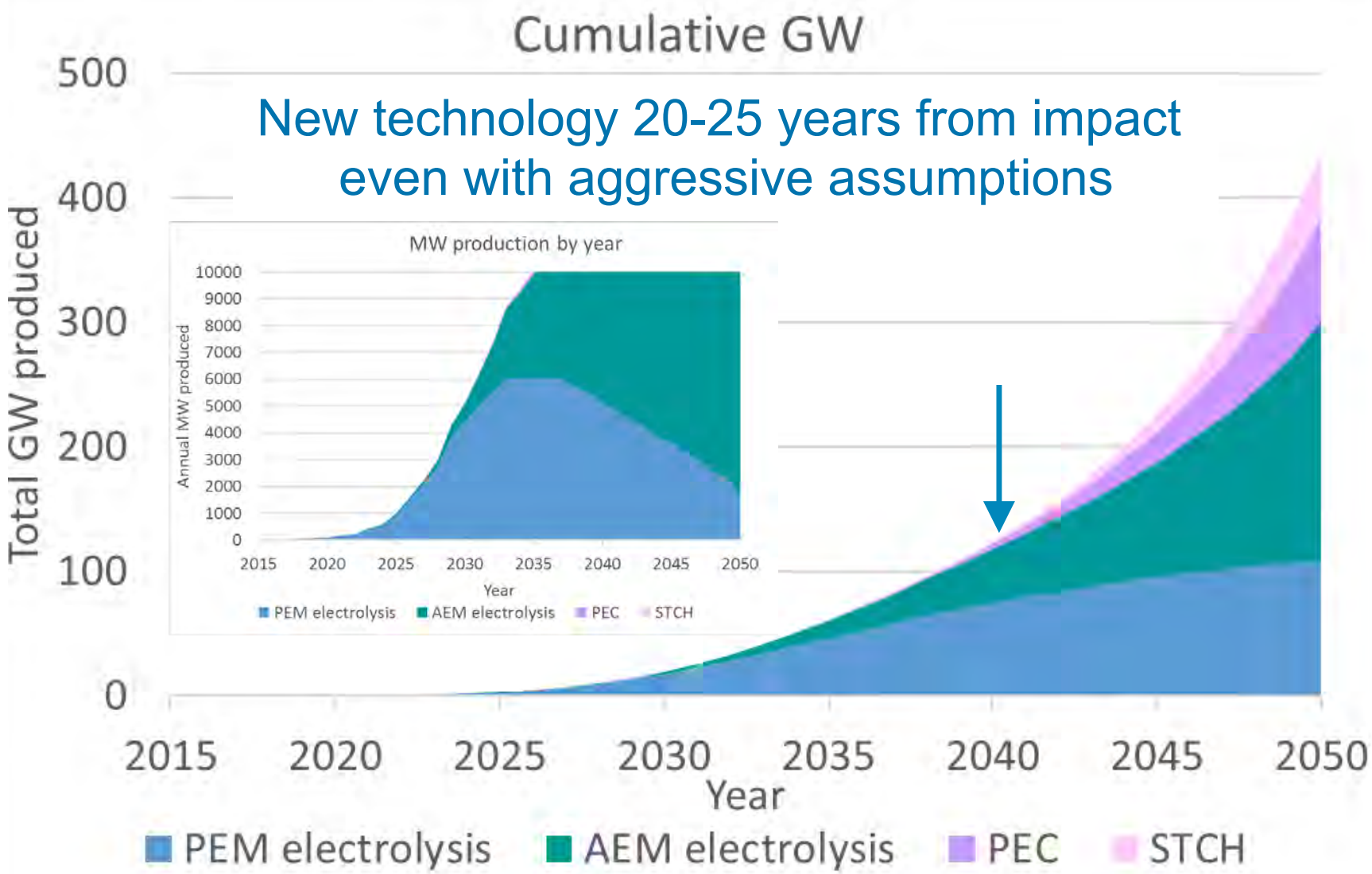
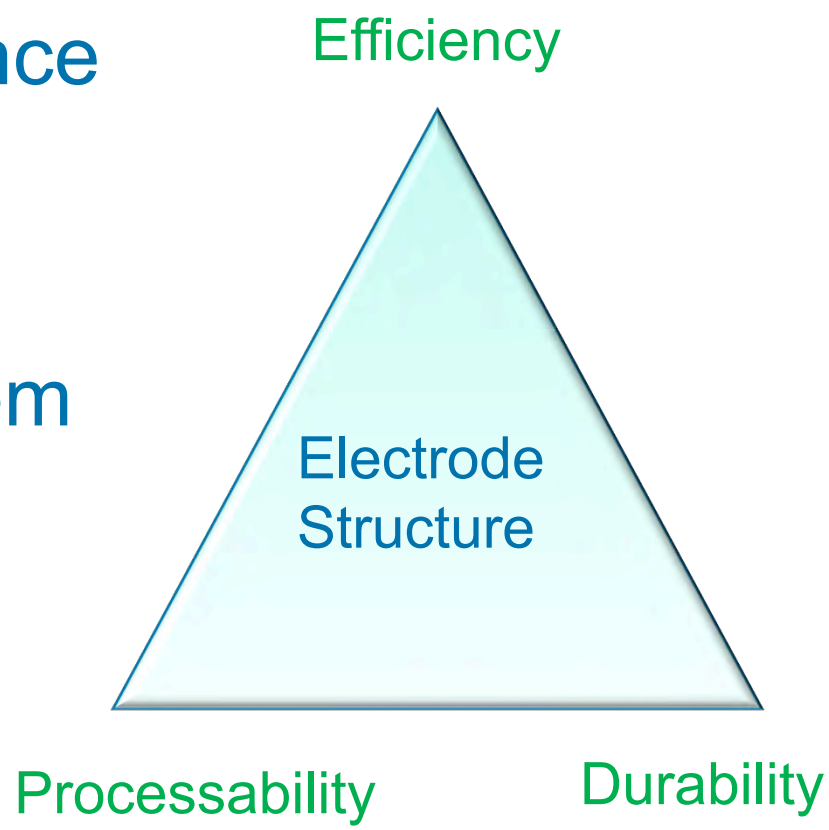
Only electrolysis can impact 1st 20 years



