# $H_2$ at Scale:

Benefitting our Future Energy System

# Update for the Hydrogen Technical Advisory Committee

December 6, 2016

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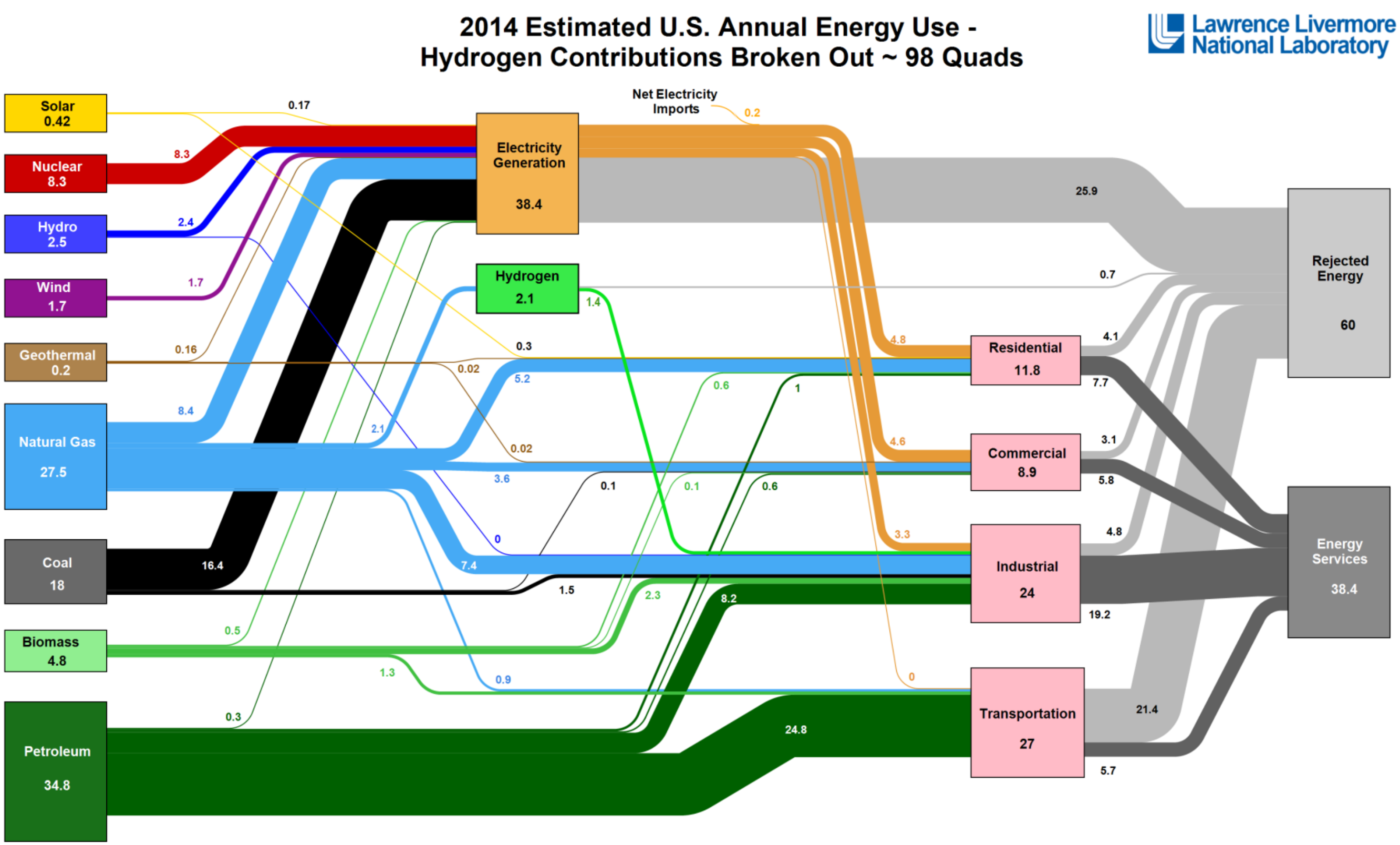
H2 at Scale webinar available at
http://energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar

