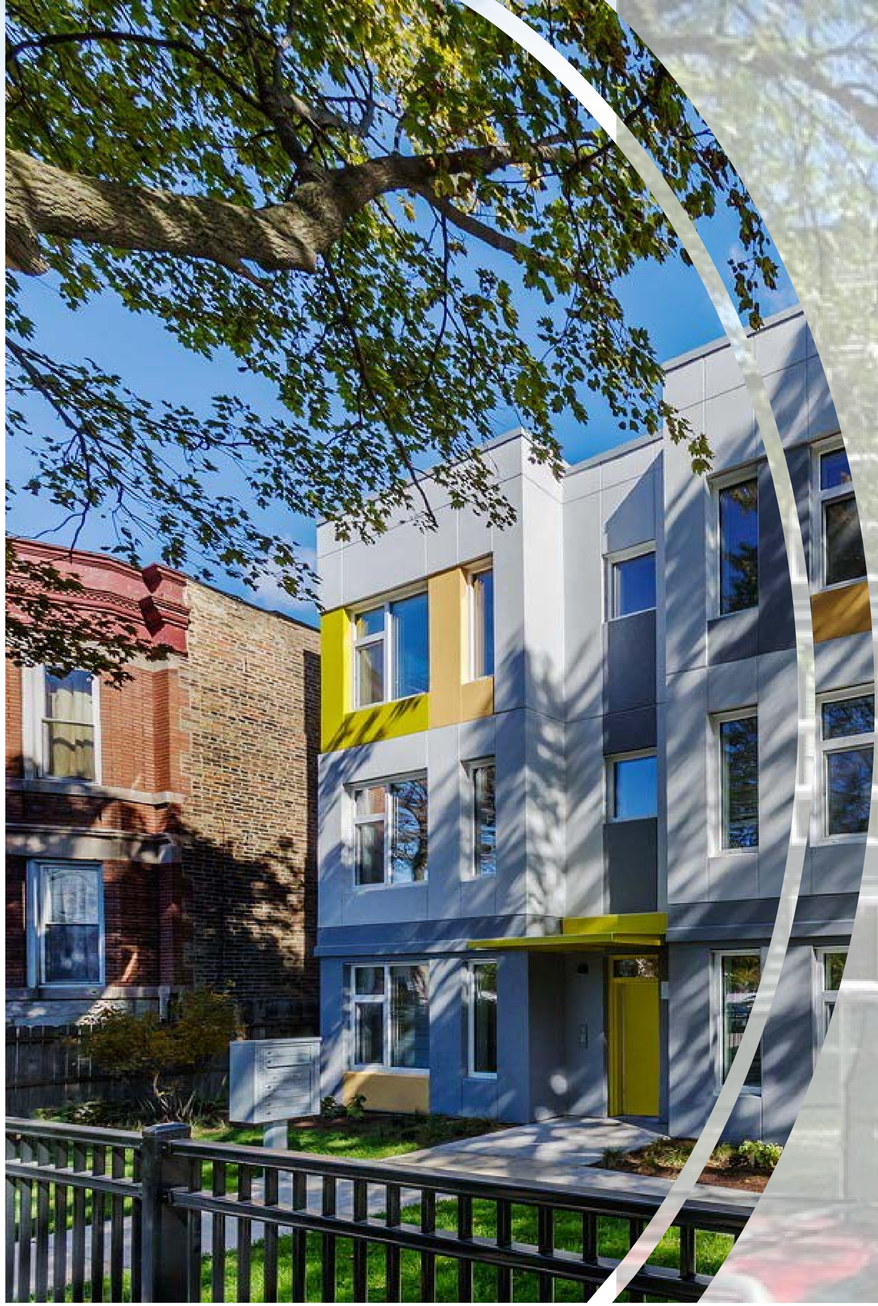
Decarbonizing Fuel-Fired Equipment in Buildings

Jason LaFleur

gti®

Now hiring 30+ openings!

02.08.22

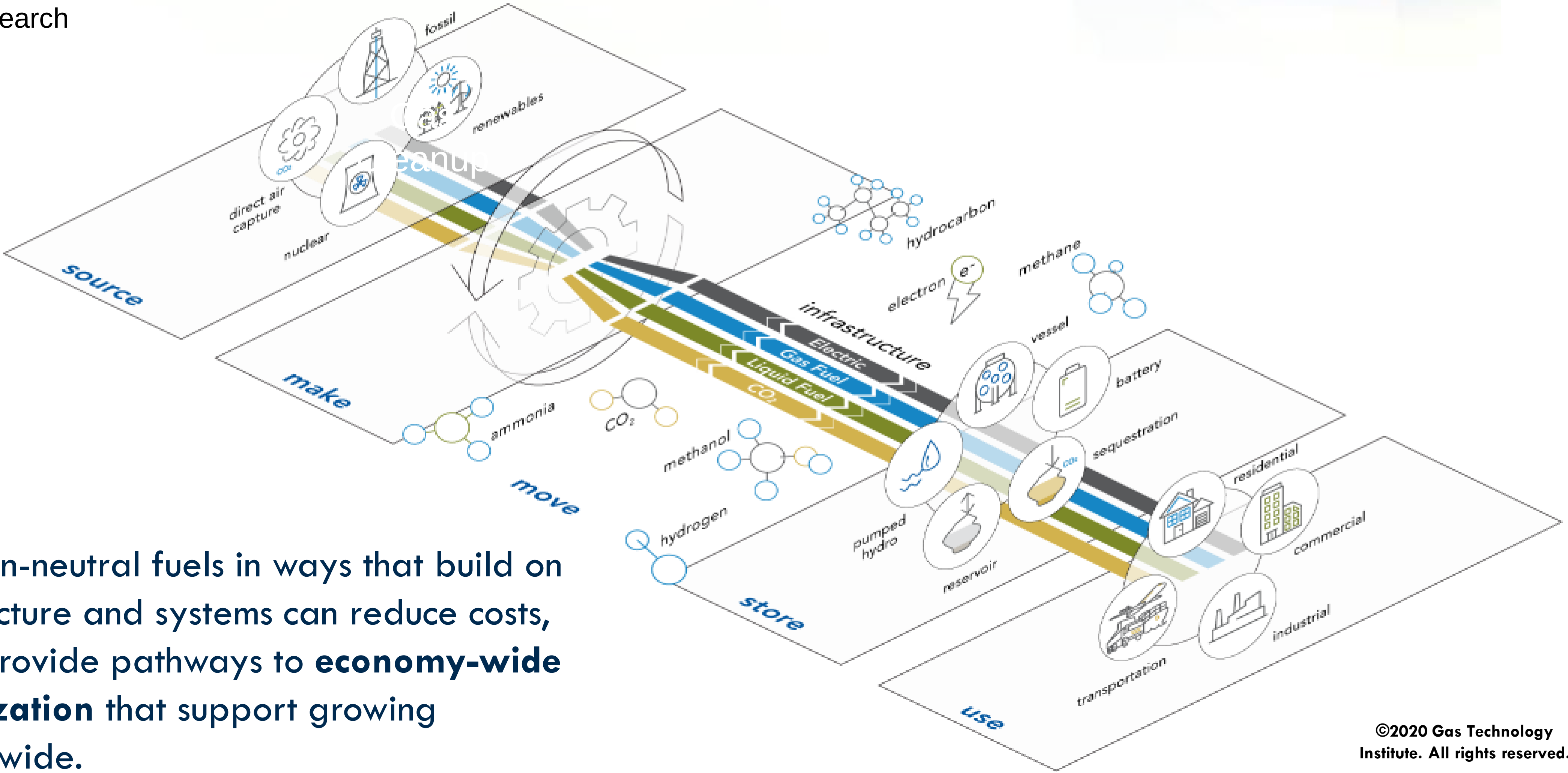


Agenda

- Background
- Energy Efficiency in 2030
- Decarbonized Fuels in 2030
- Questions

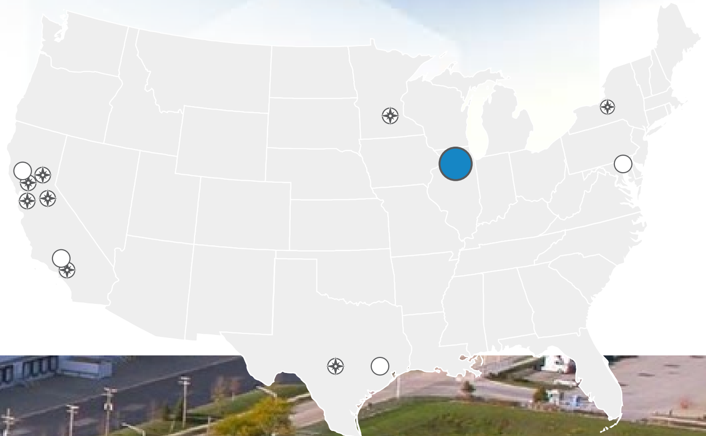
GTI envisions a low-carbon future with integrated energy systems

Education and Research
501c3 non-profit



Deploying carbon-neutral fuels in ways that build on existing infrastructure and systems can reduce costs, lower risk, and provide pathways to **economy-wide deep decarbonization** that support growing economies worldwide.

