Combined Heat and Power/District Energy System Portfolio Meeting: CHP and Decarbonization

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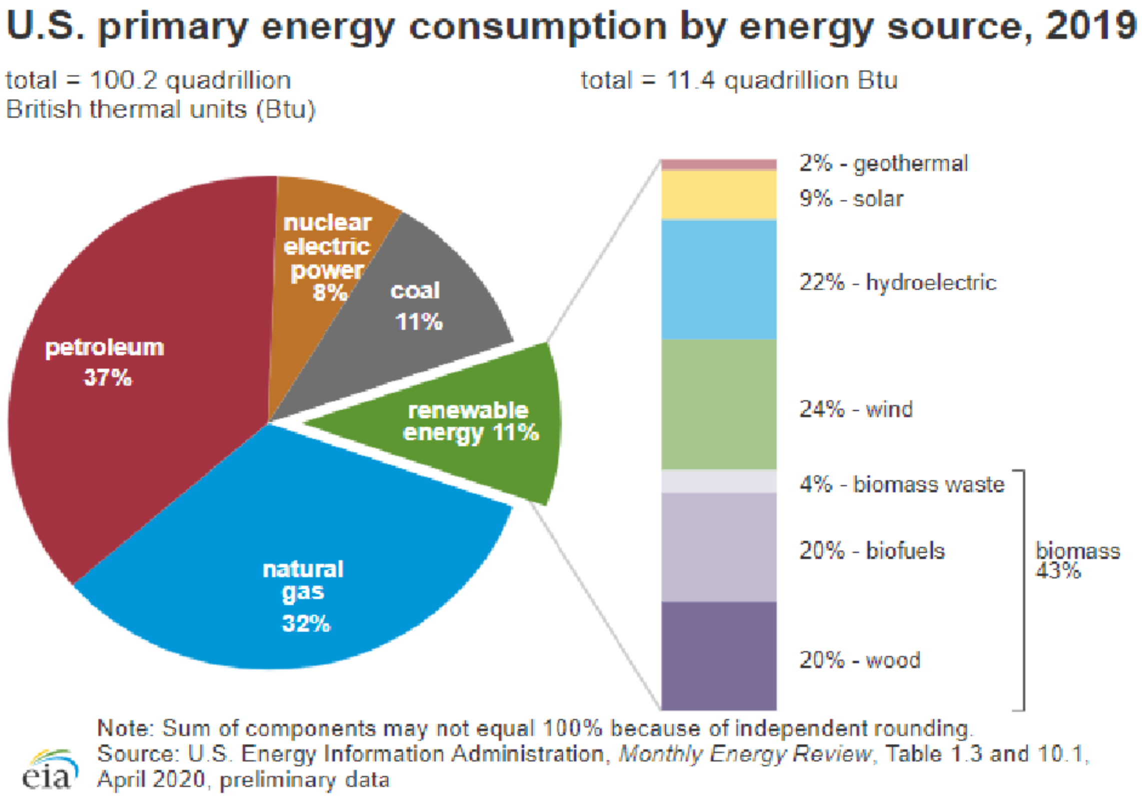
The Path to Decarbonization

- Reducing carbon today is important
- Achieving a net-zero carbon future will require a historic transformation
  - Cost of new generation and T&D
  - Cost of storage
  - Some industrial processes difficult to electrify
  - Critical facilities need dispatchable on-site power for long duration resilience and reliability
  - A renewable grid will need dispatchable generation for support
  - Commitments to decarbonize often not underpinned with concrete plans
- Renewable Fuels/RNG/Hydrogen increasingly looked at as part of the solution

Carbon free power sector by 2035
Net-zero carbon emissions by 2050

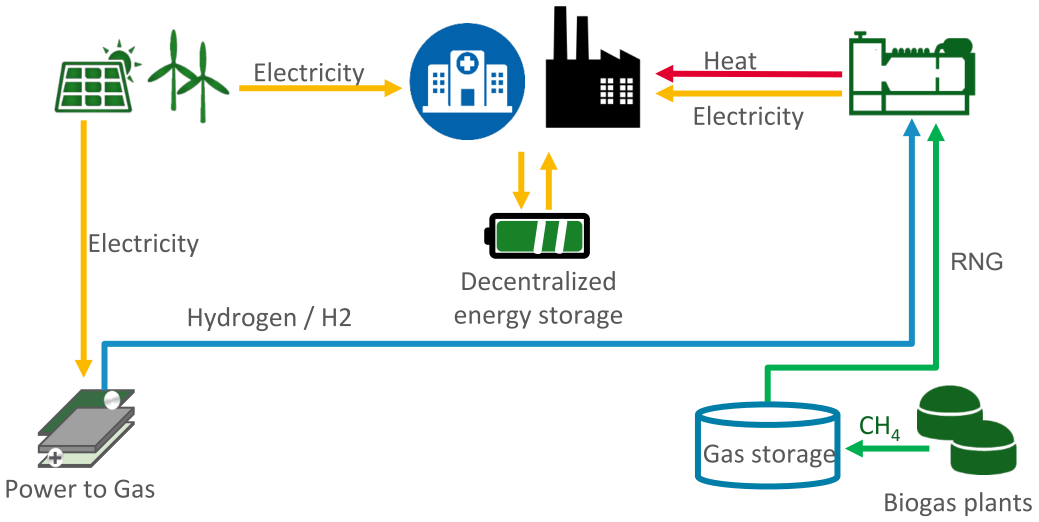
President Biden, April 21, 2021



CHP and Decarbonization

- CHP is fuel flexible - CHP currently uses renewable fuels, low carbon waste fuels, and hydrogen where available, and will be **ready to use higher levels of biogas, renewable natural gas (RNG) and hydrogen in the future**
- **CHP is the most efficient way to generate power and thermal energy**, and can reduce CO_2 emissions now and in the future
- Net-zero fueled CHP can **decarbonize thermal end-uses in industrial and commercial facilities that are difficult to electrify**
- Net-zero fueled CHP can **decarbonize critical facilities that need dispatchable on-site power for long duration resilience and operational reliability**
- CHP's high efficiency can **extend the supply of renewable, low carbon and hydrogen fuels**
- CHP can provide **dispatchable net-zero generation and regulation support to support the long-run resource adequacy of a highly renewable grid**