# Large Scale Hydrogen is Well Known

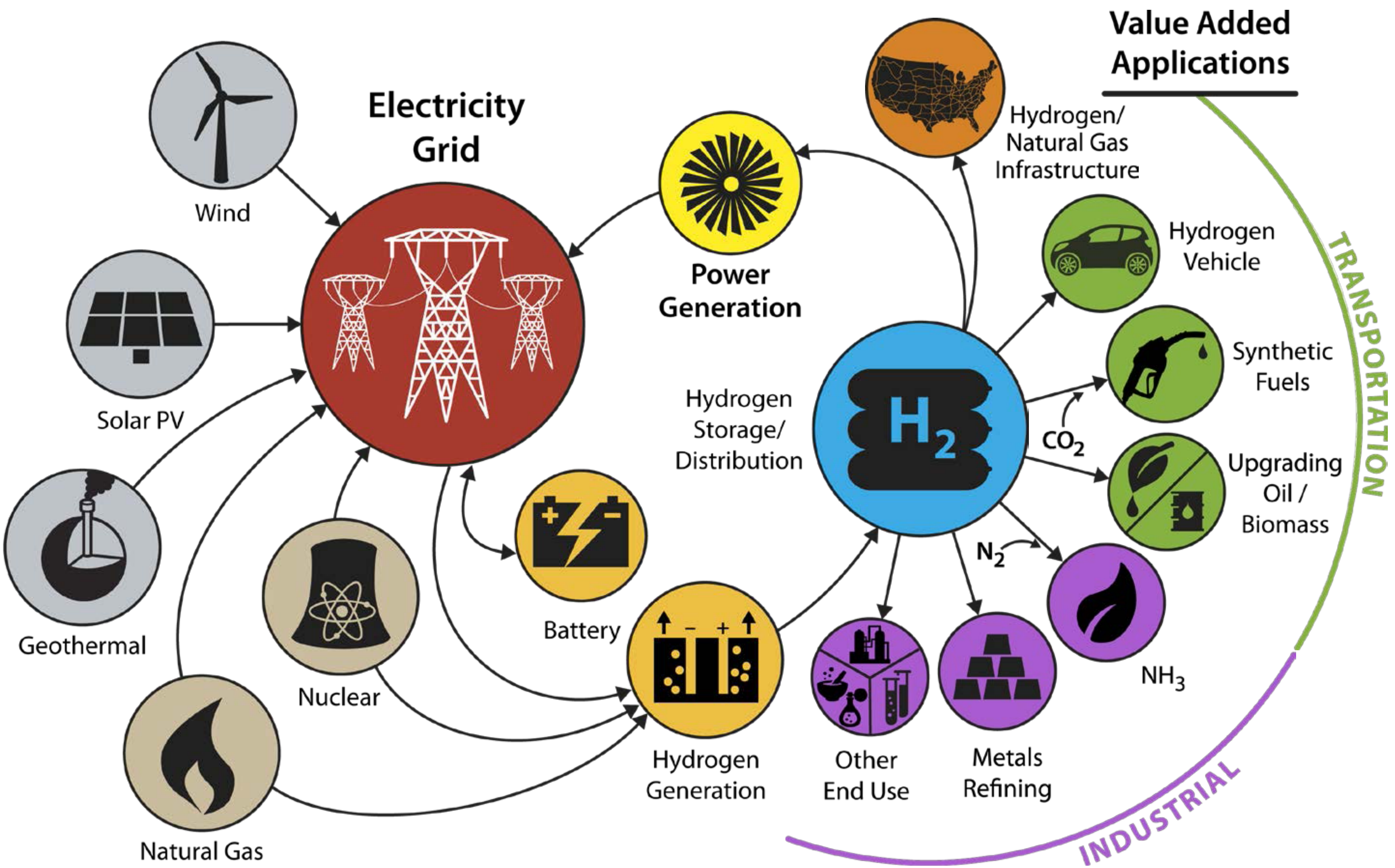



Source: LLNL September 2015. Data is based on DOE/EIA-0035(2015-03) and Annual Energy Outlook DOE/EIA-0383(2014). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate". The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-676987

- **Annual hydrogen use in the U.S. = 10 million metric tons = 1.35 Quads**
- **Hydrogen production requires 2% of national energy use**

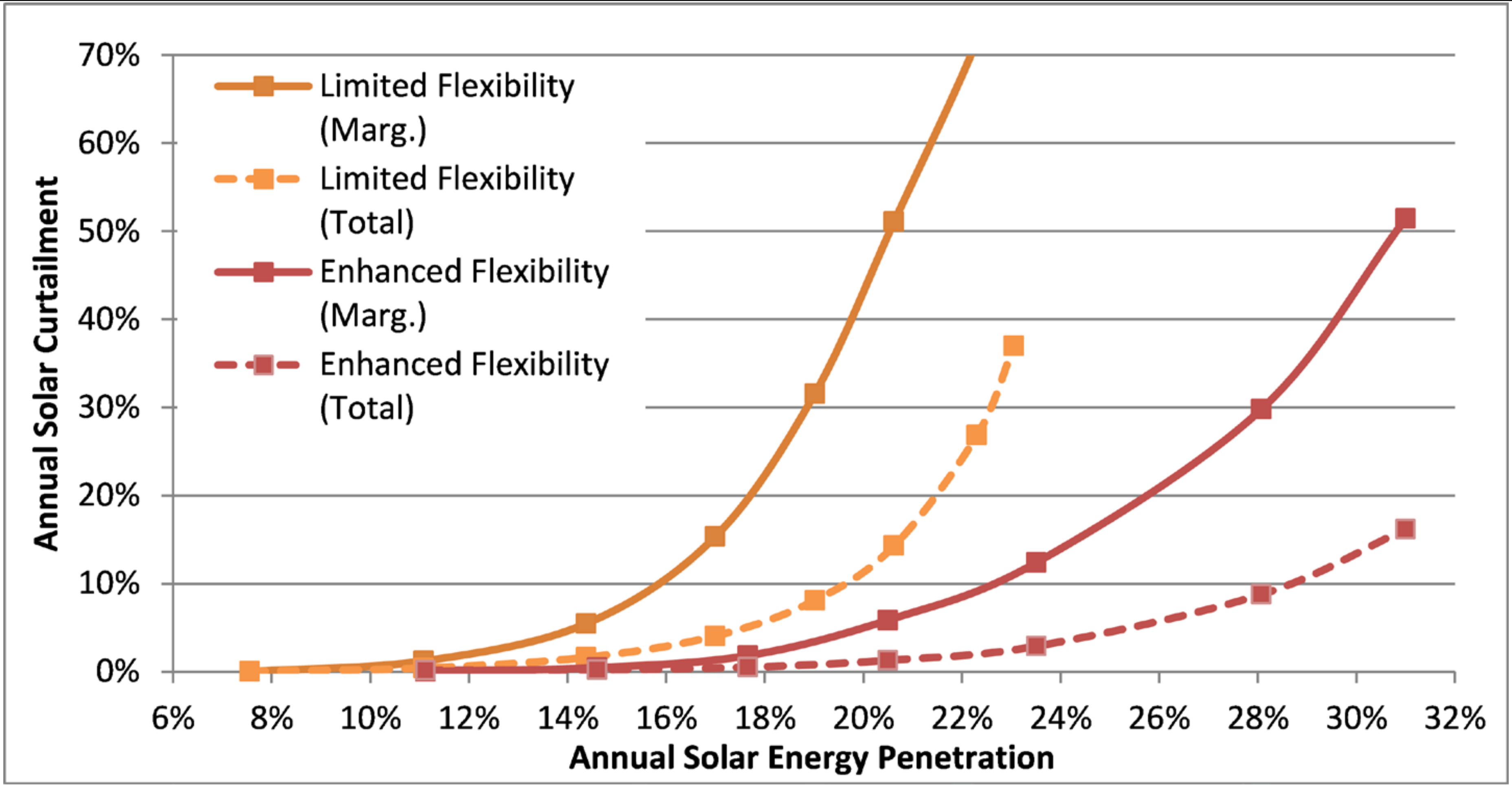
Please note, all results presented on this slide are PRELIMINARY and may be subject to corrections and/or changes. A cursory analysis was performed using available information and estimates of impacts due to changes to the modeled energy systems.

