SoCalGas A Sempra Energy utility®

Glad to be of service.®

Innovation

HYDROGEN FROM RNG

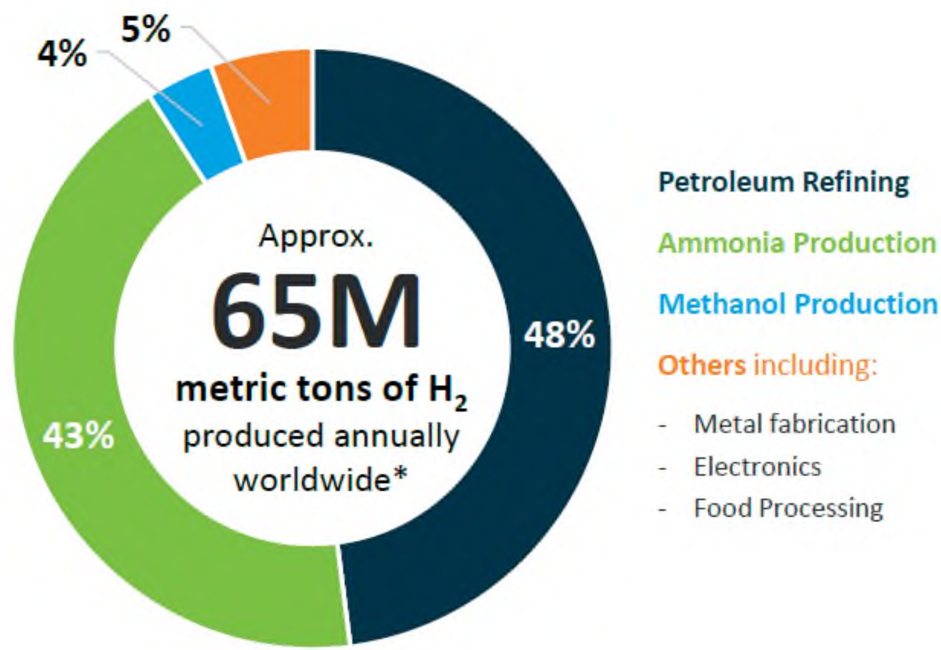
Jeff Reed, SoCalGas

Current State of Hydrogen Production and Demand

Centralized H_2 Production Facilities in the U.S.