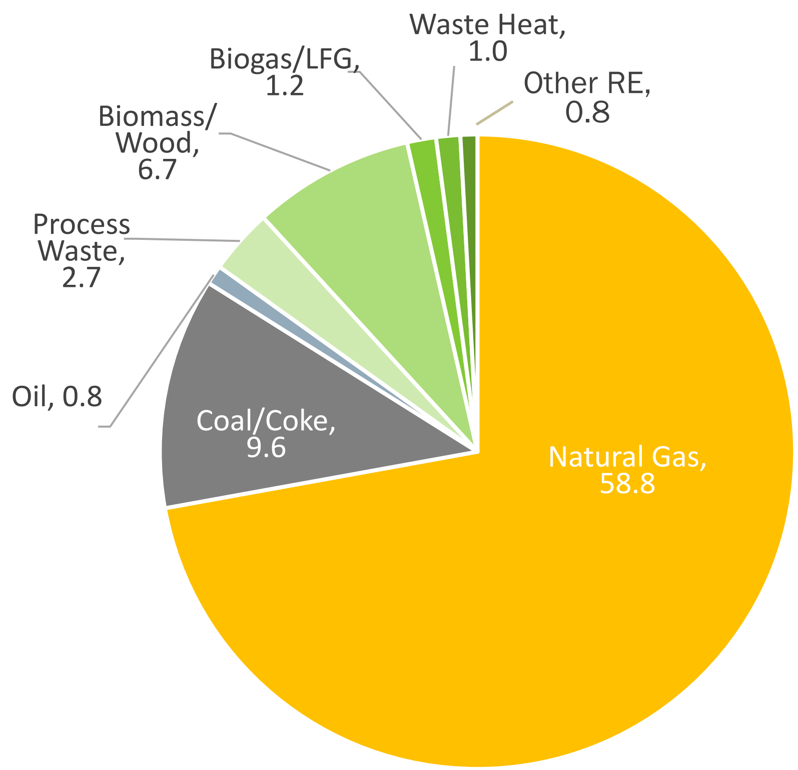
CHP in a Decarbonized Economy



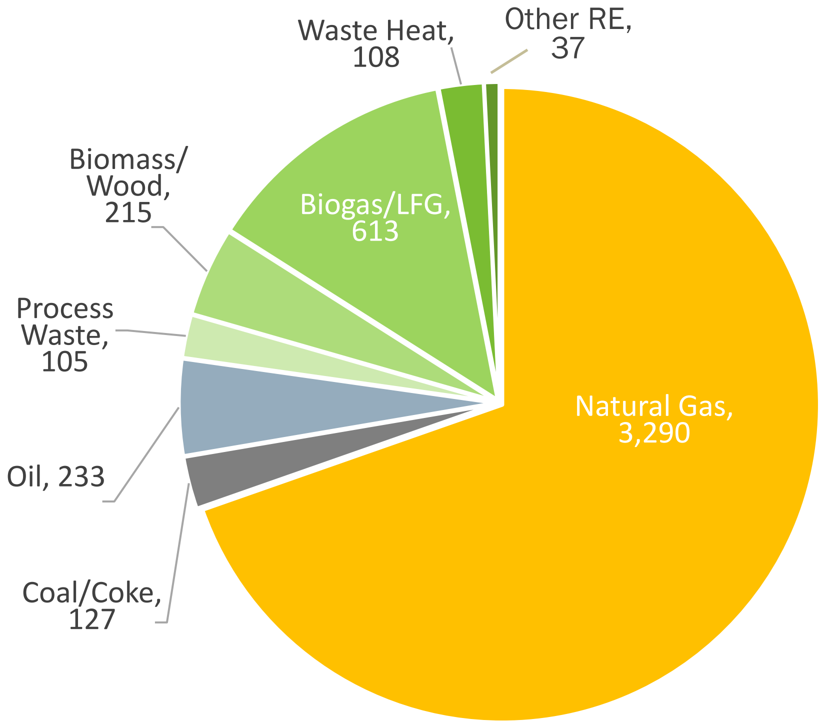
Source: Based on 2G Energy

CHP Is Fuel Flexible

81.7 GW CHP Capacity



4,718 CHP Installations

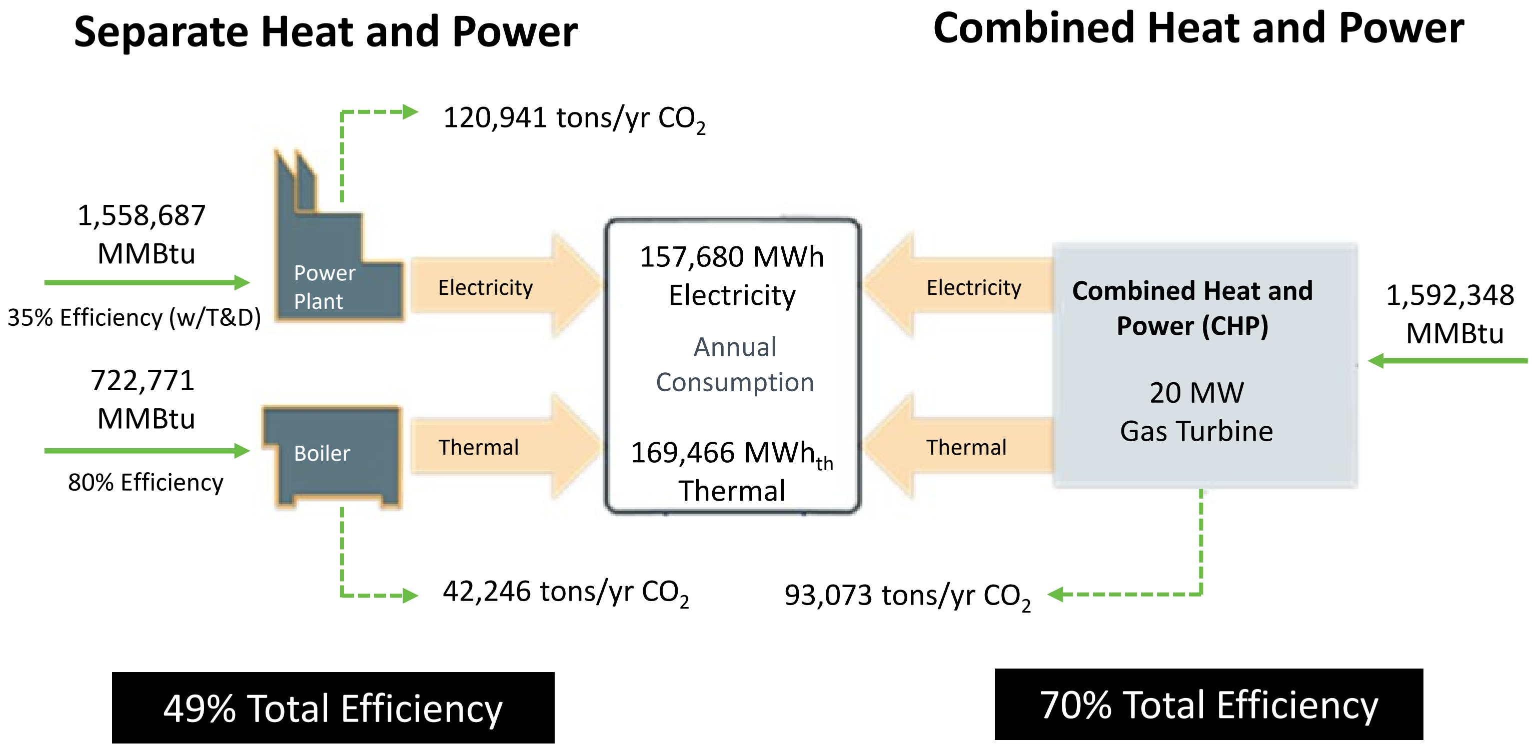


Source: DOE CHP Installation Database (U.S. installations as of August 31, 2021)

CHP Provides both Energy and CO_2 Emissions Savings

20 MW Gas Turbine CHP System

- Natural gas fuel
- 90% load factor (7,884 hours)
- 33.8% electric efficiency
- 75.7 MMBtu/hr steam output
- 100% thermal utilization
- Displaces 80% efficient natural gas boiler
- CO_2 savings based on displacing EPA AVERT Uniform EE grid emissions factor (1,534 lbs CO_2/MWh)