# Conceptual $H_2$ at Scale Energy System*




*Illustrative example, not comprehensive

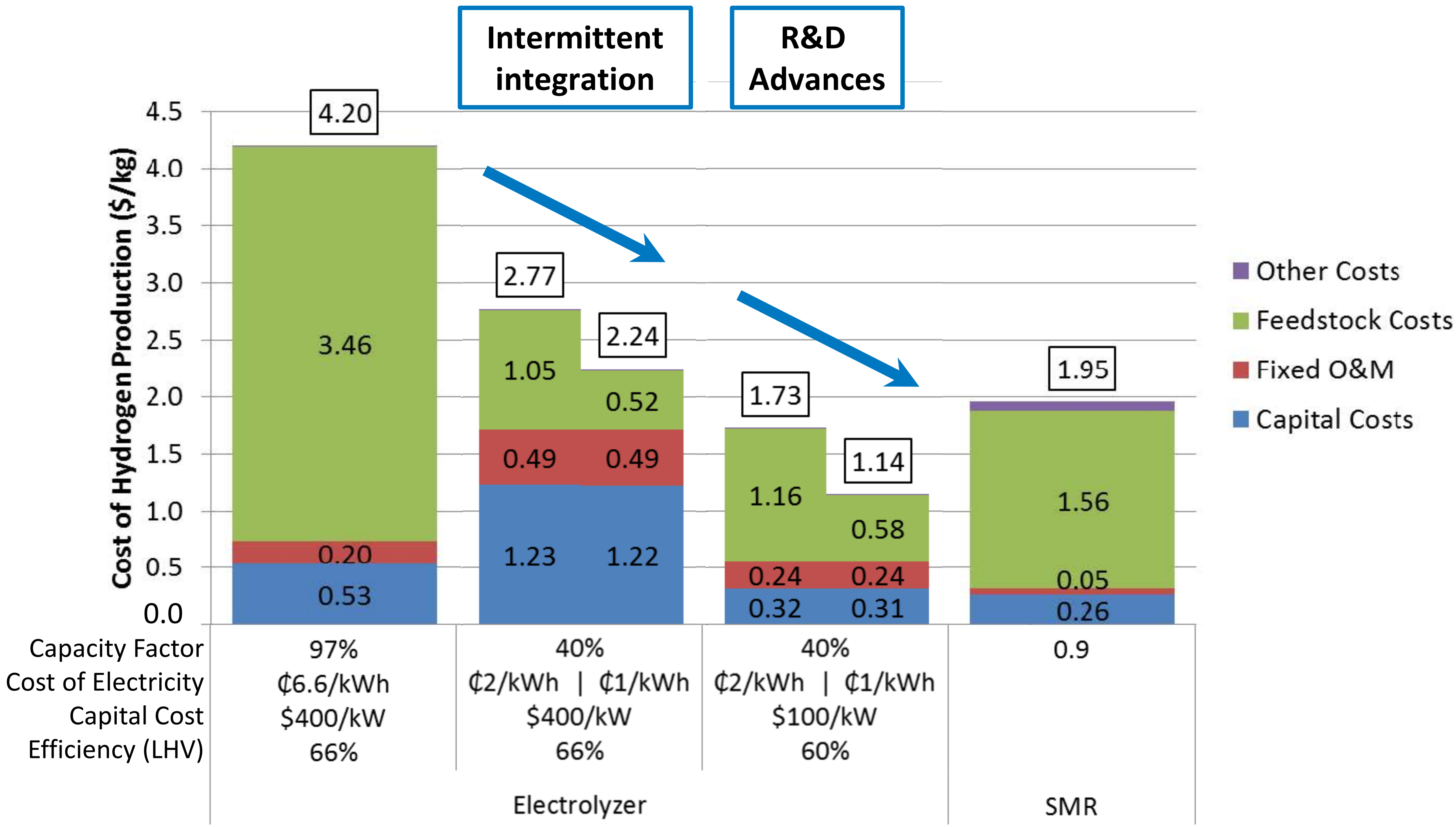
# Limitations of Mismatched Load & Generation



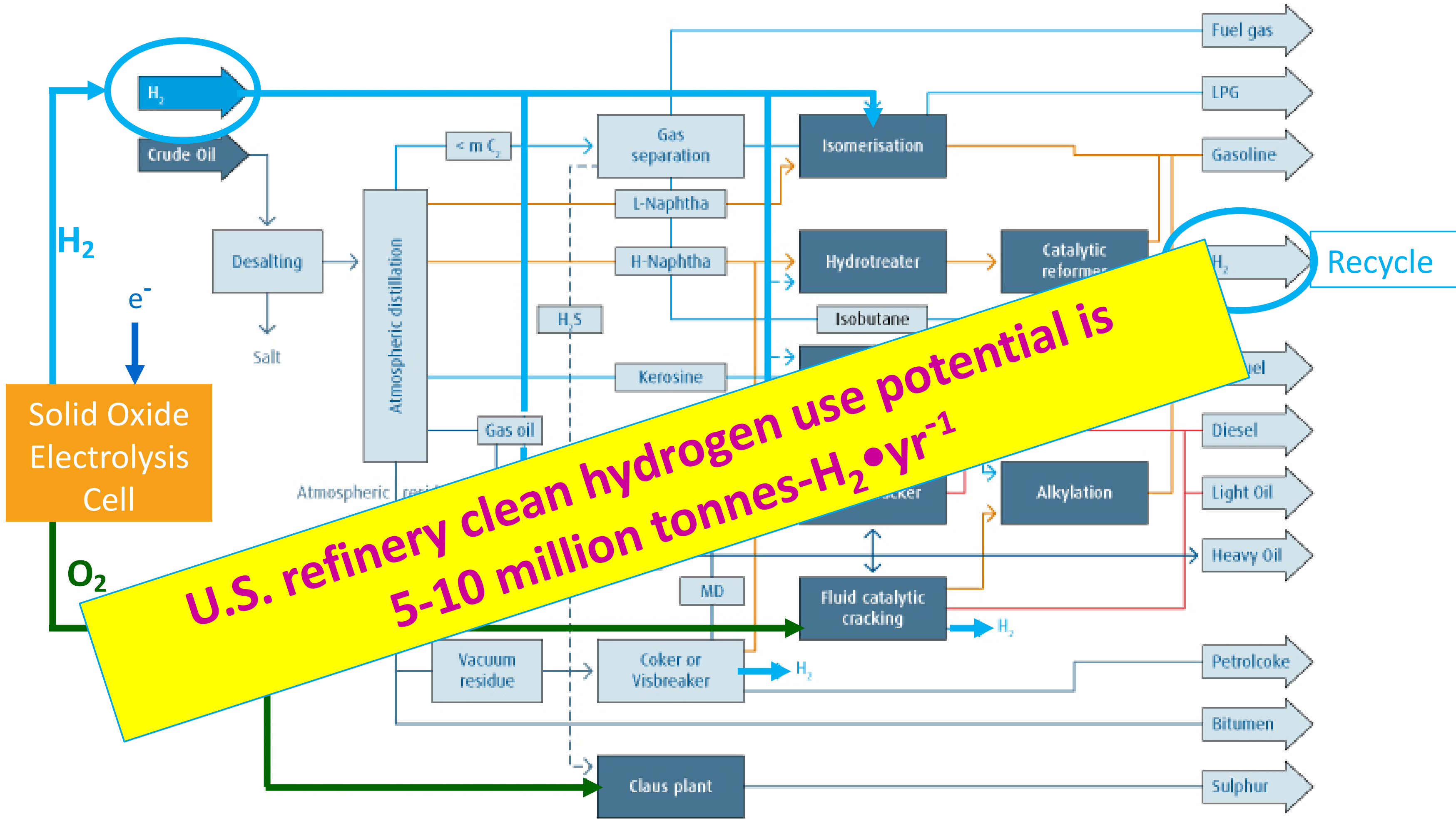

- A tipping point is reached due to increased use of low cost renewable energy
- Curtailment will lead to an abundance of low value electrons, and we need solutions that will service society's multi-sector demands

Source: Denholm, Paul, Kara Clark, and Matt O'Connell. 2016. *On the Path to SunShot: Emerging Issues and Challenges in Integrating High Levels of Solar into the Electrical Generation and Transmission System*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-65800.