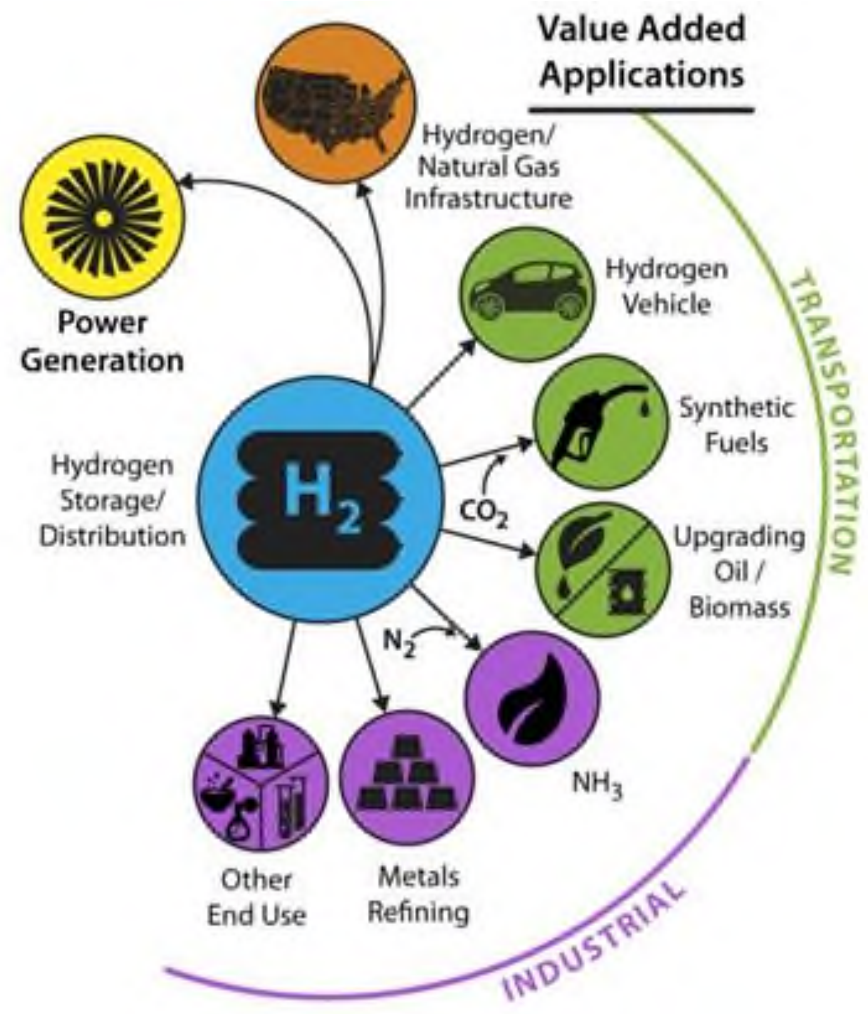
Source: NREL

Global Annual H_2 Production and Demand



Source: Markets and Markets. Hydrogen Generation Market: Global Trends & Forecasts to 2019, 2014.

