

H₂ at Scale:

Benefitting our Future
Energy System

Update for the Hydrogen Technical Advisory Committee

2016 HTAC meeting
December 6, 2016

Presented by Mark Ruth
National Renewable Energy Lab
mark.ruth@nrel.gov

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



NREL/PR-6A20-67472

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

H₂ at Scale Big Idea Teams/Acknowledgement

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)

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

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 Bidy (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 Hovsopian (INL)

Foundational Science:

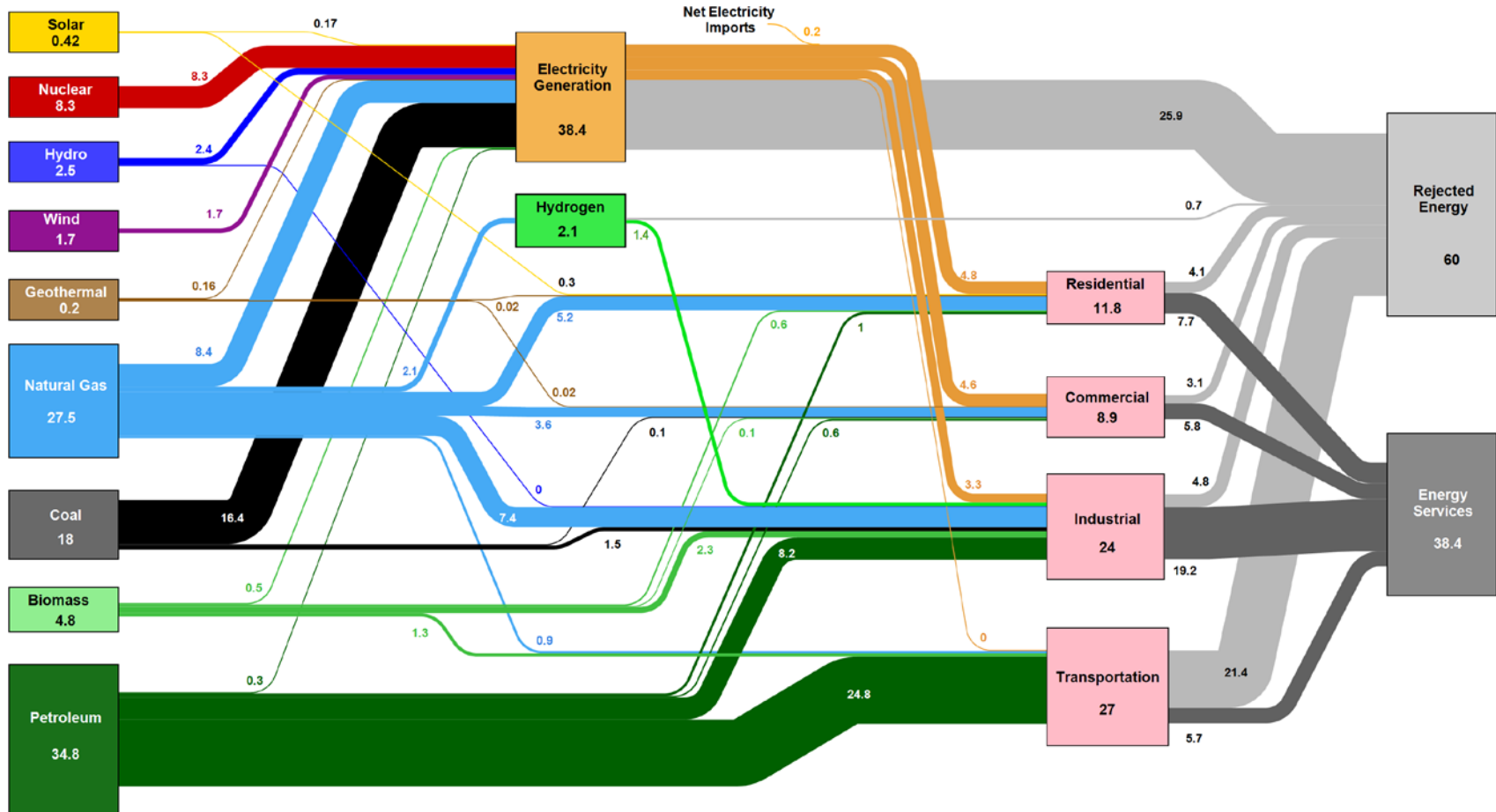
Adam Weber (lead, LBNL); Voja Stamekovic (ANL); Nenad Markovic (ANL); Frances Houle (LBNL); Morris Bullock (PNNL); Aaron Appel (PNNL); Wendy Shaw (PNNL); Tom Jaramillo (SLAC); Jens Norskov (SLAC); Mark Hartney (SLAC); Vitalij Pecharsky (Ames); Alex Harris (BNL)