Energy savings: 689,110 MMBtu/yr

CO_2 Savings: 70,114 tons/yr

Prepared by Entropy Research, LLC, 6/22/2022

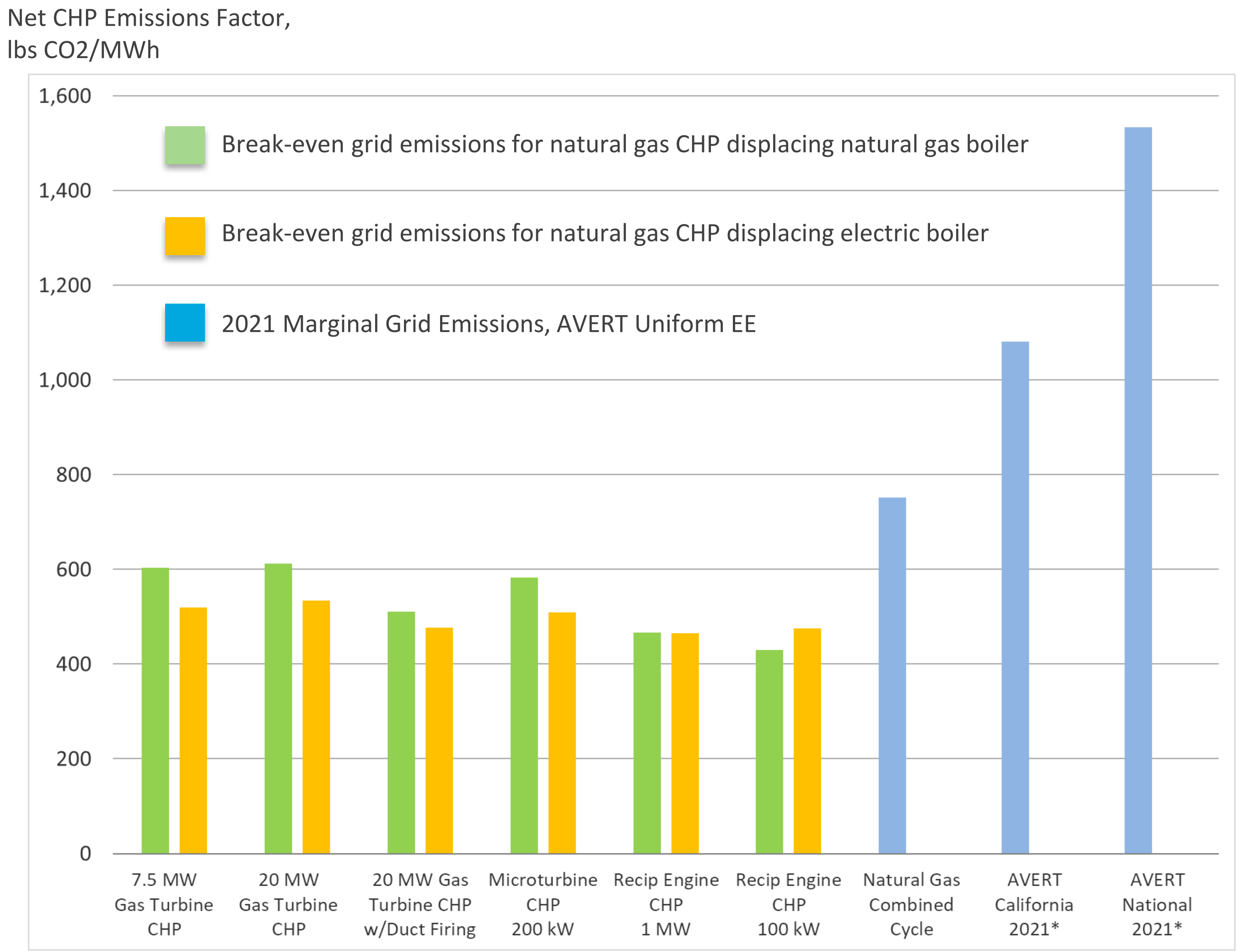
Emissions Savings from Displaced Grid Power

WRI, WBCSD and EPA recognize two frameworks for reporting GHG emissions tied to a site's electricity consumption:

- An inventory (**Attributional)** accounting framework:
  - Estimating an organization or site's indirect emissions inventory from grid electricity consumption - ***based on average grid emissions factors***
- A project (**Consequential)** accounting framework: for estimating the emissions impacts of grid connected energy projects
  - Estimating the changes in direct emissions on the grid as a consequence of an energy project - ***based on marginal grid emissions factors***
- The U.S. EPA has developed two tools to estimate regional marginal emission factors:
  - AVoided Emissions and geneRation Tool (AVERT)
  - *Non-Baseload* emissions rates from EPA's Emissions & Generation Resource Integrated Database (eGRID)

Natural Gas CHP Emissions vs Marginal Grid Emissions

- Natural Gas CHP systems have lower net GHG emissions in terms of lbs CO_2/MWh than current marginal grid generation
- Natural gas CHP <u>displacing natural gas boilers</u> provides emissions savings as long as the marginal grid emissions factor is above 430 to 610 lbs CO_2/MWh
- Natural gas CHP <u>displacing electric boilers</u> provides emissions savings as long as the marginal grid emissions factor is above 475 to 535 lbs CO_2/MWh
- Current marginal grid emissions factors range from 1,081 lbs CO_2/MWh in California to 1,925 lbs CO_2/MWh in the Rocky Mountain regions based on 2021 EPA AVERT data (1,534 national avg)



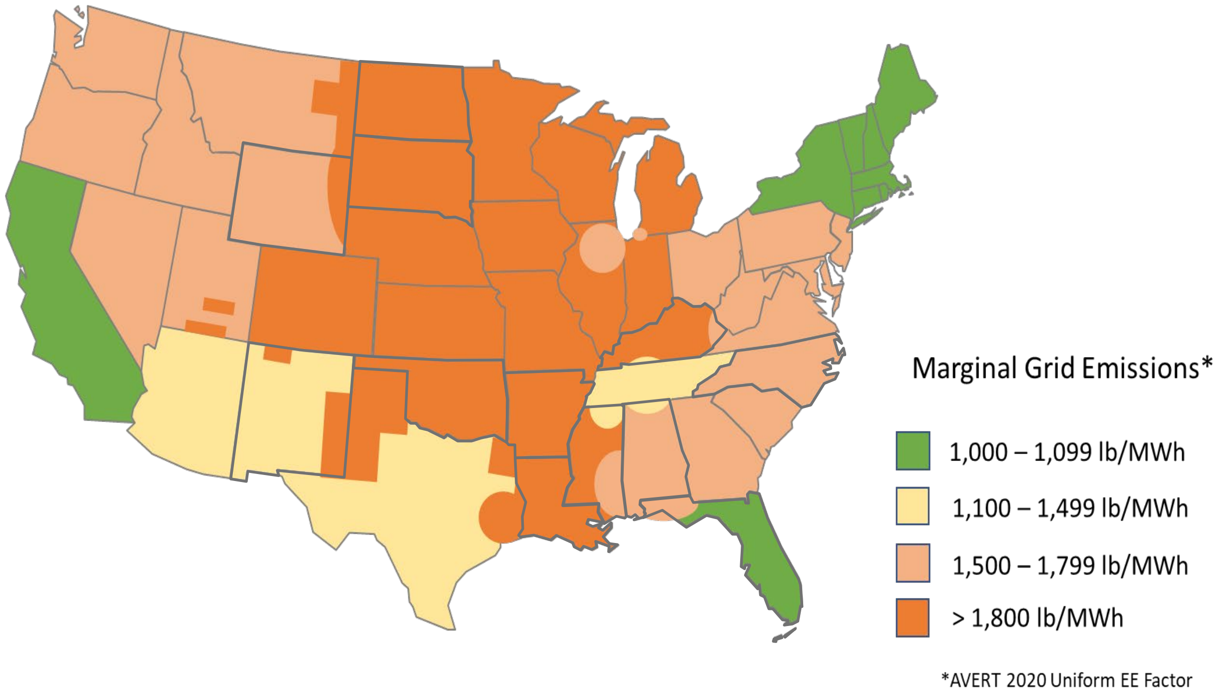
Based on 100% CHP Thermal Utilization

Prepared by: Entropy Research, LLC, 5/23/22

CHP Reduces CO_2 Emissions in all Regions Today

- CHP and renewables displace marginal grid generation (including T&D losses)
- Marginal generation is currently a mix of coal and natural gas in most regions of the US
- CHP's high efficiency and high annual capacity factor currently results in significant annual energy and emissions savings
- *"Because emissions are cumulative and because we have a limited amount of time to reduce them, carbon reductions now have more value than carbon reductions in the future"*