# Improving the Economics of Renewable $H_2$



# Refinery Demand




**~ 5 million tonnes of hydrogen was supplied to the refinery industry in 2015.**

Clean hydrogen sources would reduces GHG emissions 25%.

$H_2$-enriched burners could further reduce GHG emissions 20%.

# Iron and Steelmaking

*BELOW: The ZR Process accepts any reducing gas source – direct natural gas, syngas from a coal gasifier, coke oven gas or $H_2/CO$ mixtures.*

## ***DRI Process Development Examples***

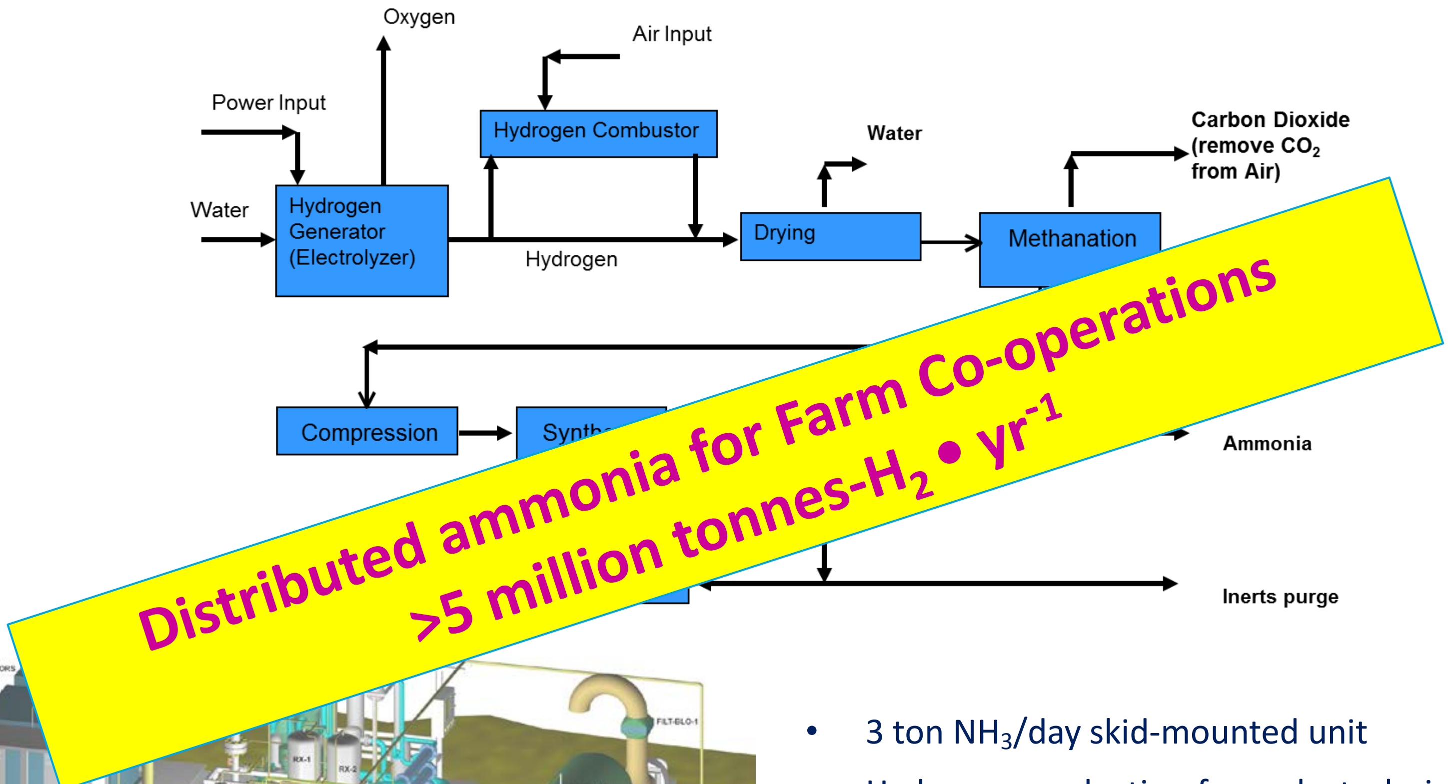
- MIDREX™
- U.S. $CO_2$ Breakthrough Program
- Europe: ULCOS
- Japan: COURSE 50
- Korea: POSCO
- University of Utah **(FIT)**

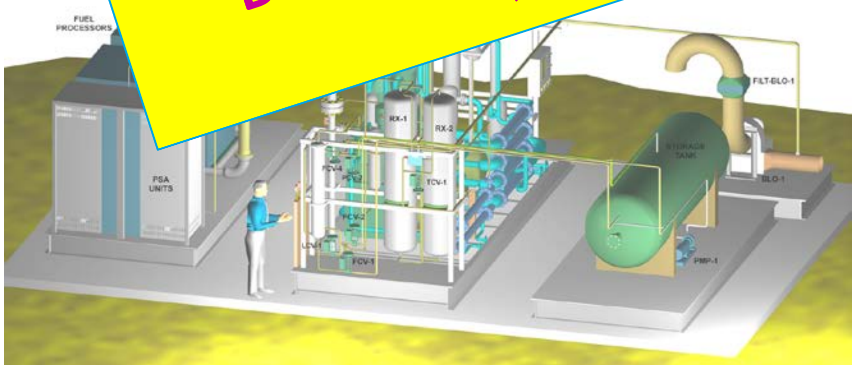
**Current U.S. DRI steel industry hydrogen potential is: > 6 million tonnes-$H_2$ • $yr^{-1}$**

*LEFT: MIDREX™ DRI shaft furnaces are being installed around the world to use various reducing gases and solids*

- DRI process technology is no longer considered nascent
- Benefits include: Process intensification; Reduced capital; Increased energy efficiency: Reduced GHG emissions; Iron ore concentrates processing`