Need larger contributions from all to make TW-scale impact

Why does development take so long?

- Not just about materials/performance
- Manufacturing is its own science
  - Cost and uniformity at scale
- Durability testing takes time
- Interactions can derail a system
  - Impact of tolerance extremes
- Design for safety and code compliance adds complexity



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The Risks of Shortcutting Development

Laptop at Japan conference

http://www.extremetech.com/extreme/129764-tech-wrecks-lessons-from-some-of-the-biggest-hardware-screw-ups/2

Boeing 787 Dreamliner battery packs

http://aircraftrecognition.blogspot.com/

Navy stress test for submarine energy system

Need to Link Technology to Markets

- New products for specific applications

Lab line: Instrumentation

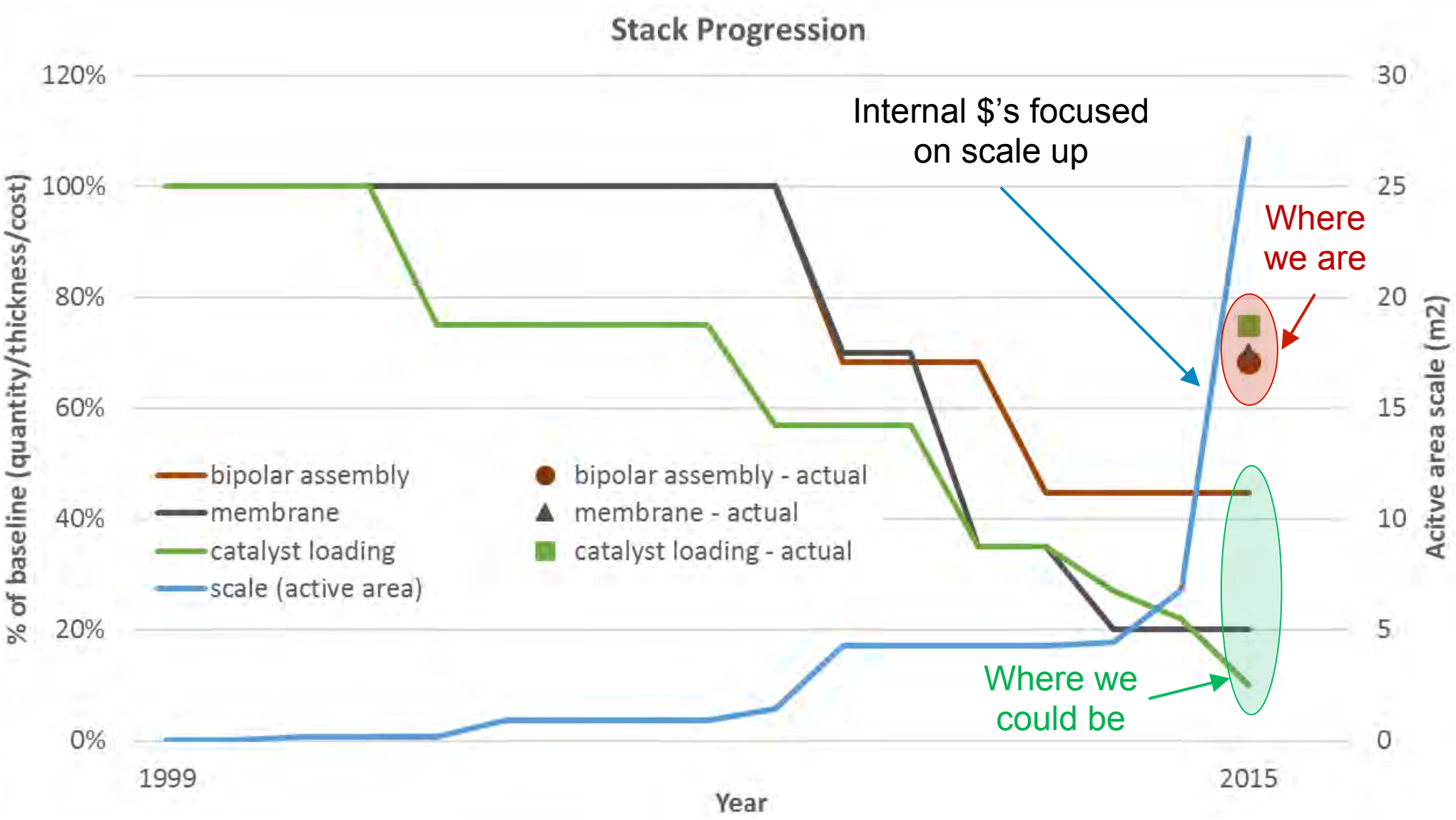
H and C-series: Power Plants/ Industrial