Source: "Time Value of Money", Larry Stein, Carbon Leadership Forum, April 2020

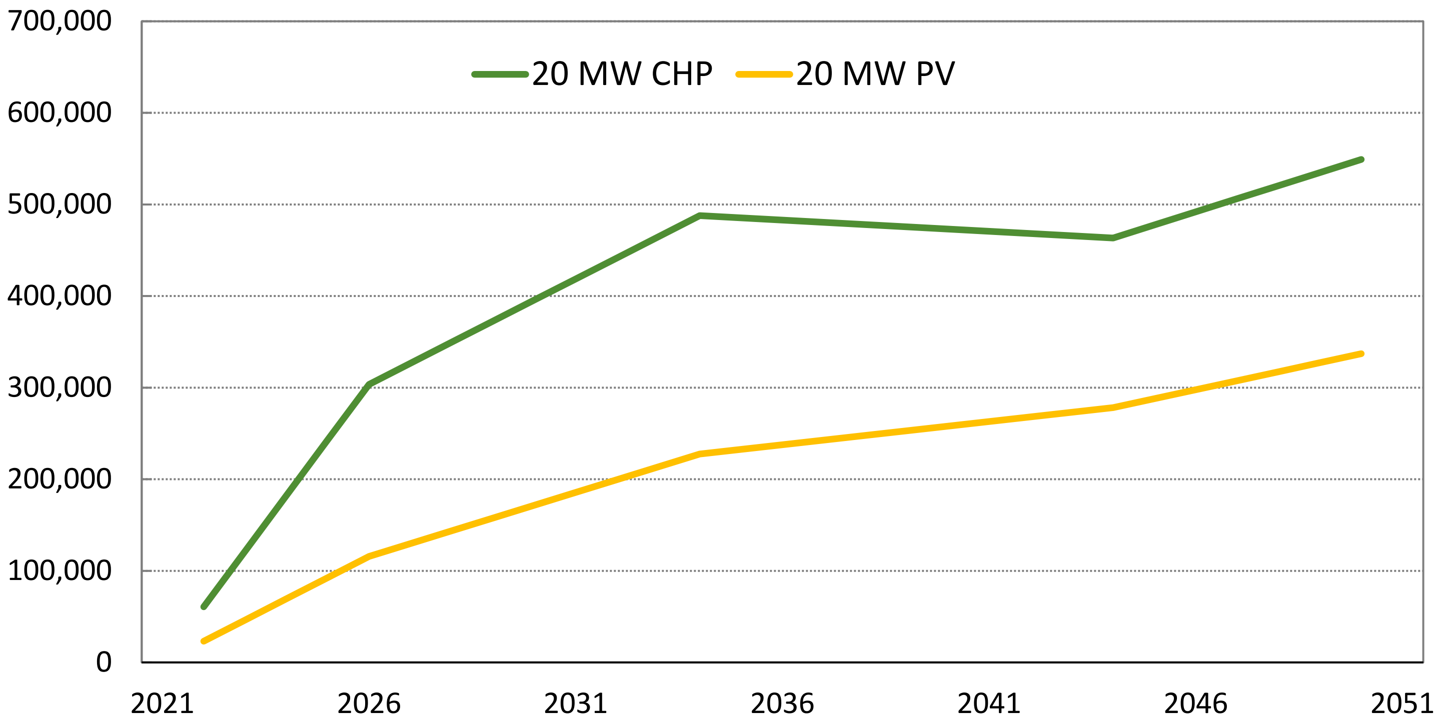


CHP Reduces Emissions as long as Fossil Fuel is on the Margin

- 20 MW of natural gas CHP with 90% capacity factor compared to 24% capacity factor for 20 MW of PV
- Natural gas CHP is a low carbon resource, not a zero carbon resource like PV or wind
- CHP's high operating efficiency and high capacity factor provide significant GHG reductions as long as fossil fuel is on the margin
- In this example, CHP reduces the same CO_{2e} in 6 - 7 years that PV reduces over 30 years
- Time value of CO_{2e} reductions has added value

Prepared by Entropy Research, LLC, 6/2/2022 based on analysis from Sterling Energy Group, LLC ©2021

Cumulative CO_{2e} Savings (Tons) Based on Displacing Marginal Grid Generation

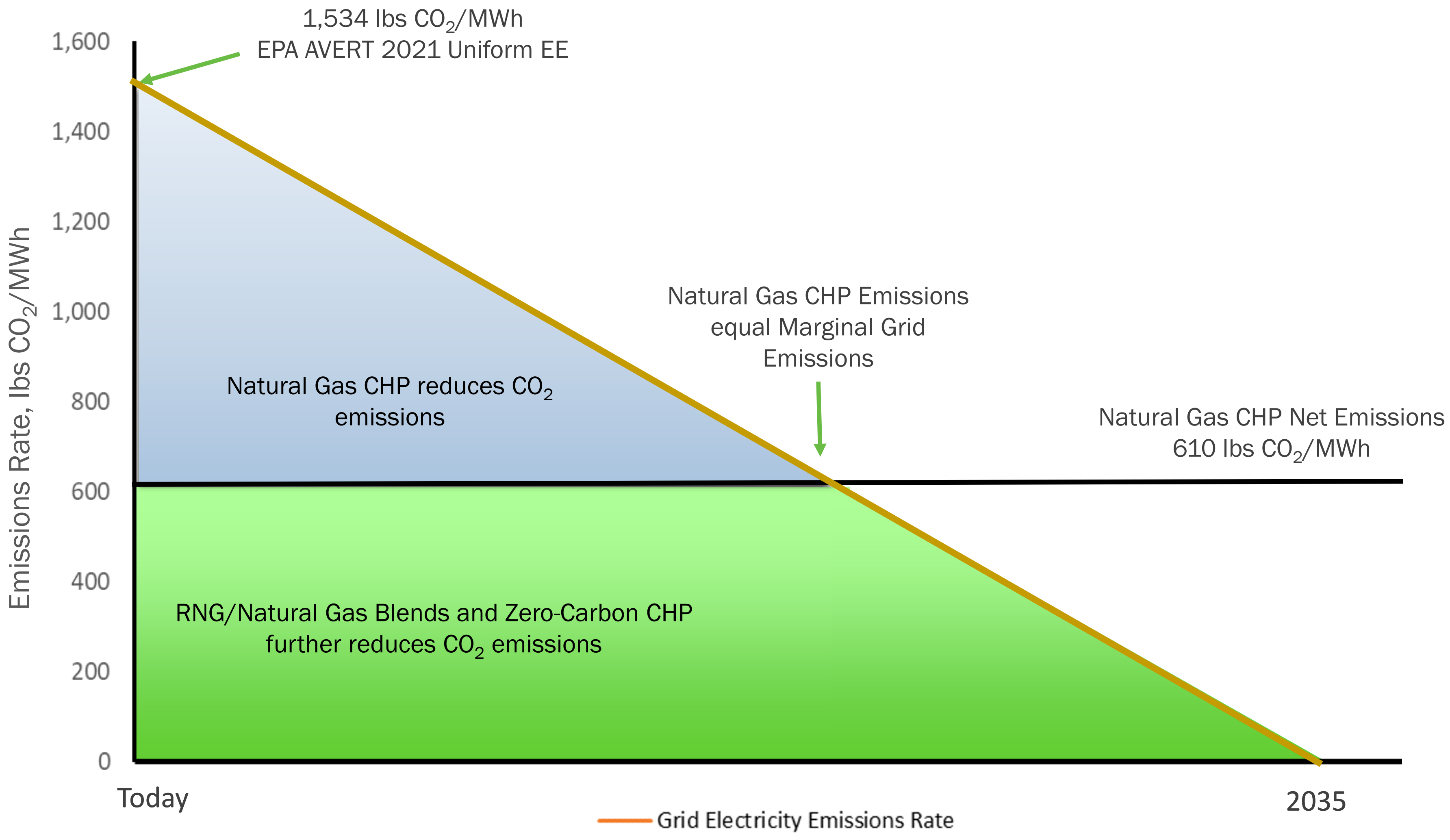


Marginal grid offsets based on NREL Cambium Mid Case:
Gagnon, Frazier, Hale, Cole (2020): Cambium data for 2020 Standard Scenarios, https://cambium.nrel.gov/
SERC-East long-run marginal emissions rates

