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Opportunities for Hydrogen Solutions

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Hydrogen transportation is here!

- FCEVs are on the road
- Fueling station network is growing

Toyota Mirai available in 2015

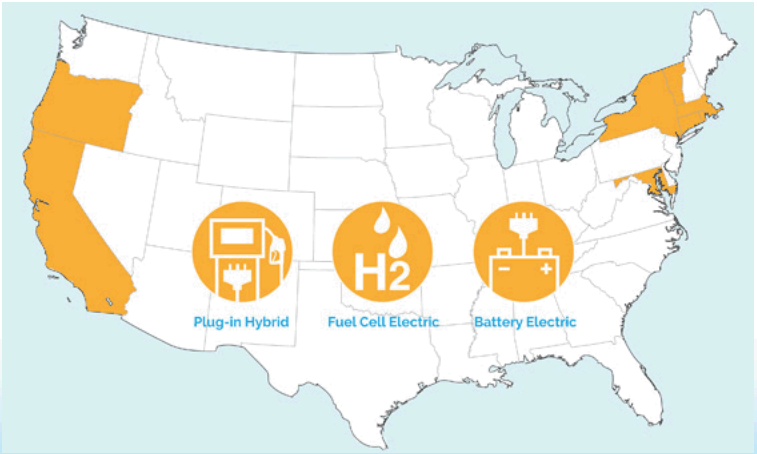
- Refueling in 3-5 minutes
- Range up to 500 km

Hyundai Tuscon available for lease in select markets

National goals for Zero Emission Vehicles (ZEVs)

- Administration goals:
  one million advanced vehicles on the road by 2015

- CA 2013 ZEV Action Plan:
  A Roadmap toward 1.5 Million Zero-Emission Vehicles on CA Roadways by 2025



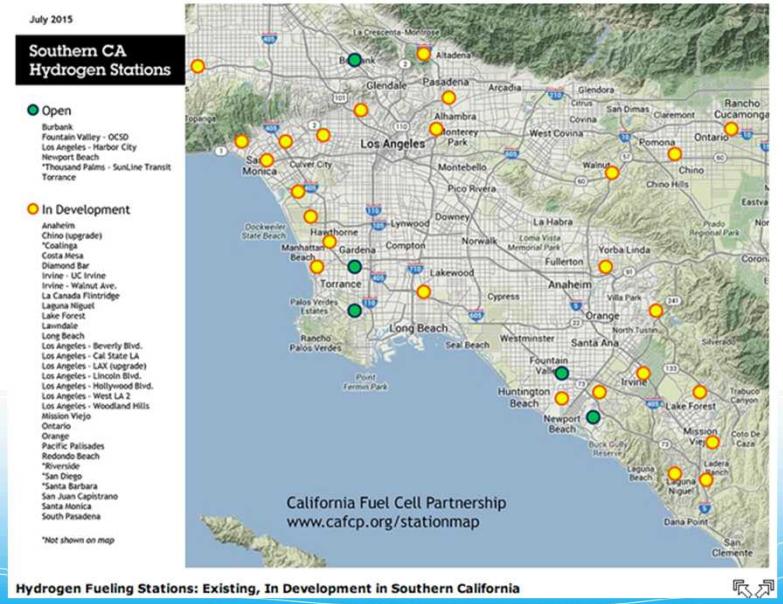
- "Eight Governors Make Zero-Emission Car Pledge":
  3.3M ZEV by 2025
  – USA Today Oct. 24, 2013

H2 fuel infrastructure deployment is biggest challenge – The State of California is addressing with investments

- CA Governor Signs AB 8
  - programs aimed at reducing auto emissions until 2024
  - Provision to fund at least 100 hydrogen stations
  - Commitment of $20 million/yr
- Cluster Communities
  - South San Francisco Bay Area
  - Santa Monica and West LA
  - Torrance and coastal communities
  - Irvine and southern Orange County
- Similar efforts in Europe (Germany), Japan, and Korea