GTI: 80-Year History of Turning Raw Technology into Source Energy Solutions



World-class piloting facilities headquartered in Chicago area

gti®

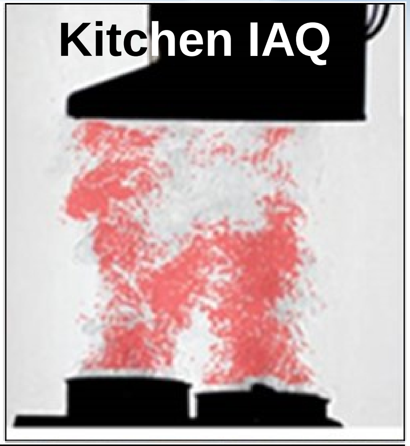
FRONTIER energy

GTI's Building Evolution Labs


Residential Nanogrid


Multifamily Microgrid


Hybrid HVAC with E/G


Kitchen IAQ


Renewable fuel blending

Direct Carbon Capture

Natural Gas Low Greenhouse Gas Options

Methane Leak Detection & Mitigation

Detection and mitigation to reduce full-cycle natural gas methane emissions

Lower Methane Emissions (5-10%)

Energy Efficiency

Expanded use of high-efficiency gas equipment

Hybrid natural gas furnace/boilers and electric heat pump systems

Building envelope improvement

Near-Term (25-50+%)

Natural gas heat pumps for space & water heating

Micro CHP systems

Deep building retrofits

Next-Gen (40-60+%)

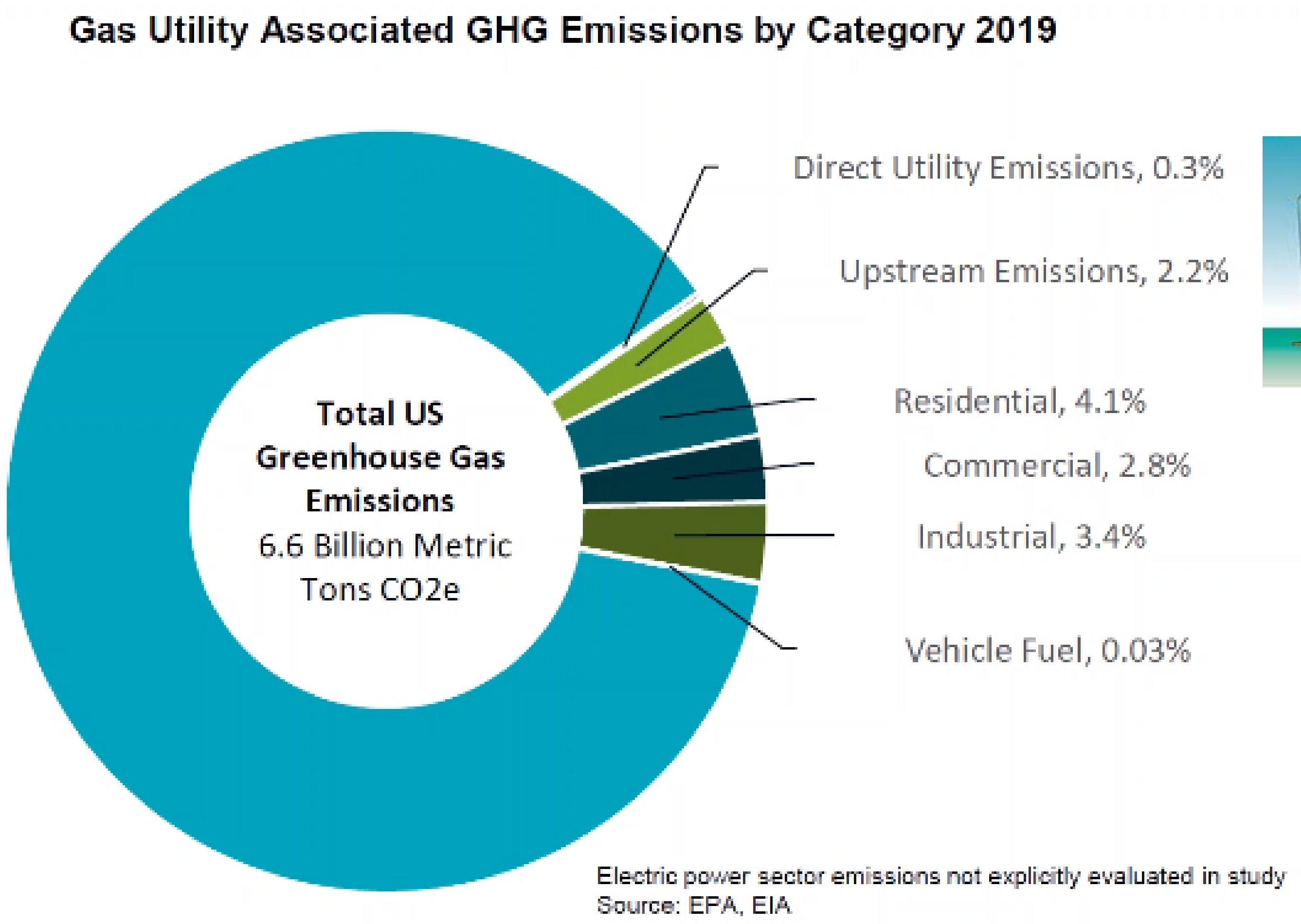
Renewables

Bio-methane/RNG, Clean hydrogen

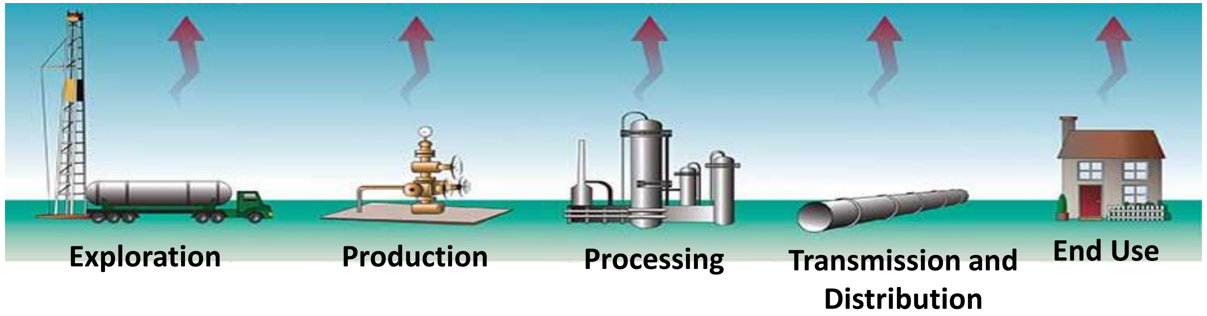
Solar thermal & geothermal /natural gas space & water heating

Renewables (Added 10-30%)

13% of US GHG Emissions from Natural Gas End Use



- 2.2% from upstream emissions



- 6.9% from buildings

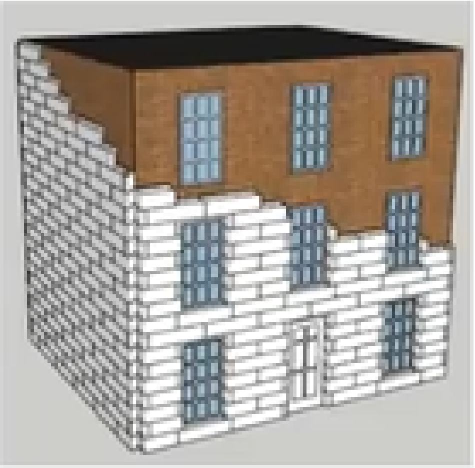
  ~97% of residential GHGs from space/water heating

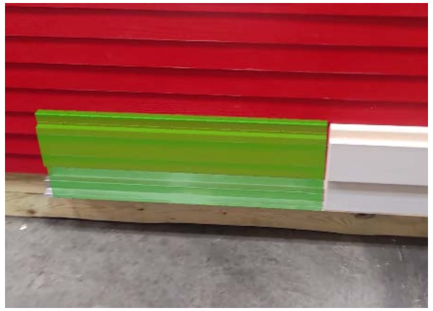
Our Work: Decarbonizing Buildings with Envelope Retrofits and Low-Capacity HVAC

One Example: Skinny R30 Wall Retrofit Panels (Recent NYSERDA Award)

3D LiDAR scanning of building facade → Digital modeling to precisely design customized suite of retrofit panels → Prefabrication and packaging of retrofit panels (with R50 vacuum insulated panels) → Augmented-reality assisted retrofit panel installation