- 2022-2026 – All hours: 1,388 lb CO_{2e}/MWh; PV hours: 1,087 lb CO_{2e}/MWh
- 2027-2034 – All hours: 910 lb CO_{2e}/MWh; PV hours: 657 lb CO_{2e}/MWh
- 2025-2044 – All hours: 587 lb CO_{2e}/MWh; PV hours: 238 lb CO_{2e}/MWh
- 2025-2044 – All hours: 799 lb CO_{2e}/MWh; PV hours: 460 lb CO_{2e}/MWh
- 618 lb CO_2e /MWh (net FCP heat rate of 5515, including 5.1% T&D loss reduction credit); Capacity Factors: 90% for CHP, 24.3% for PV

CHP's Evolving Role as the Grid Decarbonizes

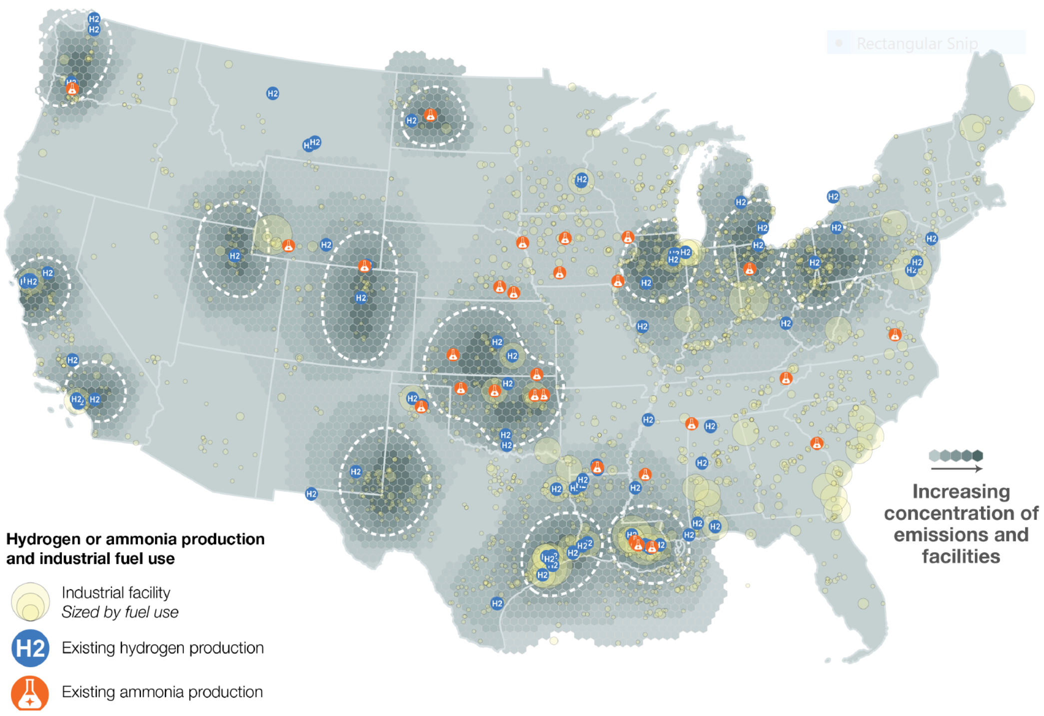
Avoided Emissions with CHP – Now and Into The Future



Renewable and Net-Zero Fueled CHP

- Existing CHP systems can utilize biogas and biofuels.
- All natural gas-fueled CHP is compatible with renewable gas, pending availability.
- Most existing turbines and engines can operate on hydrogen mixtures up to 10-40%.
- All major engine and gas turbine manufacturers are working on the capability to operate at high levels of hydrogen, targeting 2030 for 100% hydrogen prime movers.
- CHP systems can be changed out or modified in the field to 100% hydrogen-fuel blends

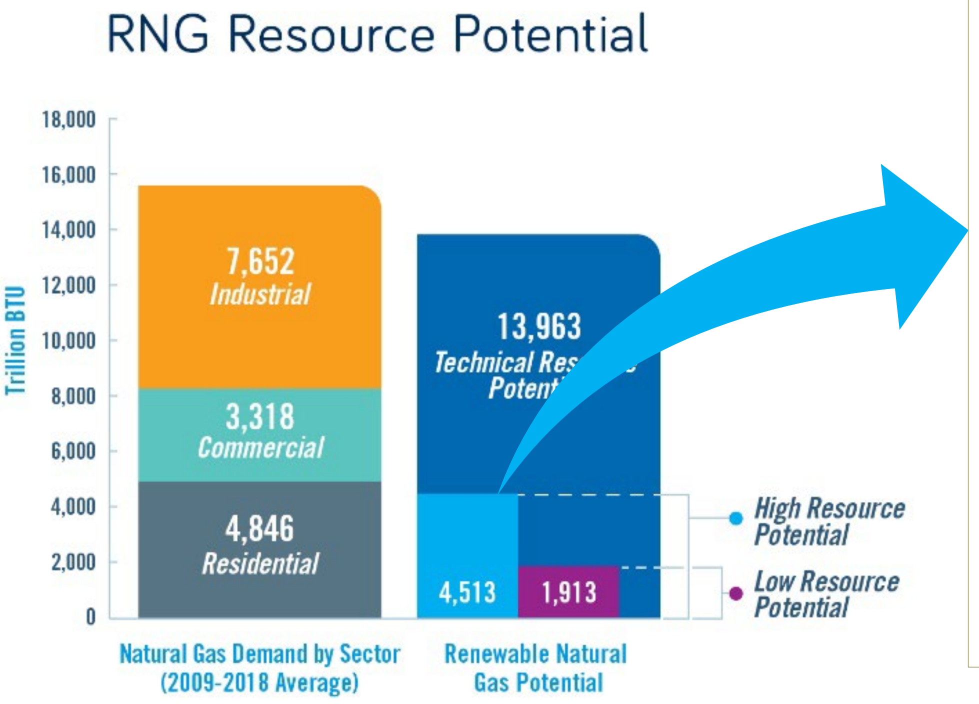
The ultimate scale of renewable and hydrogen-fueled CHP deployment will depend on resource availability.