Hydrogen Fueling Stations: Existing, In Development in Northern California

Real time map at http://cafcp.org/stationmap

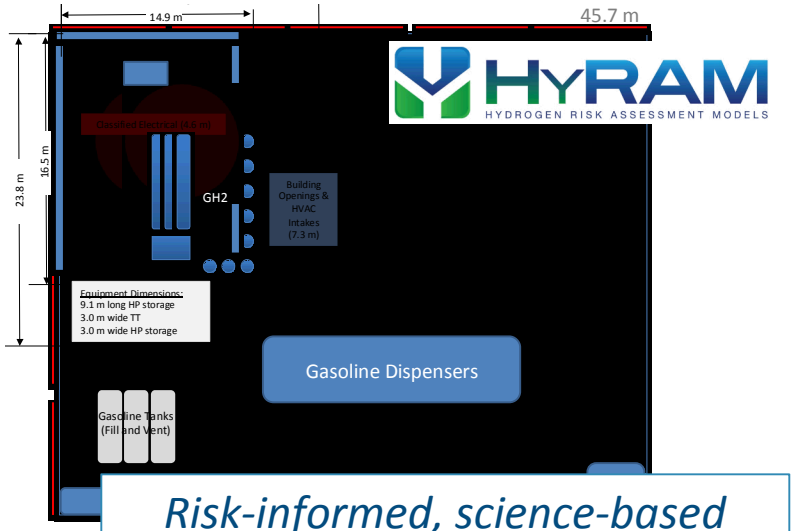


Hydrogen Fueling Stations: Existing, In Development in Southern California

R&D challenges also remain for success of infrastructure deployment

- Station capital cost
  - $1.5 to 3.5M USD/station
- Component/system reliability
  - Inadequate reliability of 700 bar H2 fuel handling and compression technologies
- Station acceptance
  - Each OEM "certifies" each station
  - Limited station qualification devices
  - Restrictive prescriptive codes

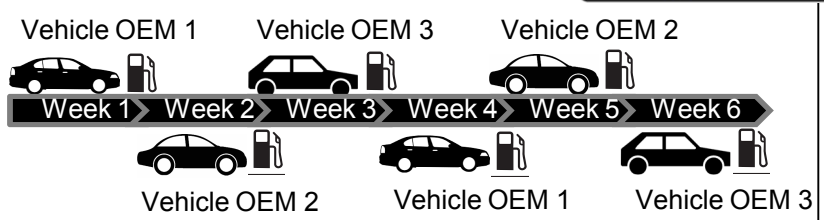
These and other issues must be solved to ensure consumer acceptance