# Ammonia Production for Fertilizer



- 3 ton $NH_3$/day skid-mounted unit
- Hydrogen production from electrolysis
- Small scale application ~ 3 MW
- Simplified process to minimize capital costs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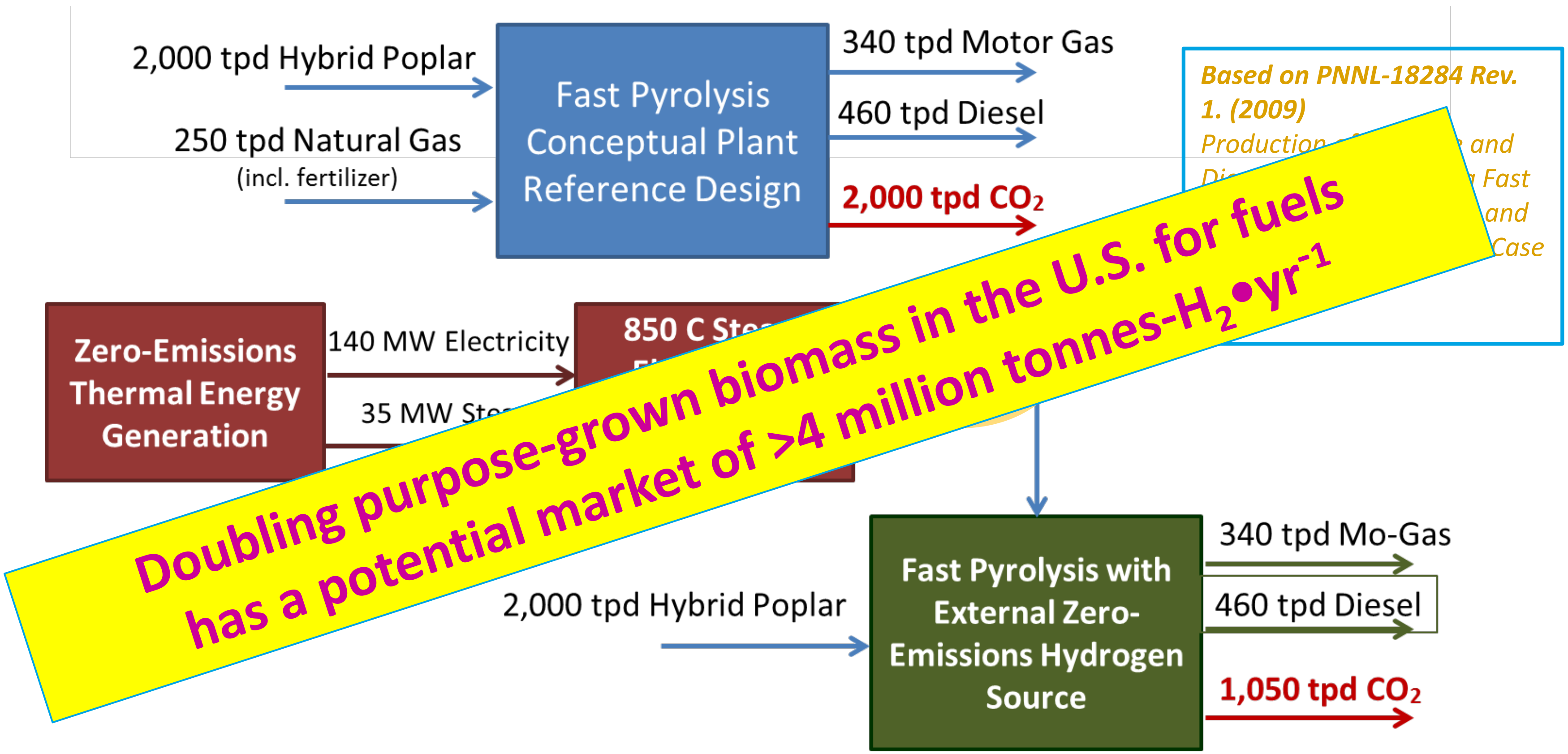
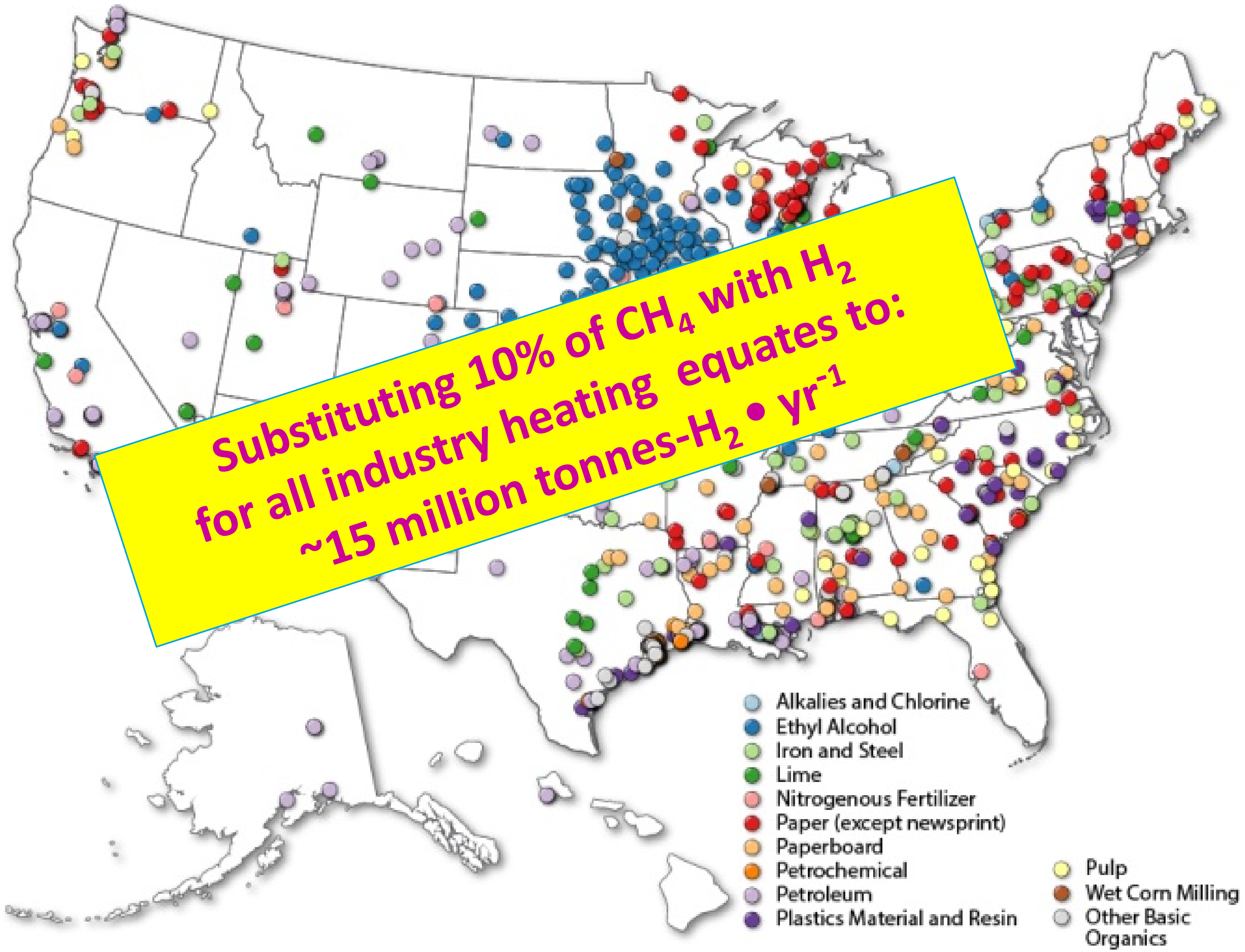
# Biofuels Upgrading