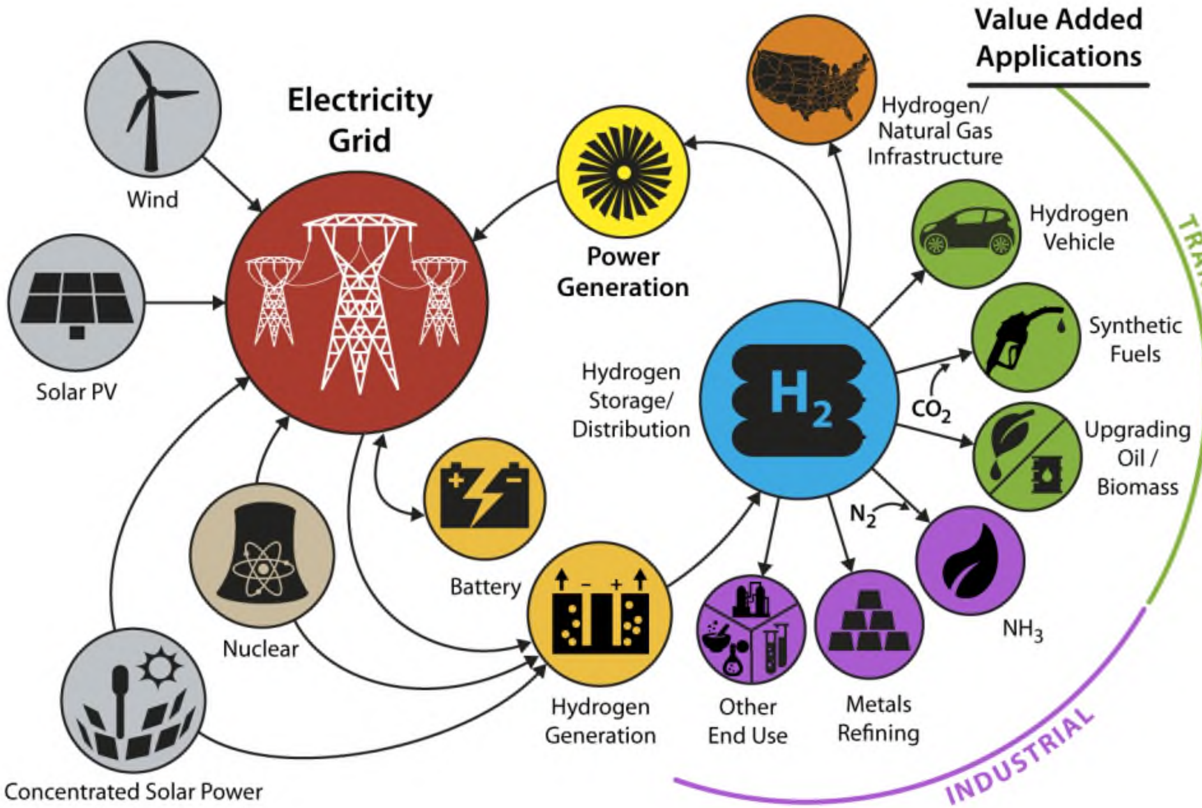
Multiple Market Segments to Consider



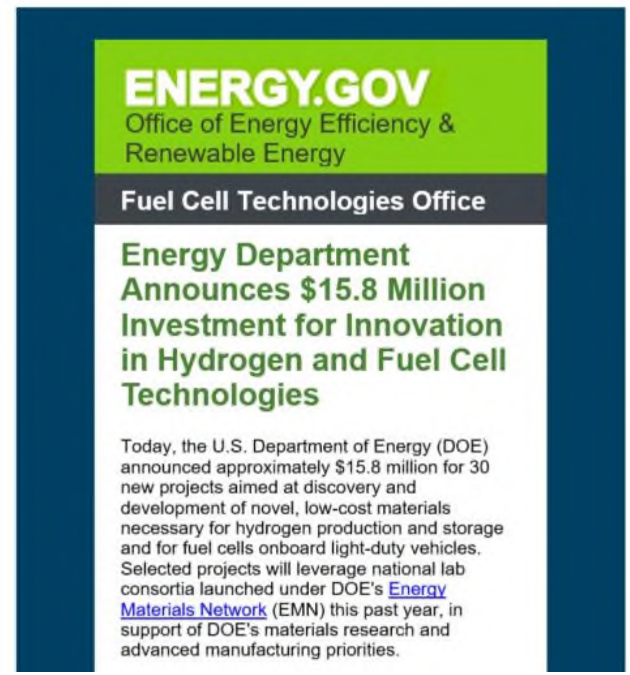
- » Petroleum Refining and Ammonia Production currently make up 91% of demand
- » Hydrogen vehicle market is small but shows signs of potential growth

GOVERNMENT AND POLICY DRIVERS

DOE Support for Hydrogen Economy



DOE's H2@Scale Energy System Vision


ENERGY.GOV
Office of Energy Efficiency & Renewable Energy

Fuel Cell Technologies Office

Energy Department Announces $15.8 Million Investment for Innovation in Hydrogen and Fuel Cell Technologies

Today, the U.S. Department of Energy (DOE) announced approximately $15.8 million for 30 new projects aimed at discovery and development of novel, low-cost materials necessary for hydrogen production and storage and for fuel cells onboard light-duty vehicles. Selected projects will leverage national lab consortia launched under DOE's Energy Materials Network (EMN) this past year, in support of DOE's materials research and advanced manufacturing priorities.

ARB Policies Support Hydrogen FCEV Deployment

» ARB 2017 Scoping Plan
  - Recommends policies to achieve 100% ZEV* sales
  - Proposes to electrify transportation using batteries AND hydrogen
  - Promotes deployment of low carbon fuels including RNG and renewable hydrogen

» ARB 2016 Mobile Source Strategy
  - 1.5 million ZEVs and Plug-in Hybrids by 2025
  - 4.2 million ZEVs by 2030