Risk-informed, science-based codes enable station deployment

Existing station acceptance process

H2FIRST



HySTEP

Hydrogen Station Equipment Performance device accelerates acceptance

Hydrogen and fuel cell technology markets are in a rapid growth phase

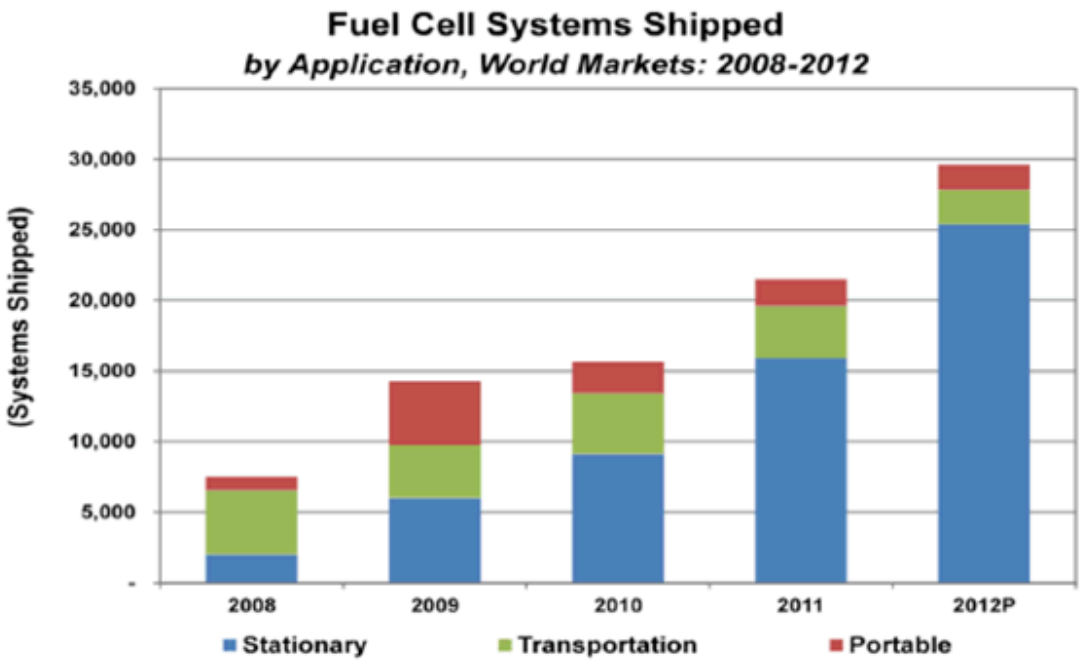


Figure 4: Fuel Cell Systems Shipped by Application, World Markets: 2008-2012. Source: Navigant Research[1]

California perspective:

- 80MW installed in CA (stationary power)
- Commercial vehicles on the road in 2014
- State of CA investing in initial 100 fueling stations

Market potential (10-20yr):

- $14 – $31 billion/year for stationary power
- $11 billion/year for portable power
- $18 – $97 billion/year for transportation

Reference: 2012 DOE Fuel Cell Technology Market Report
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/2012_market_report.pdf

Buses and fleet usage of hydrogen FCEVs

US Hybrid – AC Transit Fuel Cell Electric Buses

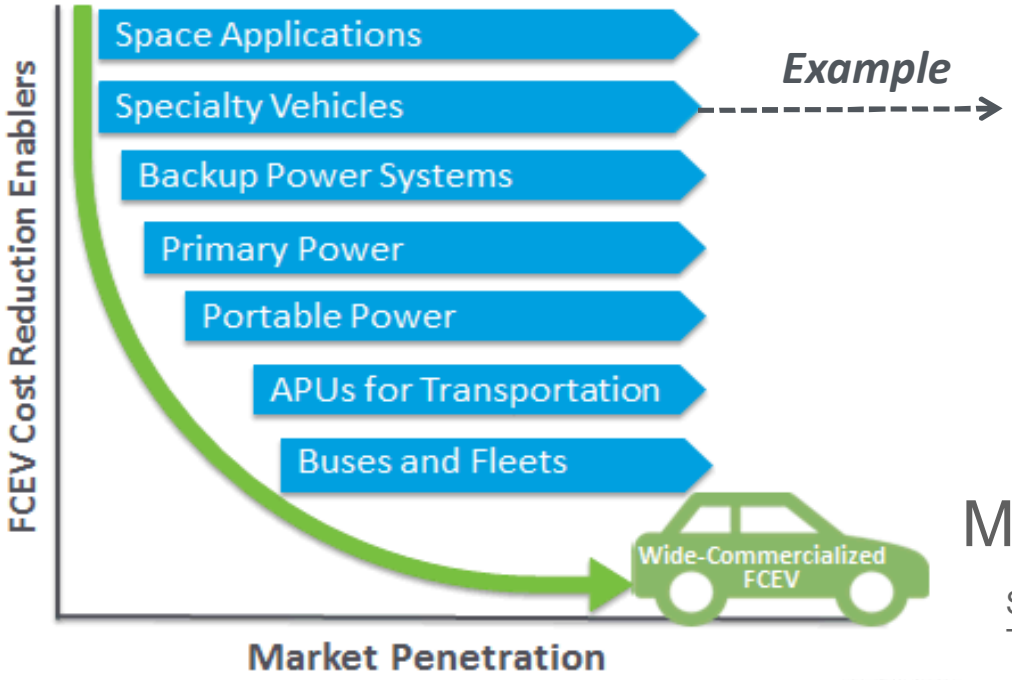
- Fleet of 12 FC electric buses in San Francisco Bay area
- 2 refueling stations; 1 with public access
- 350 km range
- 60% more efficient

Operated for more than **145,000** hours

Operated for more than **19,500** hours

Source: Satyapal, Plenary talk at DOE Fuel Cell Technologies Office Annual Merit Review, June 2015

Innovative uses of hydrogen energy



Fuel cell cargo trucks at Memphis International Airport

Source: Satyapal, Plenary talk at DOE Fuel Cell Technologies Office Annual Merit Review, June 2015

