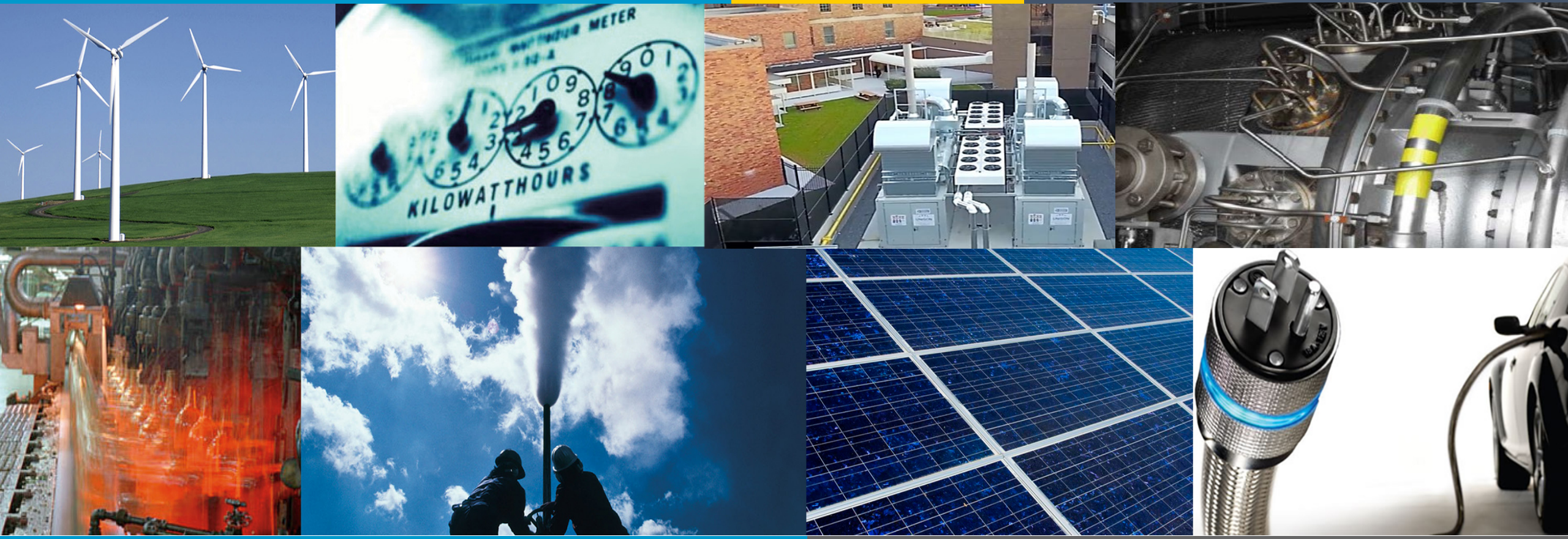
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Packaged CHP Accelerator Webinar
CHP and Hydrogen

April 29, 2021

Agenda

- Introduction
- Hydrogen and Gas Turbine CHP – Vinayaka Nakul Prasad, Siemens Energy
- Hydrogen and Recip Engine CHP – Kurt West, 2G Energy
- CHP in a Decarbonized Economy– Bruce Hedman

Vinayaka Nakul Prasad
Corporate Strategy Manager
Siemens Energy

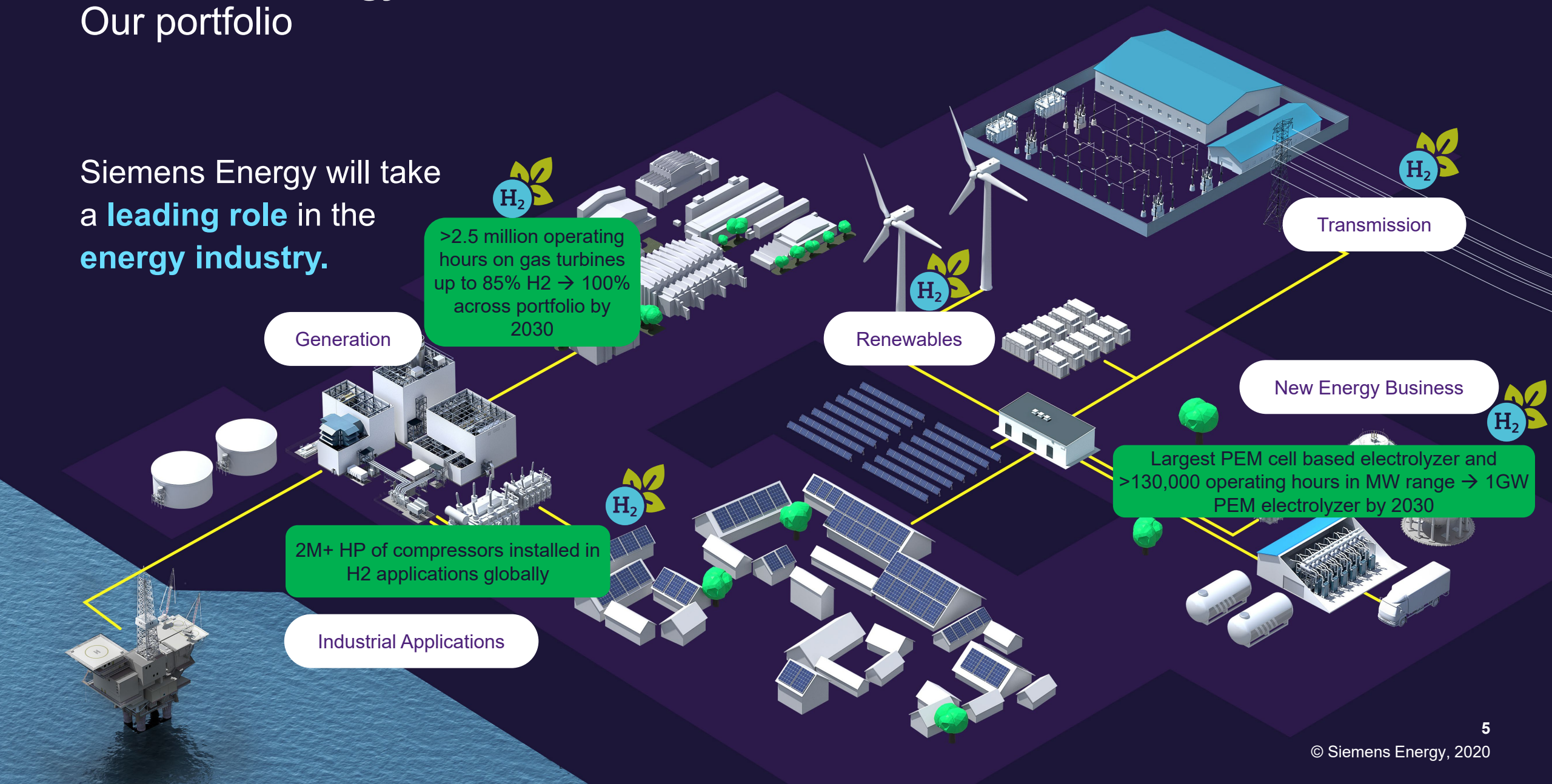
U.S. DEPARTMENT OF ENERGY

Hydrogen: The Power to Decarbonize All Energy Sectors

Dr. Vinayaka Nakul Prasad | Corporate Strategy and Technology

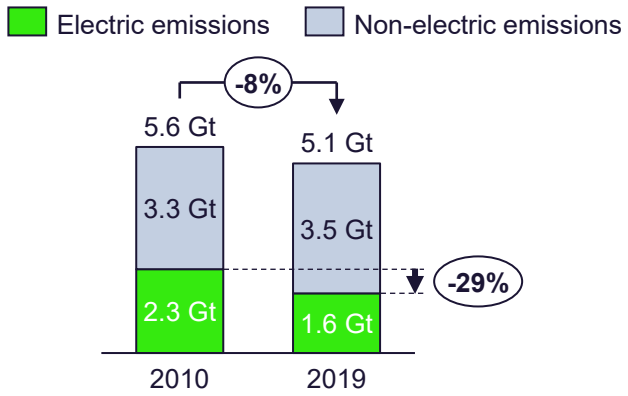
The entire energy value chain
Our portfolio

Siemens Energy will take a **leading role** in the **energy industry.**



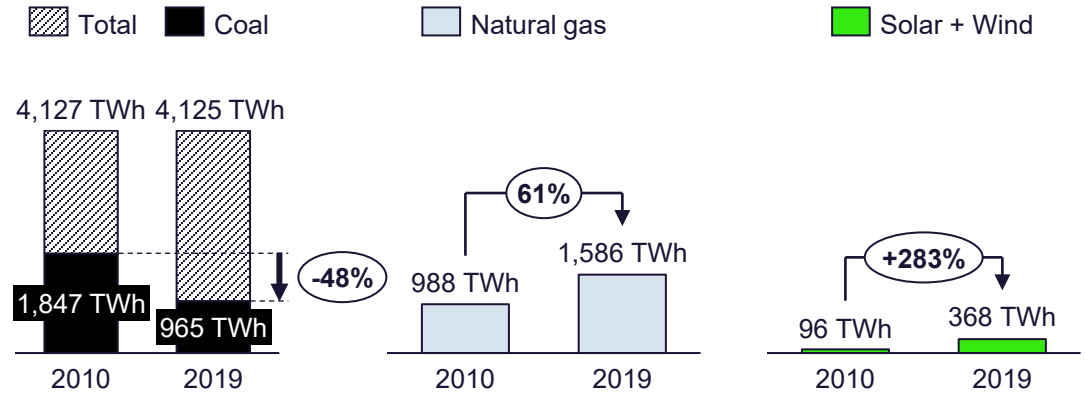
Energy-related CO_2 emissions reduced by ~10% in the past decade largely driven by the electricity sector

CO_2 emissions 2010-2019



- CO_2 emissions from electricity sector declined by almost 30%
- Other non-electric emissions have increased slightly

Electricity generation 2010-2019



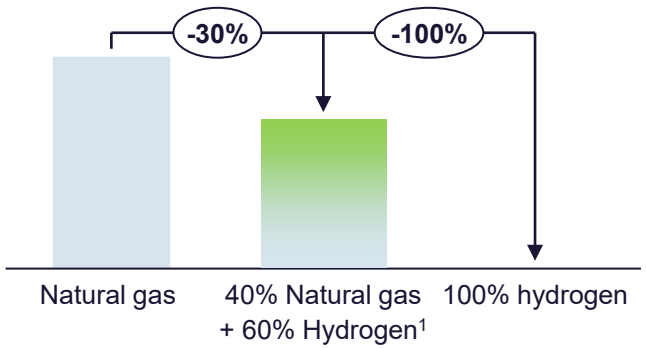
- Coal generation declined by ~50% whilst natural gas generation increased by >60%
- Solar and PV generation increased almost 3x – still <10% of total electricity generation

Coal-to-gas shift has been integral to help lower carbon emissions but sector-coupled approach required to drive deep decarbonization

April 2021 Source: EIA (https://www.eia.gov/totalenergy/data/monthly/)