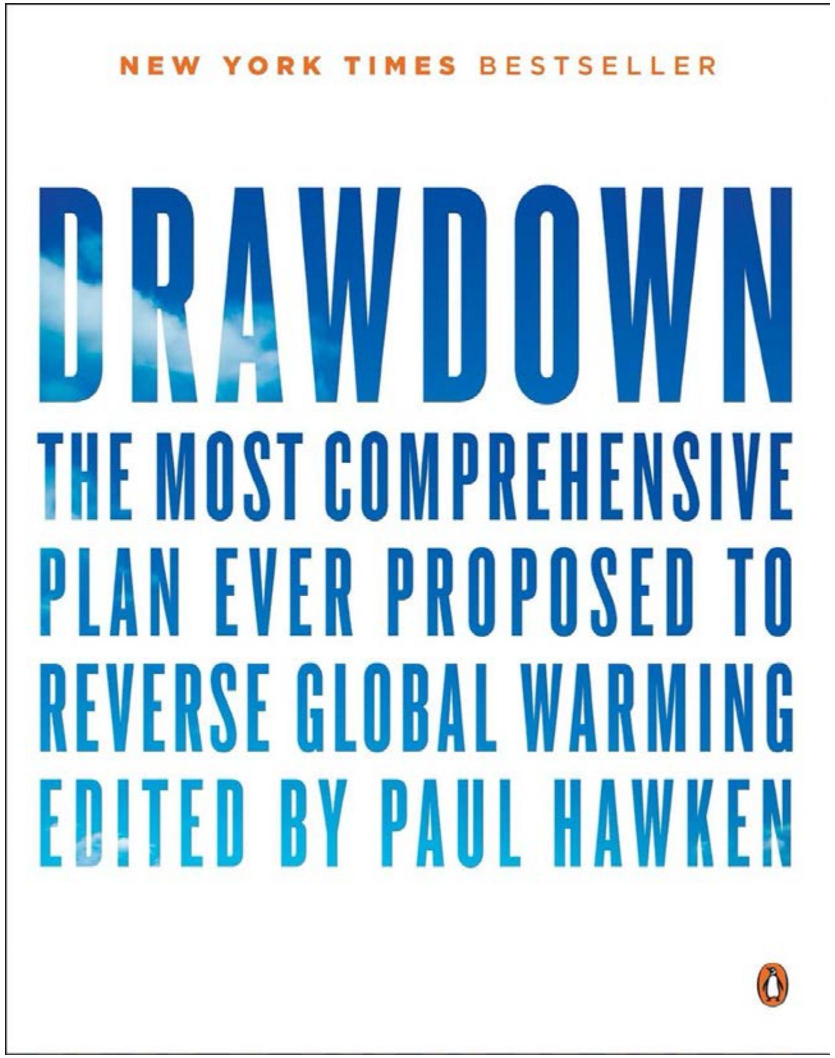
360-degree building scan performed in <15 minutes with a spatial accuracy of <1 mm





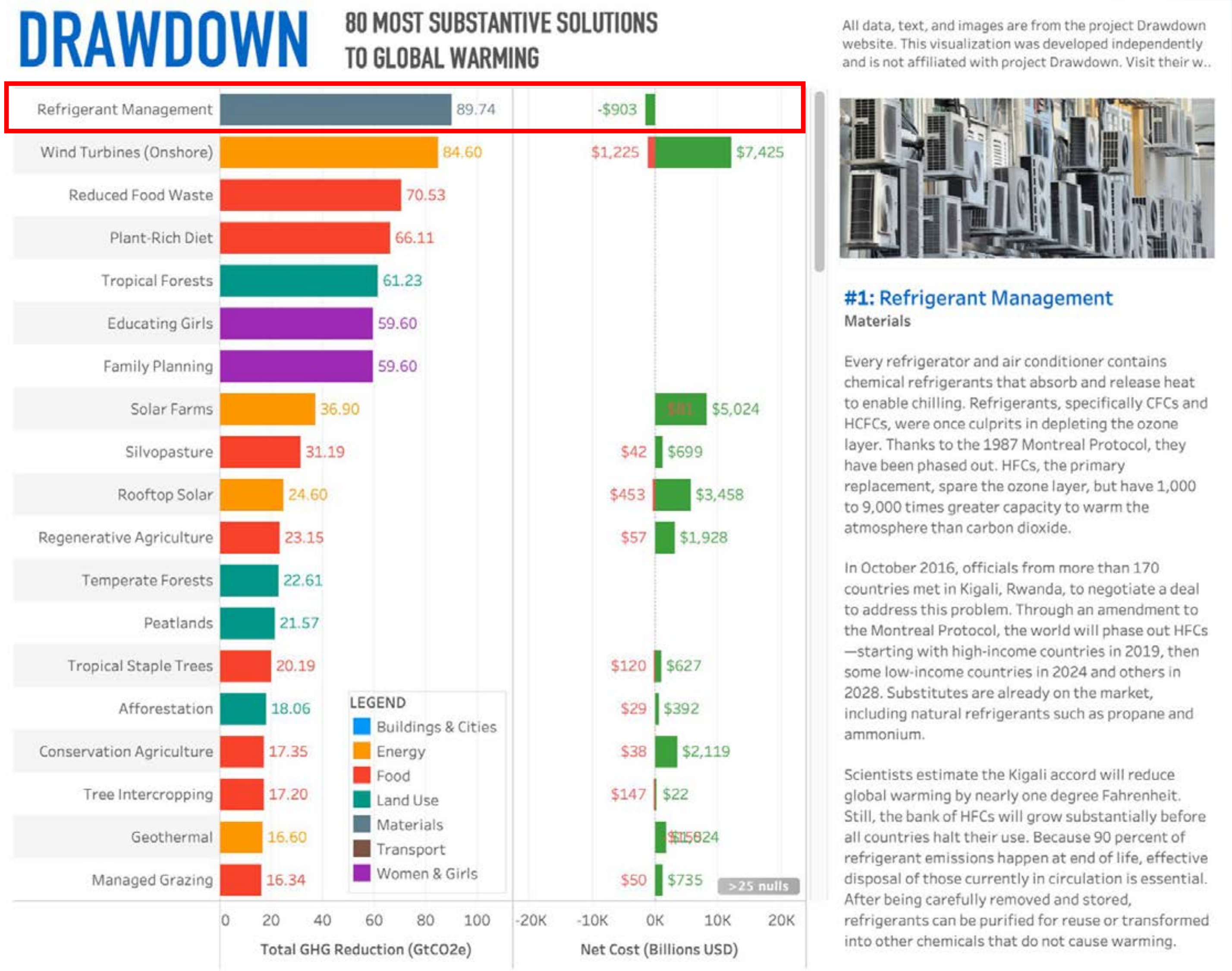
Installed cost target: $10/ ft^2$

What is the top solution for global warming?



(Source: Drawdown – The Most Comprehensive Plan Ever Proposed to Reverse Global Warming, 2017)

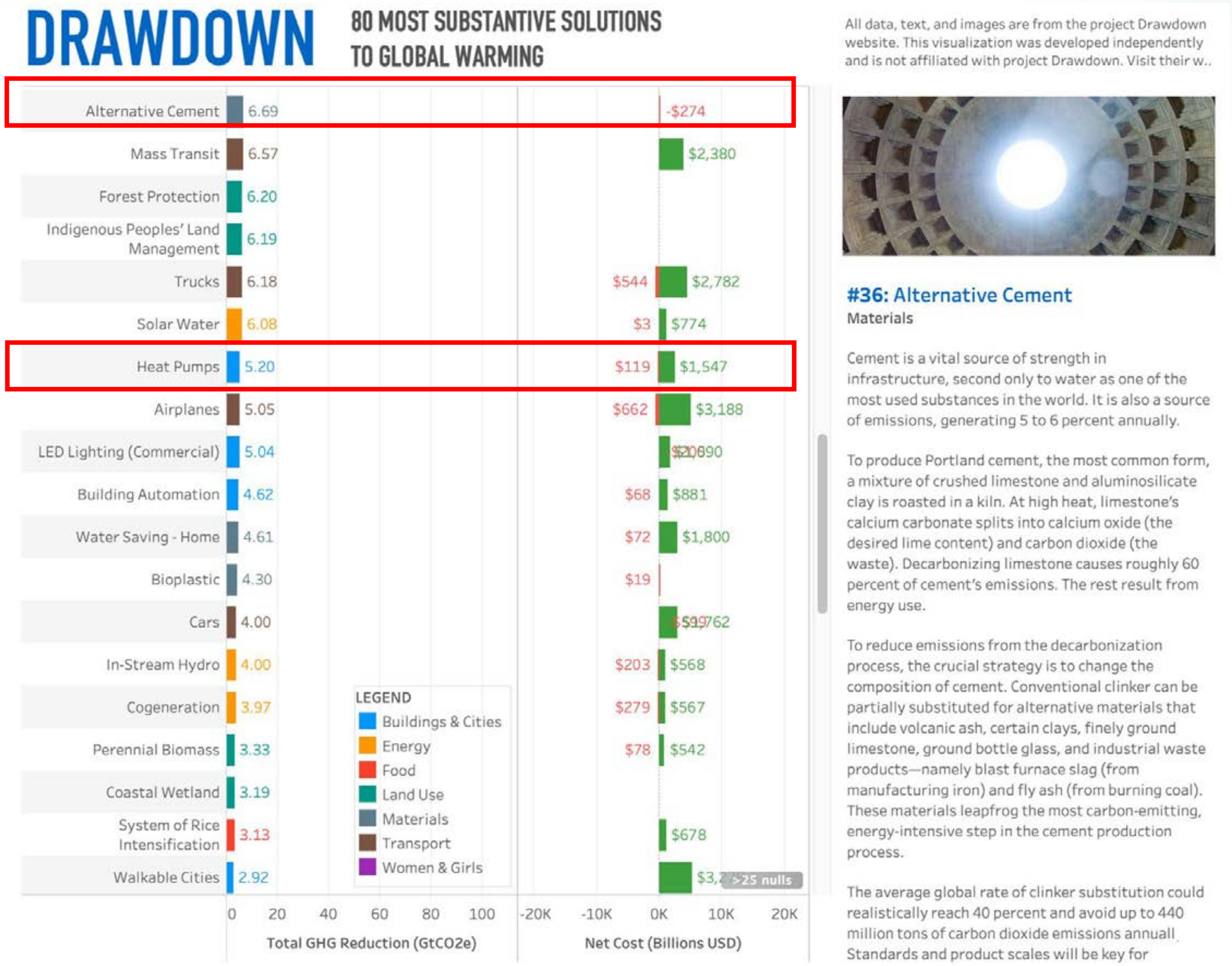
#1 – Refrigerant Management



(Source: Priopta Data Visualization of Drawdown, 2017)

