Recent Progress in Solid Oxide Cell Technology Analysis

at National Energy Technology Laboratory

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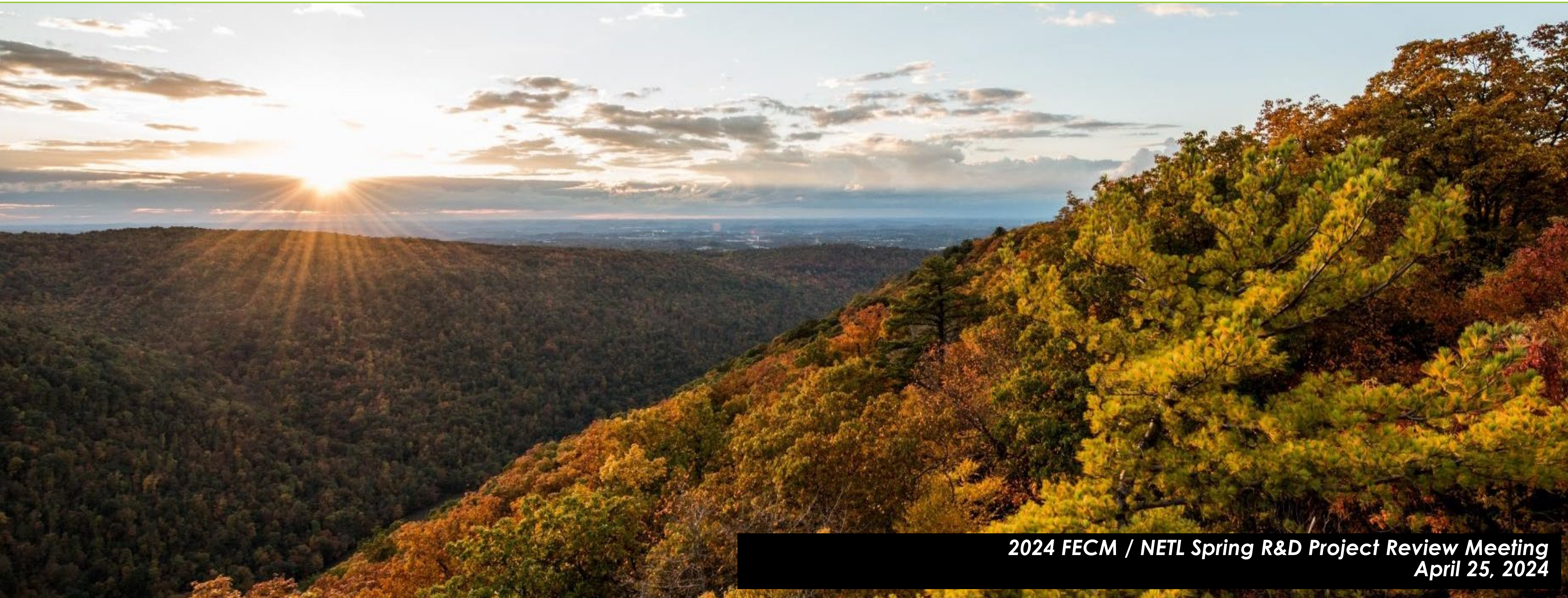
Strategic Systems Analysis and Engineering



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Agenda / Acknowledgements

- **Recent Progress in SOFC/SOEC/R-SOC Systems Analysis Efforts at NETL**
  - Techno-Economic and Market Assessment of Hydrogen-Fueled SOFC
  - Techno-Economic Analysis of Modularized SOFC Technology
  - Large-Scale Hydrogen Production with Solid Oxide Electrolysis Cell Technology
- **Future Work**
- **Wrap-Up**

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Techno-Economic and Market Assessment of Hydrogen-Fueled SOFC

TEA of Hydrogen-Fueled SOFC Systems

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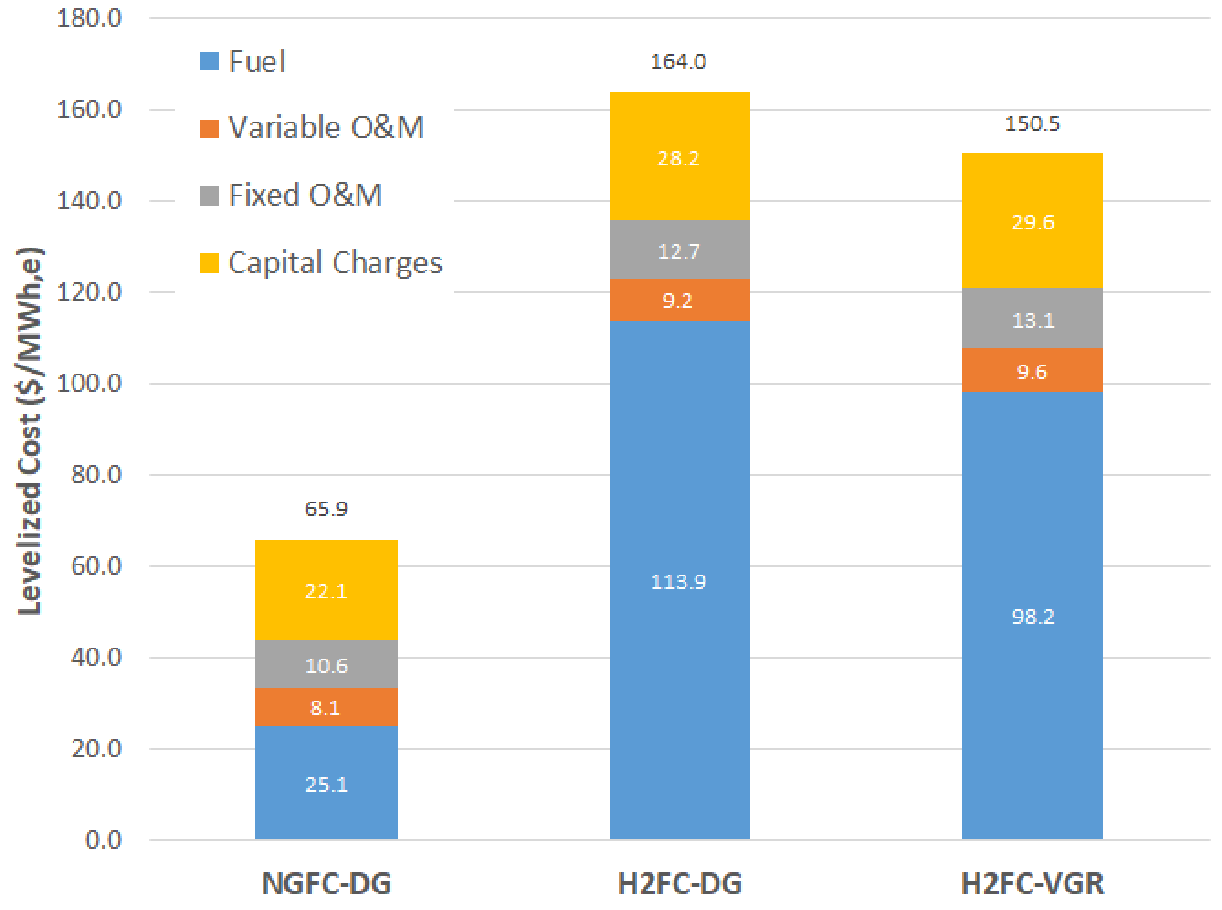
Objective/Approach