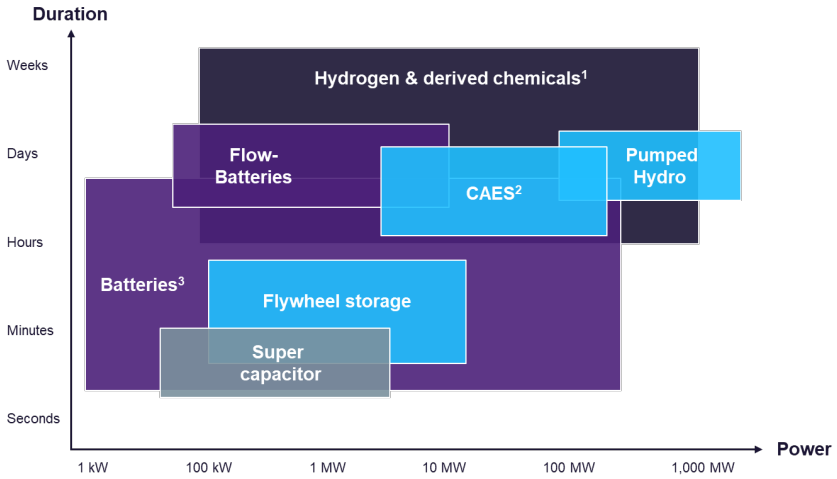
Hydrogen is a versatile zero-carbon fuel, energy storage medium and feedstock

1. Zero carbon fuel

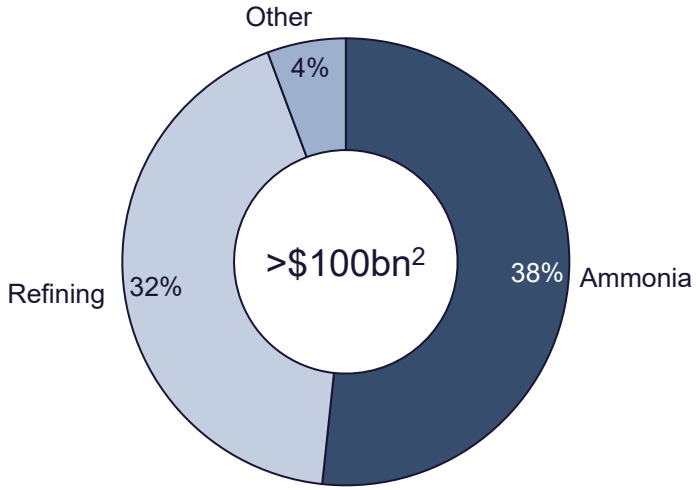


Existing gas generators can be retrofitted to accommodate hydrogen

2. Short AND long-term storage of intermittent renewables



3. Feedstock to industrial processes



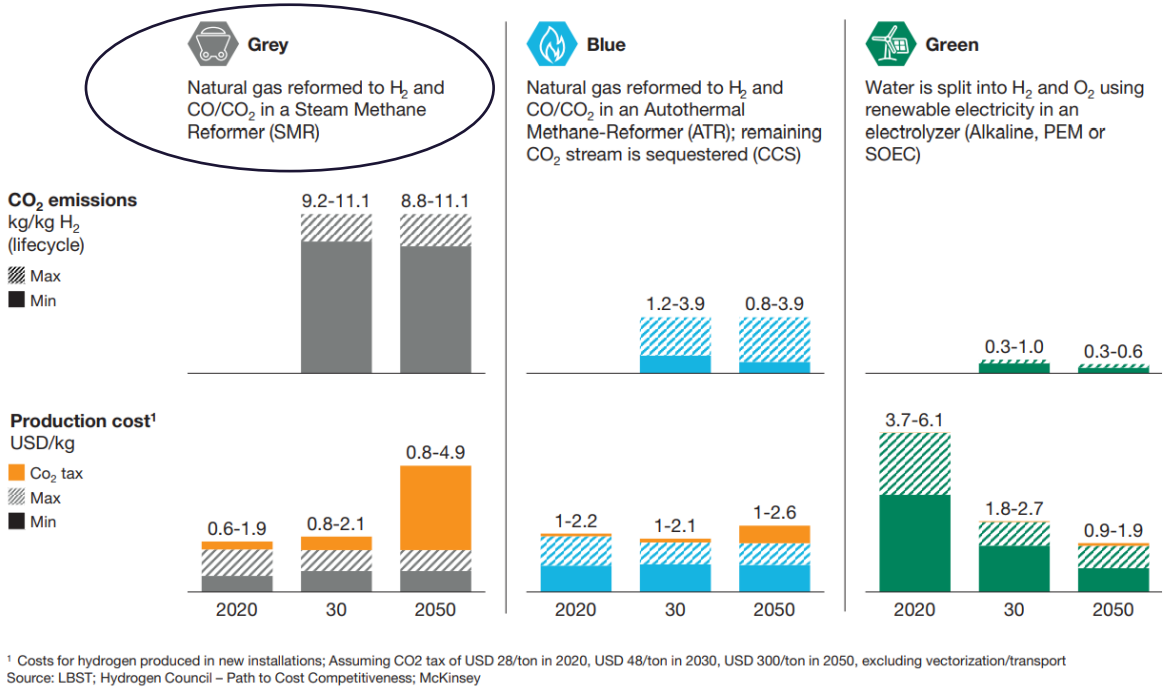
Source: IEA,

Hydrogen is a promising energy vector but is not readily available and needs to be extracted from water or hydrocarbons

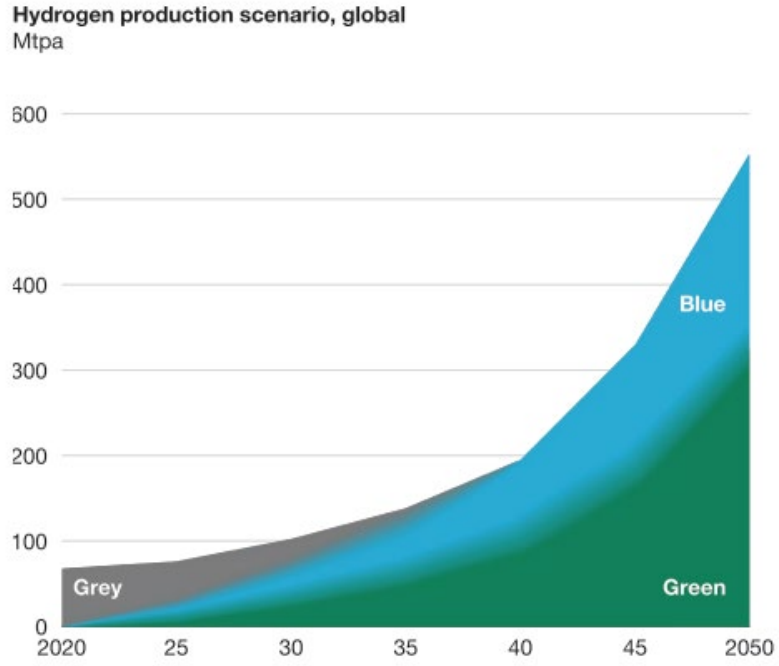
Notes: [1]Assuming that the produced hydrogen does not have any lifecycle carbon emissions. [2]Estimation of global market size

Low-carbon hydrogen paths still face economic challenges today but cost reductions will drive clean production

>95% of today's hydrogen production

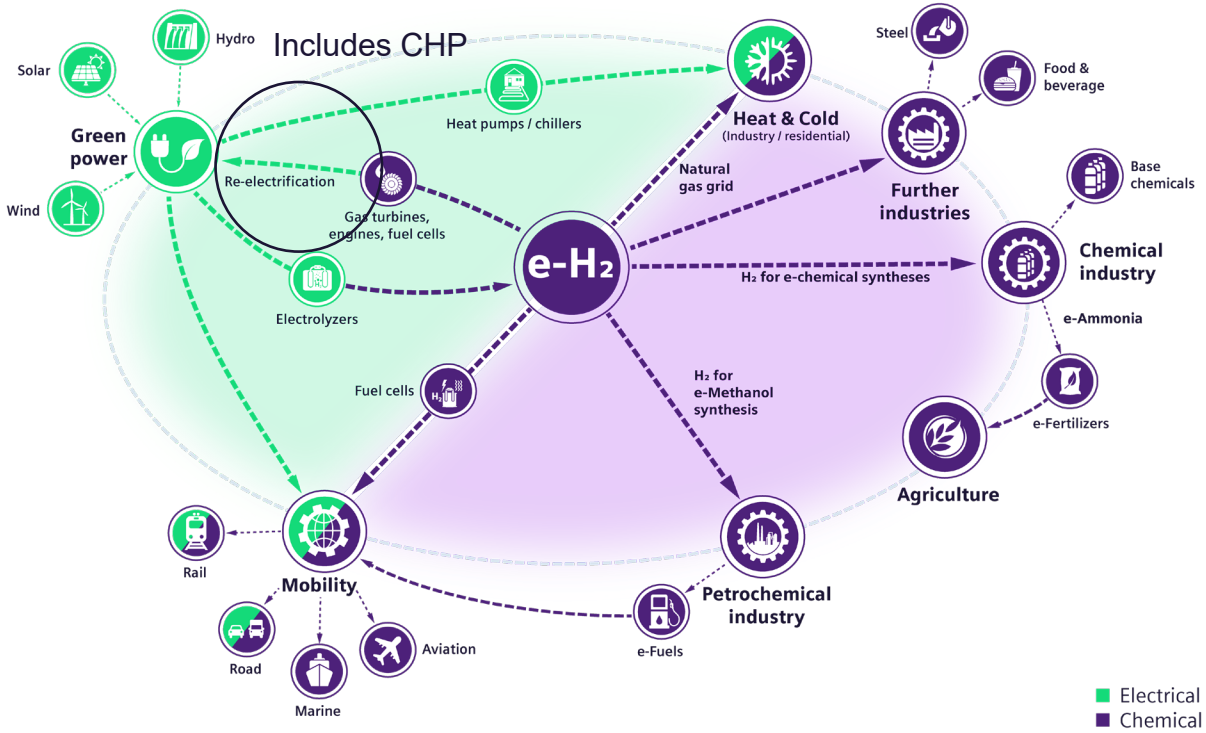


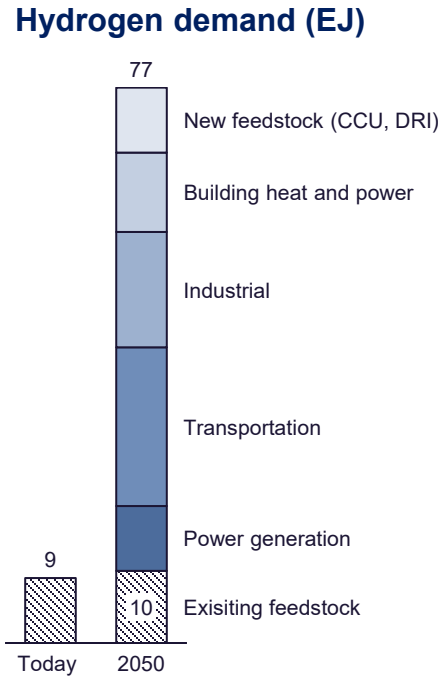
Source: Hydrogen Council



Source: Hydrogen Council

Hydrogen is a enabler to couple and lower carbon emissions of all sectors (“Power-to-X”)





Source: Hydrogen council

Future demand in sector-coupled hydrogen economy will be driven by new use cases including power generation, heat and transportation