***Zero emissions hydrogen reduces biofuels GHG by 50%.***

# Heat for Industry

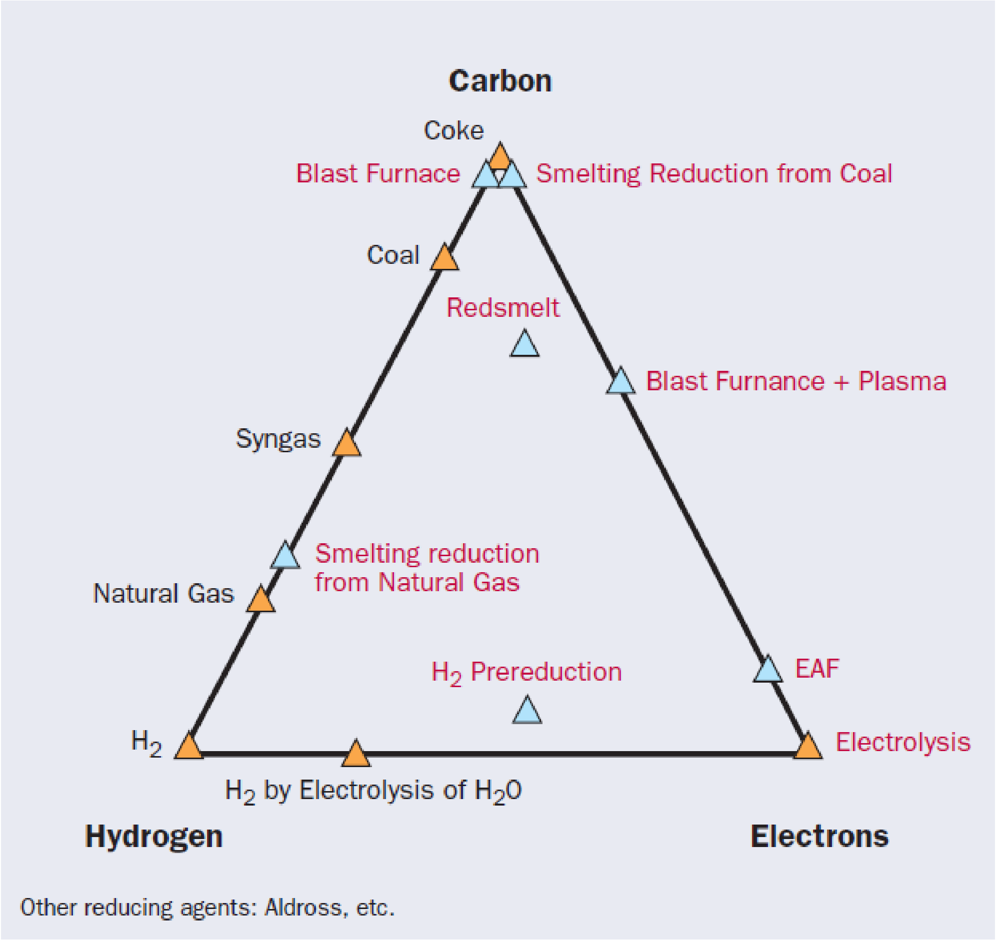



**Substituting 10% of $CH_4$ with $H_2$ for all industry heating equates to: ~15 million tonnes-$H_2$ • $yr^{-1}$**

# Potential Industrial Users of Hydrogen

- **Refineries:**
  - 5 – 10 MM tonnes
- **Steel making:**
  - 3 – 6 MM tonnes
- **Ammonia-based fertilizers:**
  - 5-10 MM tonnes
- **Biomass upgrading:**
  - 4 MM tonnes
- **Industrial heat:**
  - 15 MM tonnes

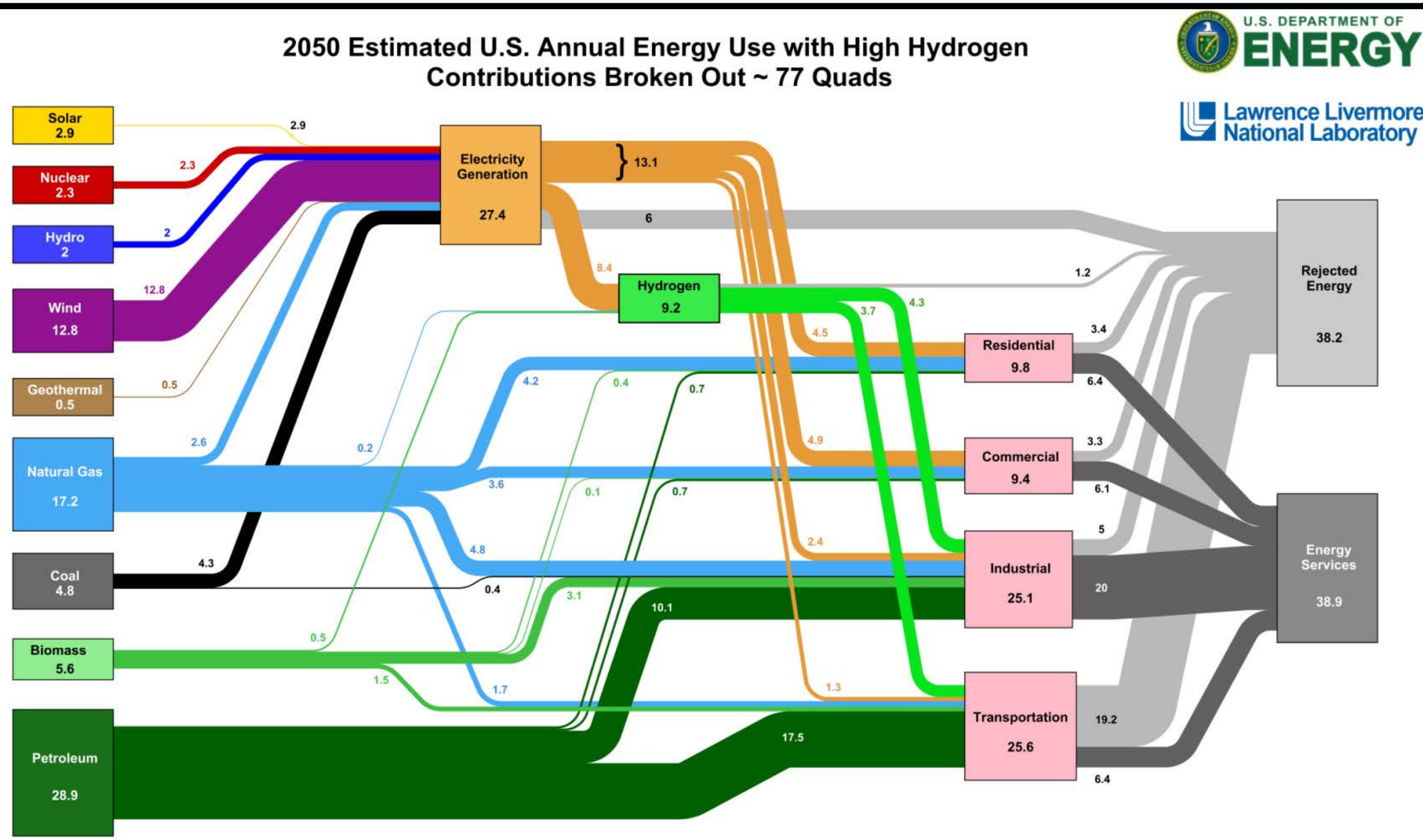
- **TOTAL:**
  - 32 – 45 MM tonnes
  - 320% to 450% of current demand