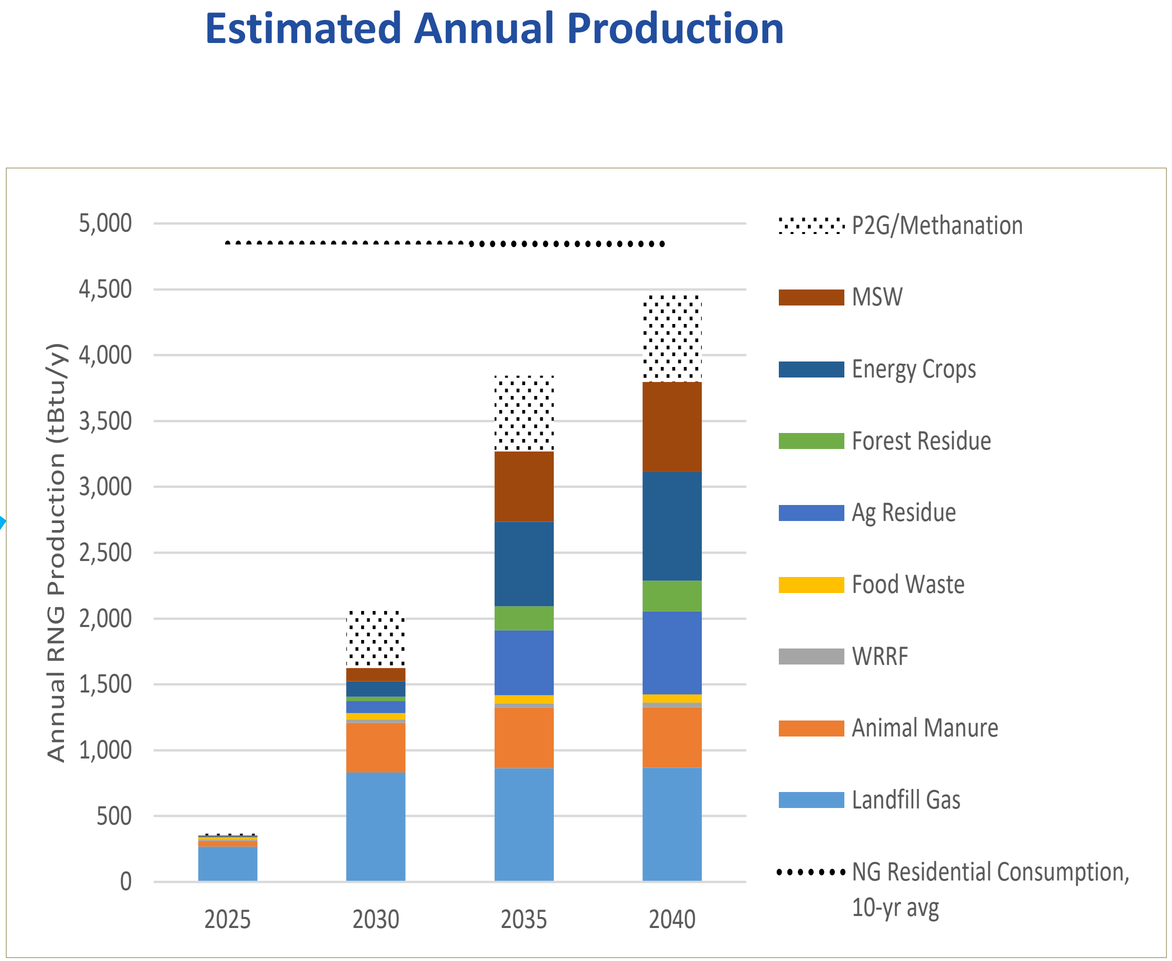


Source: Atlas of Carbon and Hydrogen Hubs, Great Plains Institute, February 2022

Renewable Natural Gas Resource Potential

- High resource case: 4.5 Tcf of RNG by 2040
- Represents 60% of current industrial natural gas use
- Cost competitive with other emission reduction strategies, $55-300/ton of GHG emission reductions



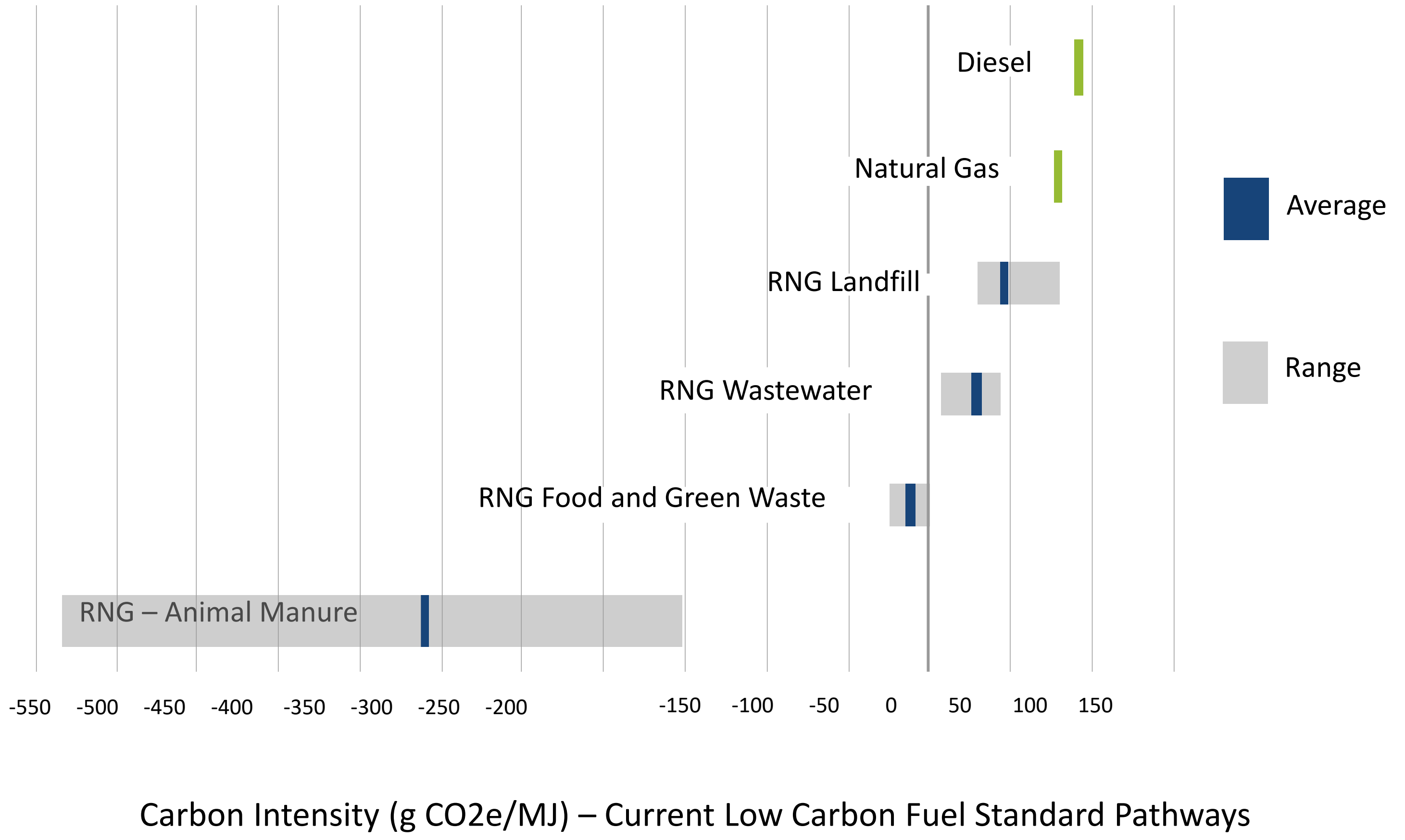


Source: AGA Foundation, Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment, 2019

Carbon Intensity of RNG Feedstocks

RNG:

- Contributes to sustainable waste management
- Reduces methane from organic wastes
- Displaces fossil fuels

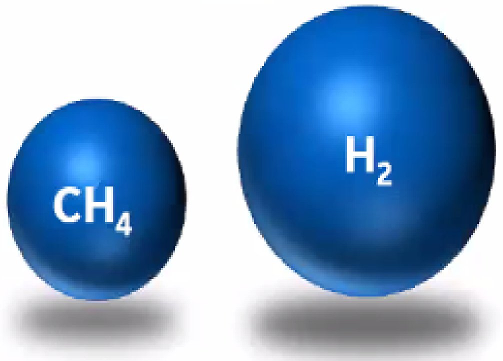


Source: WRI, Renewable Natural Gas As A Climate Strategy: Guidance For State Policymakers, 2021