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)

Large Scale Hydrogen is Well Known

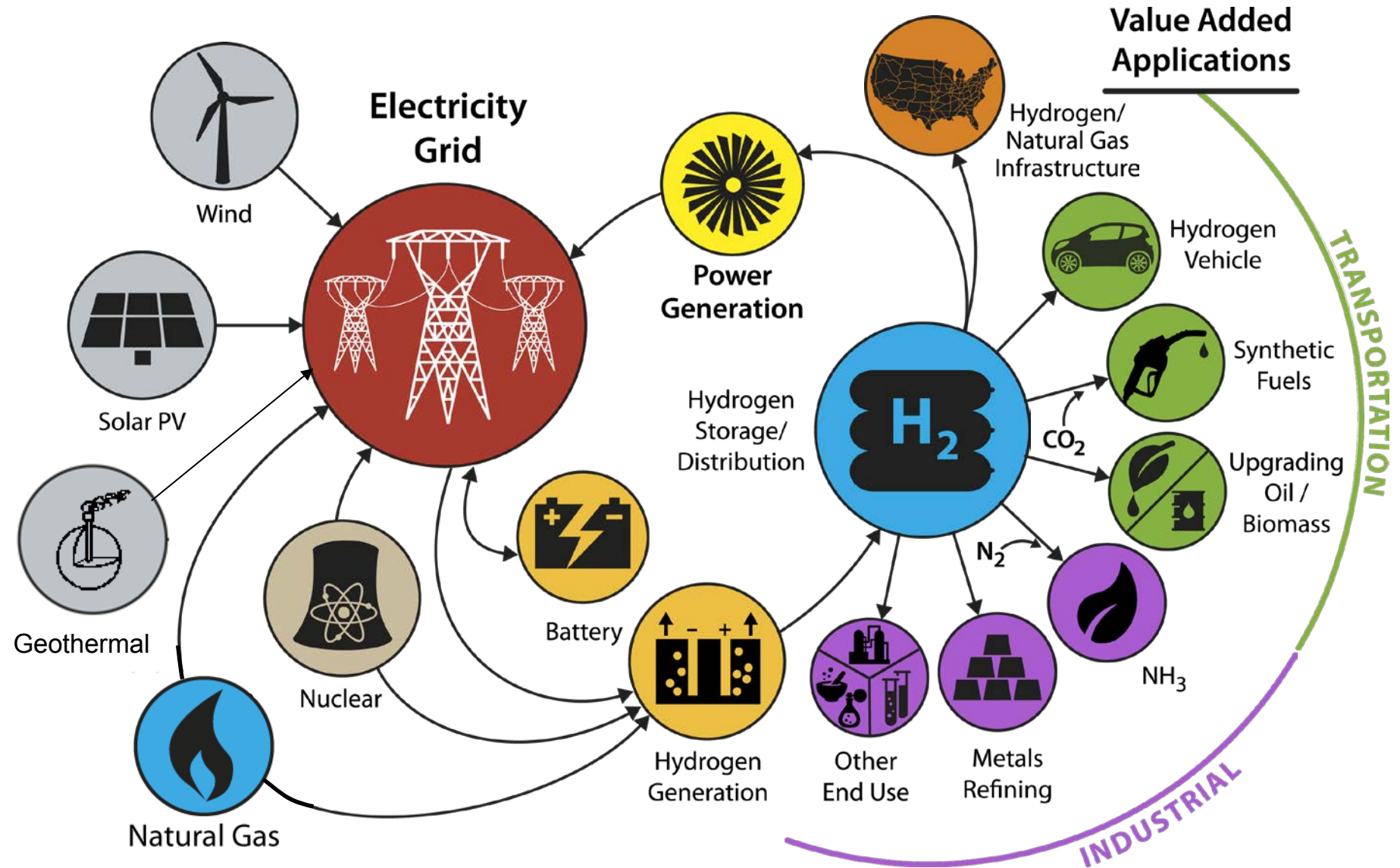
2014 Estimated U.S. Annual Energy Use -
Hydrogen Contributions Broken Out ~ 98 Quads



Source: LLNL September 2015. Data is based on DOE/EIA-0035(2015-03) and Annual Energy Outlook DCE/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-676967

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.