(Data Source: Drawdown – The Most Comprehensive Plan Ever Proposed to Reverse Global Warming, 2017)

#36 – Alternative Cement; #42 – Heat Pumps



(Source: Priopta Data Visualization of Drawdown, 2017)

(Data Source: Drawdown – The Most Comprehensive Plan Ever Proposed to Reverse Global Warming, 2017)

Refrigerants (GWP20 vs GWP100)

Methane:
GWP100 28
GWP20 84

R-134a
GWP100 1,430
GWP20 3,830

R-410a
GWP100 2,088
GWP20 4,340

R-32
GWP100 675
GWP20 2,330

R-717 (ammonia)
GWP100 **0**
GWP20 **0**

Table 1: List of the most commonly used HFCs, HCFCs and low GWP alternatives. (IPCCC Fourth Assessment Report- 2007): Atmospheric lifetime and GWP20 and GWP100

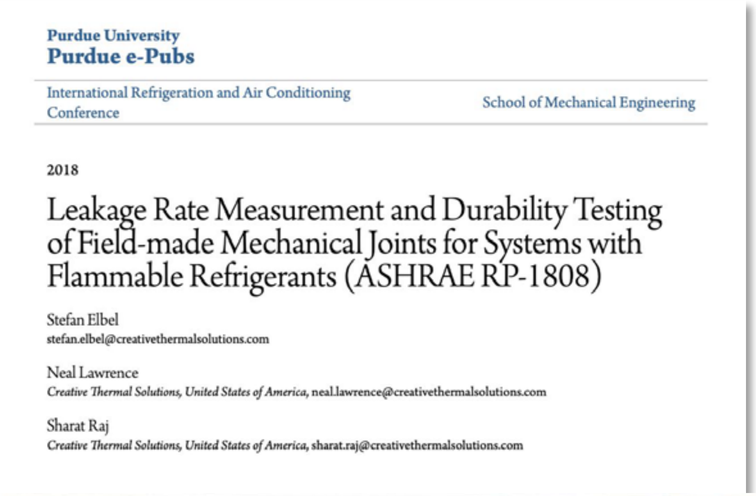
Substance	Application	20 Year GWP	100 Year GWP	Atmospheric Lifetime
HCFC -22	Air-conditioning: most commonly used refrigerant	5,160	1,810	12
HCFC -141b	Insulation foam blowing	2,250	725	9.3
HCFC-142b	Insulation foam blowing	5,490	2,310	17.9
HFC-23	Low temperature refrigerant	12,000	14,800	
HFC-32	Blend component of refrigerants	2,330	675	4.9
HFC-125	Blend component of refrigerants	6,350	3,500	29
HFC-134a	Refrigerant in domestic refrigerators, mobile air-conditioning, stationary air-conditioning, blend component of refrigerants, foam blowing agent, aerosol propellant	3,830	1,430	14
HFC-143a	Blend component of refrigerants	5,890	4,470	52
HFC -152a	Blend component of refrigerants, foam blowing agent, possible future refrigerant	437	124	1.4
HFC-227ea	Refrigerant	5,310	3,220	
HFC-245fa	Foam blowing agent Possible future refrigerant	3,380	1030	7.6
HFC-365mfc	Foam blowing agent Possible future refrigerant	2,520	794	8.6
HFC-404a	Refrigerant blend: a leading alternative to HCFC-22 in air-conditioning	6010	3922	34.2
HFC-410 a	Refrigerant blend: a leading alternative to HCFC-22 in air-conditioning, transport refrigeration	4340	2088	
HFC-407c	Refrigerant blend: a leading retrofit alternative to HCFC-22 in air-conditioning, transport refrigeration	4115	1774	
CO2	Refrigerant, foam blowing agent	1	1	
Hydrocarbons	Refrigerant, foam blowing agent	<3	<3	
Ammonia	Refrigerant	0	0	

The lifetime of HFCs ranges from 1.4 years (HFC-152a) to 52 years (HFC-143a), the average lifetime is 21.7 years. The average GWP of these HFCs, calculated over 20 years is 4582, and 2362 over 100 years. [viii]

Source: The Benefits of Basing Policies on the 20 Year GWP of HFCs, Montreal Protocol Conference, 2011

Refrigerants in Practice

Ensure installers follow manufacturer evacuation and charging process carefully-flare fittings are *especially* challenging with majority found to leak.


Purdue University
Purdue e-Pubs

International Refrigeration and Air Conditioning Conference | School of Mechanical Engineering

2018

Leakage Rate Measurement and Durability Testing of Field-made Mechanical Joints for Systems with Flammable Refrigerants (ASHRAE RP-1808)

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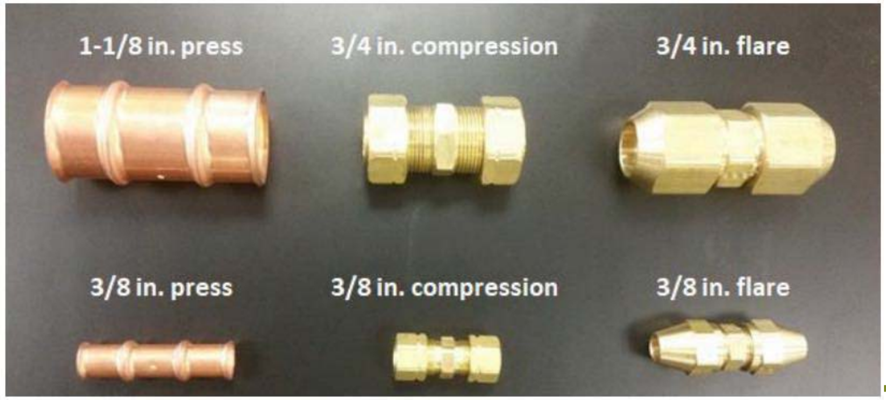
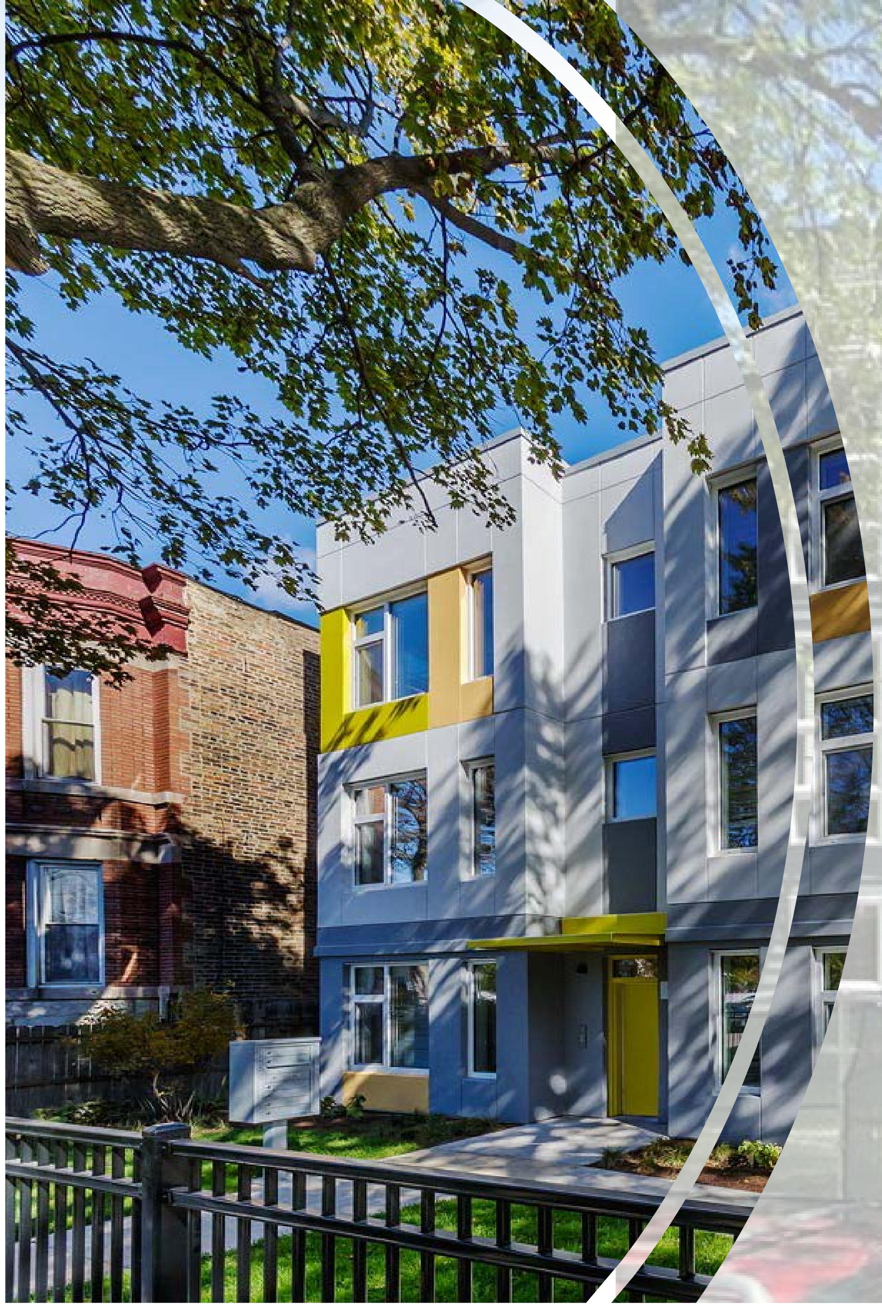


Table 3: Summary of leaks after initial assembly for all fitting types and sizes for different technician experience level and assembly difficulty (results combined for Cu-Cu and Cu-Al joints).