Use of Hydrogen as a Fuel will Require System Changes

Fuel System

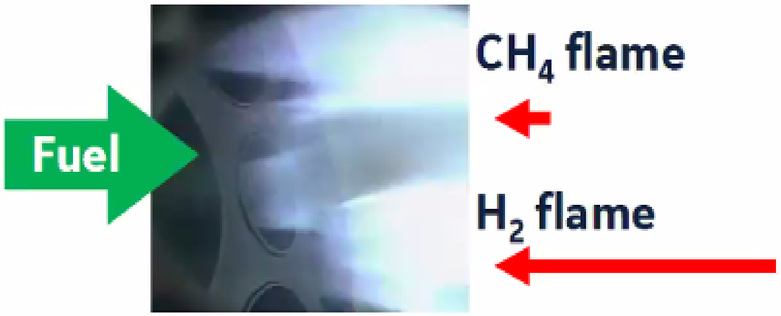
Methane (CH_4): 912 lb/ft^3
Hydrogen (H_2): 275 lb/ft^3



To deliver the same energy content, hydrogen requires 3X more volume flow

Combustion System

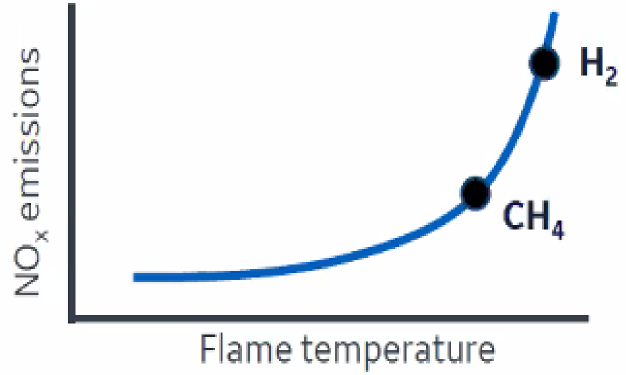
Methane (CH_4): ~30–40 cm/sec
Hydrogen (H_2): ~200–300 cm/sec



Hydrogen flames may increase risk of damage to combustion hardware

Emissions Aftertreatment

Methane (CH_4): ~3,565 °F
Hydrogen (H_2): ~4,000 °F



Operating on hydrogen may increase NO_x emissions

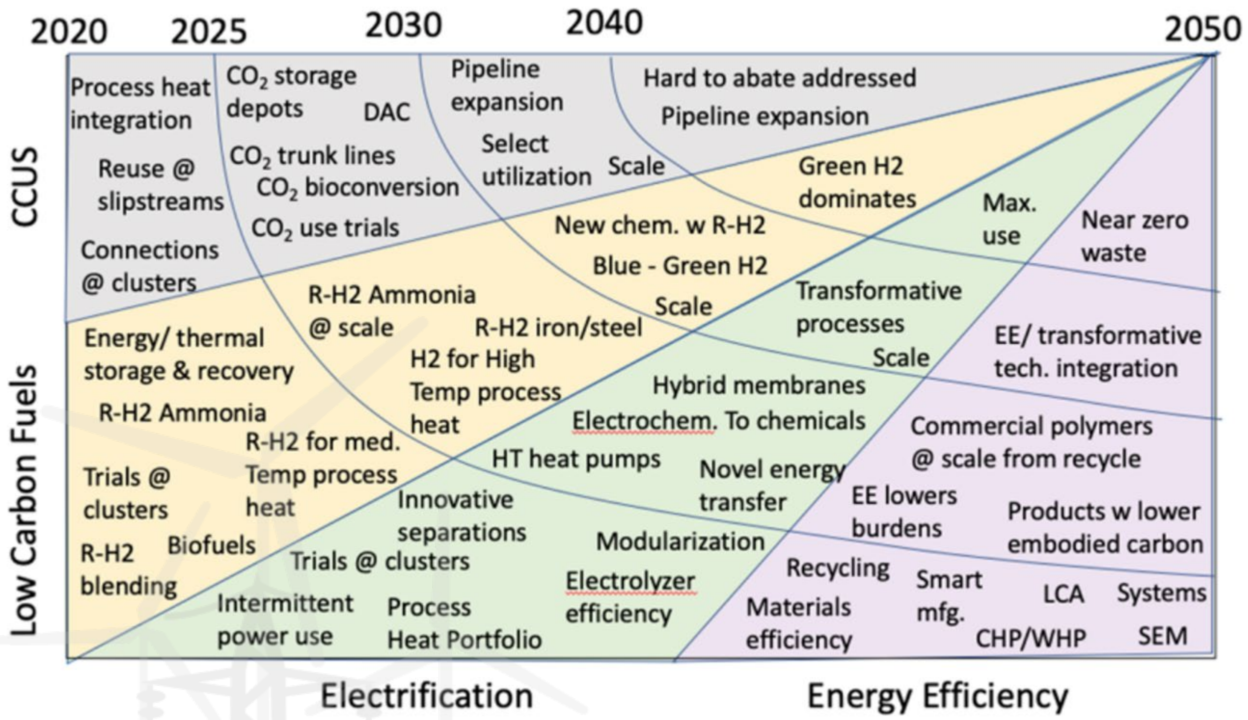
CHP for Difficult to Decarbonize Industries

- CHP is well suited to address steam and process heating needs, 95% of which is currently fossil fueled.
- CHP enables three of the four pathways for industrial decarbonization (energy efficiency; low-carbon fuels; electrification) while mitigating the need for CCUS.
- Renewable and net-zero fueled CHP can decarbonize industrial thermal processes that are difficult or prohibitively expensive to electrify.

Industrial facilities across the U.S. with challenging decarbonization pathways

CHP supports decarbonization of the industrial sector while additional technologies reach maturity.

Technology Pathways: Industrial Decarbonization



Source: Industrial Decarbonization Roadmap, DOE, May 2022 Draft

Pairing CHP with Renewables and Storage for Resilience

- CHP can be a resilient base load anchor for multi-technology microgrids, particularly those incorporating renewable generation sources like solar PV or wind.
- CHP paired with renewable DERs optimizes overall emissions reductions and resilience.
- Net-zero fueled CHP can decarbonize critical facilities that need dispatchable on-site power for long duration resilience and operational reliability

critical infrastructure, cities, and communities

United States Marine Corps Recruit Depot (MCRD) Parris Island, SC, installed a hybrid microgrid including a 3.5MW natural gas-fired CHP system plus 5.5 MW solar photovoltaic arrays to provide secure and resilient energy. The site also incorporated a 4 MW battery-based energy storage system, all of which are controlled by a microgrid control system capable of fast load shedding.