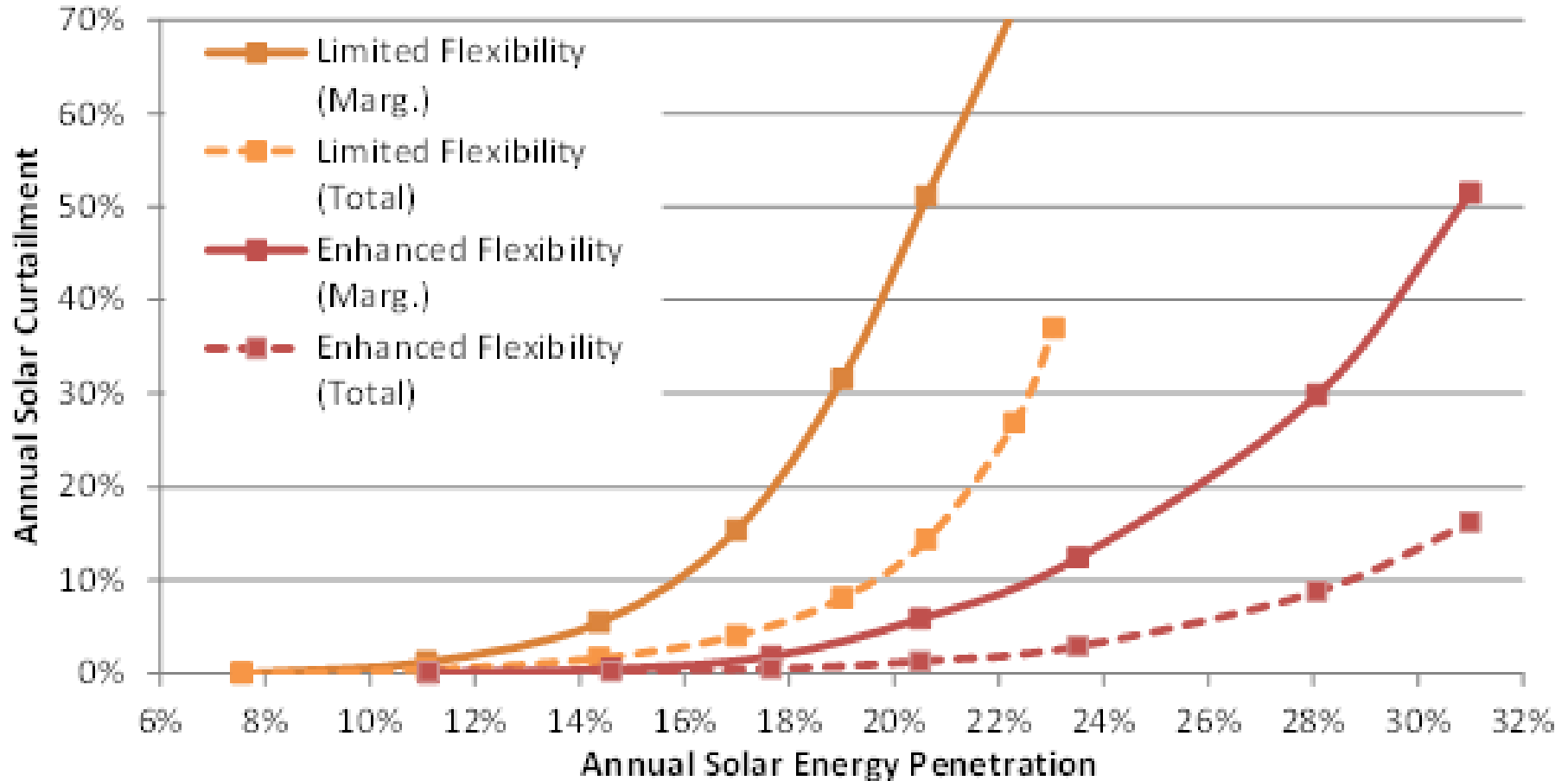
Conceptual H₂ at Scale Energy System*



*Illustrative example, not comprehensive

Limitations of Mismatched Load & Generation

Denholm, P.; M. O'Connell; G. Brinkman; J. Jorgenson (2015) Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart. NREL/TP-6A20-65023