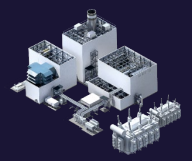
Hydrogen can transform existing assets with modest upgrades into low-carbon and future-proof energy systems

SIEMENS energy

Siemens Energy AG

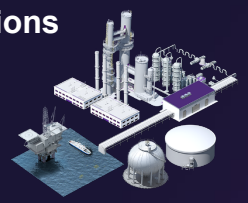
Gas and Power ("GP")

Generation

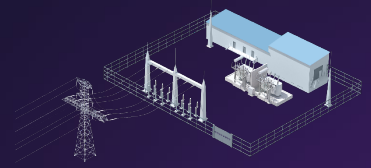


Central | Distributed

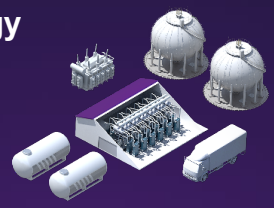
Industrial Applications



Transmission



New Energy



Siemens Gamesa Renewable Energy ("SGRE")

67% owned

Onshore

Offshore

- H_2 enabled generation
- H_2 compression and storage
- Renewable connection and integration
- H_2 Electrolyzer Systems
- Power-to-X Solutions
- Hybrid Solutions

STRONG GLOBAL PRESENCE

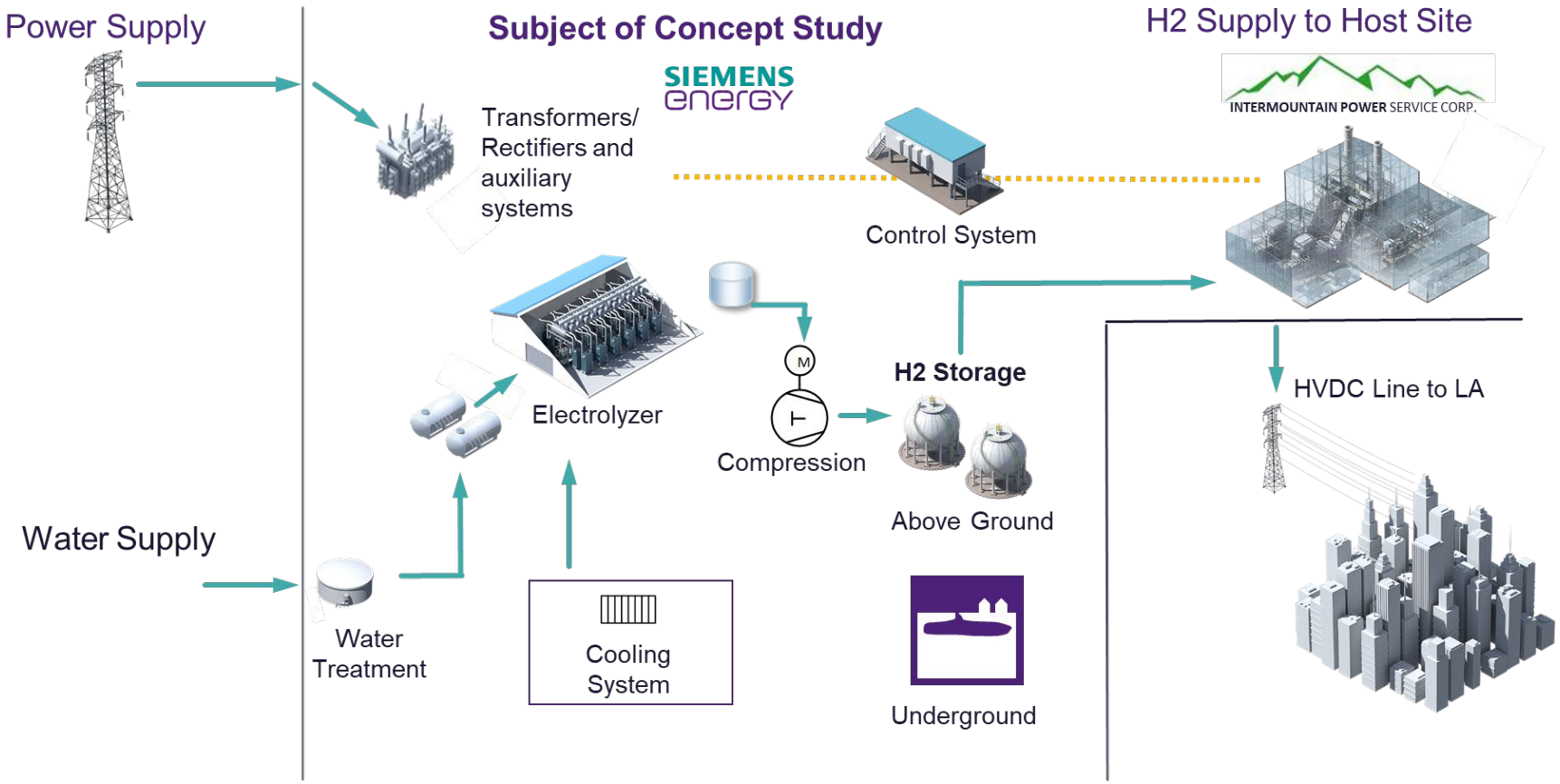
WORLD-CLASS SERVICE ORGANIZATION

EXCELLENCE IN LARGE PROJECTS

ENGINEERING HERITAGE

UNIQUE CUSTOMER APPROACH

Hydrogen energy storage integrated with a combined cycle power plant



Technology expertise in Electrolysis

Our electrolyzer portfolio scales up by factor 10 every 4 – 5 years

SIEMENS energy

0.1 MW | **1 MW** | **10 MW** | **100 MW** | **1,000 MW**

2011

Silyzer 100
Lab scale demo

2015

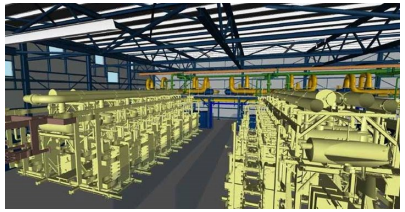
Silyzer 200

2018

Silyzer 300

2023+

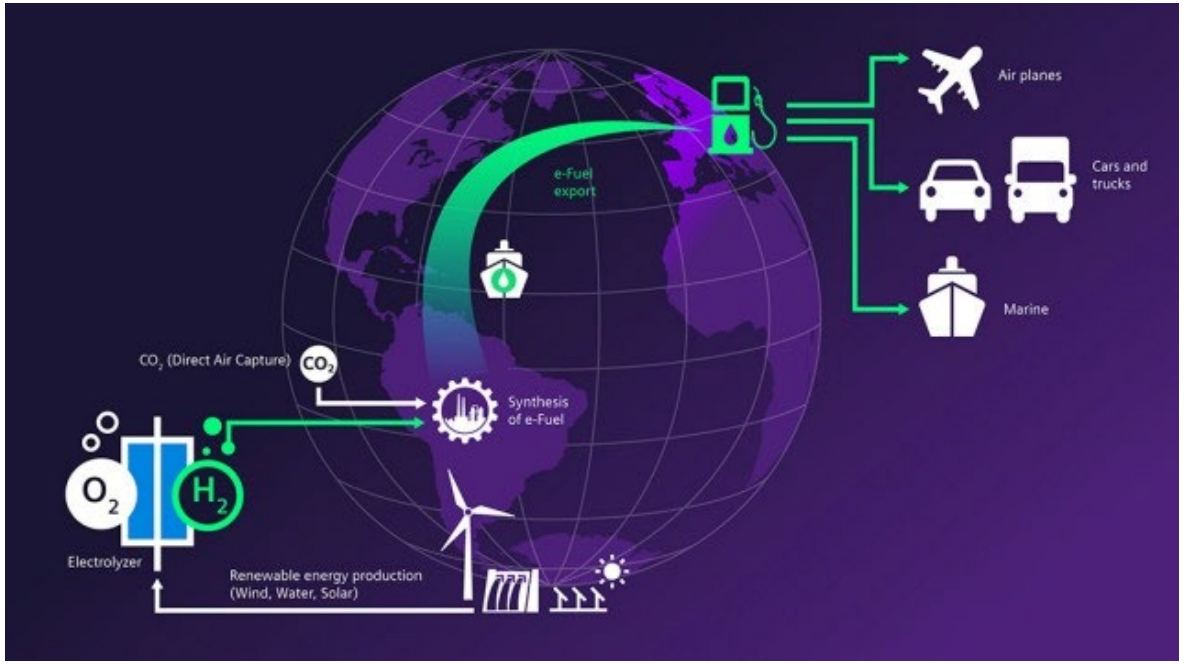
Silyzer 300 plant



2028+

Co-Development with partners in **verticals**

Haru Oni – Hydrogen based supply chain of renewable energy from Chile to Europe



https://www.siemens-energy.com/global/en/offerings/renewable-energy/hydrogen-solutions/haru-oni.html

https://newsroom.porsche.com/en/2020/company/porsche-siemens-energy-pilot-project-chile-research-development-synthetic-fuels-efuels-23021.html

H_2-Orange (with Clemson University)
Hydrogen based Combined Heat and Power solution

Project

Cooperation:	Siemens Energy Duke Energy, Clemson University
Location:	Clemson, South Carolina
Product:	Hydrogen Storage System

Use cases

- Steam
- Re-electrician of hydrogen
- Mobility / Public transportation

Challenge

- Decarbonization of the 110,000 lbs/hr of peak campus steam demand and electrical output of the SGT-400
- Economics of zero emission hydrogen production
- Regulatory process for hydrogen pilot projects in the Carolinas
- Regulation, safety, and perception with hydrogen production and usage in proximity to the campus and community

Solutions

- Conceptual study to understand economics between technology owner, asset owner and off-taker
- Explore scope and economic requirements for a pilot demonstration of the Clemson CHP system

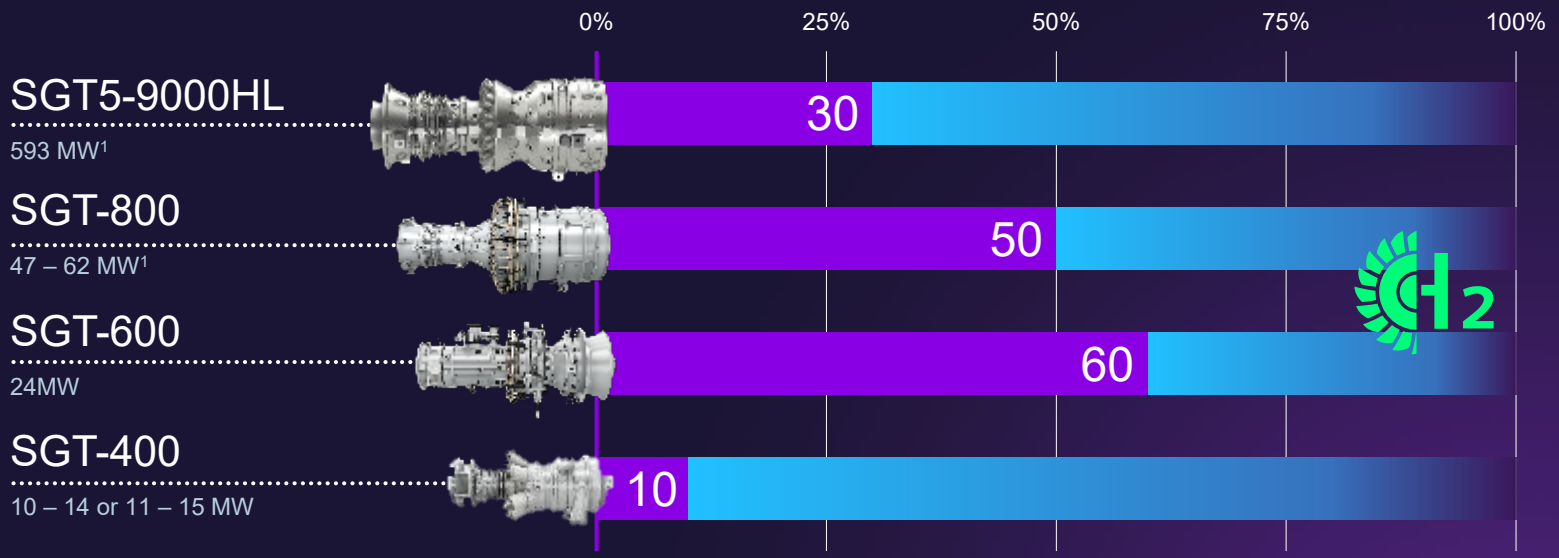
14.3 MW
output from SGT-400

33 MW
peak Campus steam demand

April 2021

Siemens is continuously investing into developing 100% hydrogen capabilities by 2030