S-series: Weather Balloons

M-series: Energy Storage and Biogas

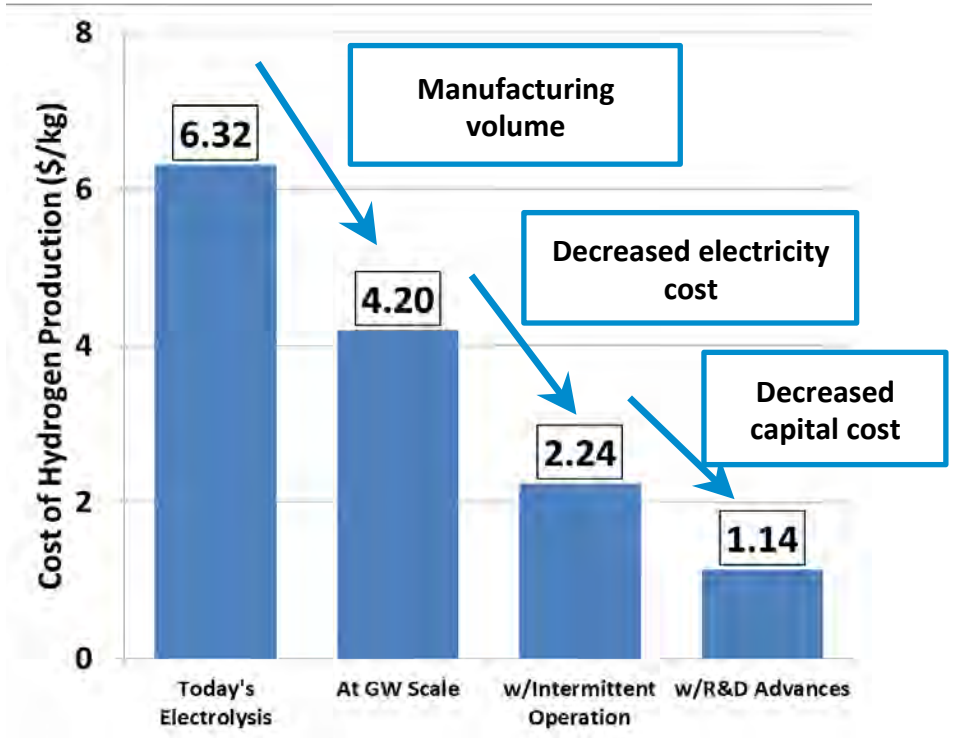
- Extremely difficult to go directly from