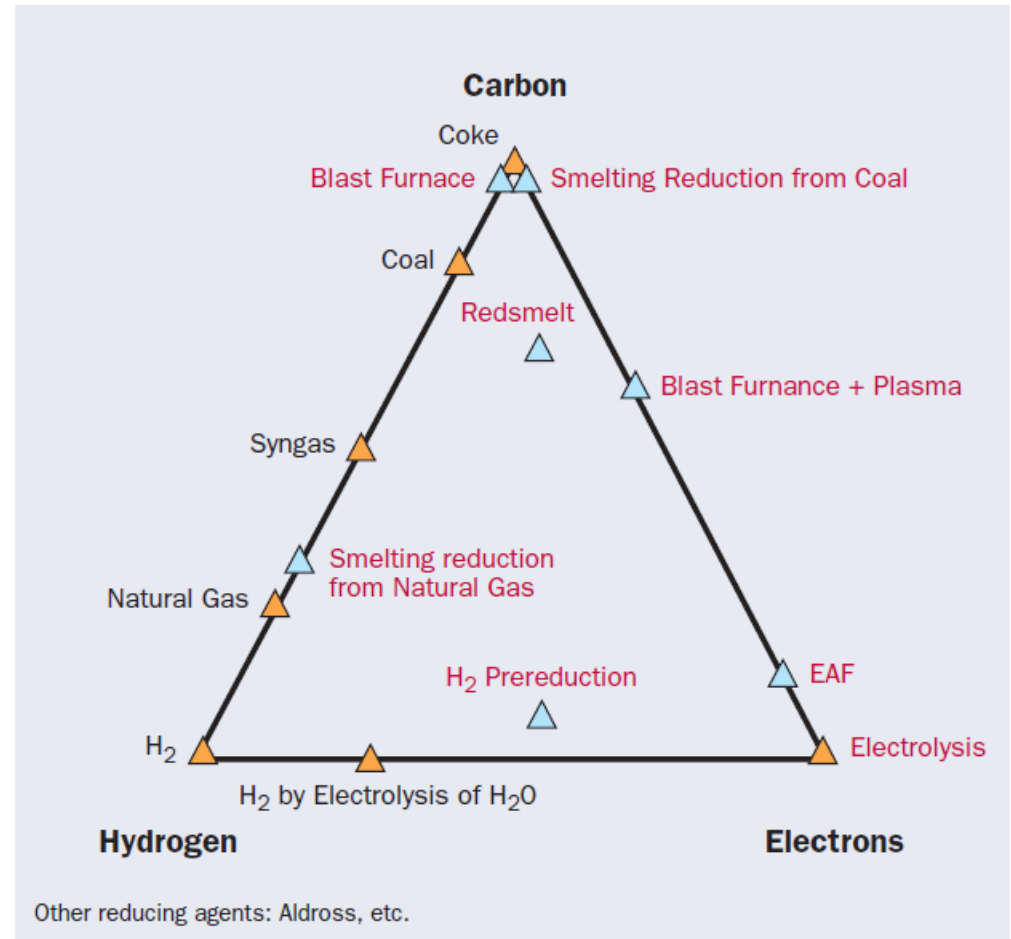


- A tipping point is reached due to increased use of low cost renewable energy
- Curtailment will lead to an abundance of low value electrons, and we need solutions that will service society's multi-sector demands