Fuel cell forklifts and industrial trucks

Early markets in hydrogen energy

Hydrogen Fuel Cell Mobile Light Tower

- Zero emissions
- Quiet alternative to mobile diesel power

Shuttle Launch
7/8/2011

On the job at SFO
4/11/2013

Caltrans Chain Control
3/16/2012

Red Carpet Construction
2010-2013 Oscars

Using fuel cells to help improve air quality at ports

Project Concept

- PEMFC unit replaces diesel generators, saving fuel cost and emissions
- Containerized unit to supply portable power for refrigerated containers

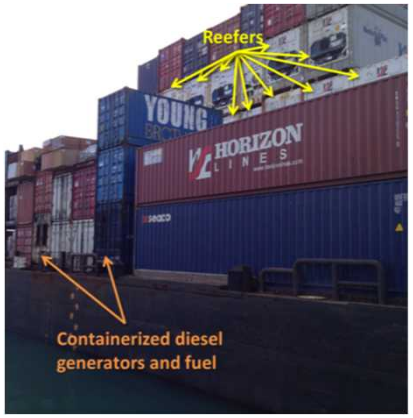
Project Scope and Goals

- Design, build, and deploy unit on land and over ocean (6-month deployment)

Impacts

- Coordinated learning of designers, users and regulators in maritime environment
- Demonstrate low-emission fuel cell power system for maritime applications
- Produce electricity from clean, domestic/local sources

Maritime Fuel Cell Generator



U.S. DEPARTMENT OF ENERGY

DOE: *Project Sponsor and Local H_2 Infrastructure*

Sandia National Laboratories

Sandia: *Technology Support and Project Management*

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

DOT/MARAD: *Project Sponsor*

YOUNG BROTHERS Your Neighbor Island Partner FOSS

Young Bros. and Foss Maritime: *Deployment Partners*

HYDROGENICS SHIFT POWER | ENERGIZE YOUR WORLD

Hydrogenics: *Prototype Production and Support*

HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

HNEI: *Local H_2 Facilitator*

ABS

American Bureau of Shipping: *Maritime Product Certification*

HYDROGEN Safety Panel

Hydrogen Safety Panel: *Project and prototype safety review*

SECTOR HONOLULU

US Coast Guard and USCG Sector Honolulu: *Maritime codes and standards*

High-speed hydrogen fuel cell ferry

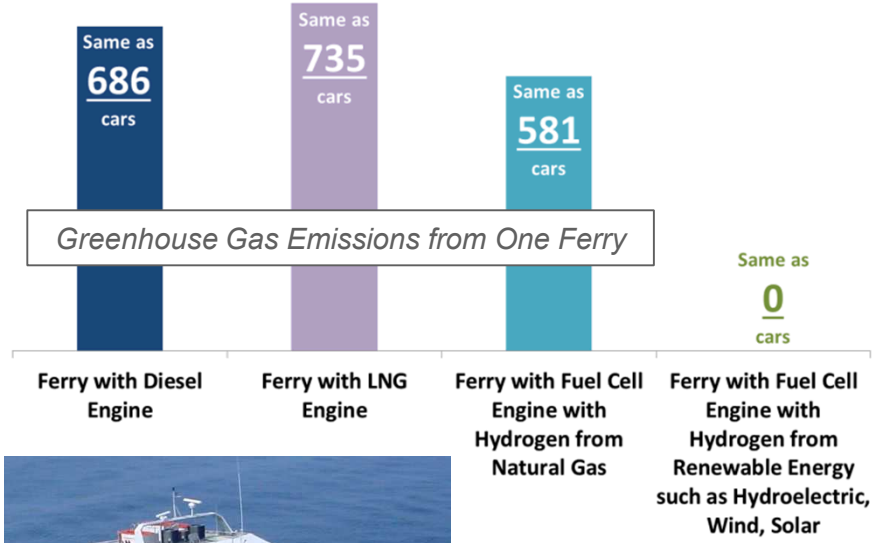
Ferry concept

- Quiet, zero-emissions
- ~150 passenger, >25 kts
- 1,000 kg/day hydrogen demand

Enables deployment of large-scale hydrogen station

- > 1,200 kg/day capacity
- Cost-effective fuel for vessels, cars, buses, and trucks