The pathway to burn 100% hydrogen



until **2023** – **100%** H^2 in **Industrial Gas turbines**

until **2030** – **100%** H^2 in **Heavy Duty Gas turbines**

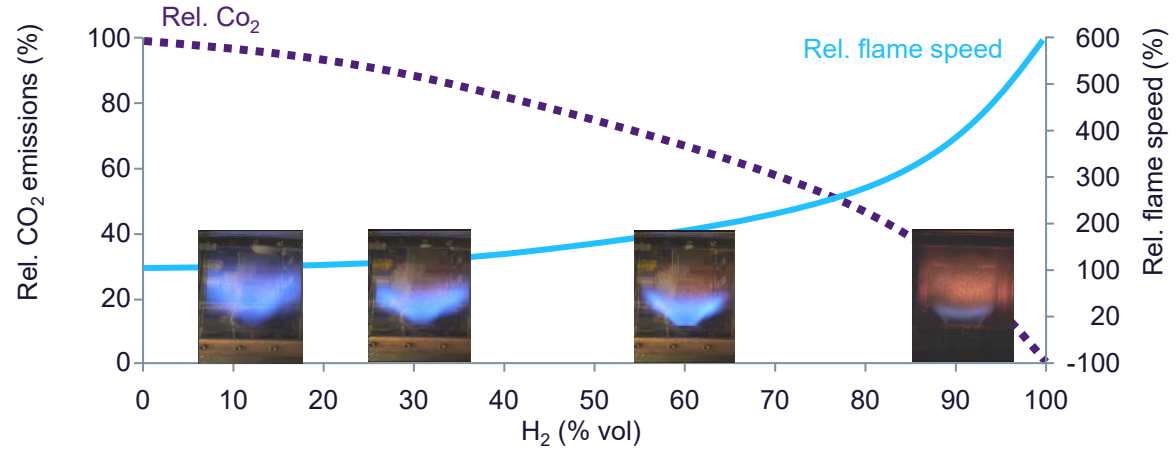
Released hydrogen capability Ongoing Development

Investments for upgrading the global fleet of **gas turbines** by making them a **key technology for transitioning** to a decarbonized world

- **Large GTs: >45 years** of accumulated experience on H_2 (syngas) combustion
- **Medium GTs: >10 years** experience based on H_2 admixture
- **Small GTs: ≈1 m OH** of high hydrogen combustion experience
- **Aero GTs:** >100k hours of recorded operation on high hydrogen fuels **(up to 78 vol%)**

1 The performance may be reduced based on H_2 concentration, emissions requirement and power rating

Hydrogen does not produce CO_2 emissions, but challenging physical properties require rapid design and testing cycles

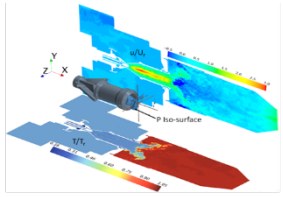


Values shown are relative to natural gas (indicative only)

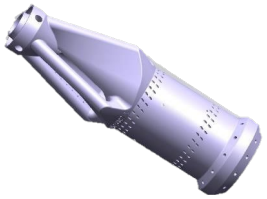
Challenges

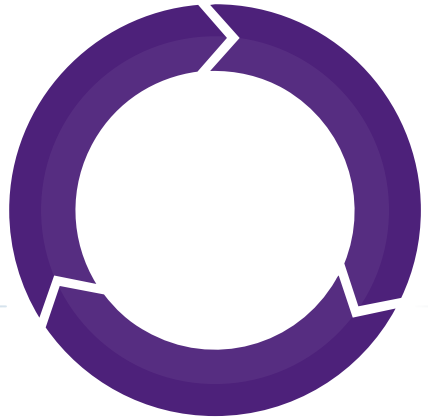
- **H2 embrittlement** requires upgrade to stainless steel materials
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher diffusivity** requires changes/re-certification of sealing and flanges
- **Higher reactivity and flame velocity** pushes flame towards burner and increases risk of explosion or flashback
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

1. High fidelity CFD
High fidelity CFD tools like LES can provide automated optimized designs



2 Rapid prototyping using AM
Additive manufacturing reduces lead time and enables better designs





3. High-pressure testing at engine conditions
High-pressure burner tests combined with full engine tests

Combustion Test Center in Berlin

Zero Emission H_2 Test center (Finspong)

Burner Tests **Engine Tests**

Siemens Energy Solution for different H_2 levels
Expected changes

Differences in Design between "standard" and H_2-Gasturbines: e.g., SGT-300 DLE & SGT-400 DLE

System/Procedures	H_2 Volume Impact on Package		
	0% – 10% – 30%[1]	10% – 30%[1] – 50% – 70%[1]	50% – 70%[1] – 100%
Burners and combustion chamber	No change	Modified burner may be required	New burner design
Combustion monitoring system	n.a.	n.a.	n.a.
Fuel supply system	No change	Ensure all components Stainless Steel	Pipe diameter increase Purging system
Control/protection systems	No change	Additional gas detection	All hazardous area electrical equipment to Gas Group IIC
O&M Procedures	No change	Leak check of gas fuel system after maintenance inspections	Start-up/shutdown on conventional fuel
	No modifications needed	**Smaller modifications may be required**	**Modifications needed**

1 Percentage varies from GT model to model and emission limit requirements

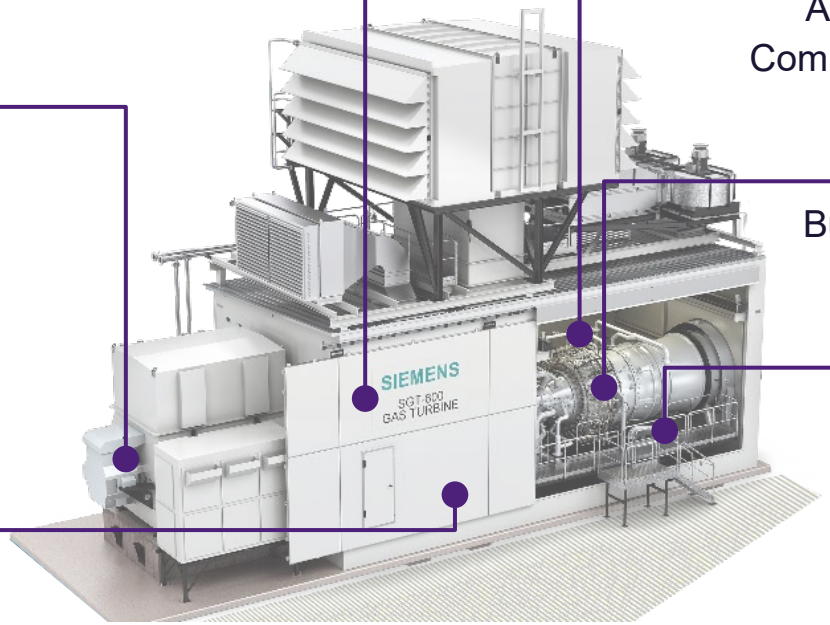
Burner Adjustment/Exchange for Industrial Gas Turbines

Main systems requiring modification when upgrading to higher H_2 content

Fire Protection System

Gas Group IIC
electrical equipment

H_2 compatibility of plant
auxiliary and peripheral systems



Additional Flame Control and
Combustion Monitoring Systems

Burner Adjustment/Exchange

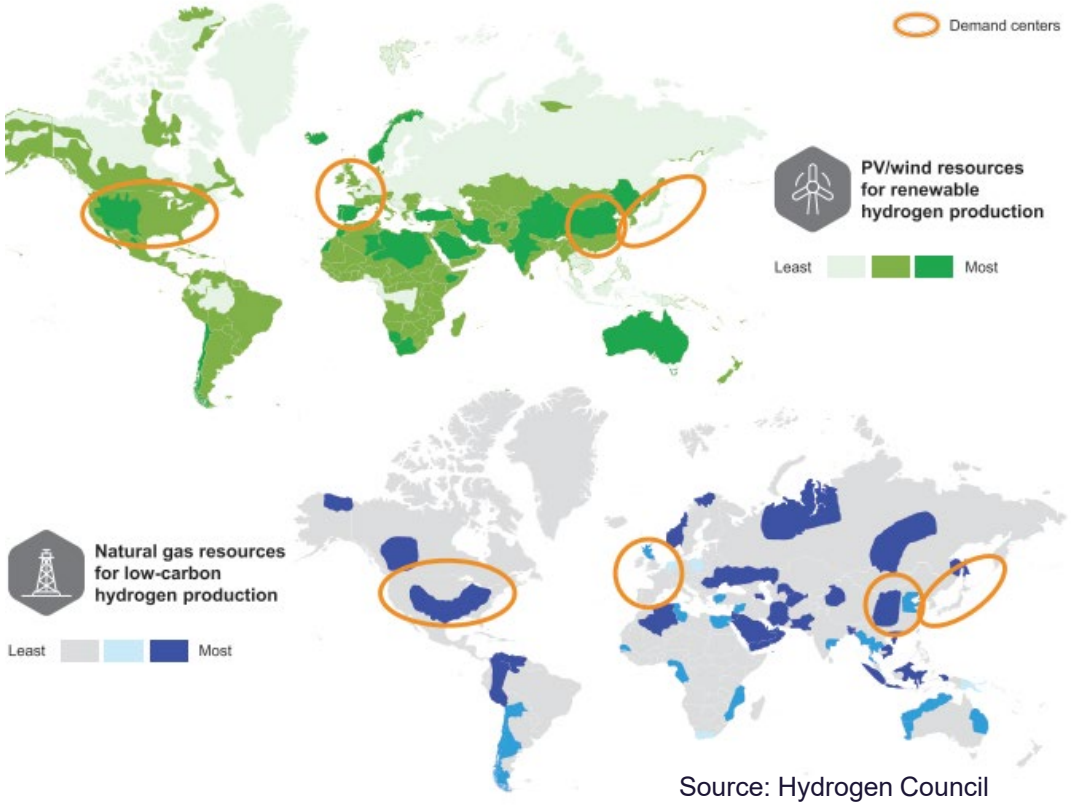
Fuel Gas System
material and set-up

Consequences and solution

- Project specific evaluation and decision on required modifications
- Power output control to ensure compliant NOx emission levels
- Conventional/non-H_2 fuels may be required for start-up and shutdown
- Re-certification with respective authorities might be required

Collaborative steps to drive a sustainable, affordable and secure hydrogen-based energy transition to net-zero

1. **R&D investments**
2. **Policy leadership**
3. **Accelerate commercialization**



Source: Hydrogen Council / McKinsey & Company

Government support can help make the U.S. a global leader in hydrogen

Contact page

Published by Siemens Energy

Dr. Vinayaka Nakul Prasad

Corporate Strategy and Technology
Siemens Energy, Inc.

