# HEC Hydrogen Sessions

# Utility Scale Hydrogen Power Generation

## May 28, 2021

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# Agenda

- Hydrogen Energy Center
- Velerity
- Carbon Emissions by Sector
- Hydrogen Power Generation Drivers
- Hydrogen Power Generation Use Cases
- Case Studies
- Illustrative Economics
- Technologies

# Hydrogen Energy Center

HEC is a nonprofit professional society focused on accelerating the hydrogen as an enabling solution for renewable energy

HEC provides public forums, conducts research and implements projects focused on accelerating the clean energy future

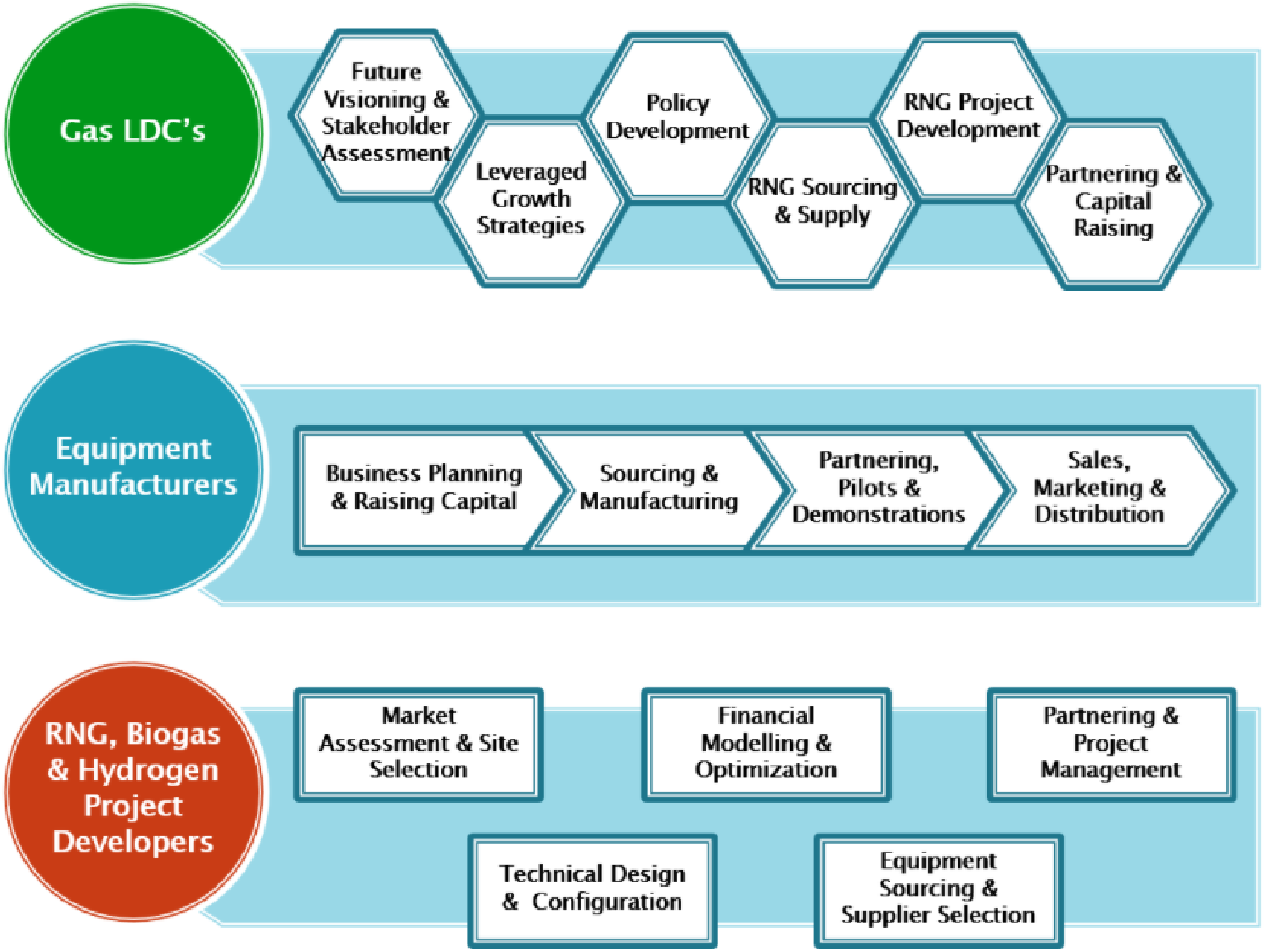
Consider supporting this important effort by becoming a member:

- Influence the course of renewable hydrogen energy technology and policy.
- Be a part of projects that really build hydrogen solutions.
- Have full access to white papers, technical reports, and meeting minutes from our projects and from other organizations.
- Immerse yourself in the hydrogen "goings-on" by connecting with developments & networking with people who are collectively driving the hydrogen "bus".