lab to large scale

Implementation lags R&D considerably



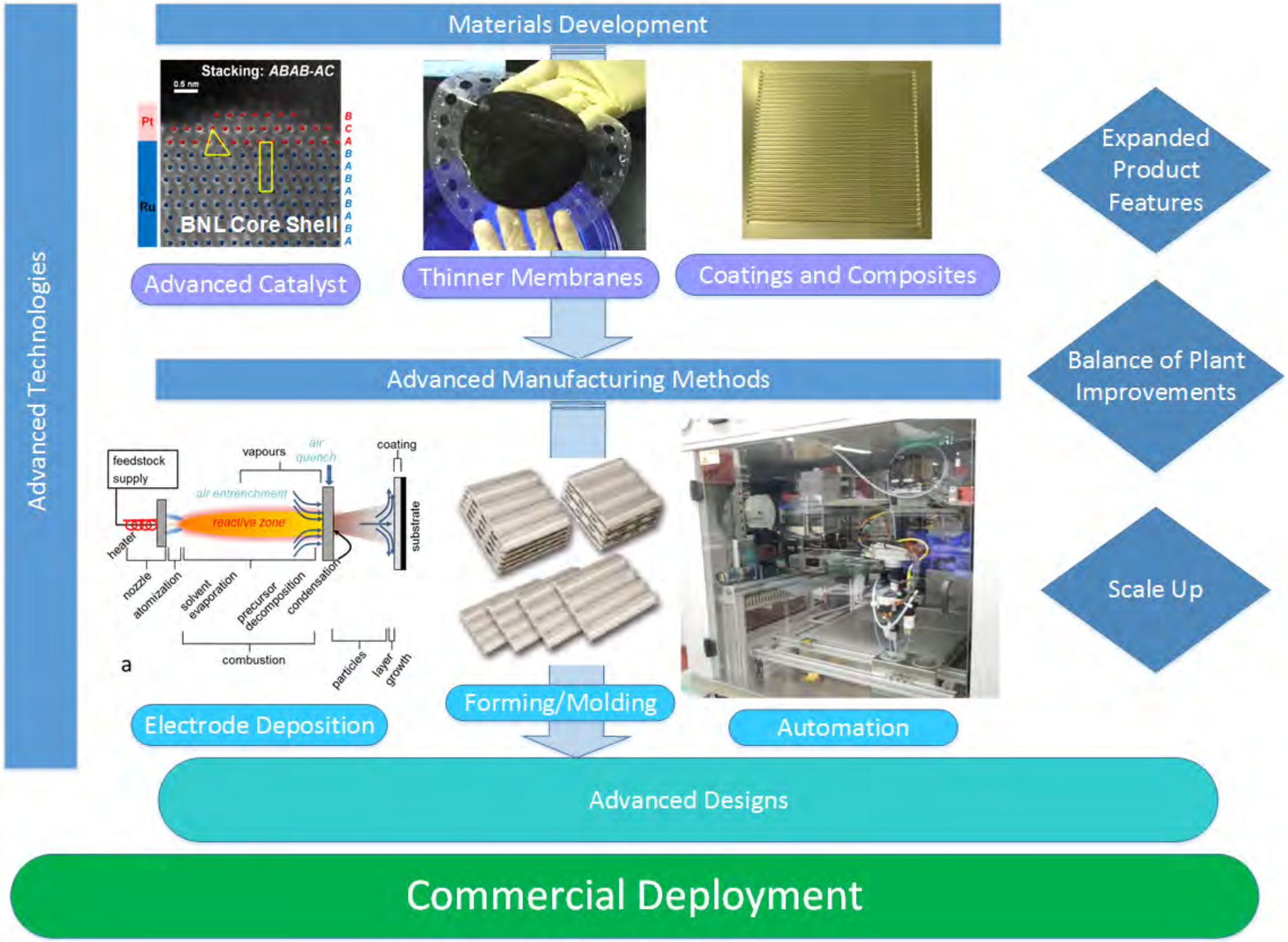
Perceptions vs. Potential of Electrolysis