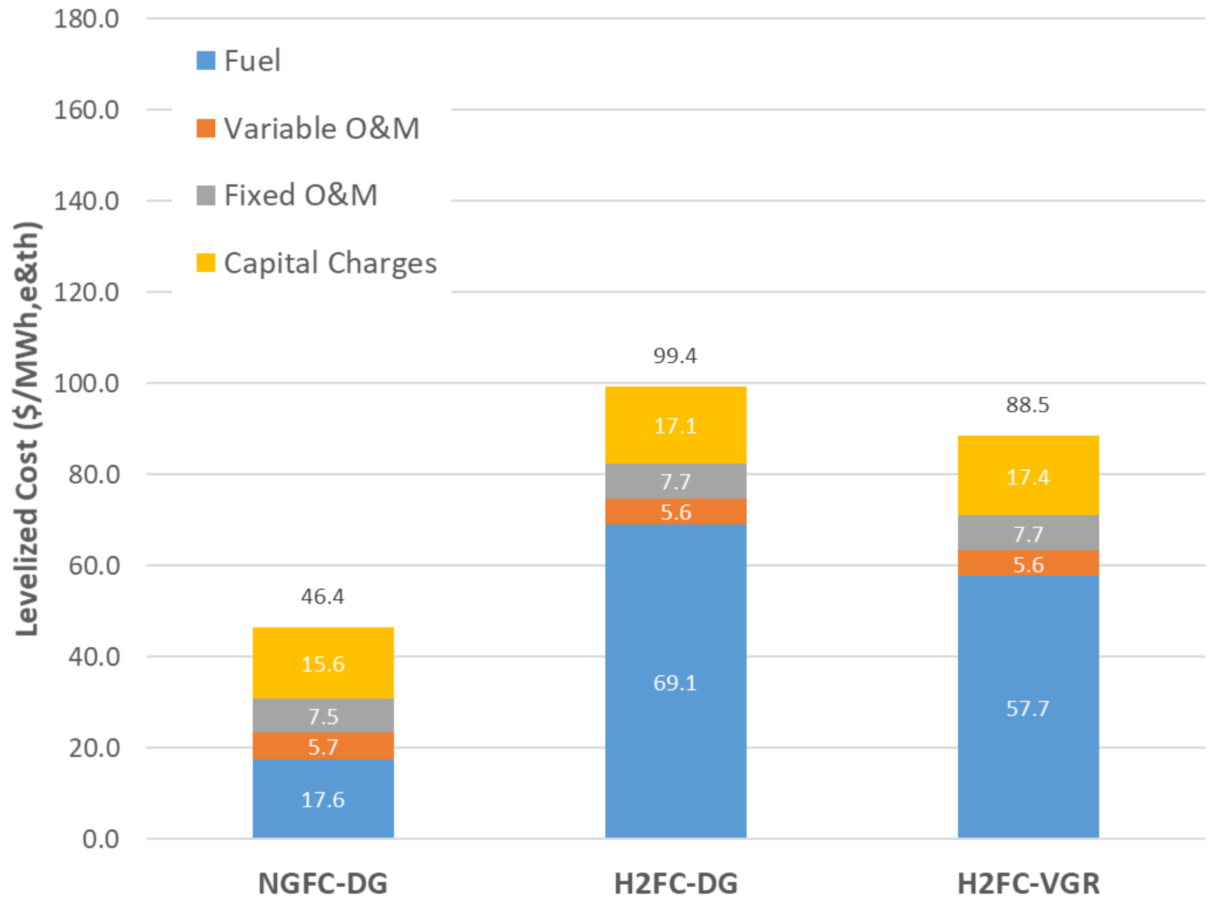
- **The objective of this study is to quantify of the cost and performance impacts associated with operating SOFC technology on pure hydrogen fuel**
- **Approach**
  - Execute an analysis of hydrogen-fueled solid oxide fuel cell configurations
  - **Investigate the impact of increased heat generation** resulting from the use of pure hydrogen fuel
  - **Assess at a smaller scale** - Preferred for comparison, given the expense and role that hydrogen may play in power generation
  - The analysis should consider system configurations that aim to mitigate the increased parasitic losses associated with the exothermic hydrogen oxidation reaction
  - Assess the impact of **operating these devices in combined heat and power (CHP)** configurations to cost and performance
  - **Develop market assessment for CHP applications**