# Upcoming Hydrogen Sessions

- May 28, 2021 — Grid Scale Hydrogen Power Generation
- June 4, 2021 — Building a Global Trade in Hydrogen
- June 11, 2021 — Electrolysis and Water Splitting
- June 18, 2021 — Hydrogen Production with Carbon Separation
- June 25, 2021 — Wind to Hydrogen

# Velerity Services



# Velerity – Illustrative Clients

CINERGY

ABB

Sierra Pacific
RESOURCES

National Grid

conEdison, inc.

CONOCO

NSTAR

elpaso

TransCanada
*In business to deliver*™

conectiv

Duke Energy

Dominion

Reliant Energy™

Promigas

Allegheny

FPL

Beacon POWER

DQE

Colonial Pipeline Company

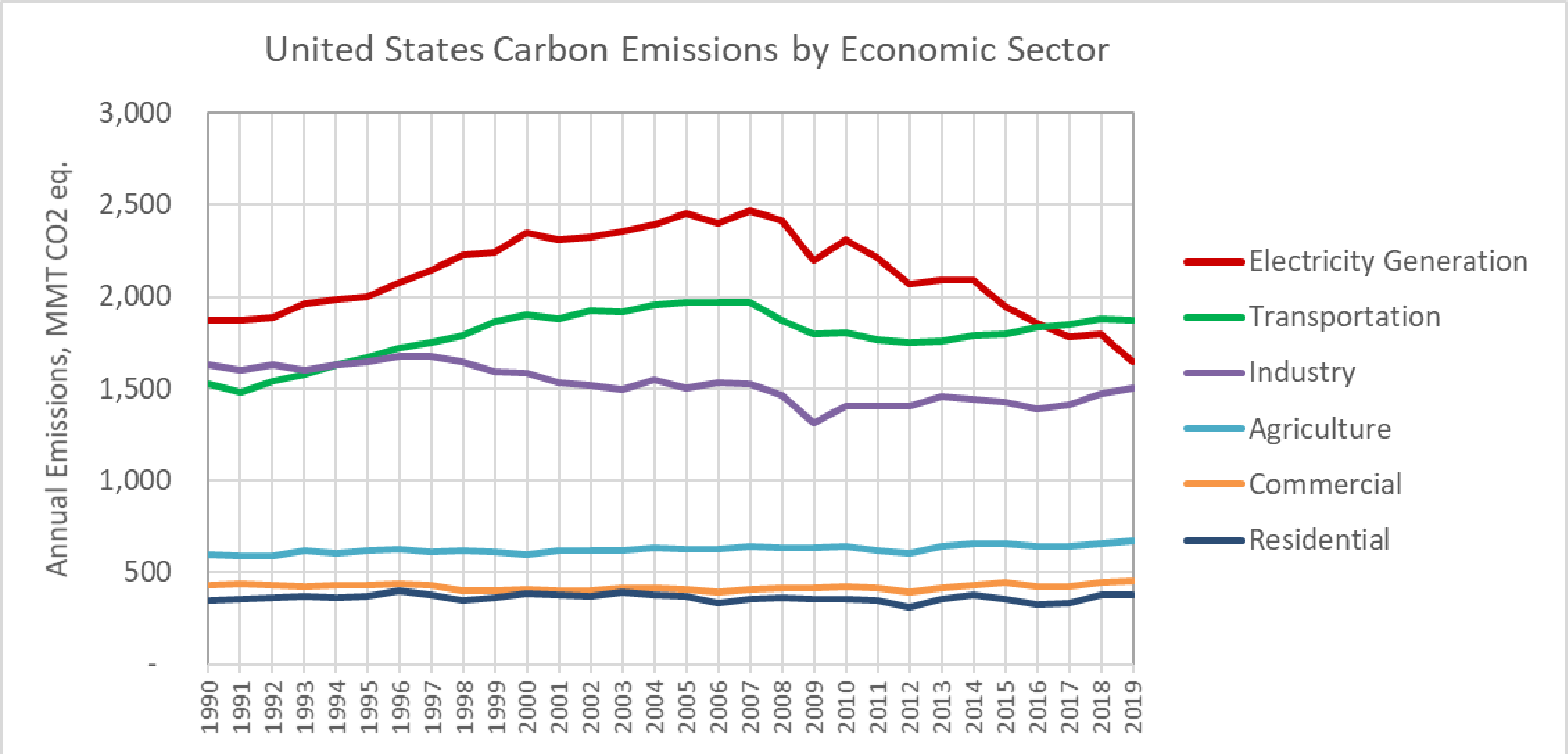
NOVA SCOTIA POWER
An Emera Company

TOKYO ELECTRIC POWER COMPANY

SafeHydrogen, LLC
Shh... Its quiet power

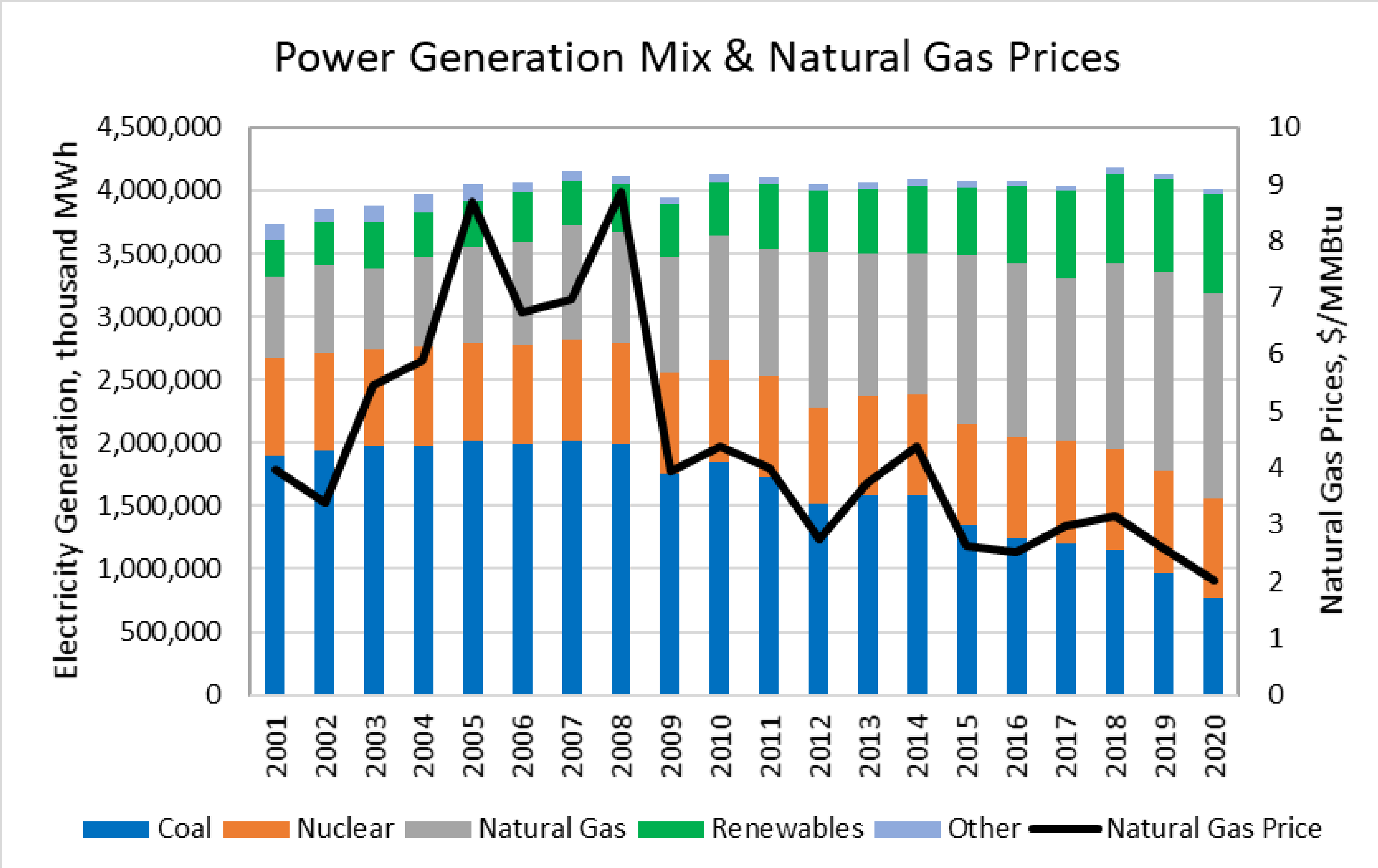
SUNOCO

# The United States electric power sector has led the reduction in carbon emissions among all the economic sectors




Source: Environmental Protection Agency, U.S. Greenhouse Gas Inventory Data Explorer (cfpub.epa.gov/ghgdata/inventoryexplorer/index.html)