Fitting Type	Fitting Size	Experienced Normal	Experienced Difficult	Inexperienced Normal	Inexperienced Difficult
Brazed	1-1/8 in.	0/10	0/5	0/5	3/5
Press	3/8 in.	0/20	0/10	0/10	0/10
Press	1-1/8 in.	0/20	0/10	1/10	0/10
Compression	3/8 in.	4/20	3/10	4/10	0/10
Compression	3/4 in.	8/20	3/10	6/10	5/10
Flare	3/8 in.	3/20	3/10	3/10	4/10
Flare	3/4 in.	14/20	9/10	10/10	10/10

(a)

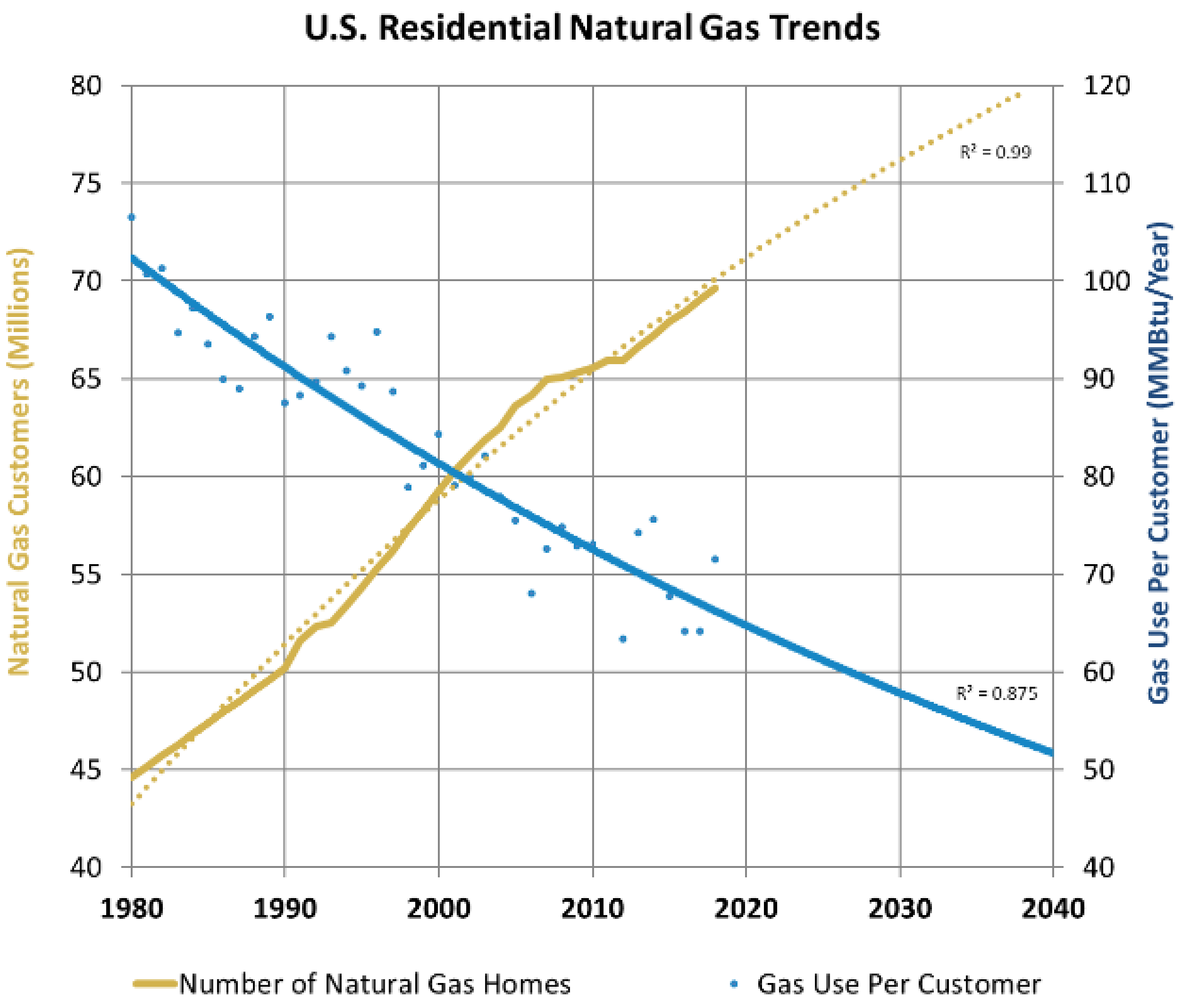
(b)



Energy Efficiency by 2030

- Current Tech – New Homes Case Study
- Current Tech – Existing Home Case Study
- Next Tech: Thermally-driven Heat Pumps
- Next Tech: Hybrid HVAC Systems

Average U.S. Natural Gas Home Use Trending Downward



New technology and utility energy efficiency programs help contribute to market transformation.

Further penetration of high-efficiency natural gas equipment and home weatherization can build on this trend.

25 million more homes (+55%) using natural gas since 1980 with **no change in total demand**.

Source: DOE-EIA. Annual variations due to weather differences (e.g., annual heating degree days)

Current Tech New Construction Case Study

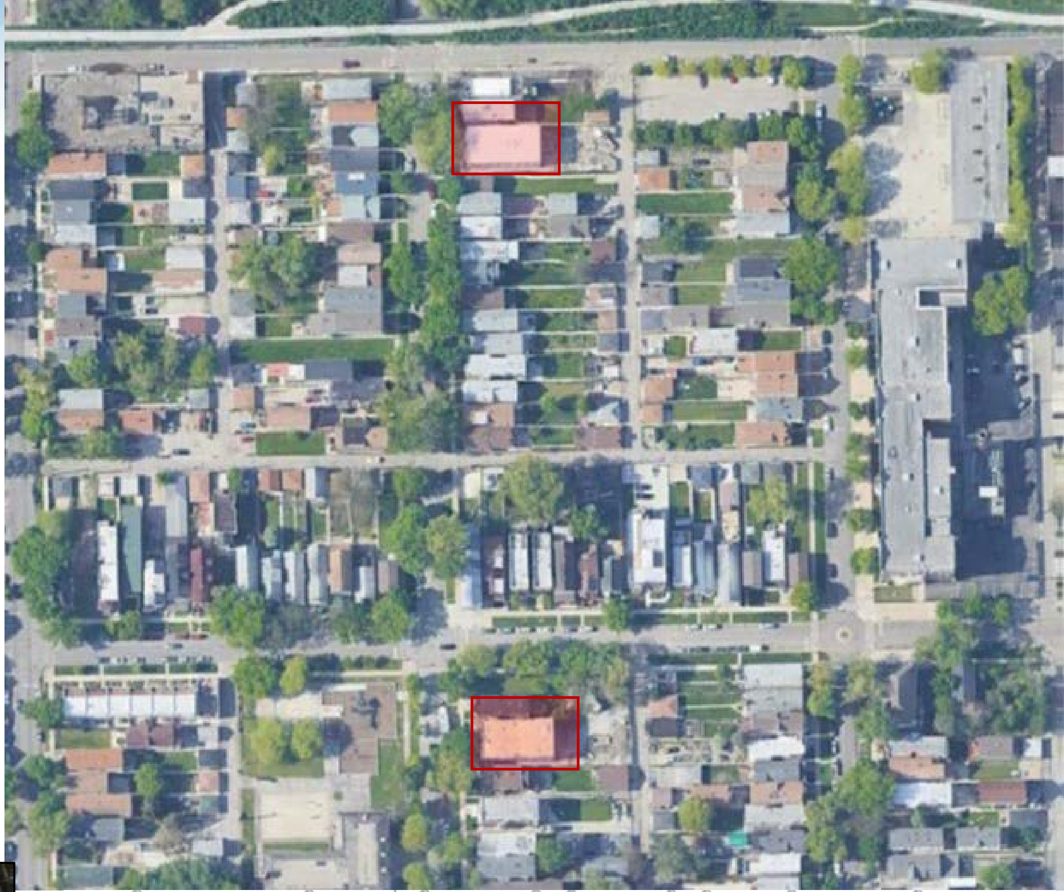
(2) New build, 6-unit properties from affordable housing developer