TEA of Hydrogen-Fueled SOFC Systems

Cost Results – Levelized Cost of Electricity



Electricity Only



Electricity with CHP

Source: NETL

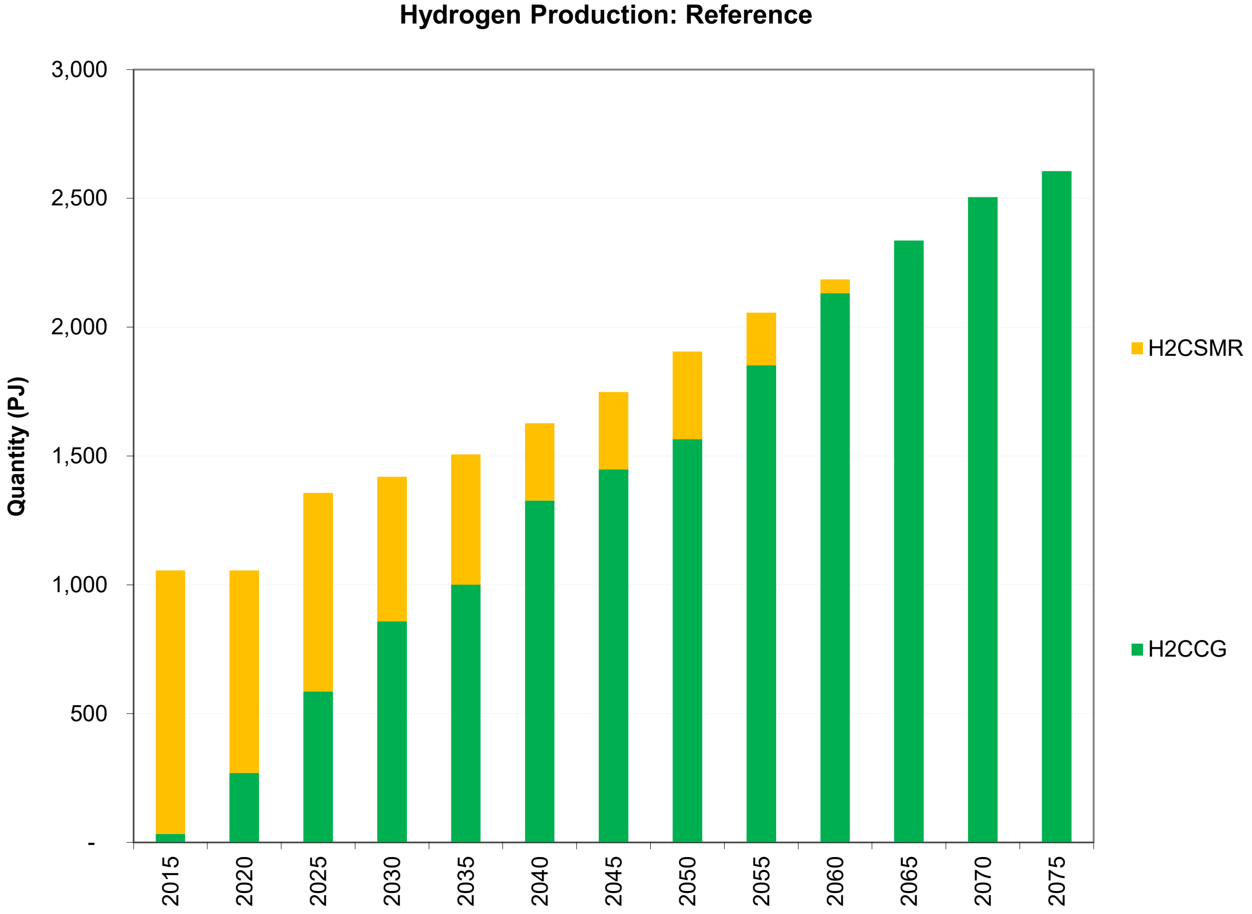
Market Assessment of H_2 Fueled SOFC

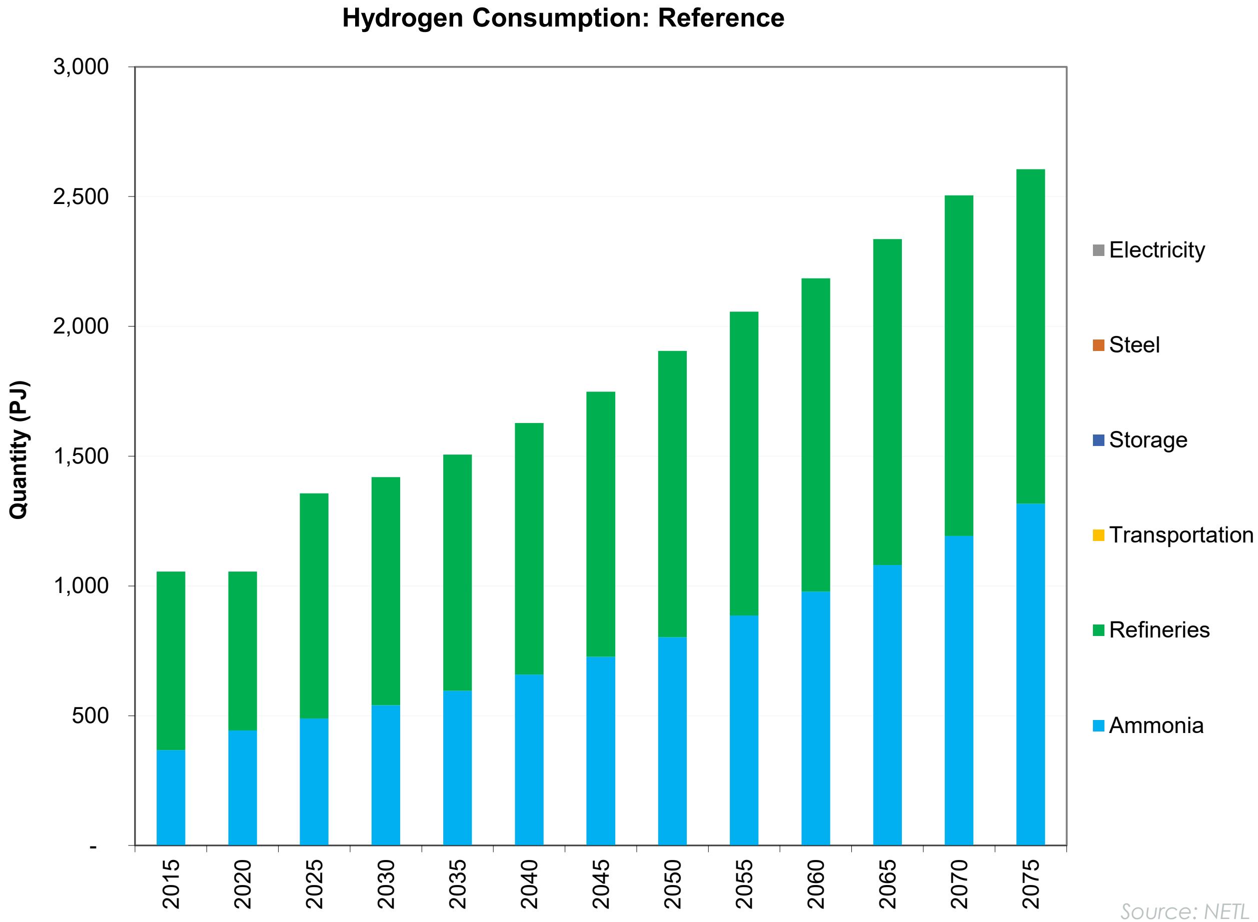
Introduction

- **Using energy market models (MARKAL and TIMES), NETL assessed several scenarios to examine the potential deployment of H_2 fueled SOFC**
- **Scenarios examined:**
  - Reference case
  - Reference with SOFC technology available
  - Net-zero by 2050 (CO_2 emissions economy wide reach net-zero)
  - Net-zero by 2050 with SOFC technology available
- **Found significant deployment potential for SOFC in the net-zero scenario since it provides an opportunity to mitigate hard-to-decarbonize industrial areas**
- **This technology pathway has the potential to reduce the marginal price of CO_2 in the net-zero scenario by almost 50%**

H_2 Production and Consumption in 2015–2075

Reference Scenario



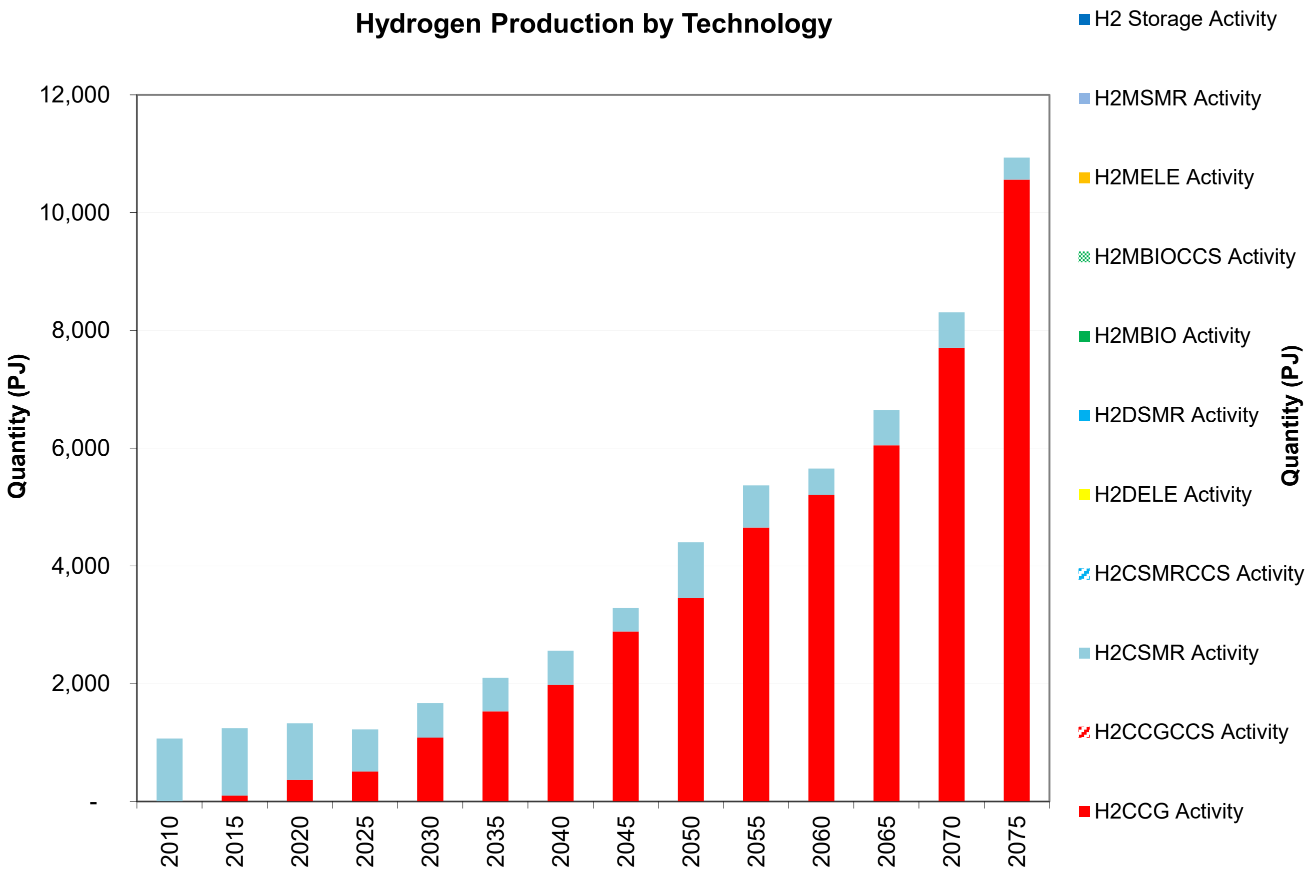


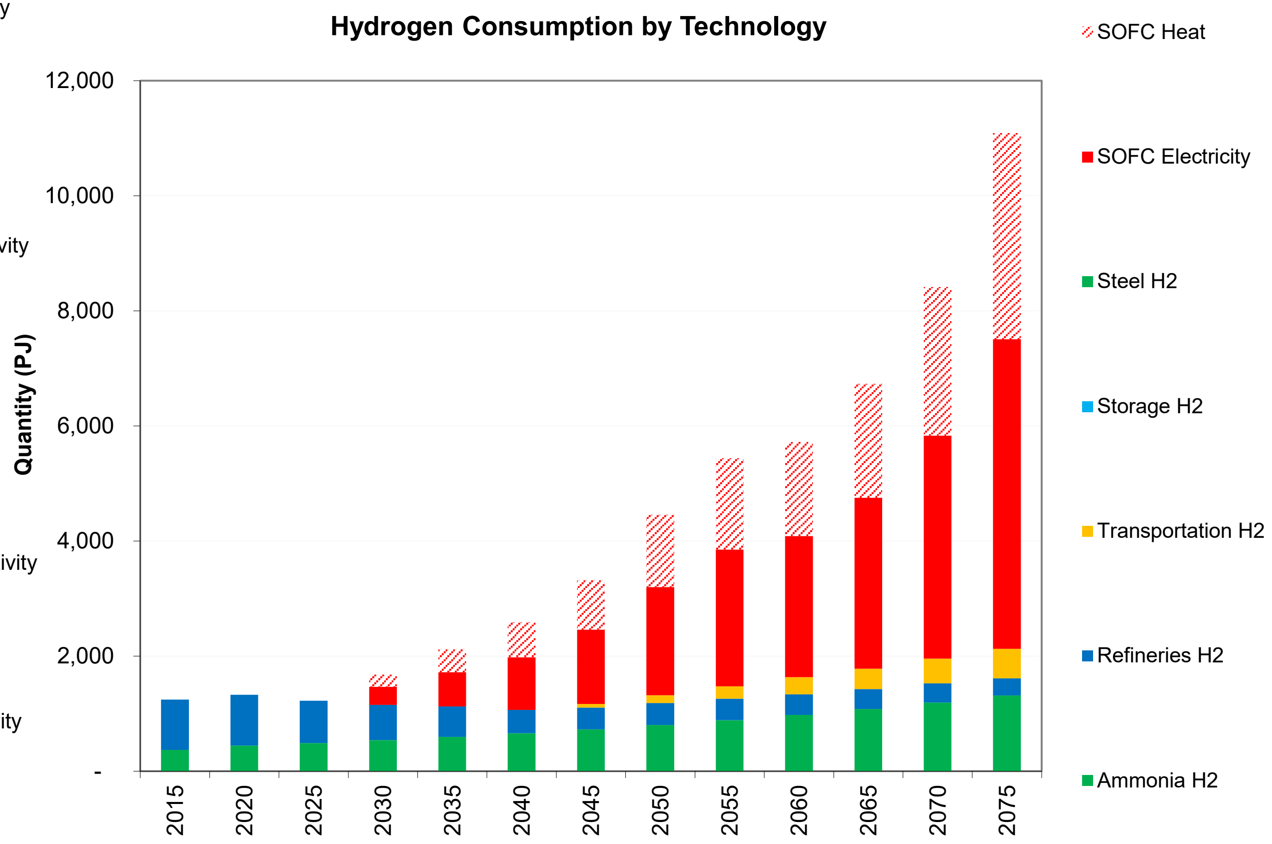
Source: NETL

SMR and CCG are the most economically attractive options for H_2 production in Reference scenario and in the long-term future, CCG replaces SMR. H_2 demand constantly increases in the ammonia and refining industries, and there is no deployment of H_2 technologies in other sectors.