# The mix of power generation shifted from coal to natural gas, as fracking drove natural gas prices down



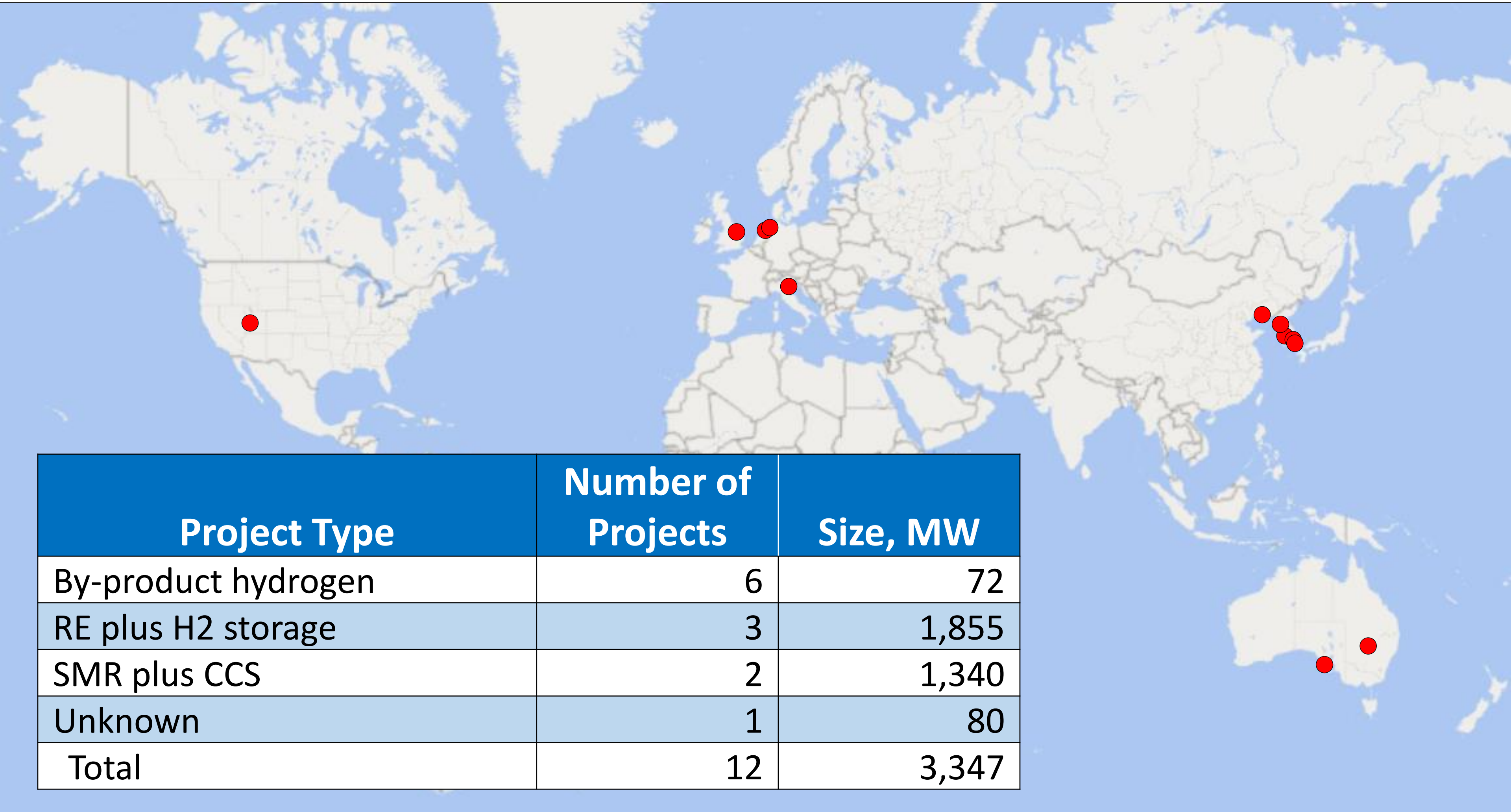
# Drivers of utility scale hydrogen power generation