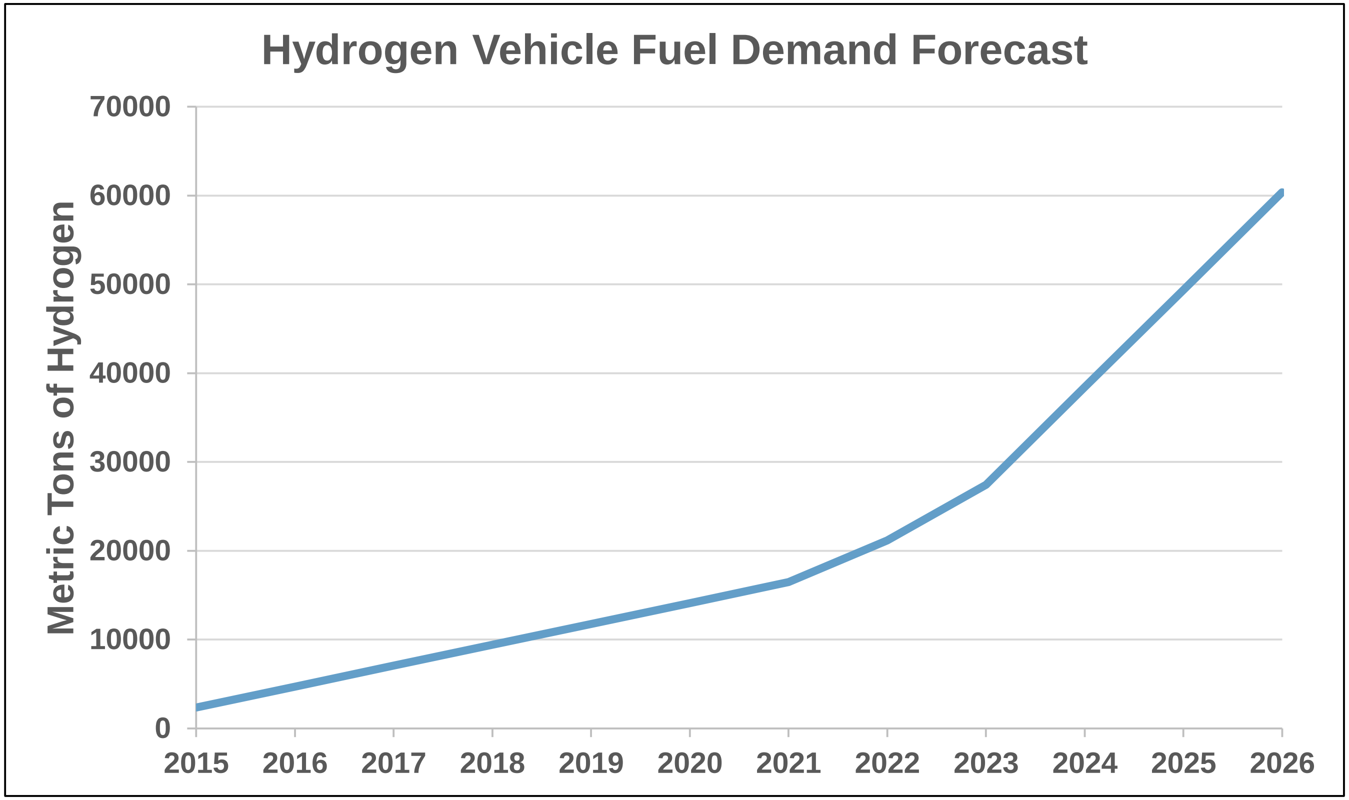
* Zero Emission Vehicle – Includes Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEVs)

ARB Forecasts Increased FCEV Deployment

- ARB 2016 ZEV Report
  - California FCEVs:
    - 13,500 in 2019
    - 43,600 in 2022
  - California Hydrogen Fueling Stations:
    - 38 in service by the end of 2016
    - 50 in service by the end of 2017
  - ARB predicts a hydrogen fueling capacity shortfall in 2020

CEC Forecasts Increased Hydrogen Demand

- CEC Transportation Energy Demand Forecast
  - High Alternative Fuel Vehicle Scenario:



SB 1505 Requires Hydrogen from Renewable Sources

- Well-to-Wheels GHGs from hydrogen use for vehicles must be 30% below the average for gasoline
- All hydrogen produced for FCEVs must be made from at least 33.3% renewable energy resources
- Immediately enforceable only for State funded stations
- Privately funded stations are exempt until 3,500 metric tons (3.5 million kg) of hydrogen are sold in the state (Estimated in 2019)
- Hydrogen fuel dispensed in California is expected to contain on average 45% renewably-sourced hydrogen (2016)

Source: 2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development

PIPELINE RNG TO RH2 APPROACHES

Pipeline-to-Station + On-site Reformation

- The current dominant approach to H2 production is reformation $CH_4 + H_20 \rightarrow CO_2 + 4H_2$
- System are optimized for large production volumes and are centralized
- Product is trucked to point of use (or, in limited cases, piped over dedicated H2 pipelines)
- Small scale reformers are being developed to convert CH4 to H2 at point of use

Current Technology
Small-scale Steam Methane Reforming (SMR)