- "The platinum problem"
  - Power per annual production (Rossmeisl, 2014):
    - Pt Fuel cells: ~0.3 TW; Ir Electrolysis: ~0.1 TW
  - See pathways to get to 1-2% loading
- Scale, cost, and reliability
  - MW scale and growing
  - Manufacturing is the cost issue (catalyst ~10%)
  - Cost competitive in industrial markets
  - 7-10 year stack life



National Renewable Energy Lab, 2016

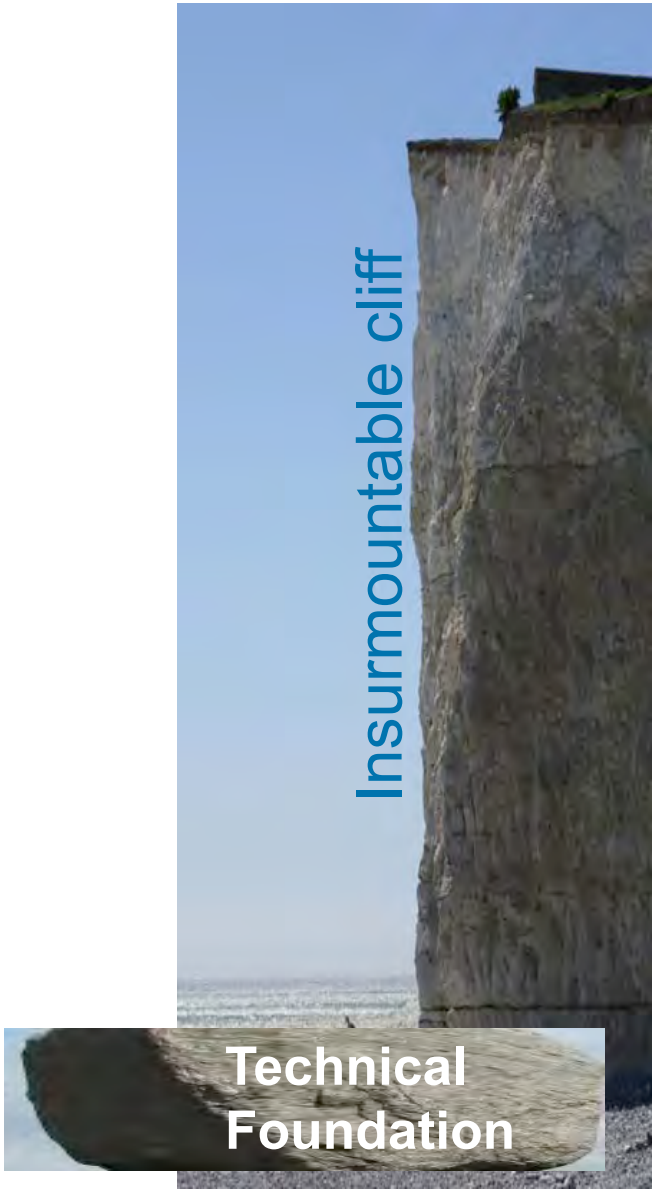
Ongoing advancements leverage fuel cells