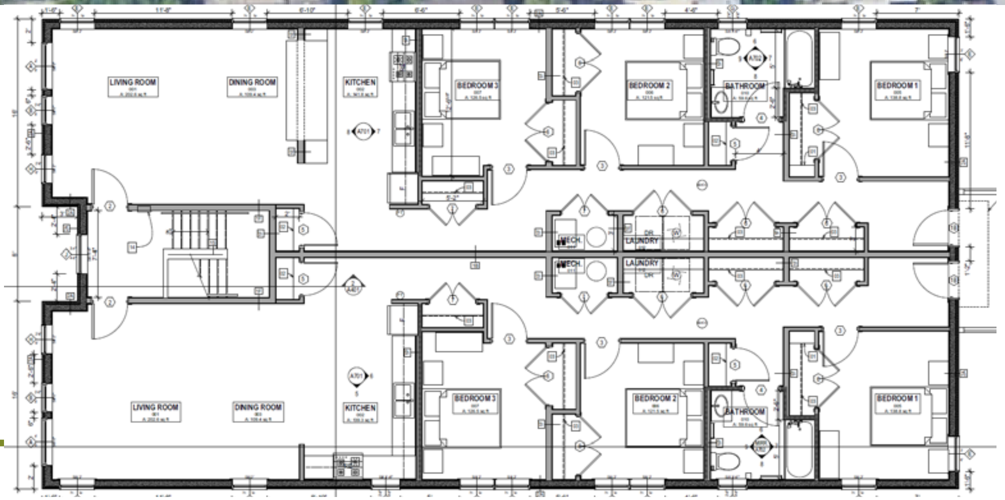
Same layout, same orientation, same location (1.5 blocks apart) built 2017-18 in Chicago; instrumented for research mid-construction

Constructed to two different standards

ENERGY STAR for New Construction (v3.1) with gas furnace

Passive House Institute US (PHIUS) 2015 with air source heat pump



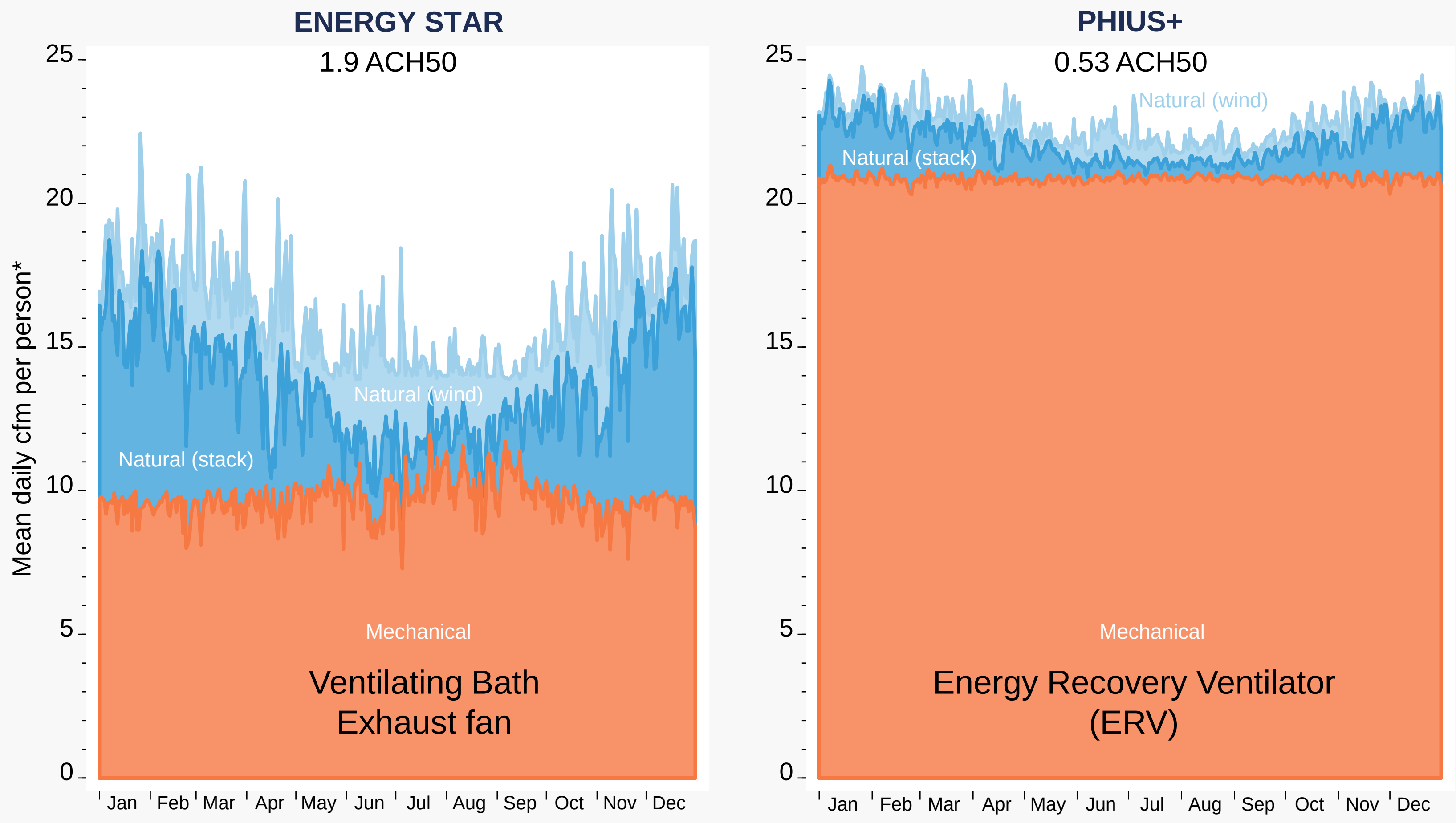


Research Evaluated:

- Energy performance
- Construction / operating costs
- Indoor air quality (IAQ)

More details: https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Passive-House-Tierra-Linda.pdf

Tighter control & higher overall air change rate

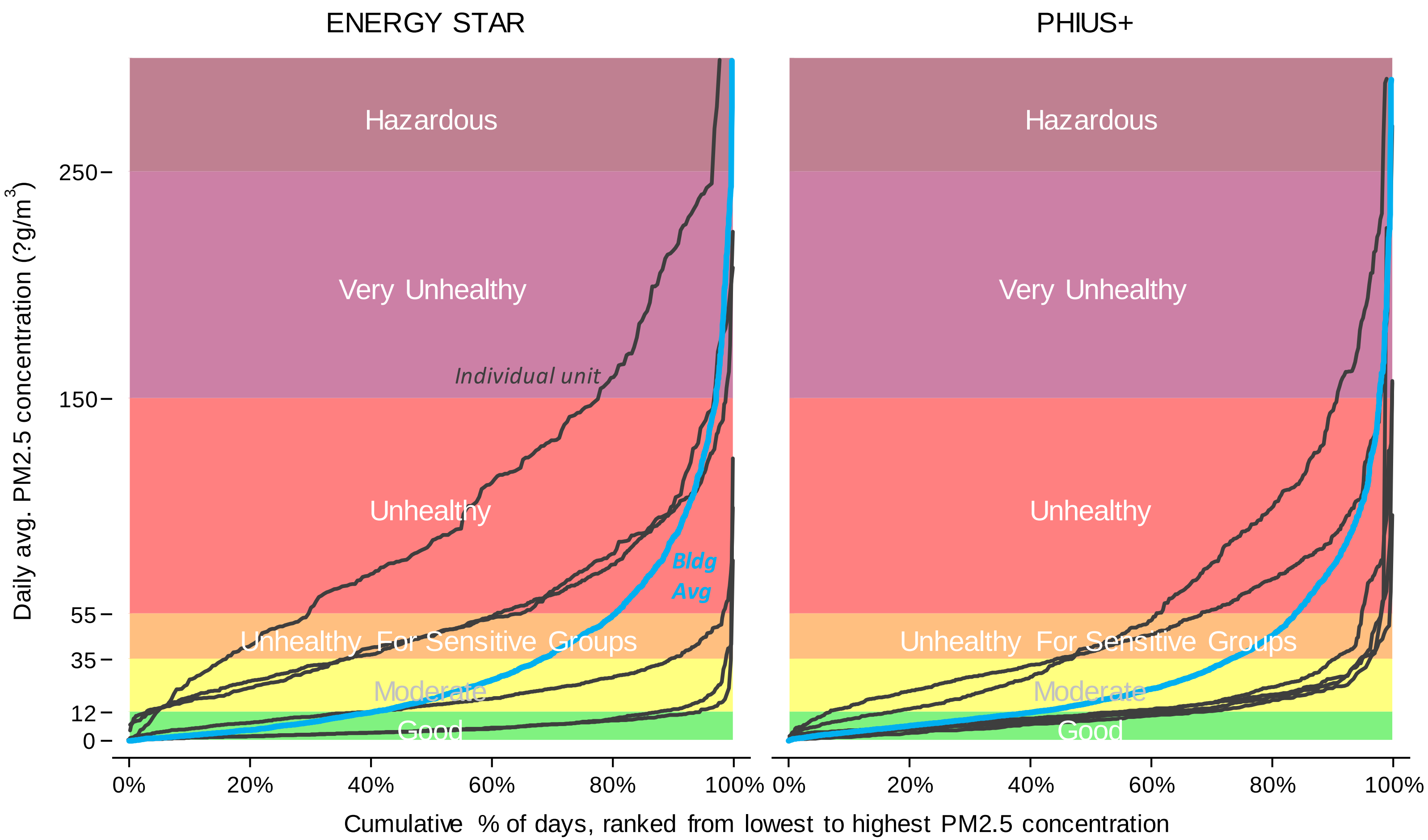


*For 4 occupants per unit
Based on CONTAM modeling under Chicago O'Hare TMY conditions