*Source: AISI Final Report, Dec. 2010.*
*Technology Roadmap Research Program for the Steel Industry*

Estimate: Richard Boardman "H2 at Scale: Enhance the U.S. energy portfolio through sustainable use of domestic resources, improvements in infrastructure, and increase in grid resiliency" H2 at Scale Workshop (November 16, 2016).

# Rough Estimate of Potential 2050 Penetration

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- **Based on 80% renewable electricity generation with hydrogen production to meet additional demands in transportation & industry**
- **$H_2$ at Scale increases wind and solar penetrations**

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# Key Events Since Last HTAC Briefing

**April**
- HTAC Briefing
- National Lab Chief Research Officer Meetings
- DOE Program Office Briefings
- CaFCP Executive Forum
- **Big Idea Summit**

**May**
- Utility Workshops (Colorado & California)
- International Partnership for the Hydrogen Economy meeting

**June**
- Fuel Cells Technology Office / Vehicle Technologies Office Annual Merit Review

**July**
- Southwest Regional Energy Innovation Forum
- Sustainable Transportation Summit
- **FCTO Webinar**

**Aug.**
- Intermountain Energy Summit
- New Mexico Regional Energy Storage and Grid Integration Meeting

**Sept.**
- Colorado School of Mines Steel Center Biennial Meeting
- Electric Power Research Institute Power Delivery and Utilization Conference
- Issued Request for Information

**Oct.**
- California Hydrogen Business Council Fall Summit
- National Press Club Event

**Nov.**
- **H2 at Scale Workshop**
- Southeast Regional Grid Stakeholder Meeting

**Dec.**
- **National Lab Analysis Project**
- Power Electronics for Electrolysis and Fuel Cells Workshop
- HTAC Briefing

# FCTO Webinar


- **July 28, 2016**
- **Over 300 registrants – New FCTO record**
- **Slide deck and presentation now available to public**
  **Please take/use/recycle**

Available at http://energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar

# $H_2$ at Scale Workshop (November 16-17)


**About 170 attendees from industry, states, academia, labs, & DOE (10 offices!)**

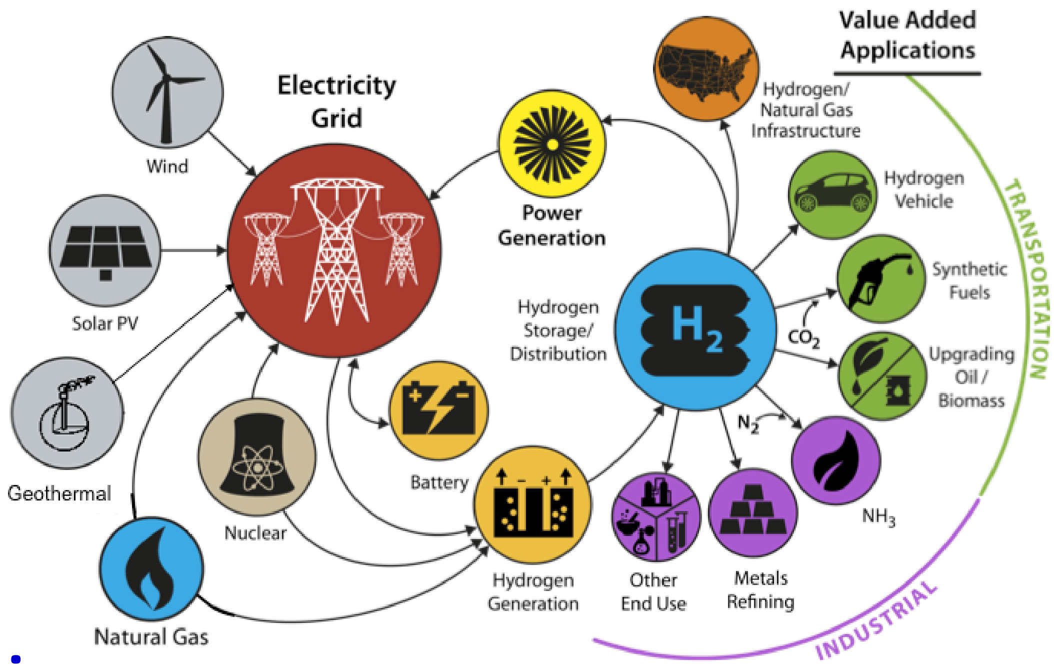
**Solicited input for roadmap**

**Key focus areas:**

- **Additional opportunities for technologies, markets, education, and demonstrations**
- **Integration with power generation**
- **Infrastructure requirements on regional, national, and global scales**
- **Policy and market drivers for fuels and natural gas end uses**
- **Challenges competing in commodity markets for chemical and metals**

# Stakeholder Engagement

- Nuclear
- Wind
- Solar
- Fossil
- Grid/Utilities
- Regulators
- Electrolysis
- Industrial Gas
- Auto OEMs/supply chain
- Fuels Production (Oil, Biomass)
- Metals/Steel
- Ammonia
- Investors




*Illustrative example, not comprehensive

**Blue**: High engagement and support

**Green:** Engaged with interest/support

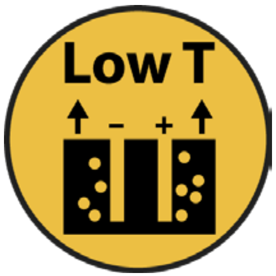
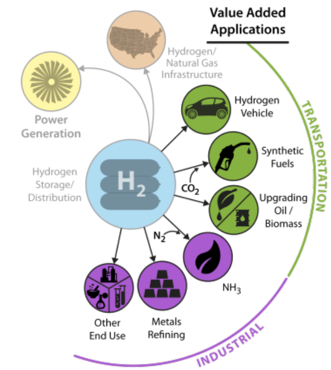
**Orange:** Limited engagement