11842 Corporate Boulevard
Orlando, FL, 32817

Phone: +1-321-332-5966
vinayaka.prasad@siemens.com

linkedin.com/in/vinayaka-prasad/

siemens-energy.com/hydrogen

Kurt West
Vice President, Business Development
2G Energy

U.S. DEPARTMENT OF ENERGY

2G – The Future of Energy

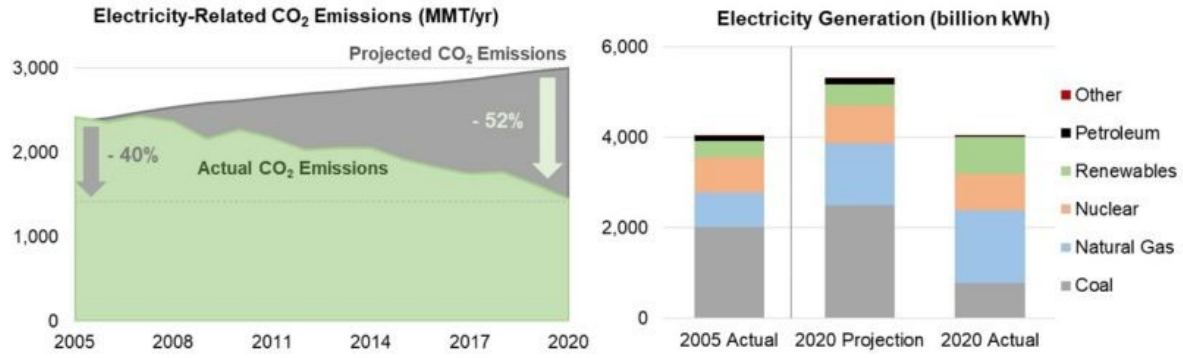
Hydrogen CHP: The lowest cost, least risk way to net zero

Powerful Together

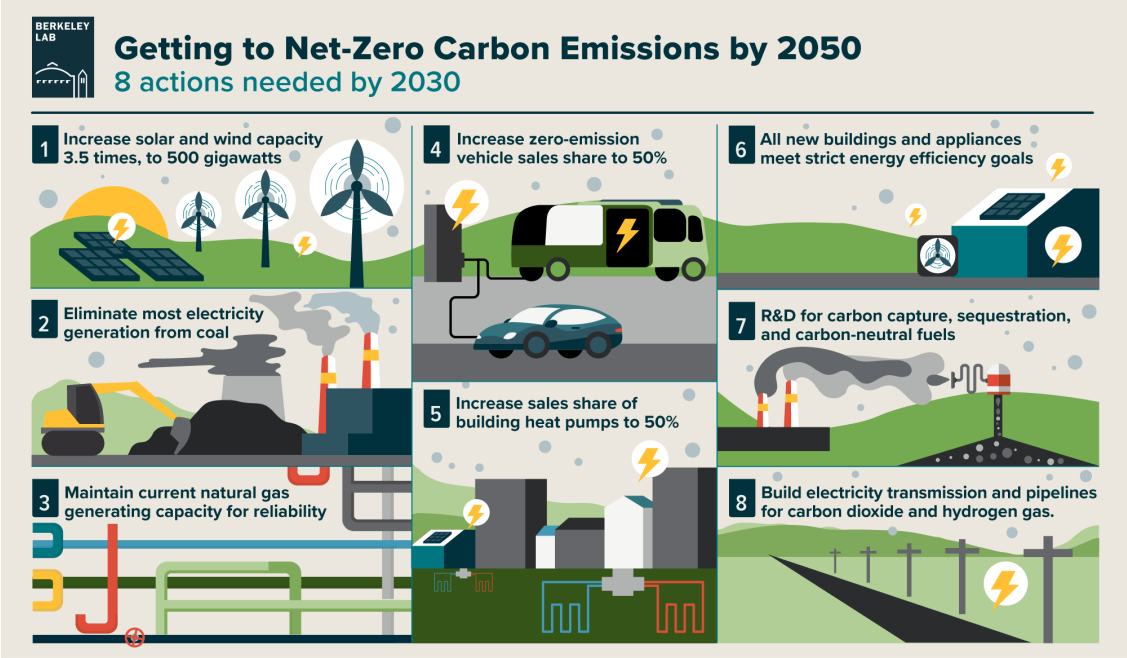
Kurt West

Vice President of Business Development

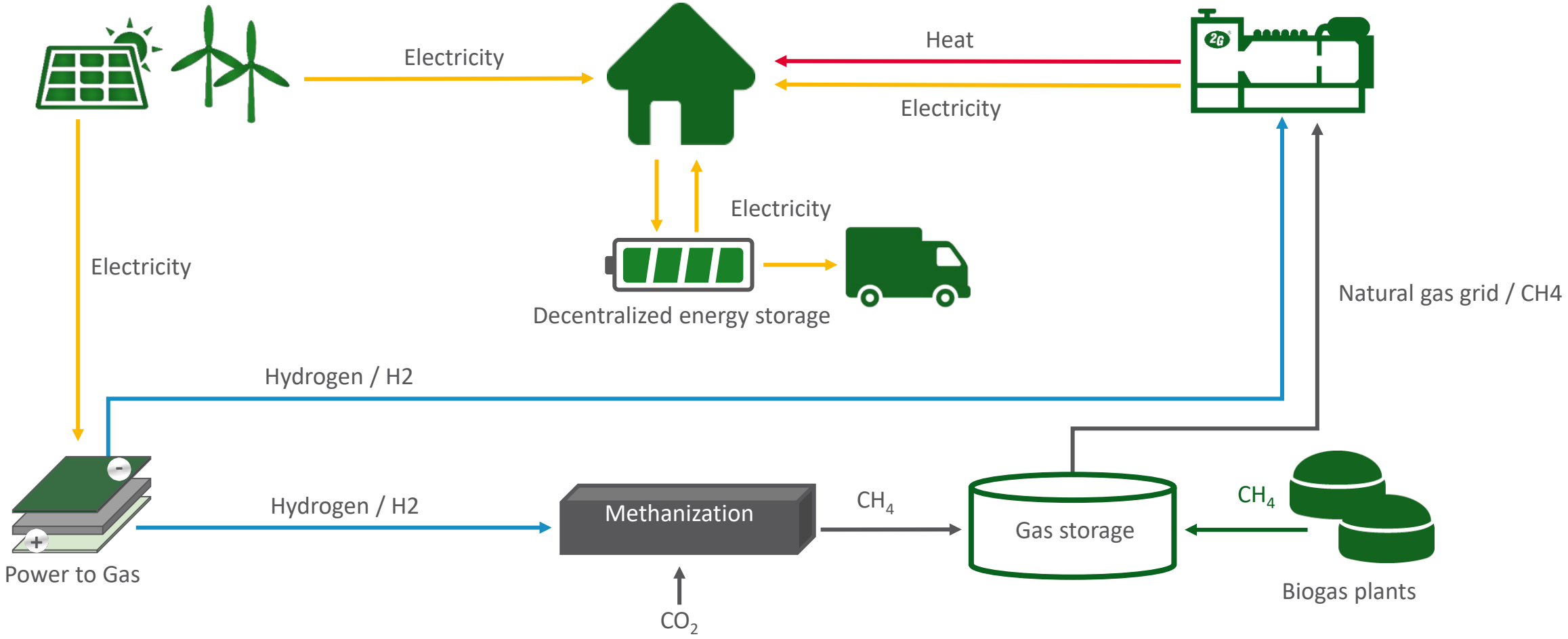
Enabling Net Zero: Time is of the essence



- Massive strides towards net zero over the past 15 years – the low hanging fruit is almost done
- H_2 CHP supports Berkeley Labs science-based framework to Net Zero
- Growing global consensus on H_2's role in energy transition



A post carbon model to embrace



Global leader in resilient renewable energy

- Founded 1995, and publicly traded.
- 7,500+ CHP plants in more than 55 countries worldwide
- ***<u>>50% of fleet run on carbon neutral/negative fuels</u>***
- Innnovative R&D, finance, and service capabilites
- Strong US track record and customer base

Natural Gas, Digester Gas, Landfill Gas, Flare Gas, Syngas & Hydrogen

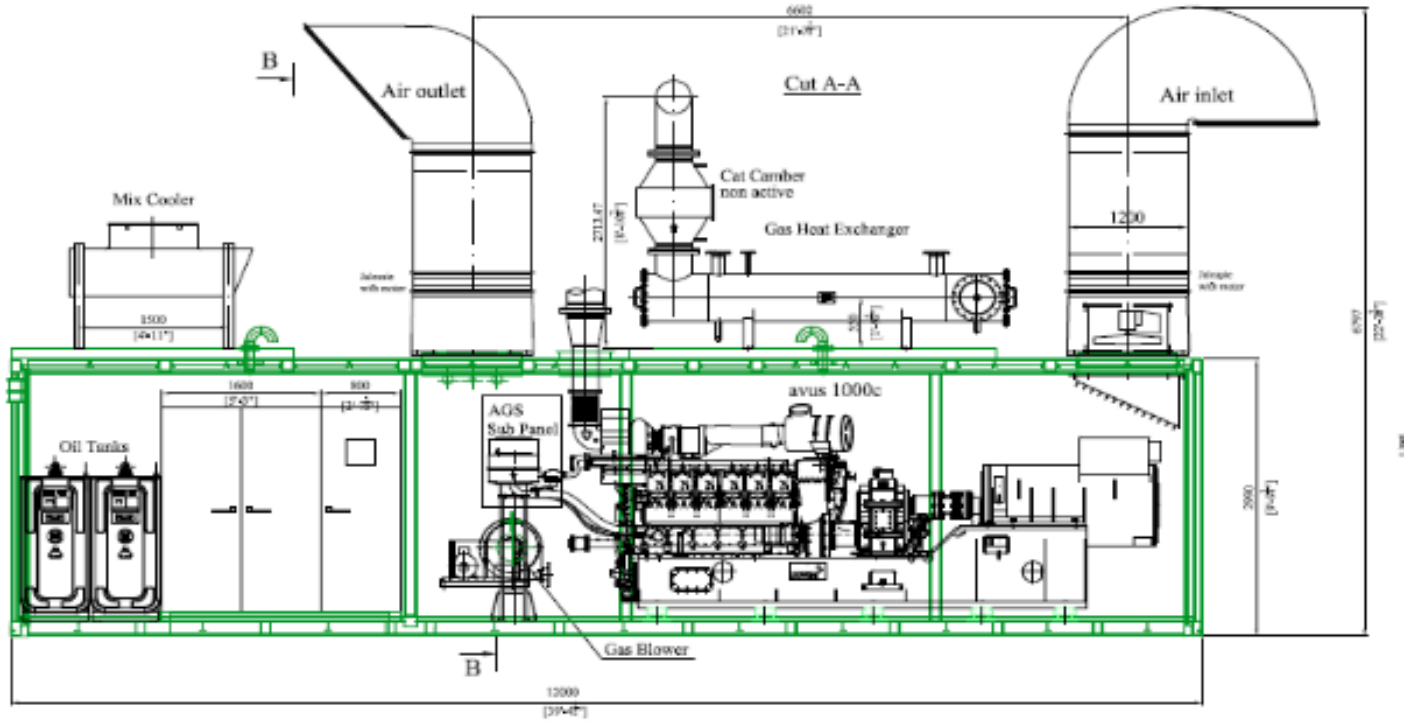
Why 2G's CHP?