More details: https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Passive-House-Tierra-Linda.pdf

Source: Slipstream Inc

Measured IAQ Performance: Particulate levels (PM 2.5)



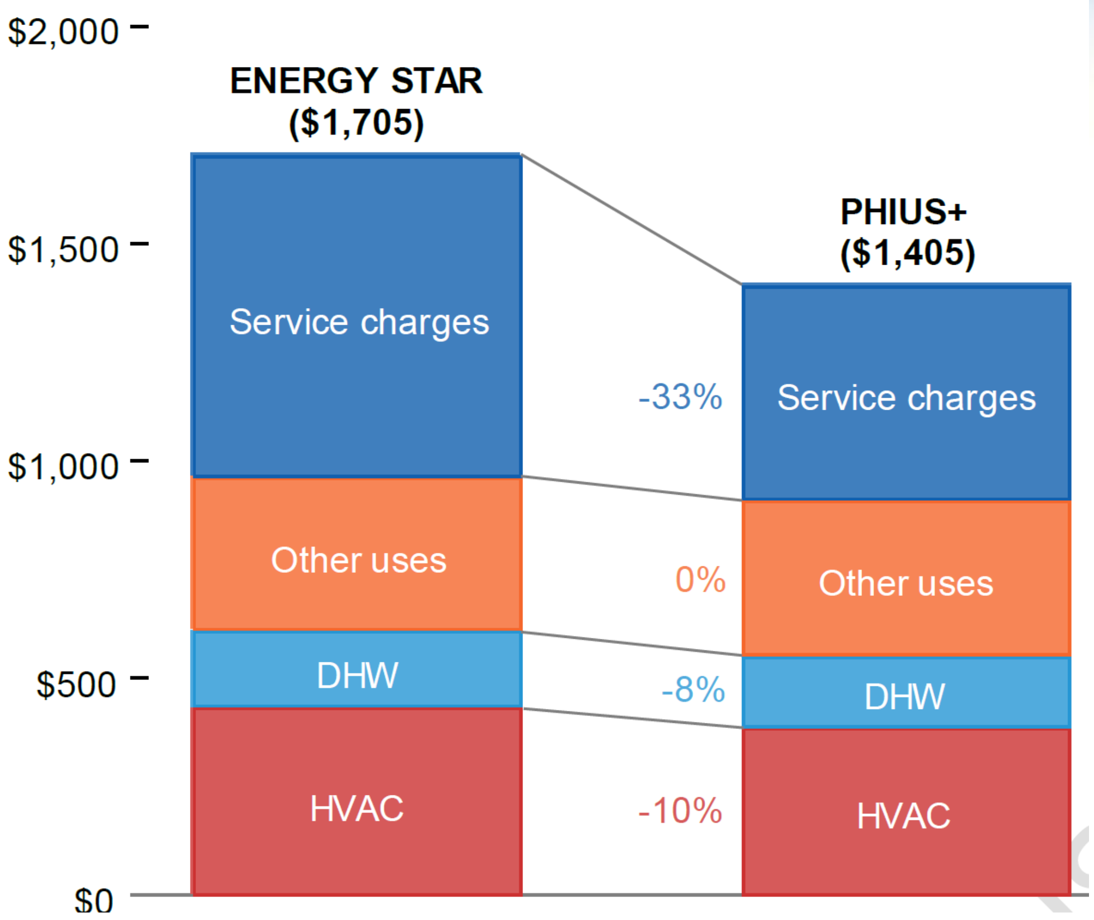
Categories are US EPA Air Quality Index breakpoints for outdoor air

More details: https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Passive-House-Tierra-Linda.pdf

Source: Slipstream Inc

Current Tech New Construction Case Study: Energy Findings

- 65% lower delivered-energy requirement for space heating (ambiguous results for cooling)
- 76% lower site-energy for heating/cooling
- 30-35% lower carbon emissions
- 19% lower tenant utility bills
- ~20% cost premium (brazed fittings, steel studs, HVAC sized for -10°F day instead of 0°F day, GC experience)



$178 / ft² construction $214 / ft² construction

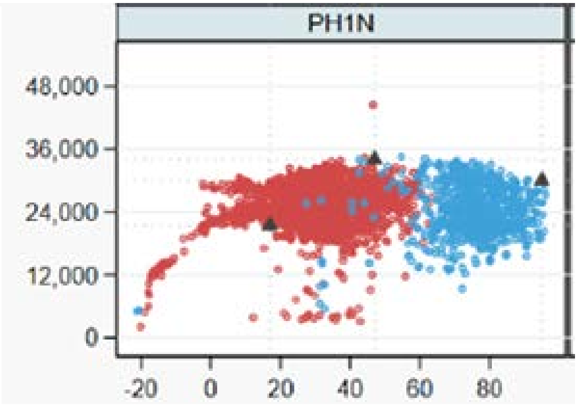
More details: https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Passive-House-Tierra-Linda.pdf

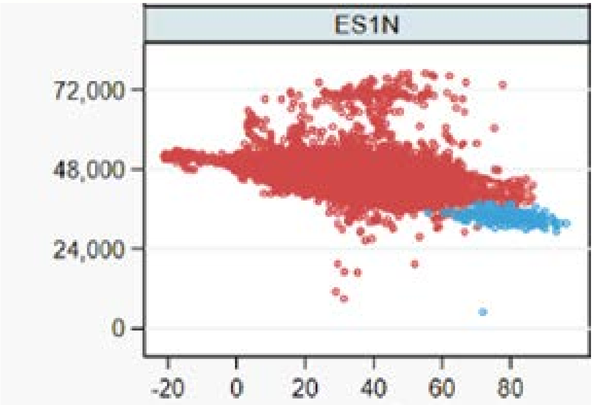
Source: Slipstream Inc

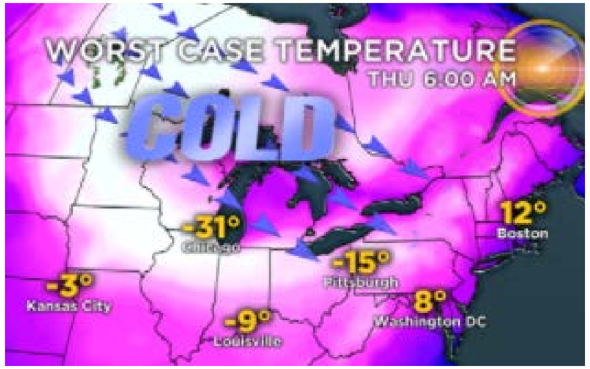
Current Tech: Ducted ASHP & Condensing Furnaces

ASHP loss of capacity with outdoor temp:

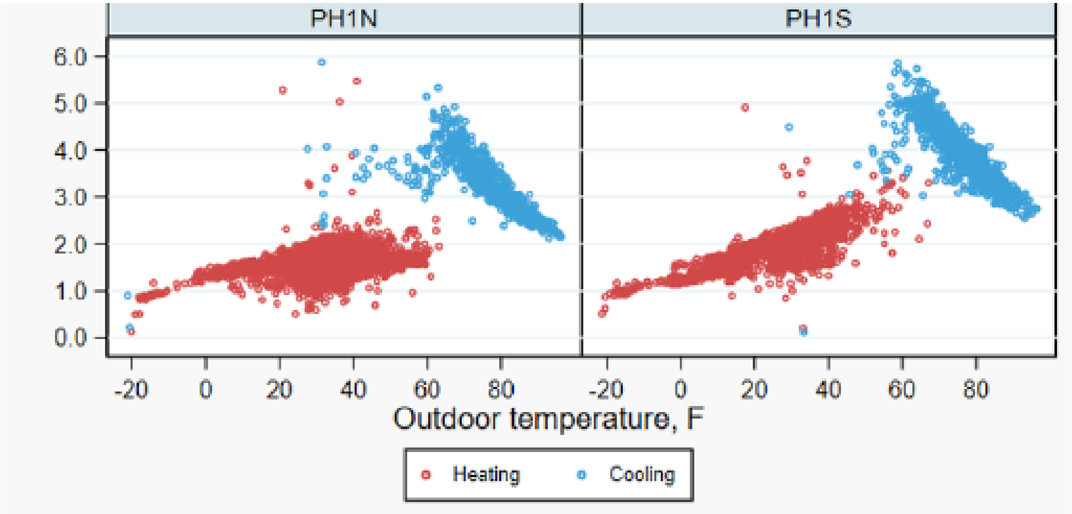
heat pump (PH1N) vs furnace (ES1N)