**Black:** Little engagement

# H2@Scale Analysis Kicking Off

- **Improving fidelity of H2@Scale value proposition in future with high penetrations of variable renewable energy**
- **Developing supply and demand curves and estimating interactions**
- **Identifying regional challenges**
- **Multilab effort with support from FCTO and DOE's Nuclear Energy Office**

# R&D Direction

| Low and High Temperature $H_2$ Generation | | $H_2$ Storage and Distribution | $H_2$ Utilization |
|---|---|---|---|
|   |   |   |   |
| Development of **low cost, durable, and intermittent $H_2$** generation. | Development of **thermally integrated, low cost, durable, and variable $H_2$** generation. | Development of **safe, reliable, and economic storage and distribution** systems. | **$H_2$ as game-changing energy carrier,** revolutionizing energy sectors. |

**Analysis**

**Foundational Science**

**Future Electrical Grid**

# Key Lessons Learned

- **Broad support across DOE**
  - Multiple program offices – Bigger than transportation and FCTO
  - Coordination across multiple DOE offices presents opportunities and challenges
- **Value proposition is not obvious thus a clear vision and unified message important**
  - Most users consider hydrogen a commodity – no value for emission-free hydrogen
- **Long timeline presents challenges**
  - Most stakeholders focus on next quarter or year
  - Only utilities have decadal viewpoint

# Next Steps

- **H2@Scale Workshop report (Jan 2017)**
- **Big Idea Summit 4 (March 2017)**
  - Revisit Summit 3 for new administration
- **Draft Roadmap (Sept 2017)**
- **Analysis of Value Proposition (Sept 2017)**
- **Gathering additional support and input**
  - What do you like? What should we change?
  - What do you see as the biggest challenges?
  - What other opportunities should we pursue?

# Supporting Slides

# $H_2$ at Scale Big Idea Teams/Acknowledgement

H2 at Scale has moved beyond this National Lab team to include DOE offices, and industrial/other stakeholders.

## Steering Committee:

Bryan Pivovar (lead, NREL), Amgad Elgowainy (ANL), Richard Boardman (INL), Adam Weber (LBNL), Rod Borup (LANL), Mark Ruth (NREL), Jamie Holladay (PNNL), Chris Moen (SNL), Don Anton (SRNL)

### Low T Generation:

Rod Borup (lead, LANL); Jamie Holladay (PNNL); Christopher San Marchi (SNL); Hector Colon Mercado (SRNL); Kevin Harrison (NREL); Ted Krause (ANL); Adam Weber (LBNL); David Wood (ORNL)

### High T Generation:

Jamie Holladay (lead, PNNL); Jim O'Brien (INL); Tony McDaniel (SNL); Ting He (INL); Mike Penev (NREL); Bill Summers (SRNL); Maximilian Gorensek (SRNL); Jeffery Stevenson (PNNL); Mo Khaleel (ORNL)

### Storage and Distribution:

Don Anton (lead, SRNL); Chris San Marchi (SNL); Kriston Brooks (PNNL); Troy Semelsberger (LANL); Salvador Aceves (LLNL); Thomas Gennett (NREL); Jeff Long (LBNL); Mark Allendorf (SNL); Mark Bowden PNNL; Tom Autrey PNNL

### Utilization:

Richard Boardman (lead, INL); Don Anton (SRNL); Amgad Elgowainy (ANL); Bob Hwang (SNL); Mark Bearden (PNNL); Mark Ruth (NREL); Colin McMillan (NREL); Ting He (INL); Michael Glazoff (INL); Art Pontau (SNL); Kriston Brooks (PNNL); Jamie Holladay (PNNL); Christopher San Marchi (SNL); Mary Biddy (NREL) ; Geo Richards (NETL)

### Future Electric Grid:

Charles Hanley (lead, SNL); Art Anderson (NREL); Bryan Hannegan (NREL); Chris San Marchi (SNL); Ross Guttromson (SNL); Michael Kintner-Meyer (PNNL); Jamie Holladay (PNNL); Rob Hovsapian (INL)

### Foundational Science:

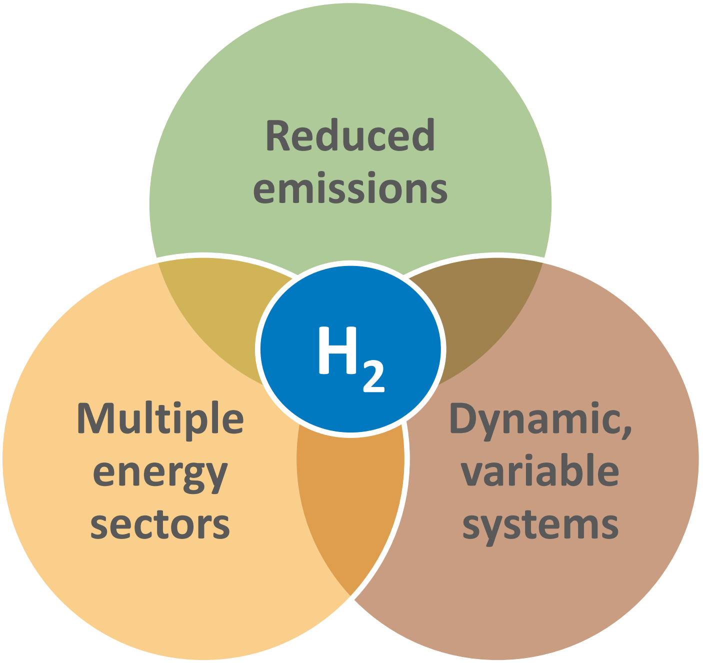
Adam Weber (lead, LBNL); Voja Stamekovic (ANL); Nenad Markovic (ANL); Frances Houle (LBNL); Morris Bullock (PNNL); Aaron Appel (PNNL); Wendy Shaw (PNNL); Tom Jaramillo (SLAC); Jens Norskov (SLAC); Mark Hartney (SLAC), Vitalij Pecharsky (Ames); Alex Harris (BNL)

### Analysis:

Mark Ruth (lead, NREL); Amgad Elgowainy (co-lead, ANL); Josh Eichman (NREL); Joe Cordaro (SRNL); Salvador Aceves (LLNL); Max Wei (LBNL); Karen Studarus (PNNL); Todd West (SNL); Steve Wach (SRNL); Richard Boardman (INL); David Tamburello (SRNL); Suzanne Singer (LLNL)

# Potential Benefits of $H_2$ at Scale

$H_2$ at Scale has the unique potential to positively impact three key energy issues




- Reducing emissions across sectors (criteria pollutants, GHG)
- Support needs of future electrical grid
- Support needs of industrial sector
- Domestic manufacturing
  - Job creation and international competitiveness
- Energy security
  - Diversity/resiliency/domestic
- Decreased water requirements