Best return on investment and lowest total cost of ownership

- Modular Solutions 60 kW – 20 MW
- Complete pre-engineered product
- Designed for service and built for the real world
- Proven by performance
- Backed by indutry best assurances

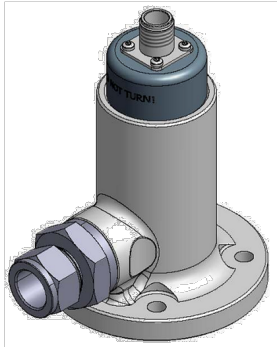
The 5 Design considerations for plug and play projects

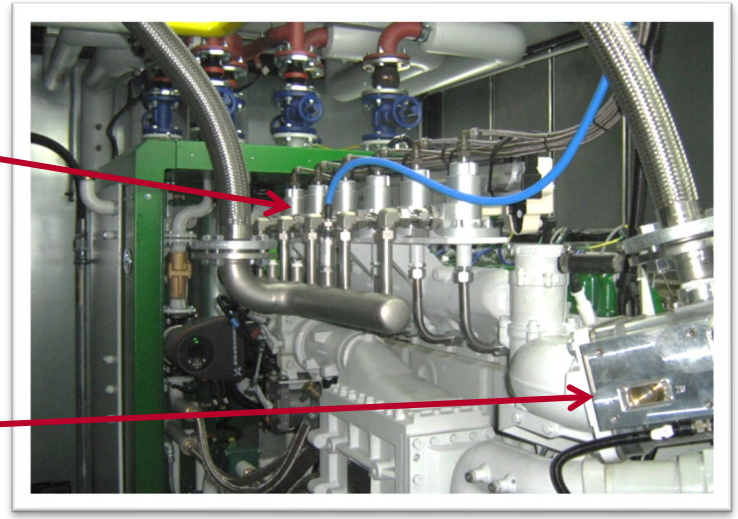
1. **Fuel**
2. Electrical
3. Thermal
4. Civil
5. Emissions



Top efficiencies – Plug and Play- Microgrid Ready

Fuel Flexibility Minimizes Fuel Supply Risk





- Simple field retrofit makes 2G Systems future proof
- Full range of carbon free flexiblity: H2, RNG or Biogas

Today's Hydrogen Line

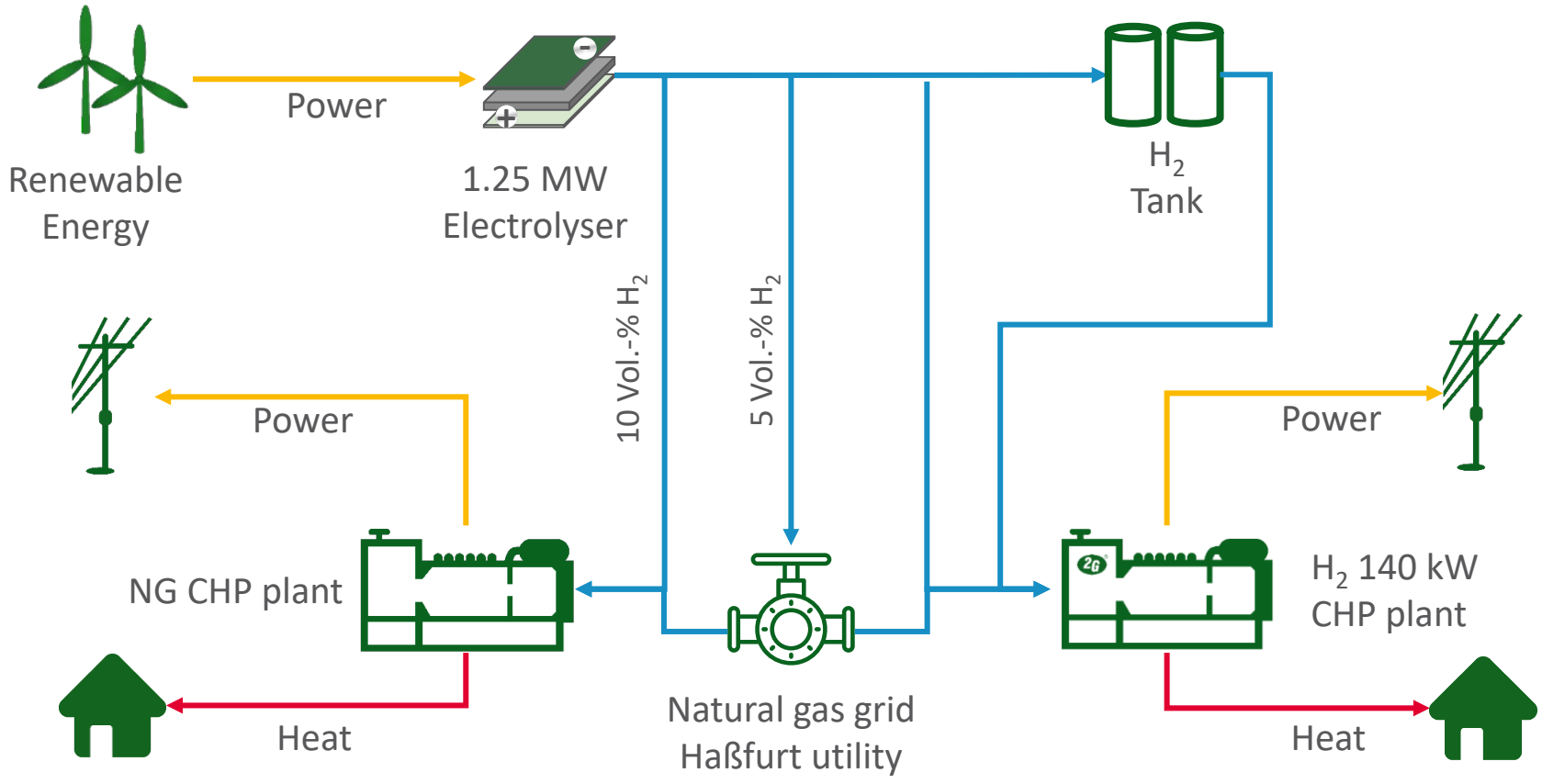
Type	Output			Efficiency		
	Electrical	Thermal		Electrical	Thermal	Total
agenitor 404c	115 kW	129 kW	440 MBTU	37.7 %	42.3%	80.0 %
agenitor 406	170 kW	183 kW	624 MBTU	39.0 %	41.9%	80.9 %
agenitor 408	250 kW	250 kW	853 MBTU	40.2%	41.9 %	82.1 %
agenitor 412	360 kW	371 kW	1,266 MBTU	40.5 %	41.7 %	82.2 %
agenitor 420	650 kW	687 kW	2,344 MBTU	41.1 %	39.3 %	80.4 %



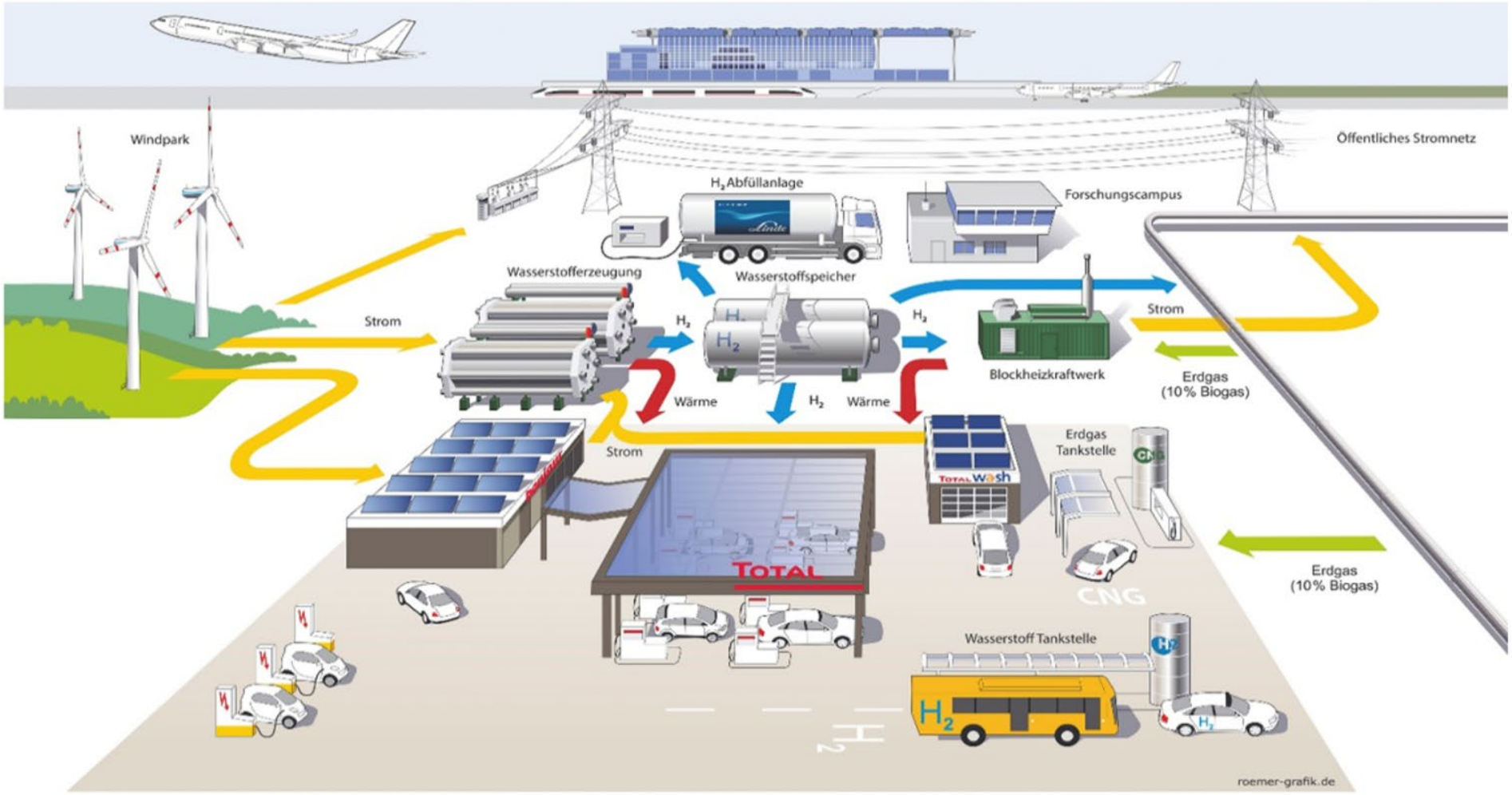


- Improved H2 derate driving higher ROI over time
- 75% reduction in NoX achieved in exceeding of all North North American requirements

Years of field performance at Utility Haßfurt



Berlin Airport



Europe’s largest grid-connected hydrogen plant

At APEX Energy Tetrow, 2G supplies the entire site with CO_2 neutral energy

Project Consists of:

- 2MW electrolyzer with H_2 storage
- 115 kW CHP from 2G
- Battery storage with 1 MWh capacity
- Fuel cell with 100kW power

World’s largest solar park looks to H_2 future

- Dubai Electricity and Water Authority installed a Agenitor 412 installed at the world’s largest solar park
  (1000MW in 2020 / 5,000MW in 2030)

- Siemens providing EPC services and integrated CHP with with own electrolyzer

Carbon Free Resiliency for Residential Buildings

Underground electrolyzer makes green hydrogen that fuels 2G trigen CHP. System is configured to fuel switch to natural gas

Key Advantages seen by the customer:

- CHP is more economical than a fuel cell
- Cold from heat increases the annual degree of utilization
- 2G's CHP works with 100 percent hydrogen

"There is only one manufacturer whose CHPs offer the right performance and can be operated with 100 percent hydrogen"
- Manuel Thielmann (managing director of Green Hydrogen GmbH) referring to 2G Energy.