H_2 Production and Consumption in 2015–2075

Reference Scenario with SOFC





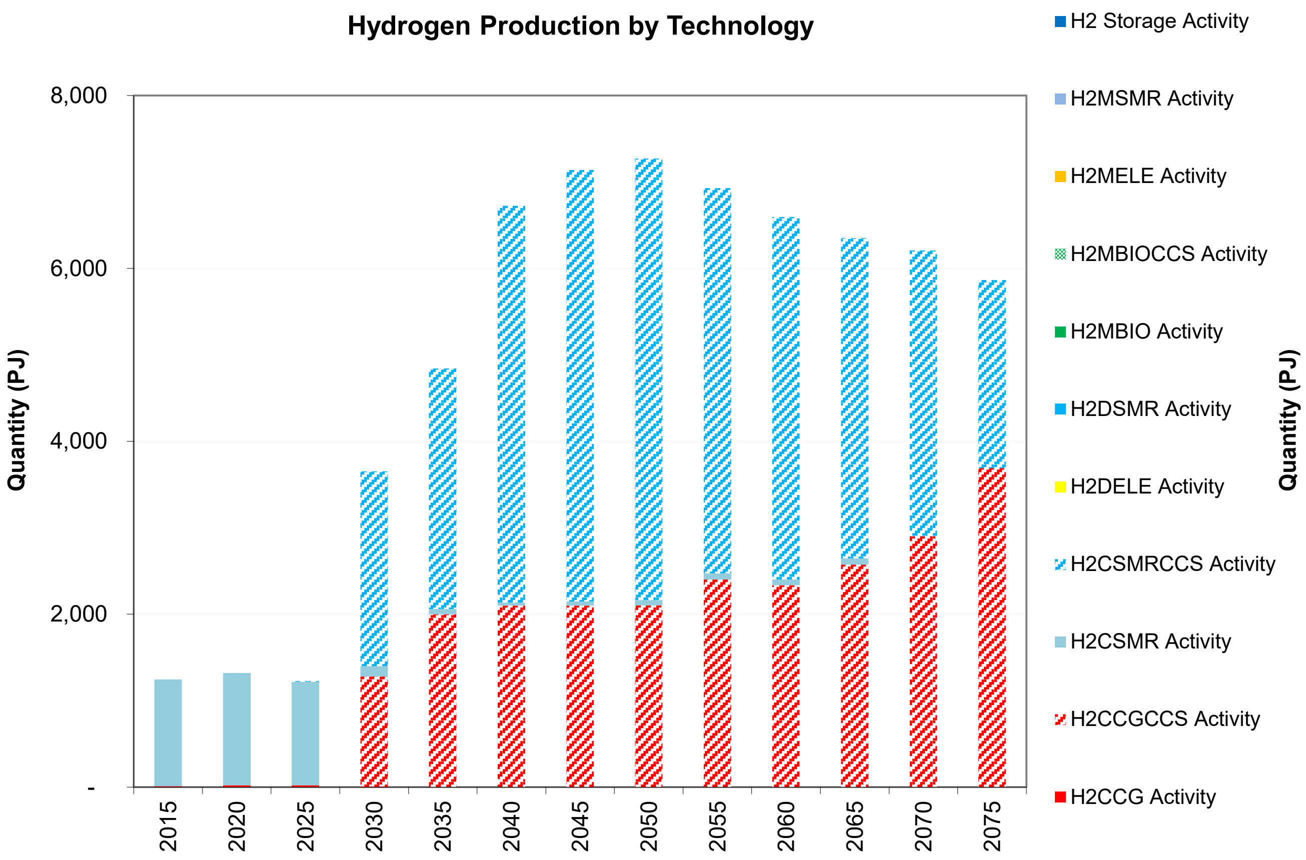
Source: NETL

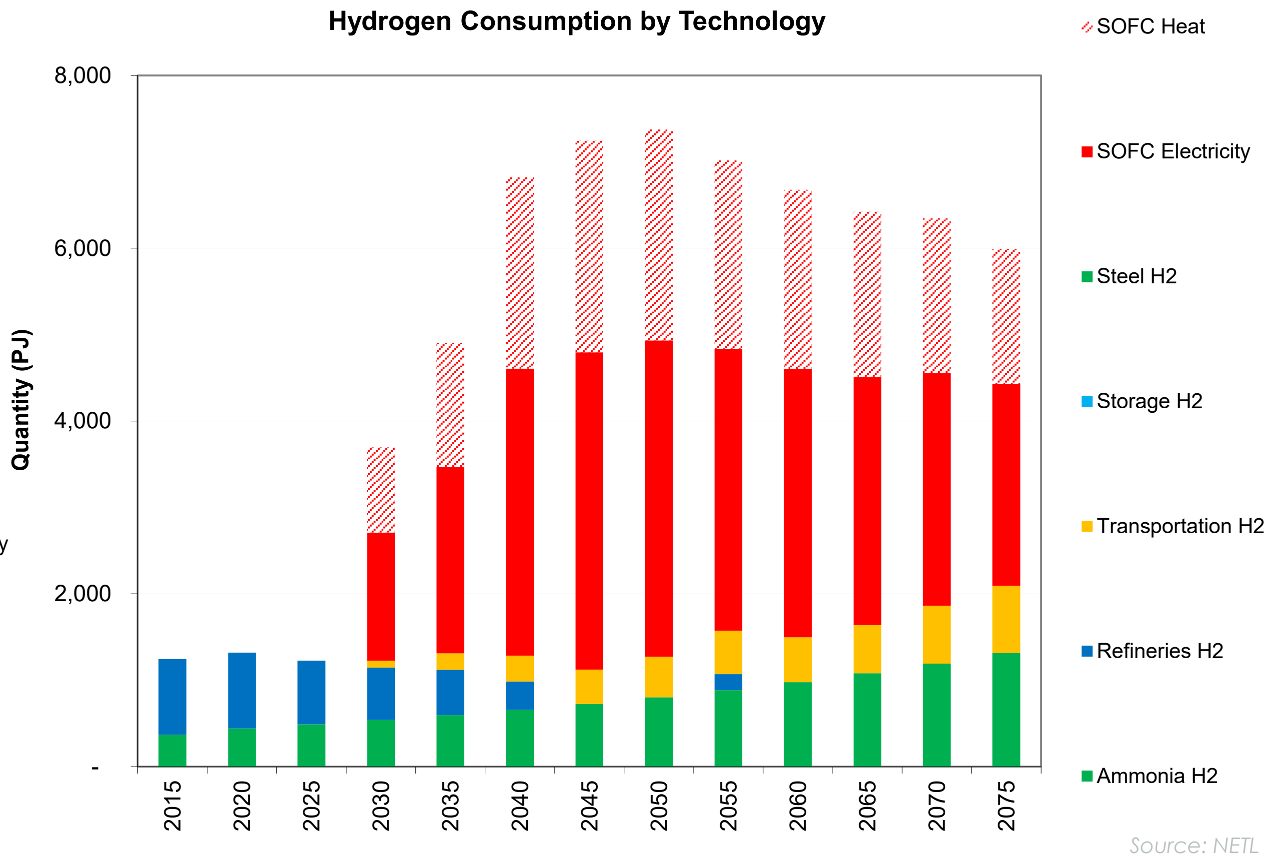
SMR and CCG are the most economically attractive options for H_2 production in Reference SOFC scenario and in the long-term future, CCG replaces SMR. H_2 demand increases exponentially after 2035; SOFC deployment is maximum in this scenario.