| | |
|---|---|
| **Increasing Pressures to Accelerate Power Grid Decarbonization** | Efforts are underway to decarbonize the electric grid by 2035, creating an opportunity for a carbon free fuel-based dispatchable solution such as hydrogen |
| **Increasing Proportion of Variable Renewable Energy** | Creating challenges for grid stability, increasing interest in zero carbon dispatchable power generation solutions such as hydrogen |
| **Low RE Power Costs & Curtailment Enabling Low Cost Hydrogen** | Solar energy has been termed the lowest cost power generation technology in history, enabling cost effective hydrogen production using electrolysis |
| **RE Oversupply & Mismatch w/Demand Needs Long Duration Storage** | For long duration storage, lithium-ion is too expensive and pumped hydro is limited. Salt dome hydrogen storage provides a cost-effective seasonal storage solution. |
| **Combined Cycle Gas Turbines Provide High Efficiency Solution for H2** | CCGT's provide a pathway for hydrogen power generation with efficiencies potentially as high as 63% |

# Four use cases dominate hydrogen power generation

| | |
|---|---|
| 1 | **Capturing excess hydrogen from industrial processes for in-the-fence power generation** |
| 2 | **Baseload power generation using hydrogen from steam methane reforming coupled with carbon capture and sequestration** |
| 3 | **Long duration energy storage using stored hydrogen generated from wind, solar and hydropower** |
| 4 | **Baseload power with methane pyrolysis feeding hydrogen to gas turbines and sequestering elemental carbon or putting the carbon black to use** |

# Twelve grid scale hydrogen power plants around the world, either operating or in advanced planning stages, have been identified

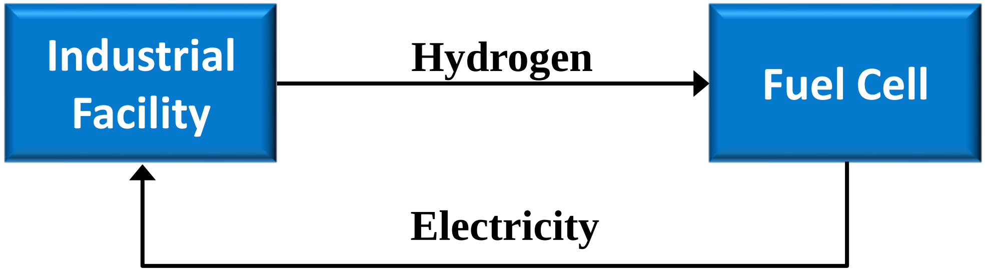


| Project Type | Number of Projects | Size, MW |
|---|---|---|
| By-product hydrogen | 6 | 72 |
| RE plus H2 storage | 3 | 1,855 |
| SMR plus CCS | 2 | 1,340 |
| Unknown | 1 | 80 |
| Total | 12 | 3,347 |

# Half of the twelve identified hydrogen generation projects utilize excess hydrogen from industrial processes

| Project | Location | Size, MW | Hydrogen Source | Generation Technology |
|---|---|---|---|---|
| Bloom Changwon | Changwon, Korea | 1.8 | Chlor-alkali | SOFC Fuel Cell |
| Fusina | Fusina, Italy | 16 | Versalis Cracker | GE Turbine |
| Grasshopper | Delfzijl, Netherlands | 1 | Chlor-alkali | Nedstack PEM Fuel Cell |
| Hanwha Energy | Seosan, Korea | 50 | Chlor-alkali | Fuel Cells |
| Ulsan | Ulsan, Korea | 1 | Chlor-alkali | Fuel Cell |
| Yingkou | Yingkou, China | 2 | Chlor-alkali | PEM Fuel Cell |

# Excess hydrogen from chlor-alkali plants is used for power generation and liquid hydrogen production for merchant markets