3 Step SMR Process

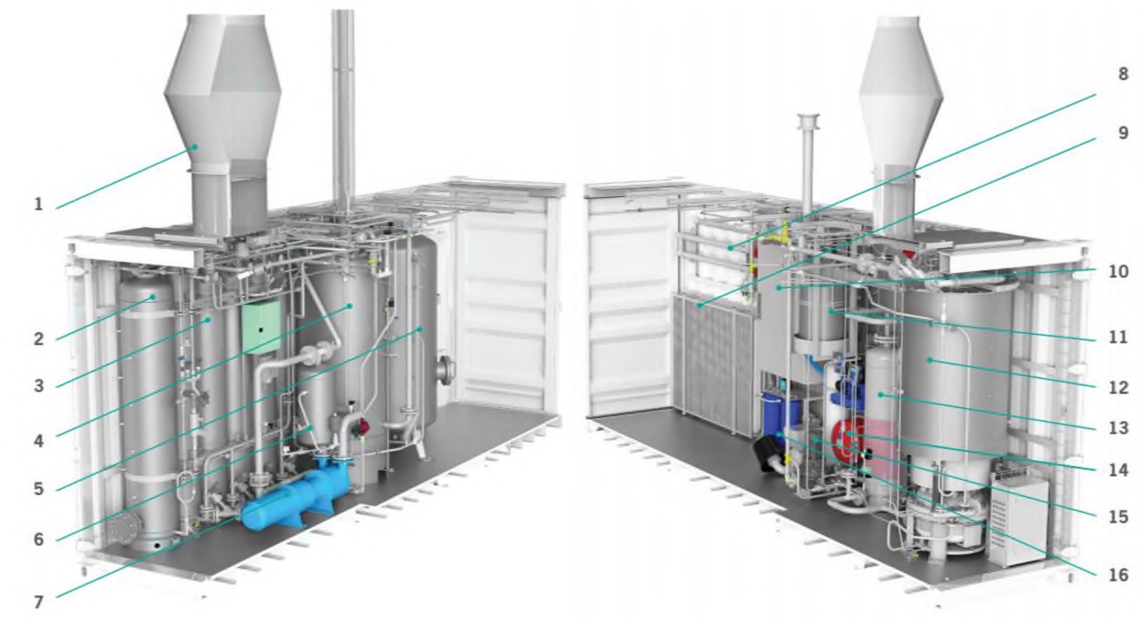
- *Reforming* – Endothermic catalytic reaction, High pressure (300-400 psi), High temp (1500-1600°F)

  $CH_4 + H_2O \Leftrightarrow CO + H_2$

- *Shift Conversion* – Exothermic catalytic reaction, possibly in 2 steps:
  - High temperature shift: 650-750°F
  - Low temperature shift: 450°F

  $CO + H_2O \Leftrightarrow CO_2 + H_2$

- *Gas purification* – Remove CO_2 by amine scrub or pressure swing absorption



1. Ventilation fan
2. Desulphurisation vessel
3. PSA-vessels
4. Off-gas storage
5. Hydrogen storage
6. Water separator for vacuum pump
7. Vacuum pump
8. Coolant heater
9. Reformate cooler
10. Electronics cabinet
11. Steam generator
12. Reformer unit
13. Low temperature shift
14. Coolant expansion vessel
15. Burner air blower
16. Water purification system

The HY.GEN small scale SMR unit fits in a standard shipping container.

Advanced Technology
Distributed Solar SMR

Project

- Develop and demonstrate a Solar Thermochemical Advanced Reactor System (STARS) that converts methane and water into hydrogen and byproducts such as methanol and plastics.

Objectives

- Design, fabricate and test the next version of solar thermochemical system at the SDSU Brawley Test Site.
- Produce hydrogen at a rate of 25 kg/day.
- Demonstrate a solar-to-chemical energy conversion efficiency of greater than 75% (>20% renewable energy content).
- Provide adequate data for commercialization, manufacturing and operational schemes.
- Prepare for commercial pilot fueling station installation

Accomplishments

- Designed and fabricated the TRL 6 reactor.
- Began on-sun testing at SDSU Brawley.

Pacific Northwest NATIONAL LABORATORY

A STARS test system deployed at SDSU Brawley

Advanced Technology Compact Plasma SMR

Project

- Develop catalytic nonthermal plasma (CNTP) technology to efficiently produce hydrogen on an as-needed basis for distributed hydrogen generation from natural gas and water.

Objectives

- Conversion efficiency: > 75%
- Startup time: < 30 minutes
- Subscale unit production capacity: ~ 1Kg H_2/day
- Production Cost: $ 2-4 gge H_2

Accomplishments

- Designed and fabricated a bench scale CNTP reactor.
- Demonstrated the feasibility of CNTP technology: 8 hrs, 450ºC, 90% CH_4 conversion
- Optimized operating parameters CNTP reactor for H_2 production.
- Designed, fabricated and operated scaled-up 2kg H_2/day reactor. Tested steady-state and pulsed plasma.
- Demonstrated technical/engineering feasibility of CNTP H_2 production

Plasma visible during demonstration of the CNTP reformer.

Distributed H_2 production and fueling concept

JPL
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Another Approach -- TriGen