Potential Industrial Users of Hydrogen

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

- ❑ **TOTAL:**
 - ❑ 32 – 45 MM tonnes

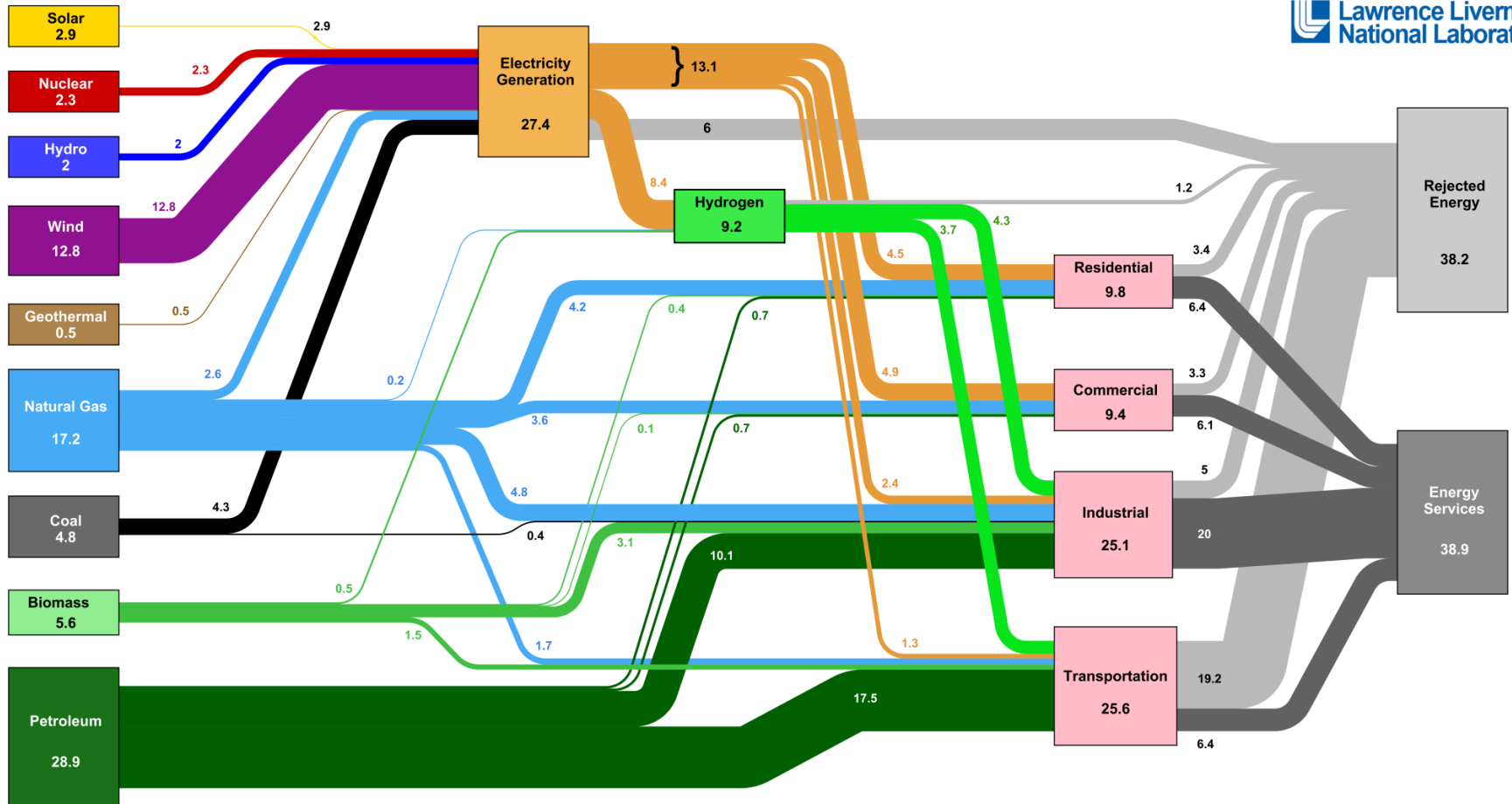


Source: AISI Final Report, Dec. 2010.
Technology Roadmap Research Program for the Steel Industry