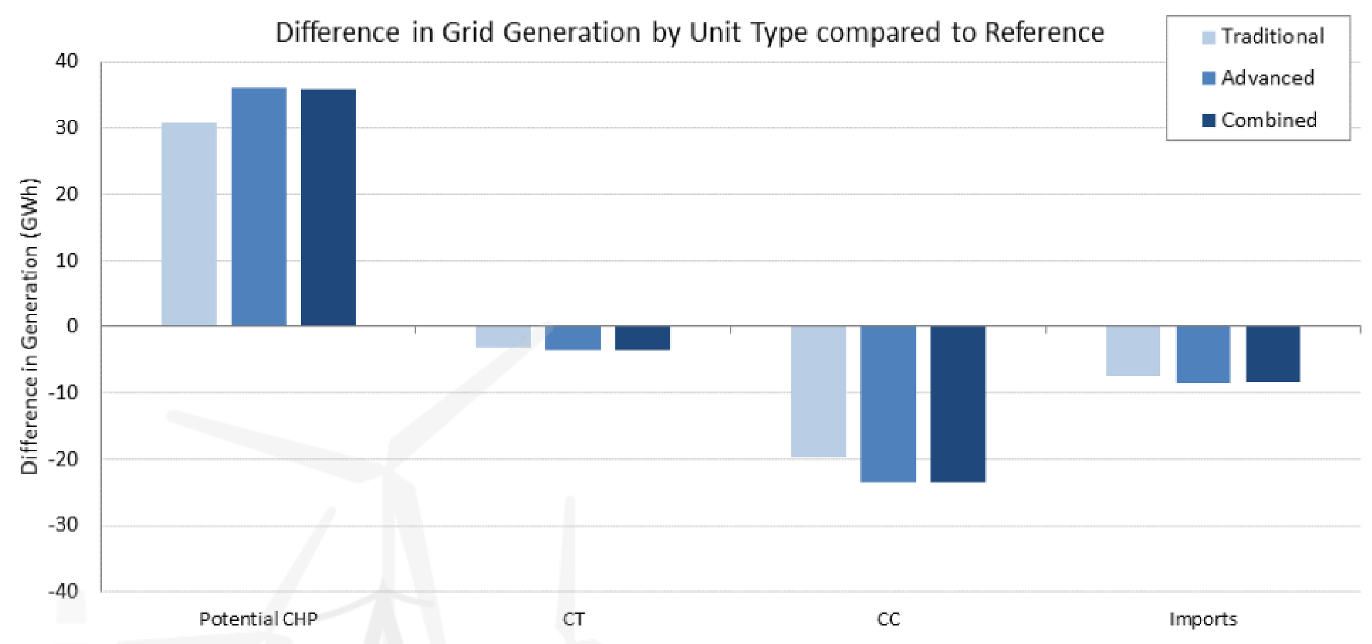
CHP Can Provide Flexible, Efficient Grid Support

CHP can provide a targeted solution to accelerate a complex and challenging transition away from fossil fuels on the grid:

- Net-zero fueled CHP can accelerate independence from less efficient combustion resources as additional renewables come online.
- CHP can provide dispatchable net-zero generation and regulation support to support long-run resource adequacy
- To the extent that net-zero fuels are part of a decarbonized grid, CHP can be the most efficient way to use them.

independent system operators (ISOs) | Utilities

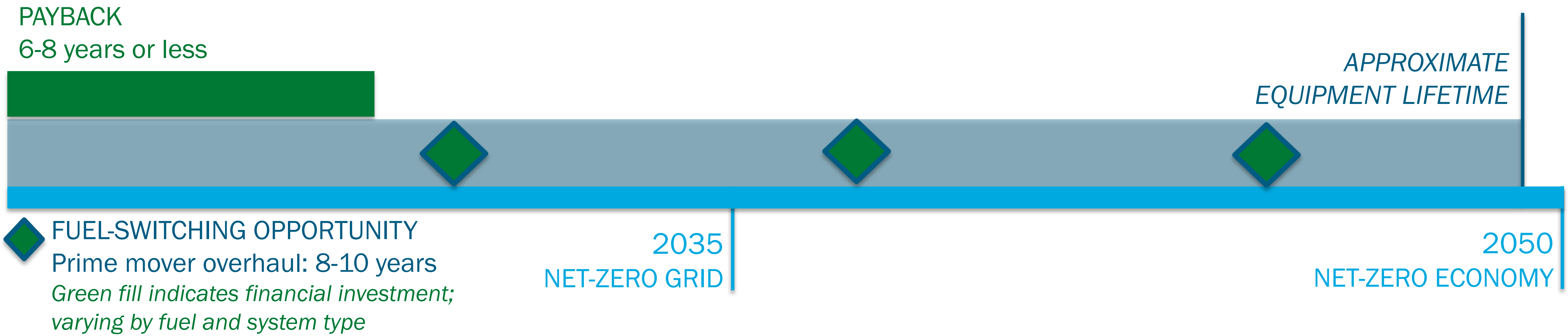
Modeling shows advanced CHP in California offsets combined cycle, combustion turbines, and imports, deepening emissions savings from renewables.



Potential Impact of Flexible CHP on the Future Electric Grid in California, NREL, Sept. 2021.

CHP Life Cycle Offers Multiple Opportunities for Reoptimization

- **Payback periods and regular maintenance schedules offer multiple decision points for reoptimization of emissions reduction measures as the grid evolves and other decarbonization options mature:**
  - **Payback:** Typical payback for CHP installations is between 6–8 years. After the initial equipment and installation costs are recovered, future investment decisions can be based on operating costs only.
  - **Fuel-switching opportunity:** Industrial CHP prime movers require periodic overhauls on an 8 to 10-year cycle (at ~10 to 15% of the original installation cost), **which offer at least three opportunities** to switch fuel or select an alternate decarbonizing path.



Meeting the Challenge

Leveraging AMO's CHP program model and expanding to include a broad range of clean on-site energy and storage technologies to meet decarbonization goals.

solar PV | wind | solar thermal | bioenergy | geothermal heat pumps | battery storage | thermal storage renewable/net zero CHP | waste heat to power | district energy technologies

Near-term goals:

- Decrease emissions as quickly as possible
- Minimize the use of fossil fuels
- Complement increased use of wind, solar, and storage
- Provide long-duration resilience

Long-term objectives:

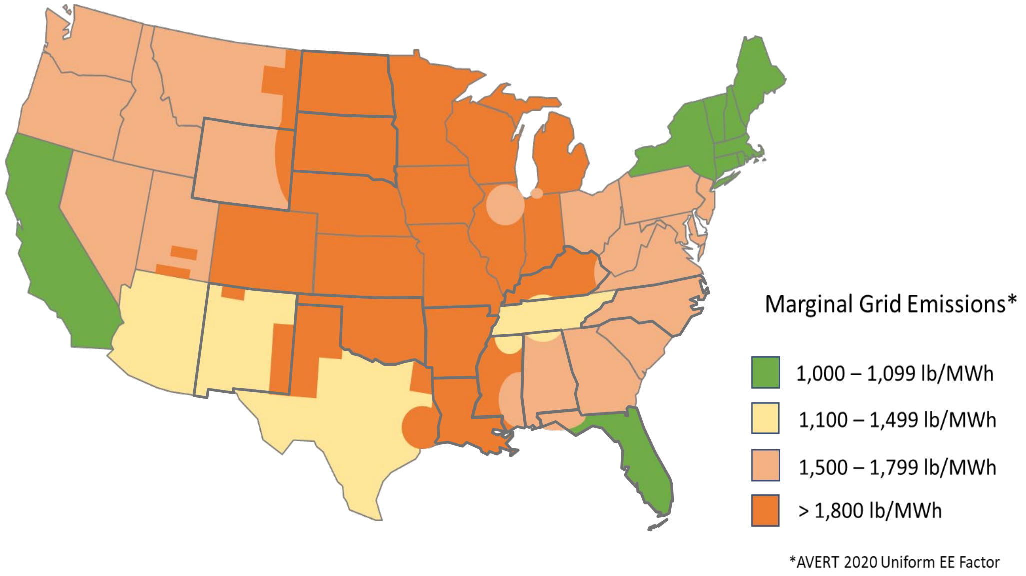
- Use renewable fuels in high-impact applications (hard to decarbonize industries, critical facilities that need long duration resilience and operational reliability), most efficiently
- Support a resilient, renewable energy sector and economy

DOE's Evolving CHP Program

- **Focus future program activities on renewably fueled CHP**

  biofuels | waste heat | green hydrogen

- **Natural gas-fired CHP for:**
  – Heavily fossil geographies
  – Hard-to-decarbonize industries
  – Long-term resilience
  – Sites with fuel flexible outlooks



- **R&D investments pair with deployment priorities to prepare for the future by:**
  - Addressing challenges with renewable fuels, such as hydrogen
  - Developing technologies for flexible grid connections