Kirkwall Airport Orkney Islands, Scotland

Green hydrogen to decarbonize heat and power at a remote island airport

- 170kWe Hydrogen CHP coupled to airport's existing heating system to meet the building's heating and power requirements
- Doosan Babcock is Project EPC
- Set to be commissioned in 2021

Lowest cost/Least risk H_2 technology

- Lowest CAPEX per KwH
- Proven global performance on 100% H_2
- Full range of mixtures and widest fuel optionality
- Turn up and turn down - start and stop
- Rapid project delivery
- Guaranteed long term performance

Kurt West

Vice President of Business Development

904-829-7073

k.west@2-g.com

www.2g-energy.com

CHP in a Decarbonized Economy

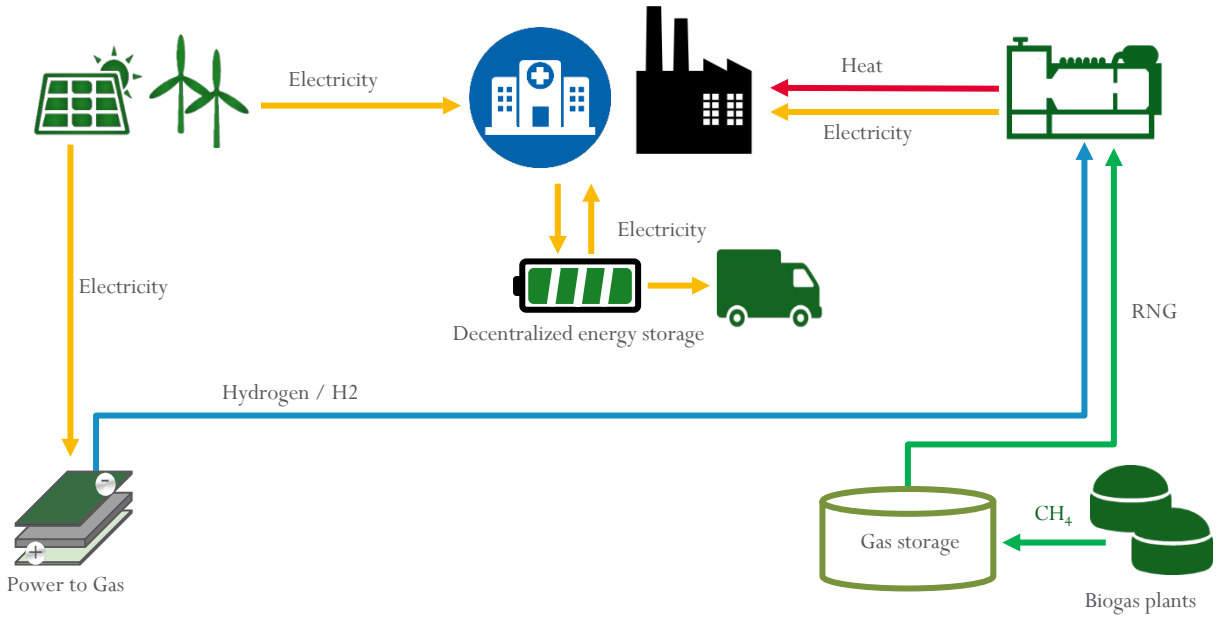
U.S. DEPARTMENT OF ENERGY

CHP and Decarbonization

- Reducing carbon today is important
- Fully electrifying the economy will not be easy
  - 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
  - Commitments to decarbonize often not underpinned with concrete plans
  - The grid will need dispatchable generation for support
- RNG/Hydrogen increasingly looked at as a critical part of decarbonization
- CHP will play an important role now and in the future

President Biden announced the United States will target reducing emissions by 50-52 percent by 2030 compared to 2005 levels (April 23, 2021)

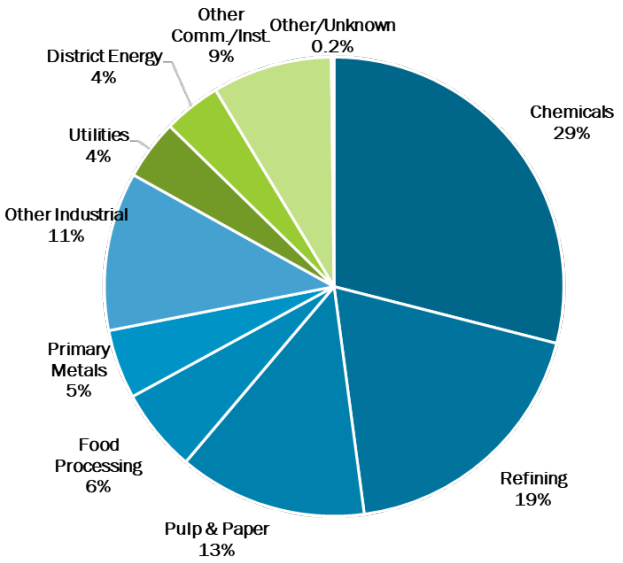
CHP in a Decarbonized Economy

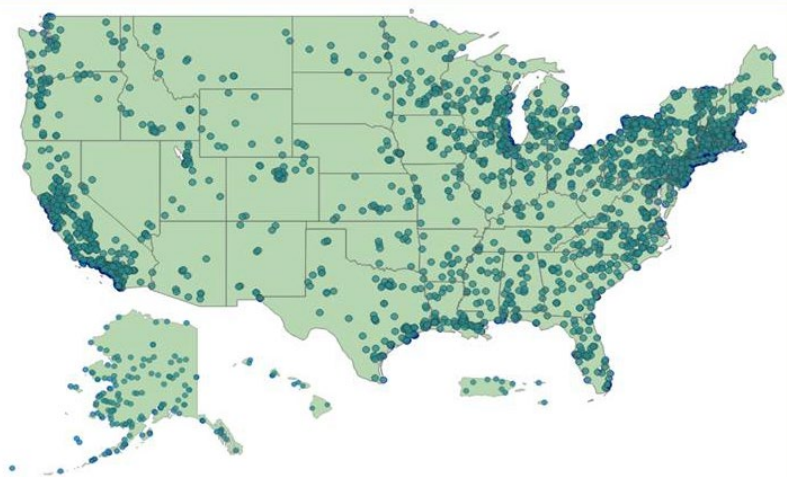


CHP Today in the United States

- CHP increases energy efficiency in industrial, institutional and commercial applications
  - ✓ 80.8 GW of existing CHP at more than 4,600 facilities saves 1.7 Quads of fuel and 232 MMT CO_2 annually
- CHP improves energy reliability & resilience for both the user and the grid
  - ✓ Growing interest in CHP for resilience and sustainability, especially in critical infrastructure facilities
  - ✓ CHP serves as a resilient anchor for clean microgrids
- CHP uses a variety of fuels – fossil and renewable
  - ✓ 72% natural gas fueled
  - ✓ 15% biomass, biogas, and municipal and process waste fueled - and growing

Existing CHP Capacity

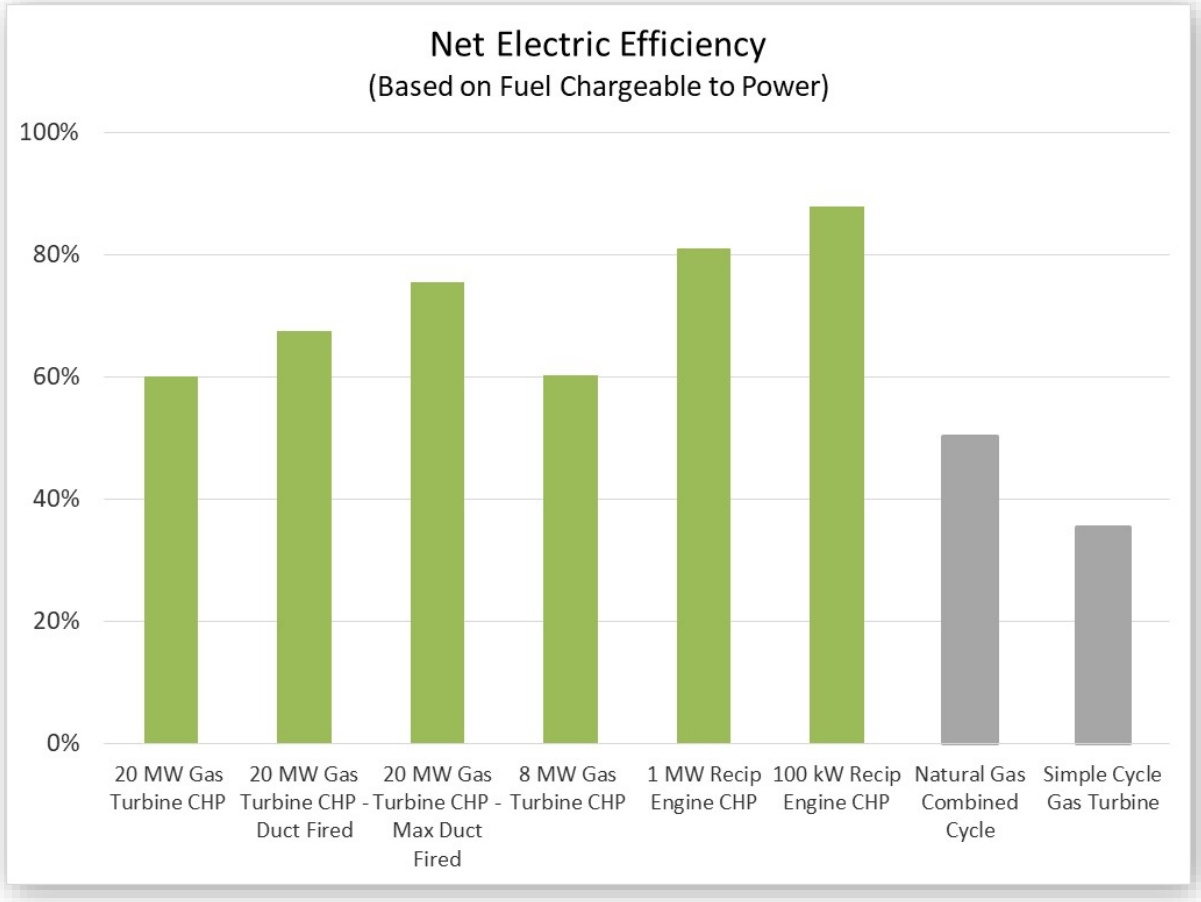




Source: DOE CHP Installation Database (U.S. installations as of July 31, 2020)