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

2050 Estimated U.S. Annual Energy Use with High Hydrogen Contributions Broken Out ~ 77 Quads

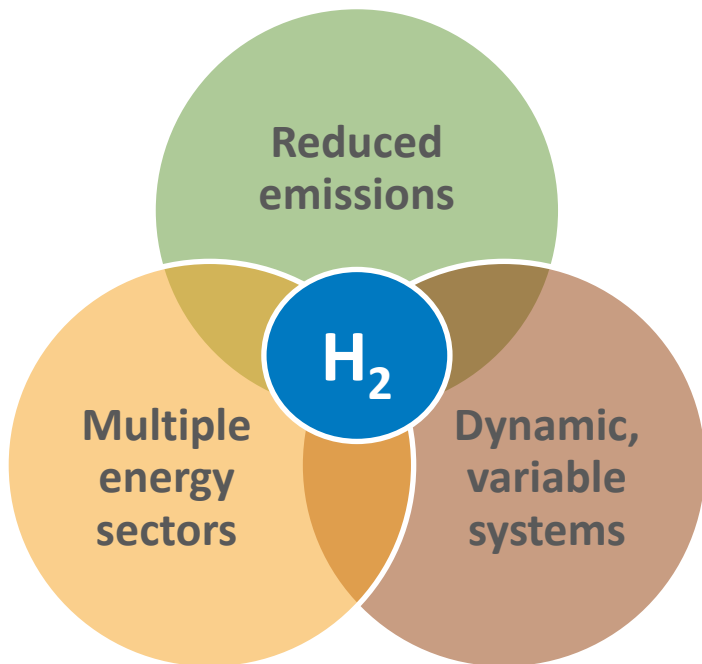


Source: LLNL September 2015. Data is based on High Hydrogen Estimations and DOE/EIA-0383(2014). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed 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

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Potential Benefits of H₂ at Scale

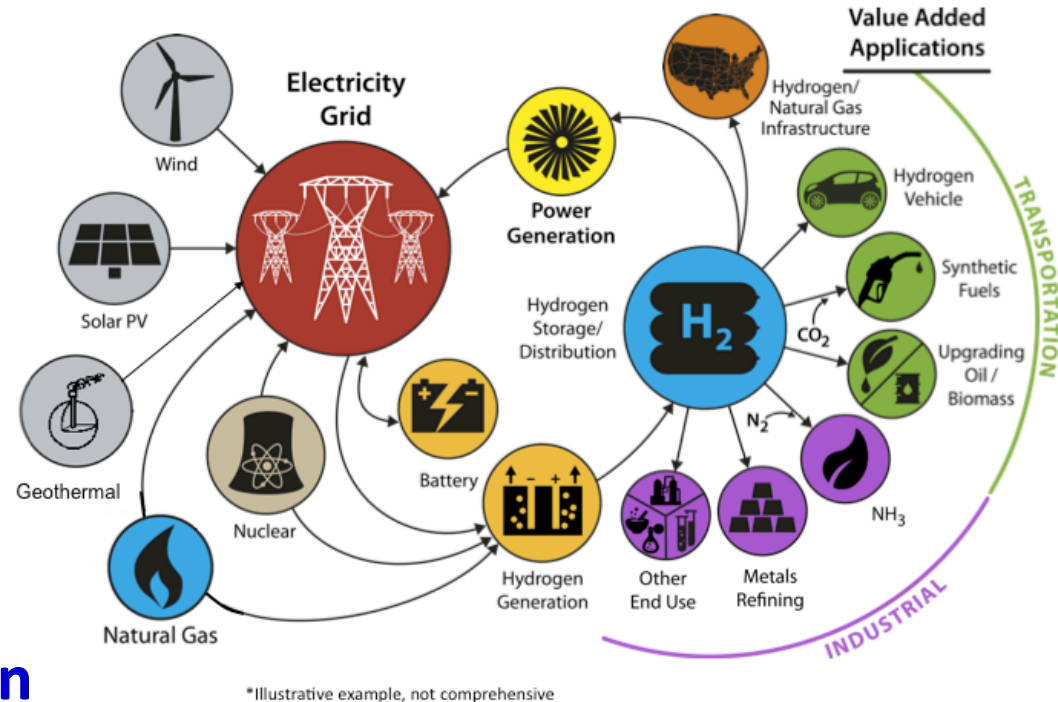
H₂ at Scale as the unique potential to positively address three key energy issues



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

Stakeholder Engagement

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



Blue: High engagement and support
Green: Engaged with interest/support
Orange: Limited engagement
Black: Little engagement

Key Events Since Last HTAC Briefing



DOE Big Idea Summit

- **April 22-23**
- **Highlighted by Secretary Moniz**
- **Cross-office collaborations identified**