PRELIMINARY RESULTS – SUBJECT TO CHANGE – DO NOT CITE OR QUOTE

H_2 Production and Consumption in 2015–2075

Net-Zero Scenario with SOFC



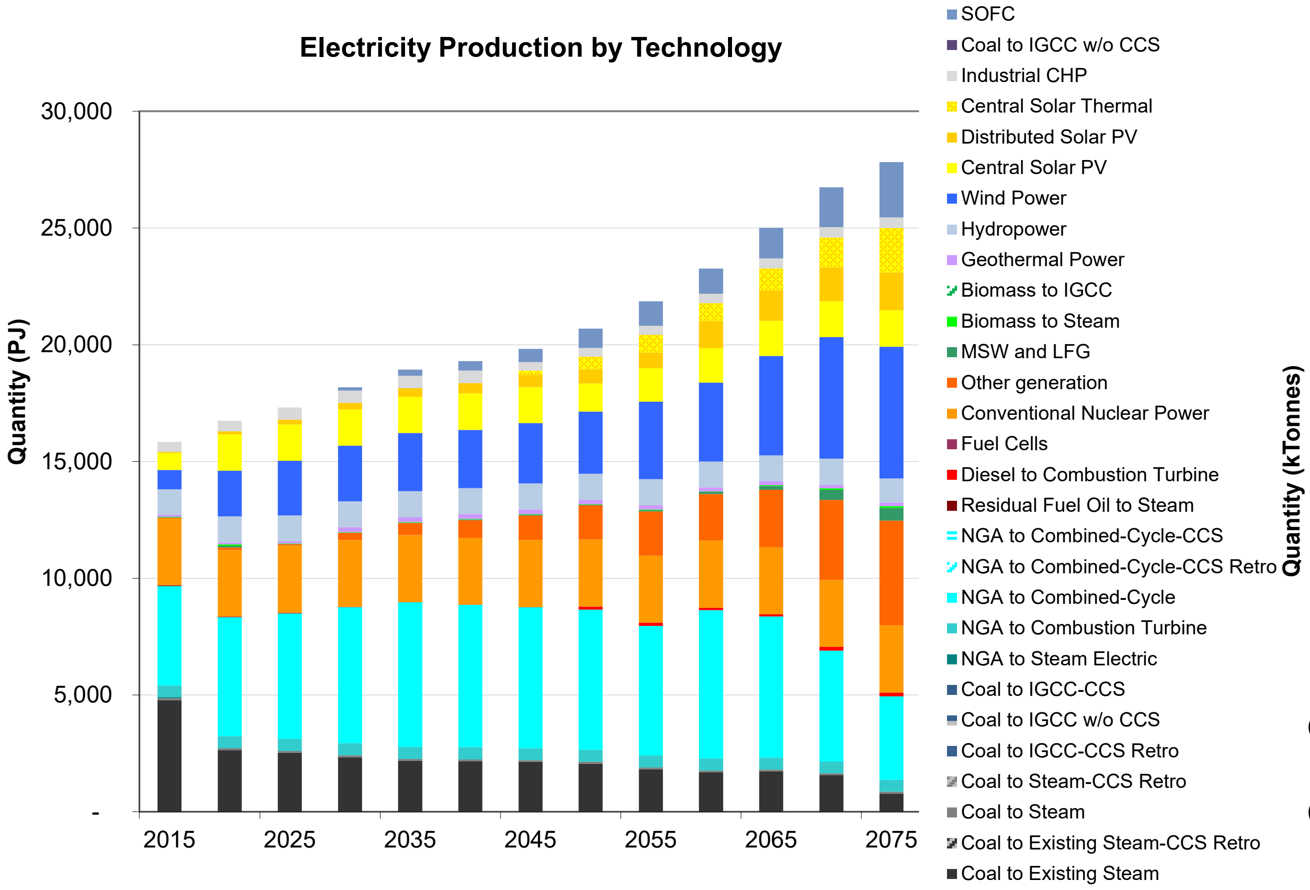


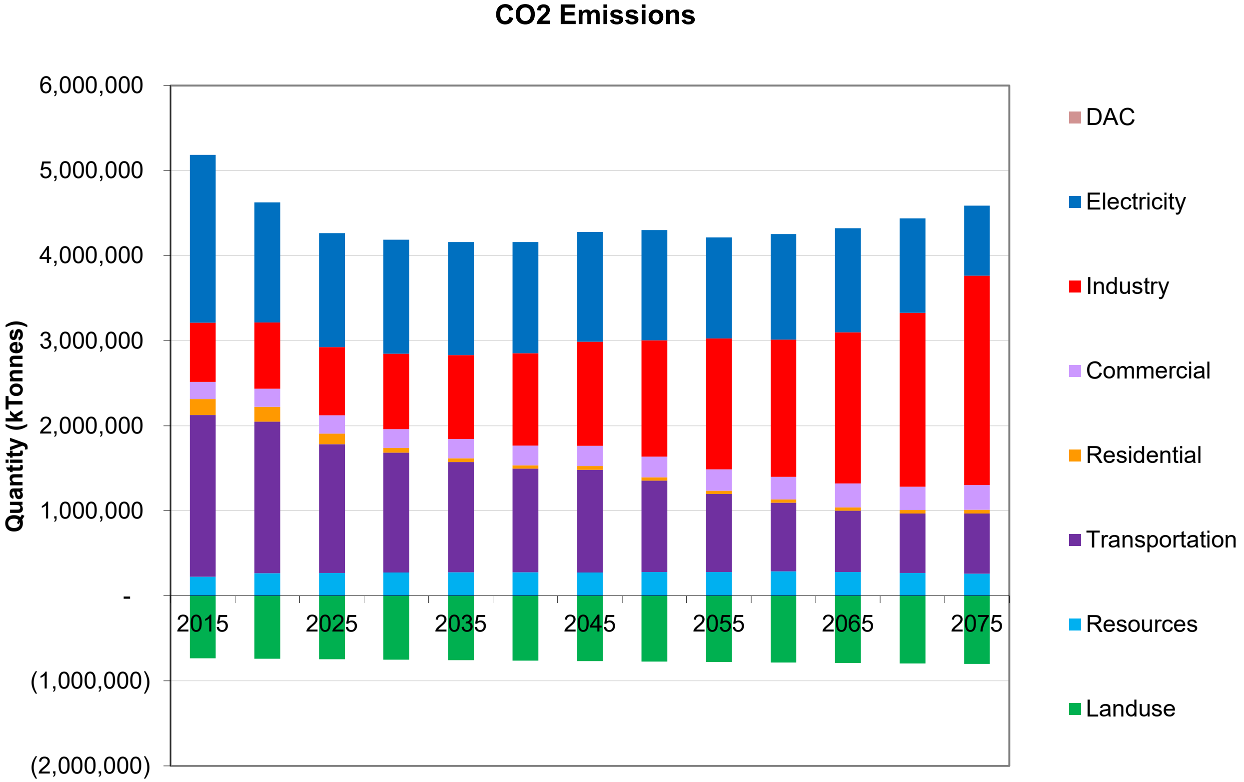
Source: NETL

H_2 production relies on technologies with capture and storage. New H_2 demand goes to electricity production and process heat via SOFC.

Electricity Production/CO_2 Emissions in 2015–2075:

Reference Scenario with SOFC



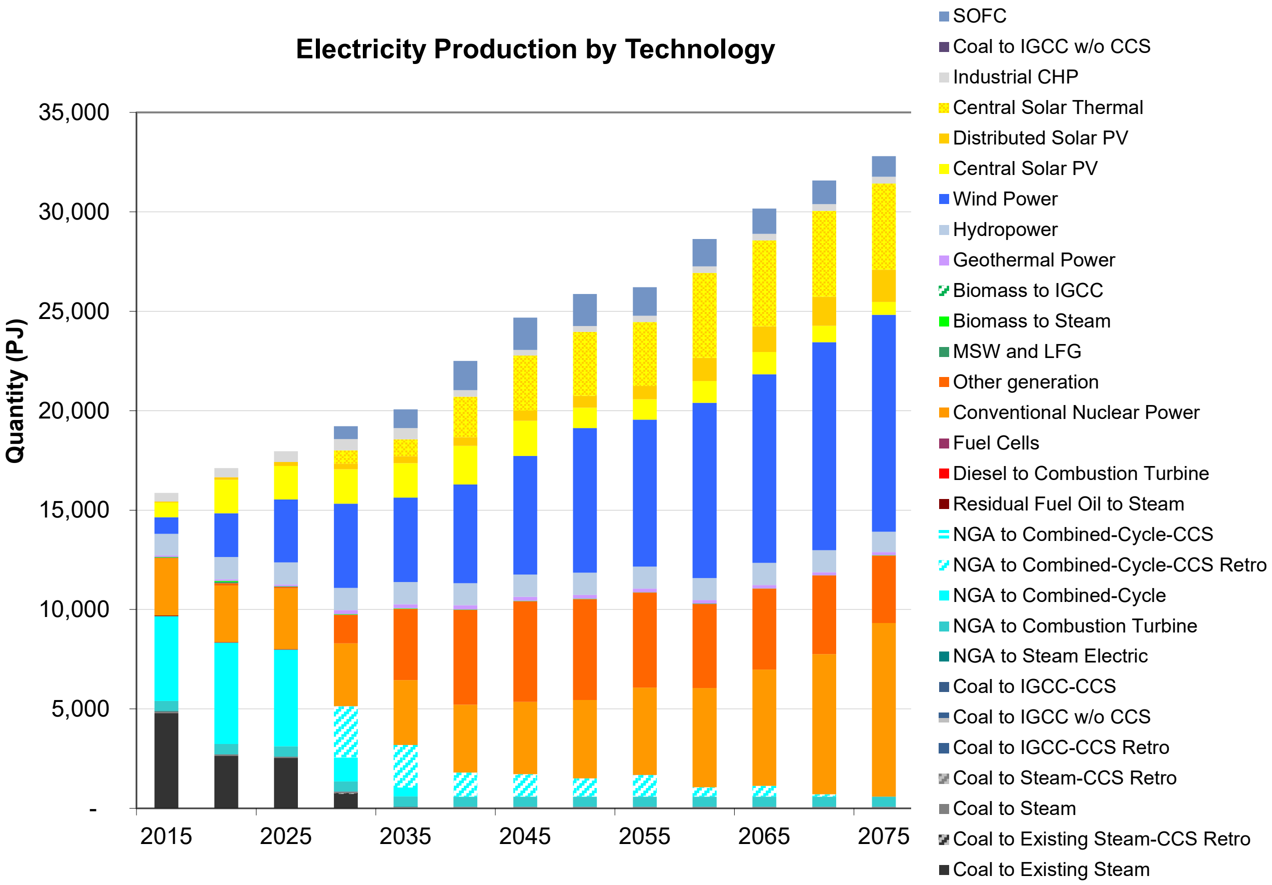


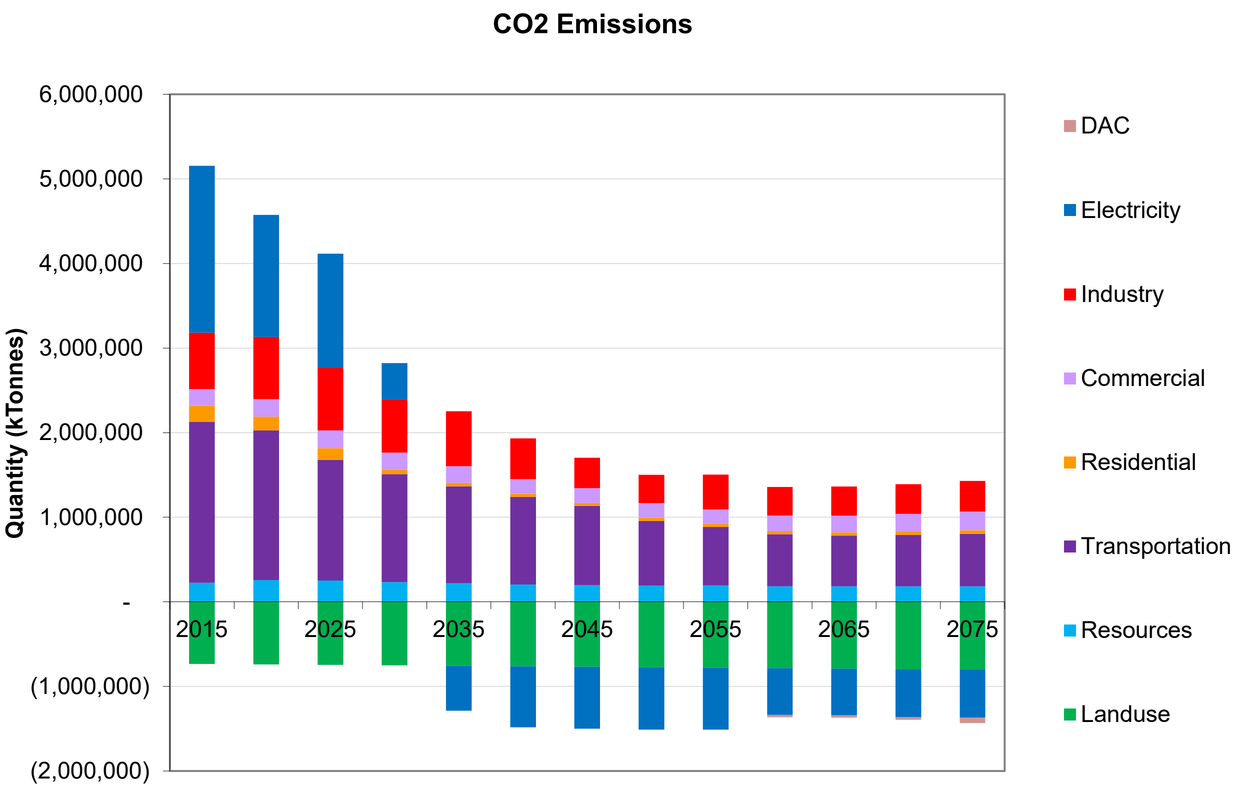
Source: NETL

Electricity generation from H_2 - SOFC increases after 2035 and it is more competitive than Solar PV. CO_2 emissions is increasing after 2040 and higher than in Reference scenario due to industrial CO_2 increase (as result of H_2 production from fossil fuels w/o CCS).

Electricity Production/CO_2 Emissions in 2015–2075:

Net-Zero Scenario with SOFC





Source: NETL

PRELIMINARY RESULTS – SUBJECT TO CHANGE – DO NOT CITE OR QUOTE

Marginal CO_2 Price

NATIONAL ENERGY TECHNOLOGY LABORATORY

Source: NETL

Techno-Economic Analysis of Modularized SOFC Technology

TEA of Modularized SOFC

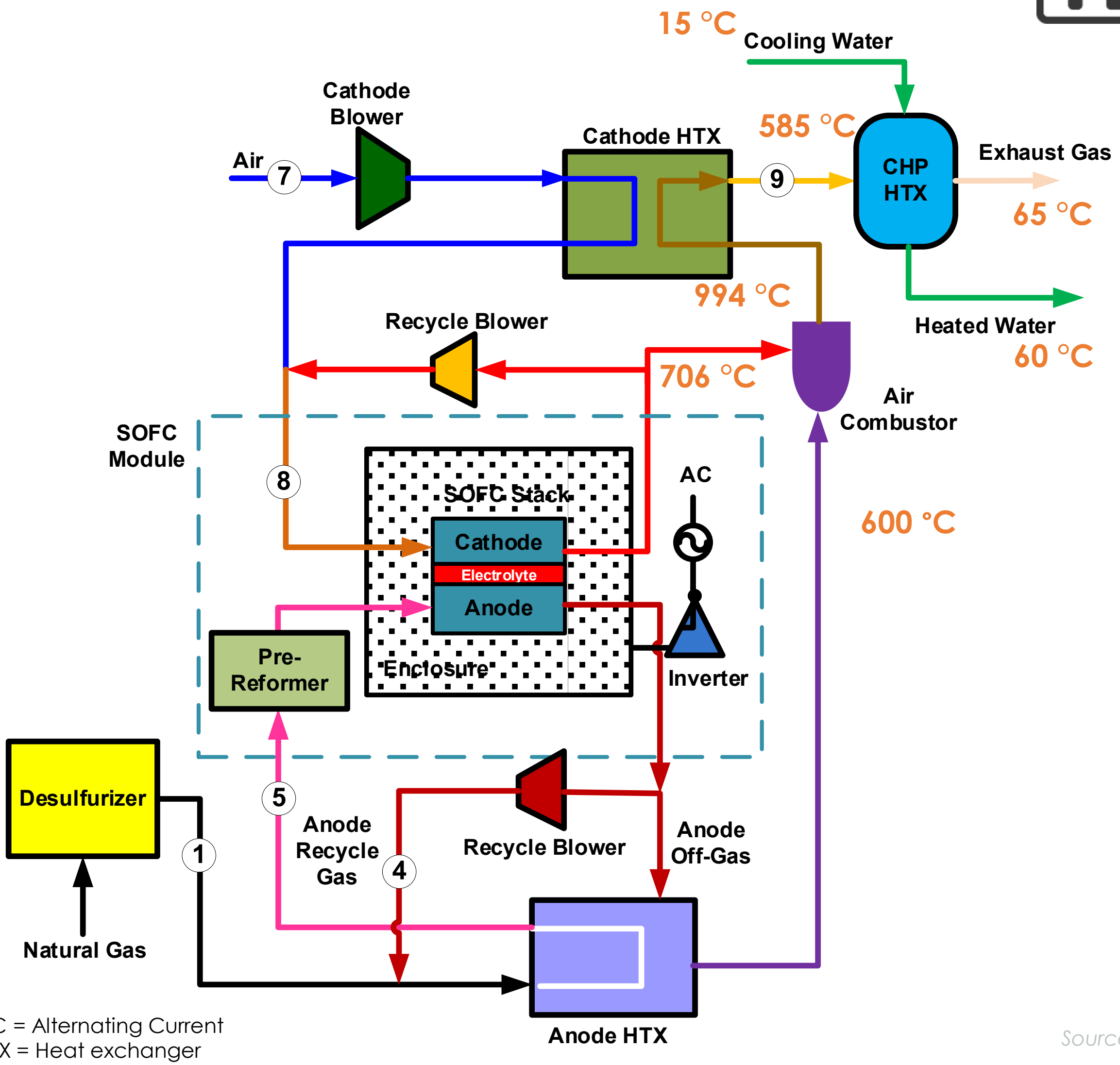
Objective/Approach

- **Modern grid dynamics have elucidated the need for a more modular, flexible approach for development of electric generation units.**
  - Prior NETL analyses have focused on large-scale (>500 MWe) SOFC systems. When considering a dynamic grid with increased VRE penetration, the pathway toward SOFC commercialization will likely leverage smaller scale SOFC systems
- **NETL is developing a techno-economic assessment of SOFC systems at the 10–250 kWe scale to evaluate the applicability of current programmatic cost targets of $225–250/kWe per stack and $900–1000/kWe per system at these scales**
- **Approach**
  - Use the NGFC-DG (distributed generation) model from prior work
  - Performance models run at 250 kWe, gross
  - Performance characteristics will be nearly identical between cases
  - SOFC vendor information (as it is available) will be used to change performance points, equipment costs, stack/module sizes, etc.