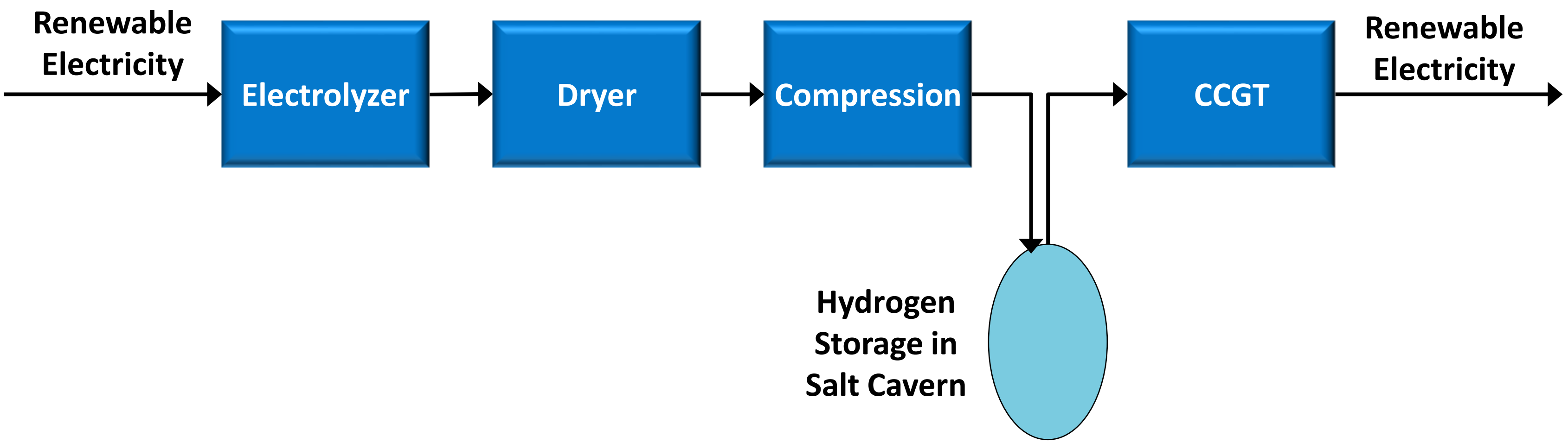



| | | |
|---|---|---|
| Hydrogen volume | 27 | tons/day |
| Hydrogen price | 1.00 | $/kg |
| Electricity production | 75,085,714 | kWh/yr |
| Electricity price | 0.10 | $/kWh |
| Fuel cell size | 10.08 | MW |
| Fuel cell efficiency | 50% | |
| Capital investment | $ 19,159,664 | |
| NPV @8% | $ 159,893 | |

# Three projects are storing hydrogen produced by renewable energy using electrolyzers, and producing power to optimize arbitrage

| Project | Location | Size MW | Hydrogen Source | Generation Technology |
|---|---|---|---|---|
| Intermountain Power | Delta, Utah | 840 | Renewable Energy | Mitsubishi Turbine |
| Port Lincoln | Port Lincoln, Australia | 15 | Renewable Energy | Turbine & Fuel Cell |
| Project Neo | New South Wales, Australia | 1,000 | Renewable Energy | Fuel Cells |

# These projects need a significant gap between the electricity purchase price and electricity sales price for the financials to pencil out




| | | |
|---|---|---|
| Renewable electricity purchase | 1,000,000 | MWh/yr |
| Renewable electricity cost | 0.02 | $/kWh |
| Electricity production | 423,360 | MWh/yr |
| Electricity price | 0.16 | $/kWh |
| Electrolyzer size | 254 | MW |
| Cavern hydrogen capacity | 5,300 | tons |
| Turbine size | 107 | MW |
| Capital investment | $ 295,988,636 | |
| NPV @8% | $ 21,650,514 | |

# Two plants plan to use natural gas reformation combined with carbon capture and sequestration for hydrogen power generation