CHP Is the Most Efficient Way to Generate Power with Natural Gas

- CHP has higher net electric efficiency than state-of-the-art marginal natural gas generation (combined cycle)
- CHP systems have lower net GHG emissions than marginal natural gas generation
- Natural gas CHP can meet marginal loads more efficiently and with less CO_2 emissions
- CHP's efficiency and emissions advantages will remain as the natural gas infrastructure decarbonizes over time



Prepared by: Entropy Research, LLC, 3/29/21

CHP's High Efficiency Saves Emissions 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
- Natural gas CHP's high net electric efficiency and high annual capacity factor currently results in higher energy and emissions savings than PV and wind on a per MW basis
- *"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"*

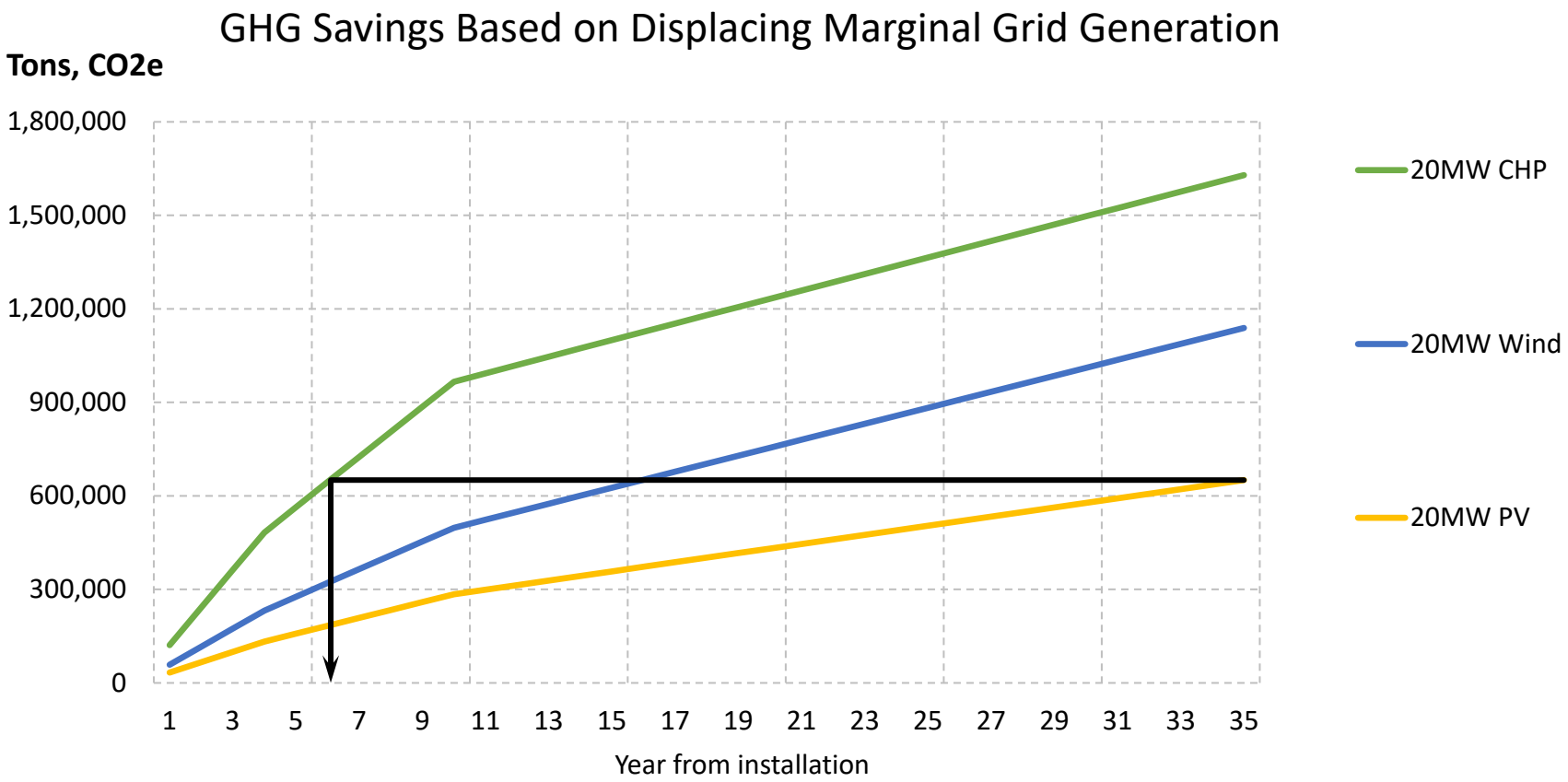
Source: "Time Value of Money", Larry Stein, Carbon Leadership Forum, April 2020

Category	Industrial CHP	Utility Solar PV	Utility Wind
Capacity, MW	**20.0**	**46.4**	**32.8**
Annual Capacity Factor	90%	24.3%	34.3%
Annual Electricity, MWh	157,680	98,771	98,554
Annual Thermal Provided, MWh_{th}	160,061	None	None
Annual Energy Savings, MMBtu	**556,152**	**862,690**	**860,792**
Annual CO_2 Savings, Tons	**76,452**	**76,547**	**76,379**
Annual NOx Savings, Tons	51.9	42.0	41.9

Savings based on EPA AVERT Uniform EE Emissions Factors as a first level estimate of displaced marginal generation

Prepared by: Entropy Research, LLC, 3/29/21

CHP Will Reduce Emissions as long as Fossil Fuel is on the Margin



Base Case marginal grid offsets based on Long Term Dispatch Modeling of Regional Utility Generation Resources

- Y1-4 average 95% coal, ~1,900 lb CO_2e/MWh
- Y5-11 average ~55% coal, ~1,440 lb CO_2e /MWh
- Y12 on, 100% NGCC, ~840 lb CO_2e /MWh
- ~561 lb CO_2e /MWh (net FCP heat rate of 4800, including 4.1% T&D loss reduction credit)
- Capacity Factors: 95% for CHP, 20% for PV, and 35% for Wind

CHP saves more GHG emissions in 6 years as the same capacity of solar PV does in 35 years

CHP and Long Term Decarbonization

- CHP is fuel flexible - CHP currently uses renewable fuels, low carbon waste fuels, and hydrogen mixtures where available, and will be ready to use higher levels of biogas, renewable natural gas (RNG) and hydrogen in the future
- Renewable/hydrogen fueled CHP can decarbonize thermal end-uses in industrial and commercial facilities that are difficult to electrify
- Renewable/hydrogen fueled CHP can decarbonize critical facilities that need on-site power for long duration resilience and operational reliability
- Renewable/hydrogen fueled CHP offers an alternative to expensive process conversions to electric technologies
- CHP's high efficiency can extend the supply of renewable and low carbon fuels

RNG/H2 Technologies and Feedstocks

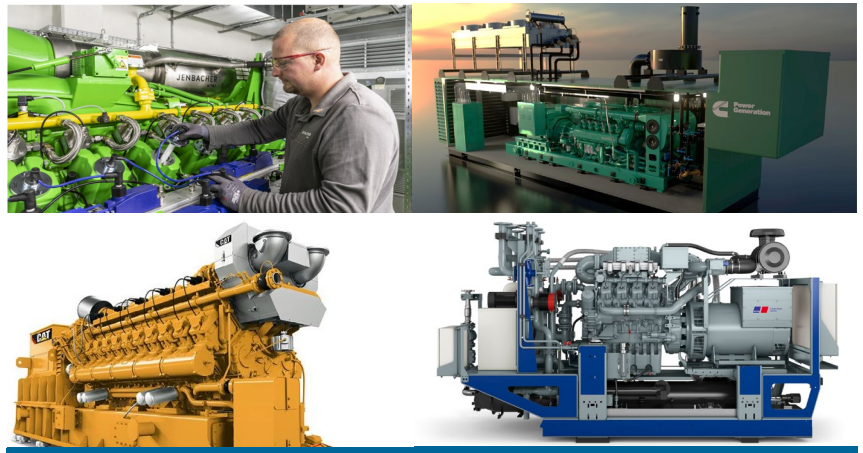
- *Food Waste*
- *Animal manure*
- *Wastewater Treatment (WWTP)*
- *Landfill gas (LFG)*

- *Agricultural residue*
- *Forestry and forest product residue*
- *Energy crops*
- *Municipal solid waste (MSW)*

- *Green Hydrogen from renewable electricity*
- *Blue Hydrogen from natural gas with carbon capture*

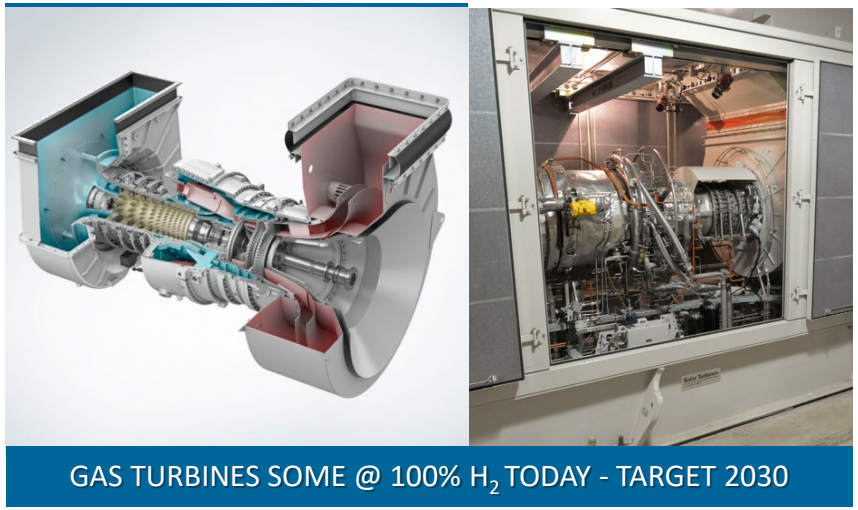
Source: AGA Foundation, Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment, 2019

CHP and Hydrogen



RECIP ENGINES SOME @ 100% H_2 TODAY - TARGET 2030

MICROTURBINES 70 TO 100% H_2 TESTING



GAS TURBINES SOME @ 100% H_2 TODAY - TARGET 2030

FUEL CELLS 100% H_2 COMPATIBLE TODAY

DOE Team

Anne Hampson, Program Manager, Technology Partnerships,
US DOE Advanced Manufacturing Office

Anne.hampson@ee.doe.gov

Packaged CHP Accelerator Coordinator	eCatalog Coordinator	Packaged CHP Accelerator Support
Bruce Hedman	Rich Sweetser	Trent Blomberg
Entropy Research	Exergy Partners	ICF
202-251-0017	703-707-0293	703-272-0346
bhedman.entropyresearch@gmail.com	rsweetser@exergypartners.com	trent.blomberg@icf.com

https://betterbuildingssolutioncenter.energy.gov/accelerators/packaged-chp

https://chp.ecatalog.lbl.gov/