TEA of Modularized SOFC

Proposed System

- 250 kWe, gross
- Advanced case: 100% internal reformation
- Atmospheric system without carbon capture
- Air combustor
- CHP option to produce heated water at 140 °F



AC = Alternating Current
HTX = Heat exchanger

Source: NETL

TEA of Modularized SOFC

Preliminary Results - Performance

Performance Summary	MOD-250	MOD-250-CHP
Total Gross Power Output, kWe	250	250
Recovered Thermal Power, kWth	-	96
Total Auxiliaries, kWe	3.5	3.5
Net Power, kWe	**246.5**	**246.5**
Net Plant Electrical Efficiency (HHV)	60.2%	60.2%
Net Plant Thermal Efficiency (HHV)	-	23.4%
Net Plant Combined Efficiency (HHV)	**60.2%**	**83.6%**
Natural Gas Feed Flow, kg/h (lb/h)	28.1 (62.0)	28.1 (62.0)
Net Plant Heat Rate (HHV), kJ/kWh (Btu/kWh)	5,980 (5,670)	5,980 (5,670)
HHV Thermal Input, kWth	410	410
Carbon Dioxide Capture Rate, %	NA	NA

HHV = Higher heating value

Source: NETL

Large-Scale Hydrogen Production with Solid Oxide Electrolysis Cell Technology

Large-Scale H_2 Production via SOEC

NATIONAL ENERGY TECHNOLOGY LABORATORY

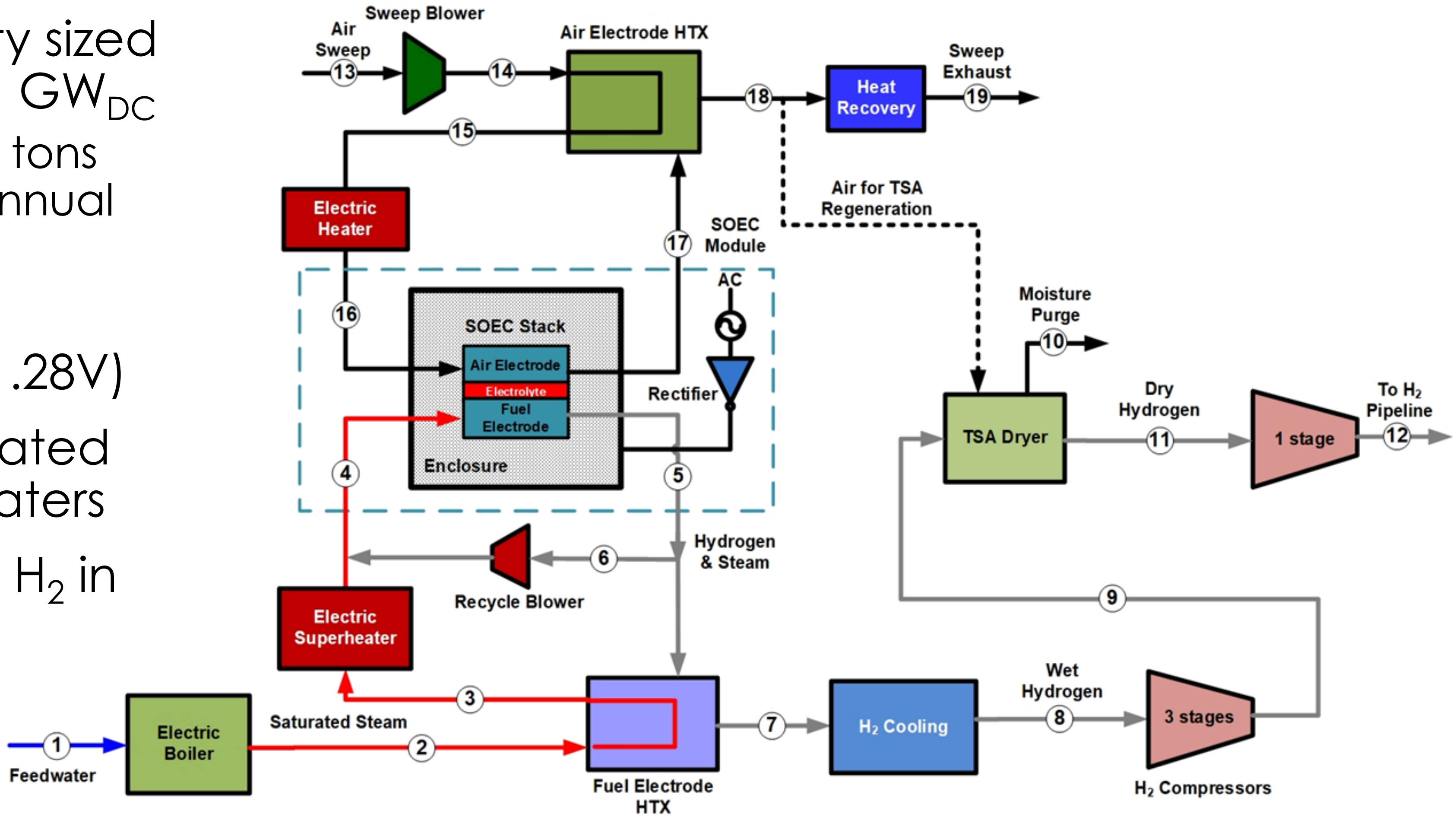
Objective/Approach

- **The objective of this study is to establish a detailed TEA to assess the effectiveness of incremental technology improvements needed for solid oxide electrolysis cell (SOEC) technology to achieve the U.S. DOE's Hydrogen Shot goal of hydrogen production at less than $1 per kilogram.**
- **Approach:**
  - **A literature review on long-duration SOEC stack tests** informed the state-of-the-art basis for the techno-economic pathway.
  - The pathway considers **incremental technology improvements** to key system parameters, with system performance and cost assessed for each pathway step.
  - Each step is assessed at both **atmospheric and pressurized operating conditions**
  - Sensitivity studies are conducted to understand the relative impact of each parameter and identify avenues for additional cost reductions.
  - **System efficiency and levelized costs of hydrogen (LCOH)** for each case are presented.

Large-Scale H_2 Production via SOEC

System Design Basis

- SOEC H_2 production facility sized to an electrolysis load of 1 GW_{DC}
  - Produces ~250,000 metric tons annually, about 2.5% of annual U.S. H_2 production
- Stacks operated near the thermoneutral voltage (≈1.28V)
- All steam and heat generated by electric boilers and heaters
- H_2 recycle to ensure >10% H_2 in the feed to the stack
- Sweep air flow controlled to ensure <35 mol% oxygen in air-electrode exhaust