Importance of Collaboration

- Challenging cell environment: acidic, highly oxidizing (O_2 side), high pressure (H_2 side)
- Metallurgy, polymer, catalyst materials issues
- Importance of porosity and wetting properties
- Manufacturing and cell perspective from industry

Breaking down the problem for GW scale



- New technologies need to build from existing legacy
- Leverage knowledge across fields
- KOH → PEM → AEM

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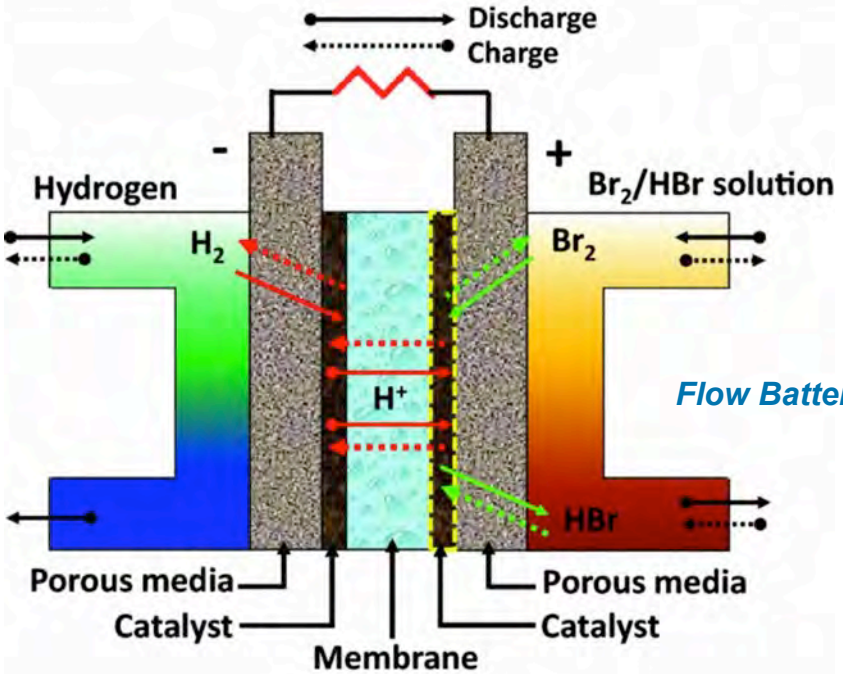
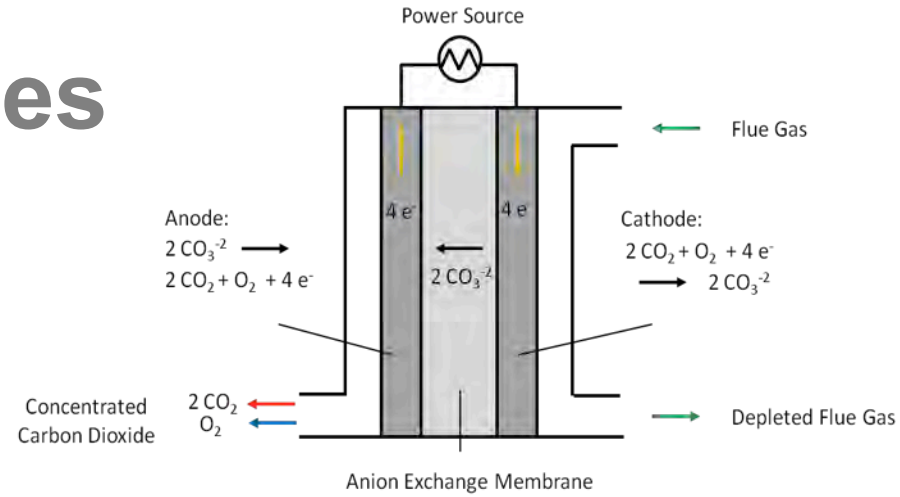
Solar fuels and other electrolysis