Feasibility study in progress funded by DOT/MARAD



Passenger ferry

Port-side hydrogen station

pictures are illustrative only

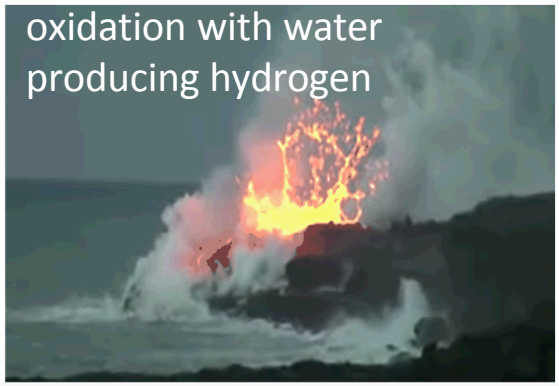
These vessels "have the potential to provide the Bay Area and the country with an entirely new green industry."
– *letter from Monique Moyer, Director, San Francisco Port*

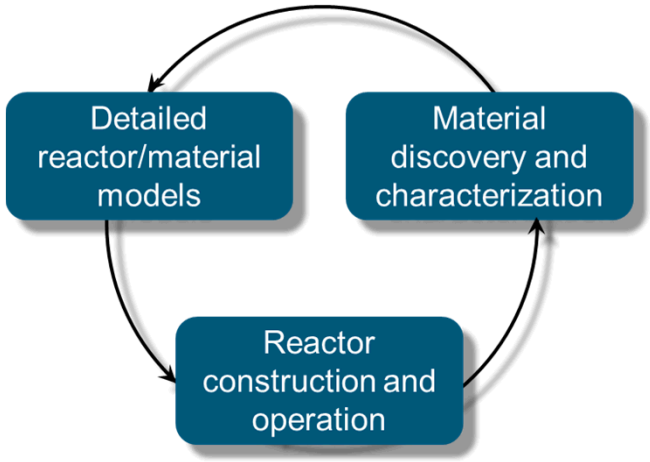
Large-scale H2 production using solar power

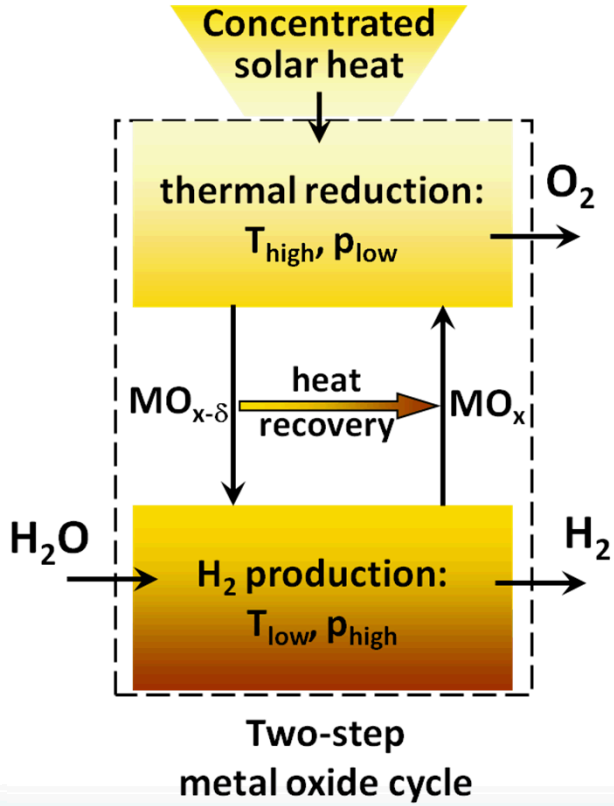
Two-step thermochemical water-splitting cycle