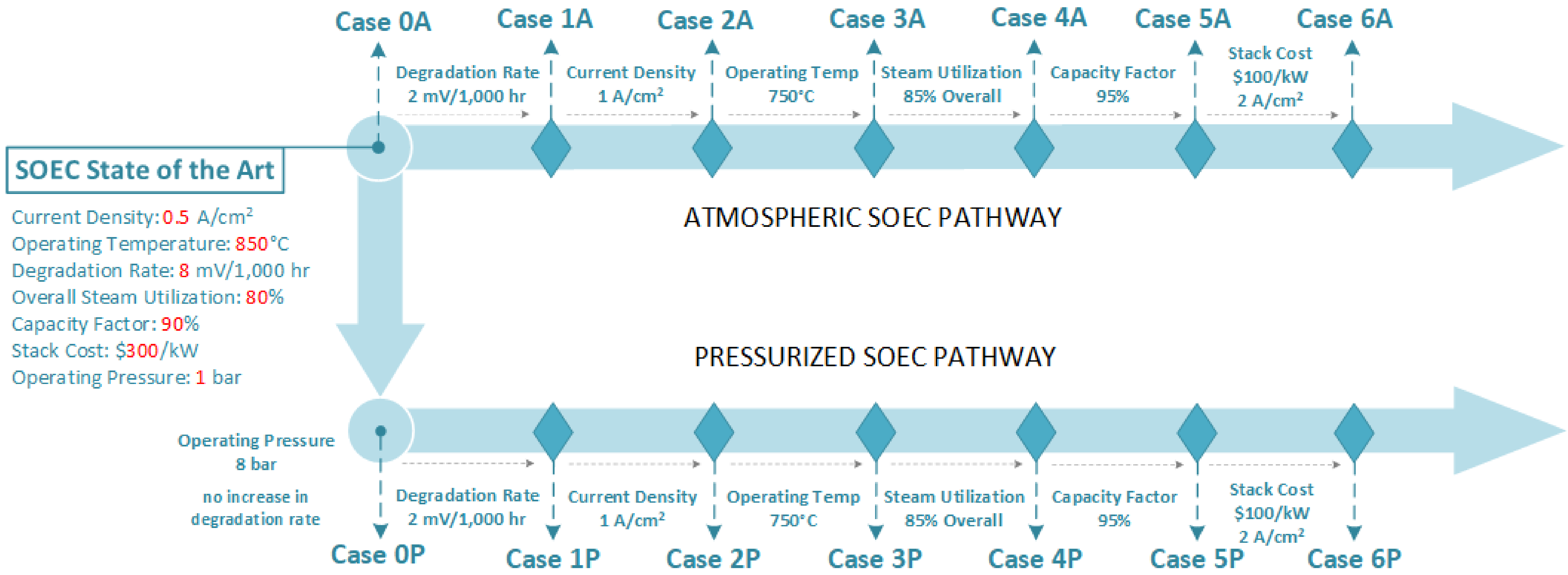


DC = Direct current
HTX = Heat exchanger
TSA = Temperature swing absorption

Source: NETL

Large-Scale H_2 Production via SOEC

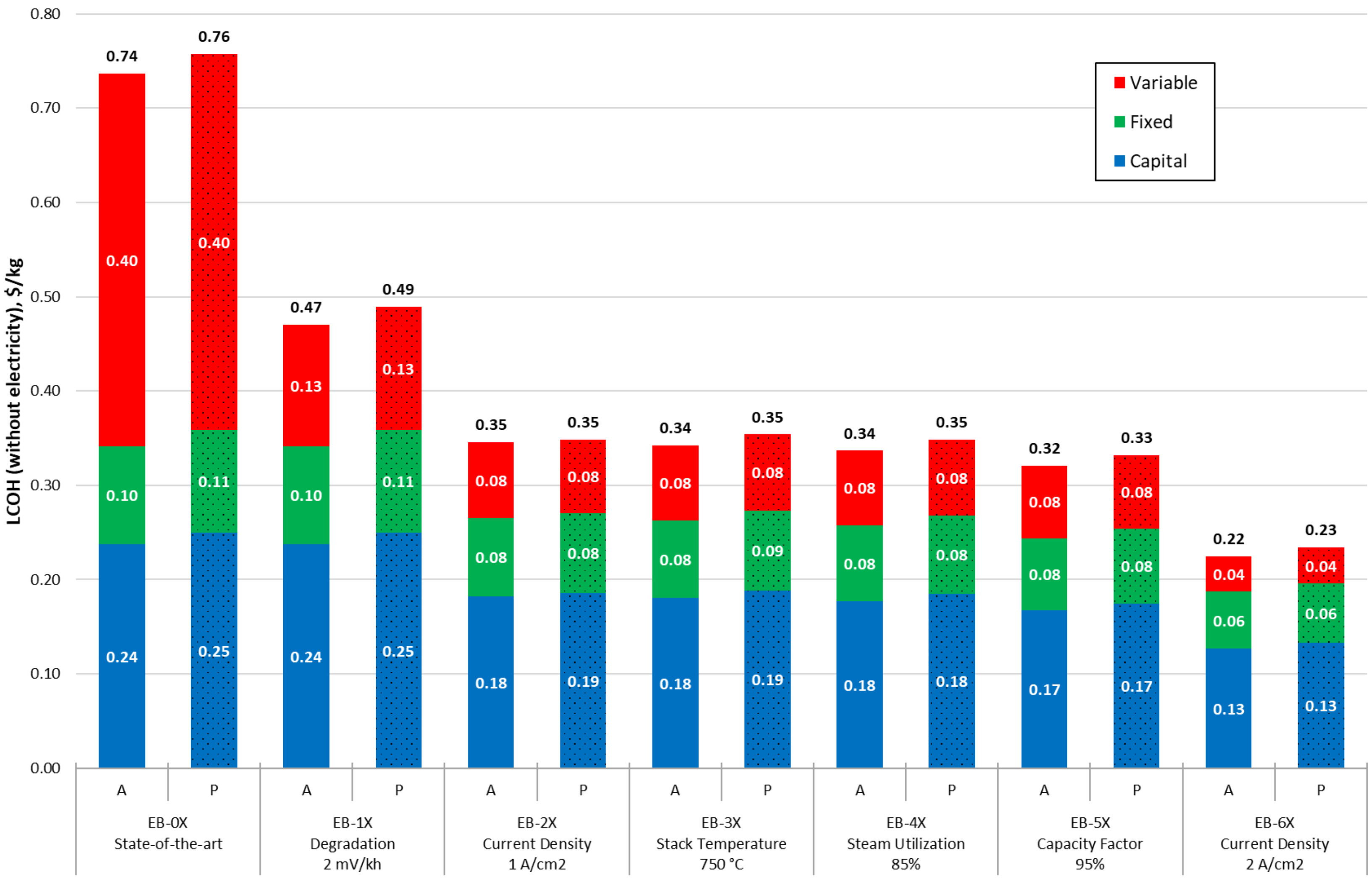
SOEC Pathway



Source: NETL

Large-Scale H_2 Production via SOEC

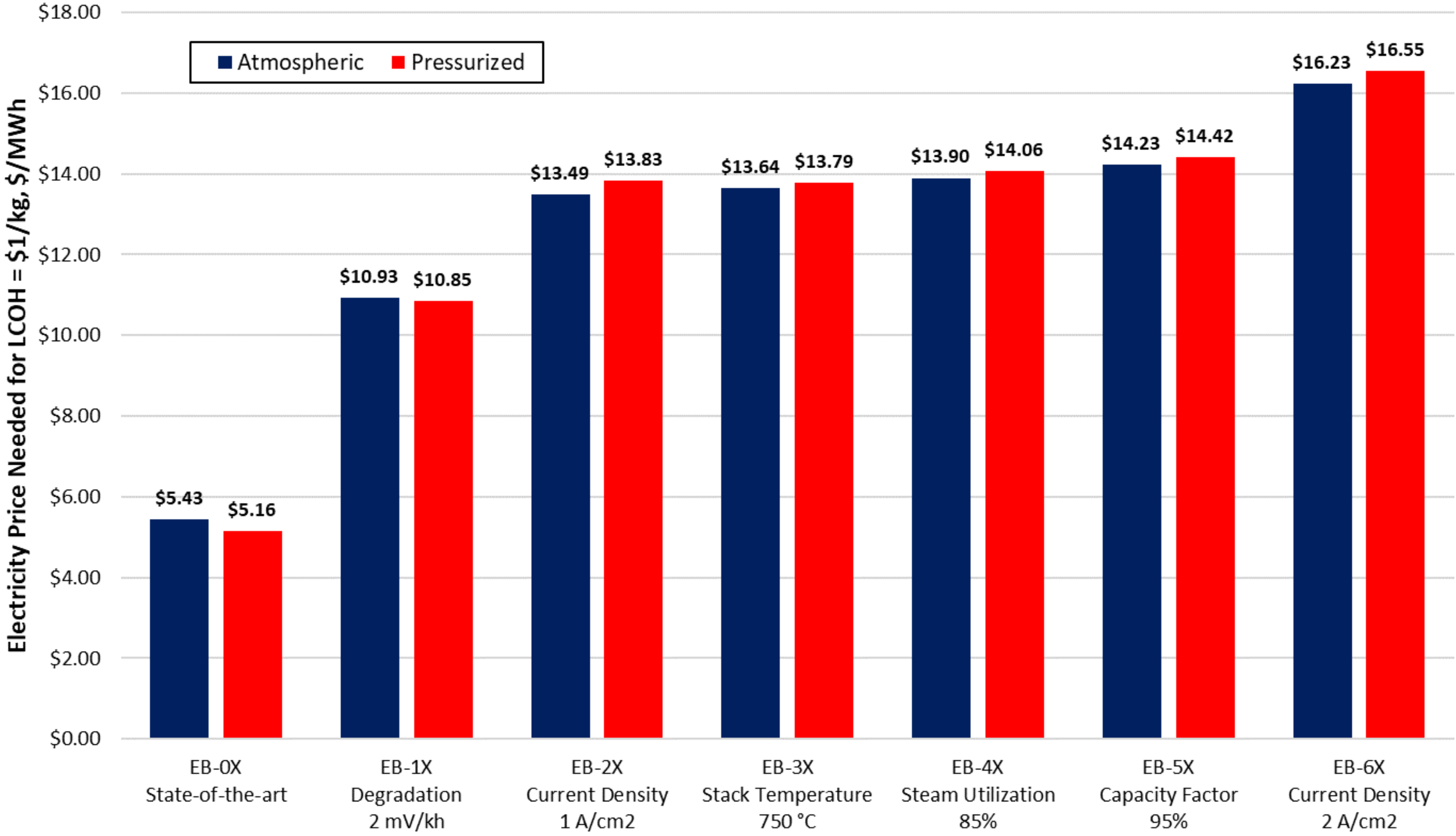
Preliminary Cost Results - Atmospheric & Pressurized LCOH without Electricity



Source: NETL

Large-Scale H_2 Production via SOEC

Preliminary Cost Results - Electricity Price Needed for $1/kg



Source: NETL

On-going / Future Work

Performance and Cost of Hydrogen Fuel Cells

- **Current Status:**
  - Market Assessment of H_2 Fueled SOFC
    - Finalize/Publish Results – May/June 2024
  - Techno-Economic Analysis of Modularized SOFC Technology
    - Finalize Results – Summer 2024
  - Large-Scale Hydrogen Production from SOEC Technology
    - Finalize/Publish Results – May/June 2024
    - Abstract submitted for full presentation at ECS PRiME – October 2024
- **Future Work:**
  - Re-engage NETL IDAES/PSE Team (dynamic operation/business case)
  - Enhance R-SOC analysis with additional configurations
  - Alternate fuels for SOFC operation modes

Questions/ Comments

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