- Need collaboration between industry and academics

Synergistic Technologies

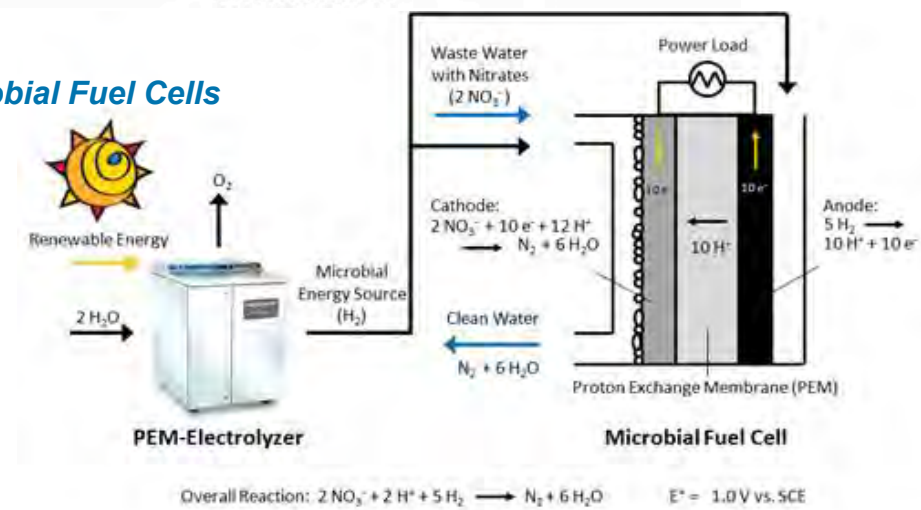


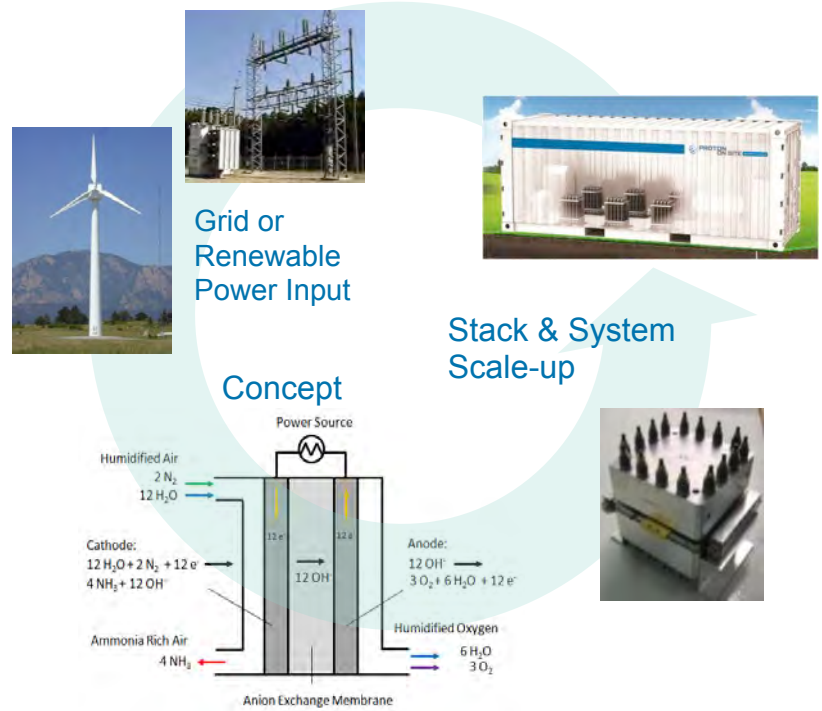
Flow Batteries



Electrochemical Pumping/Compression/Conversion

Microbial Fuel Cells





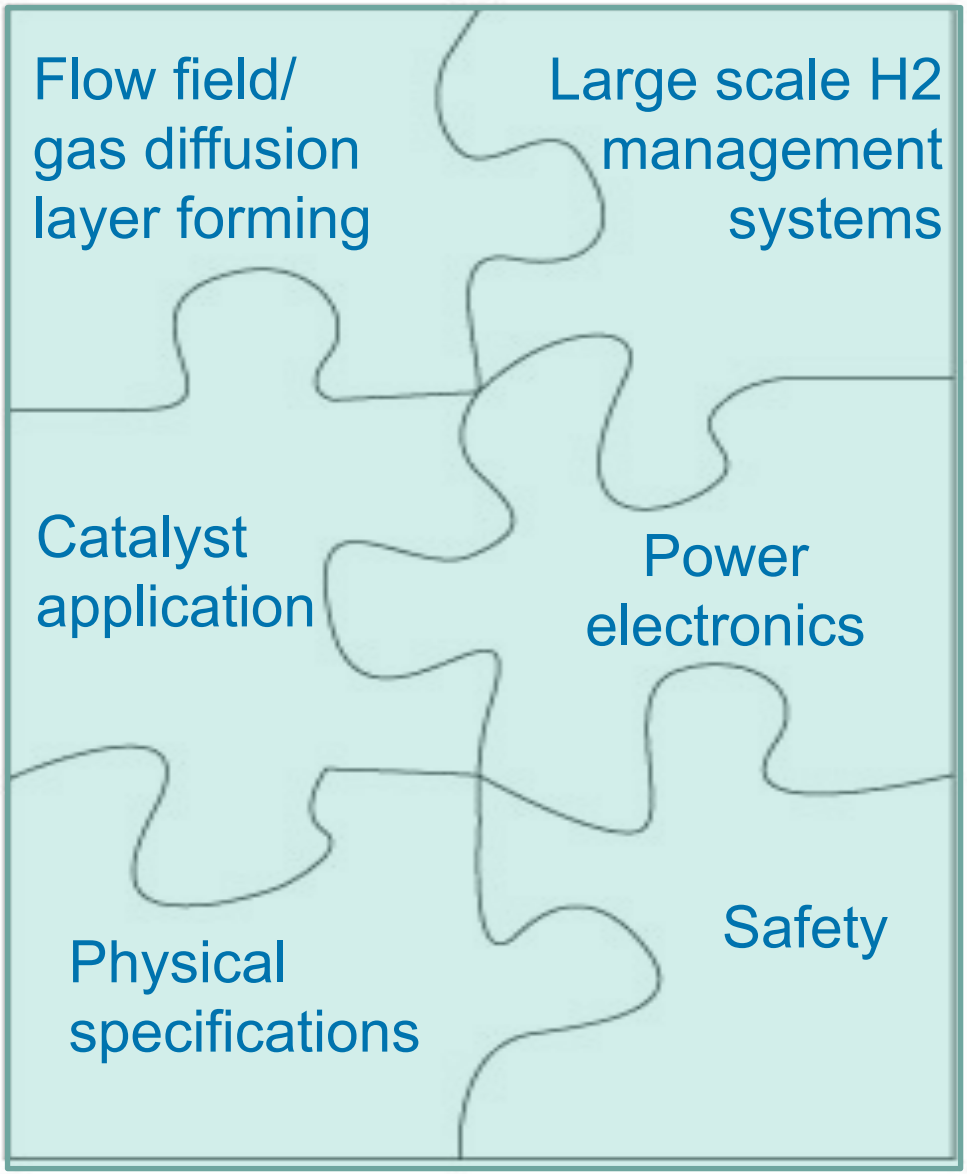
Electrochemical Conversion of N_2 to Ammonia

Building Blocks

End system will leverage the most cost effective option

Develop transferable capability on existing platforms

- Follow manufacturing maturity/cost curve
- Large scale components
- Materials and form factors can be tailored later



Conclusions

Proton funding agencies

- Hydrogen is an essential part of decarbonization
- Need to be realistic about timeframes for technology development and leverage what we have
- Address near term needs as well as new science/discovery
- Find synergies between both and drive progress