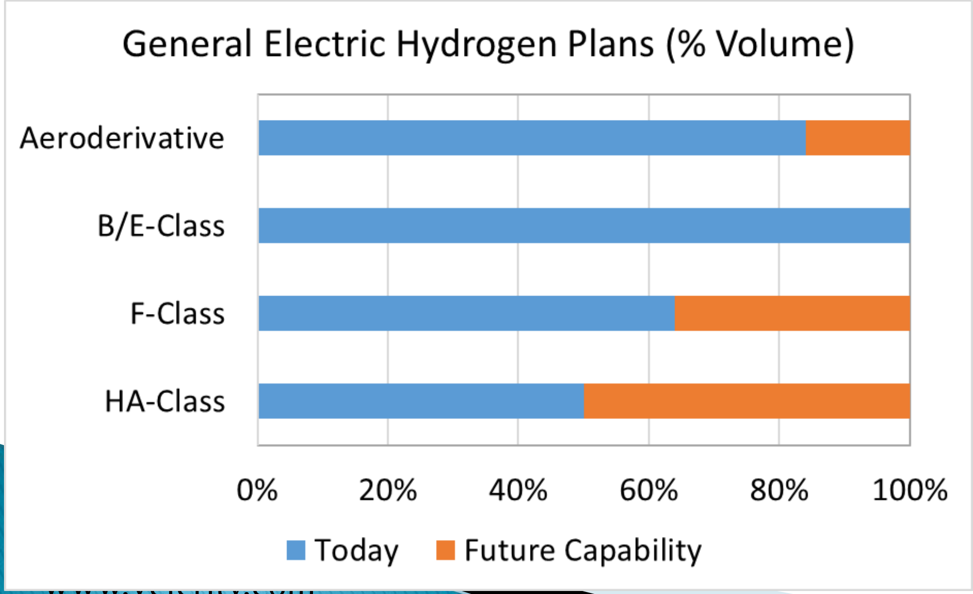
| Project | Location | Size, MW | Hydrogen Source | Generation Technology |
|---|---|---|---|---|
| Keadby | Scunthorpe, United Kingdom | 900 | Natural Gas | Turbine |
| Magnum | Eemshaven, Netherlands | 440 | Natural Gas | Mitsubishi Power Turbine |

# All of the major turbine manufacturers have developed hydrogen ready turbines

- Baker Hughes
  - 100% H2 capability was demonstrated on GE10-1 with steam injection at Enel combined cycle power plant in Fusina, Italy

Baker Hughes NovaLT-16

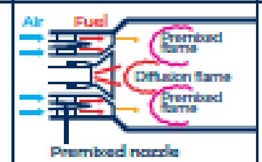
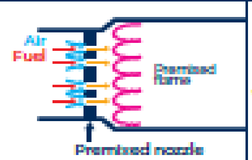
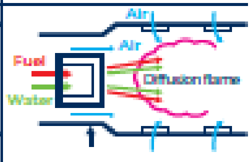
- General Electric



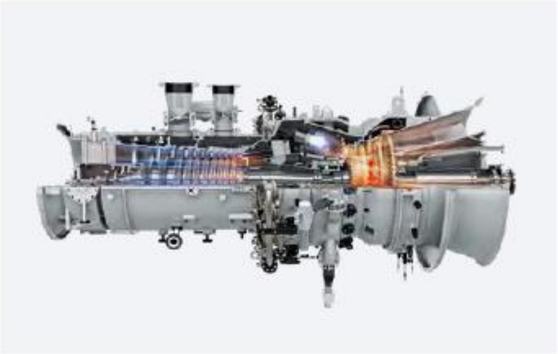

GE 7HA.03

# Key focus of innovation is on NOx abatement and managing higher hydrogen flame speeds

- Mitsubishi Power
  - Offers three different types of combustors
  - Collaborating with Vattenfall, Gasunie and Equinor in the Vattenfall Magnum Carbon-Free Gas Power project, converting one of Magnum's three 440 MW CCGT to 100% hydrogen by 2025.

| | Multi-nozzle combustor | Multi-cluster combustor | Duffusion combustor |
|---|---|---|---|
| Combustor type | Premix | Premix | Diffusion |
| Structure |  |  |  |
| Dilution for low NOx | Not applicable (Dry) | Not applicable (Dry) | Water, steam and $N_2$ |
| Cycle efficiency | No efficiency drop because of no steam or water injection | No efficiency drop because of no steam or water injection | Efficiency drop occurs because steam or water are injected to reduce NOx |
| Hydrogen co-firing ratio | Up to 30% vol. | Up to 100% vol. (under development) | Up to 100% vol. |

- Siemens
  - Aeroderivative gas turbines up to 100% vol. H2 in diffusion combustion mode with NOx abatement using water.



Siemens SGT-600

# Bloom Energy has demonstrated a niumble capacity, introducing a hydrogen SOFC fuel cell and SOFC electrolyzers for hydrogen production

- Bloom Energy Hydrogen Energy Server
  - Nameplate Output 300 kW
  - Fuel Hydrogen
  - Efficiency 52%
  - Heat Rate 6,824.28 Btu/kWh
  - Hydrogen consumption 18.81 kg/hr

# Question and Answer