MW scale concentrating solar power facilities provide heat for

1. Metal oxide reduction
2. Oxidation with water ***producing hydrogen***



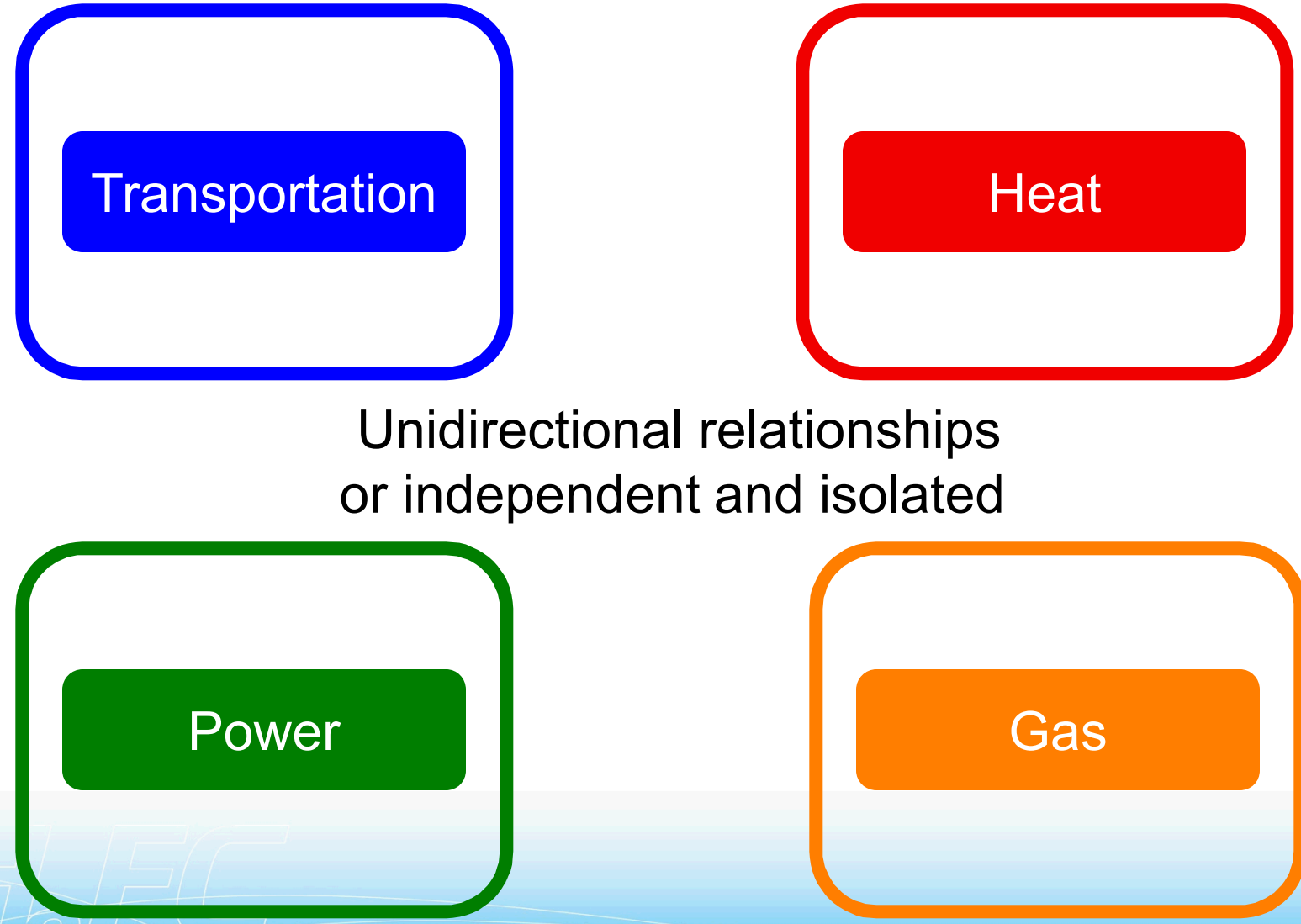




Two-step metal oxide cycle

The challenge is to develop efficient and scalable solar-powered reactors up to 100,000 kg/day

Traditional (naïve) grid structure



Hydrogen enables grids integration

H2 Transportation

Gas/H2 to Trans.

Heat

Trans. to Power

Managed as an integrated energy system H2 production and storage enables:

- Sustainability (clean energy)
- Efficiency
- Flexibility
- Security

Heat to Gas/H2

Power

Power to Gas/H2

Gas / H2

Summary

- Hydrogen and fuel cell technology markets are growing
- Legislation and stakeholder commitments are essential to success of hydrogen transportation technologies
- Many innovative solutions for zero emissions transportation solutions
- Hydrogen is lynchpin for ***grids integration***
  - Combining traditional energy distribution grids
  - Including transportation in energy grids management