R&D Focus	Research Activities	DOE Programs	Impact
Ammonia	<ul style="list-style-type: none"> • Modular Plants • Catalyst R&D • Process intensification • Ammonia Fuel Cells 	ARPA-E AMO FCTO FE	<ul style="list-style-type: none"> ✓ Decrease cost of NH₃ production >25% ✓ Improve process efficiency ✓ Improve NH₃ handling safety
Refineries	<ul style="list-style-type: none"> • Electrolysis and refinery heat integration • H₂ and O₂ combustion • Integrated coke gasification • NE & RE energy utilization 	FE FCTO AMO NE & RE	<ul style="list-style-type: none"> ✓ >75% GHG footprint reduction ✓ Facilitate heavy crude refining ✓ Coke by-product management ✓ Expand markets for RE & NE
Chemicals	<ul style="list-style-type: none"> • Catalyst R&D for H₂-dependent chemicals • CO₂ reduction chemistry • Process intensification • Hybrid electricity/chemicals 	ARPA-E AMO NE & RE FCTO	<ul style="list-style-type: none"> ✓ Sustainable chemicals production ✓ Pathway to CO₂ utilization ✓ Domestic workforce with competitive manufacturing
Biofuels	<ul style="list-style-type: none"> • Modular plants for distributed production • H₂ (and O₂) incorporation in bio-refineries 	BTO VTO NE & RE FCTO	<ul style="list-style-type: none"> ✓ Increase biofuels potential production >30% ✓ 100% zero-emissions biofuels ✓ Expand markets for local RE
Metals & Glass Refining	<ul style="list-style-type: none"> • Direct reduction of iron process development • Metals annealing/tempering • Materials codification 	ARPA-E AMO SC	<ul style="list-style-type: none"> ✓ 10x increase in U.S. steel production with associated heavy manufacturing ✓ >5% impact on world GHG
Combustion Processes	<ul style="list-style-type: none"> • Flame chemistry and heat transfer studies • Burner and turbine testing 	ARPA-E AMO FE	<ul style="list-style-type: none"> ✓ Movement toward Zero-emissions process heating ✓ Clean power generation
H2 Heat Pumps	<ul style="list-style-type: none"> • Low temperature heat use • Industrial and residential energy efficiency studies • Power systems integration 	ARPA-E AMO FE	<ul style="list-style-type: none"> ✓ 5% efficiency improvement for manufacturing industries ✓ 10% efficiency improvement for power generation turbines ✓ >50% cooling water reduction

FCTO Seminar

H2 @ Scale – A Potential Opportunity

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Presenter:
Bryan Pivovar : National Renewable Energy Laboratory

DOE Host:
Erika Gupta : Fuel Cell Technologies Office

U.S. Department of Energy
Fuel Cell Technologies Office
July 28th, 2016

- **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>

H₂ at Scale Workshop (November 16-17)



About 170 attendees from DOE (10 offices!), states, industry, and academia

Solicited input for roadmap

Key focus areas:

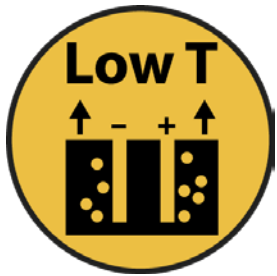
- Additional opportunities for technologies, markets, education, and demonstrations
- Integration with power generation
- Infrastructure requirements on regional, national, and global scales
- Policy and market drivers for fuels and natural gas end uses
- Challenges competing in commodity markets for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

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 H₂ Generation



Development of **low cost, durable, and intermittent H₂ generation.**



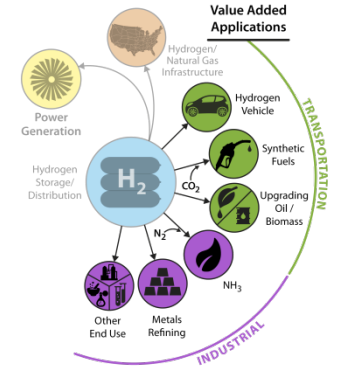
Development of **thermally integrated, low cost, durable, and variable H₂ generation.**

H₂ Storage and Distribution



Development of **safe, reliable, and economic storage and distribution systems.**

H₂ Utilization



H₂ 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 DOE presents opportunities and challenges
- **Value proposition is not obvious thus a clear vision and unified message important**
- **Long timeline presents challenges**
 - Most stakeholders focus on next quarter or year
 - Only utilities have decadal viewpoint
- **Most users consider hydrogen a commodity – no value for emission-free hydrogen**

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 other opportunities should we pursue?