Compressor COP excluding air handler power for two ducted heat pumps



More details: https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Passive-House-Tierra-Linda.pdf

Source: Slipstream Inc

EPRI National Electrification Assessment

- Electric Power Research Institute (EPRI)
- Electric loads increase (EVs, space heat, water heat)
- Storage increases
- Gas use increases in all scenarios providing non-intermittant generation

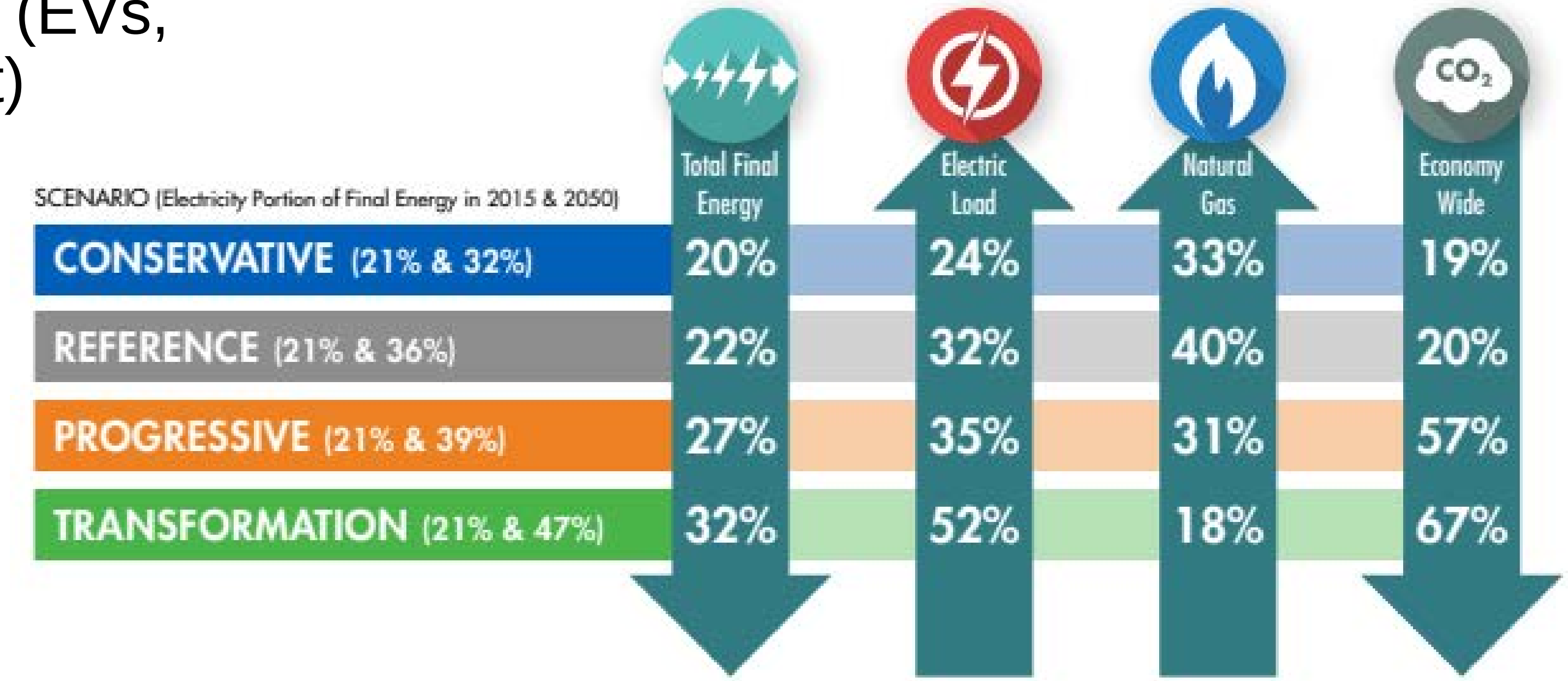
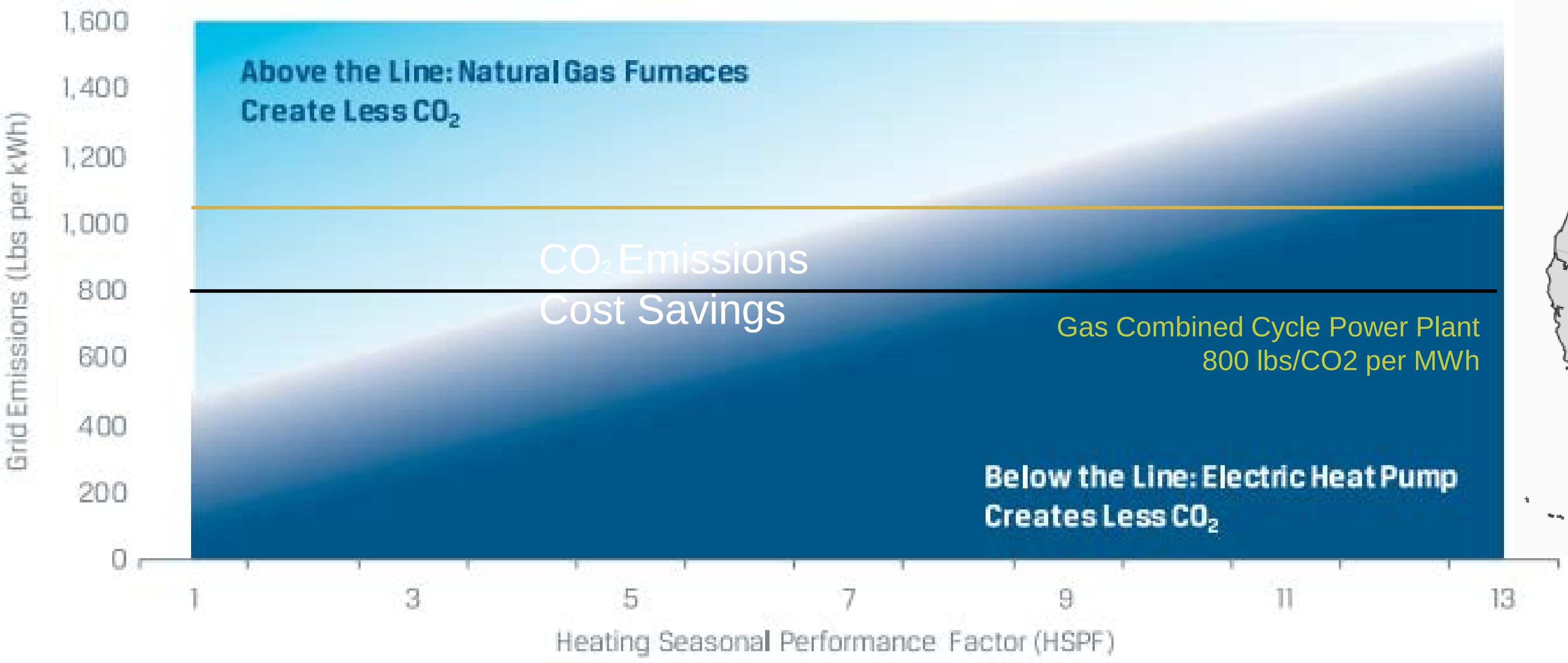


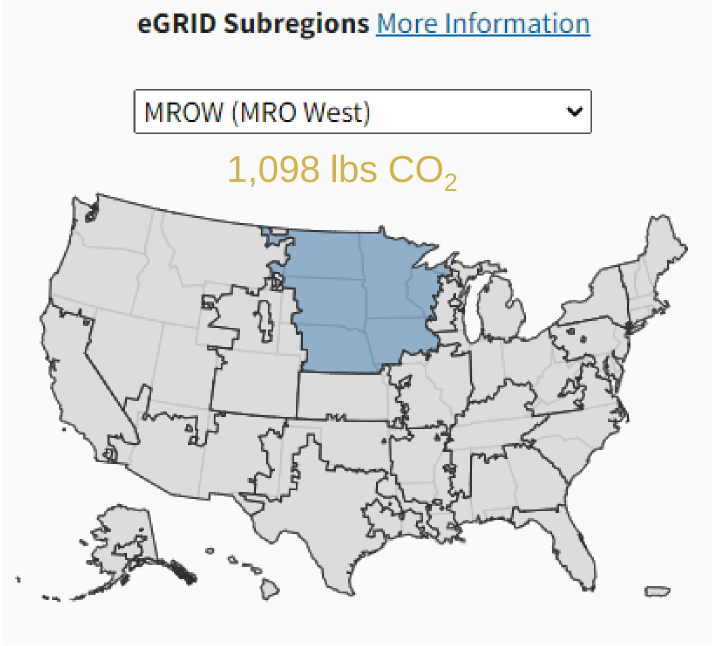
Figure ES-2. High-level Overview of Modeling Results

Source: US National Electrification Assessment (EPRI 2018)

Current Tech GHGs: On-site vs At-Plant Combustion

Emissions Reduction For Electric Heat Pumps (EHP)
Based on Weather and Electric Grid Emissions





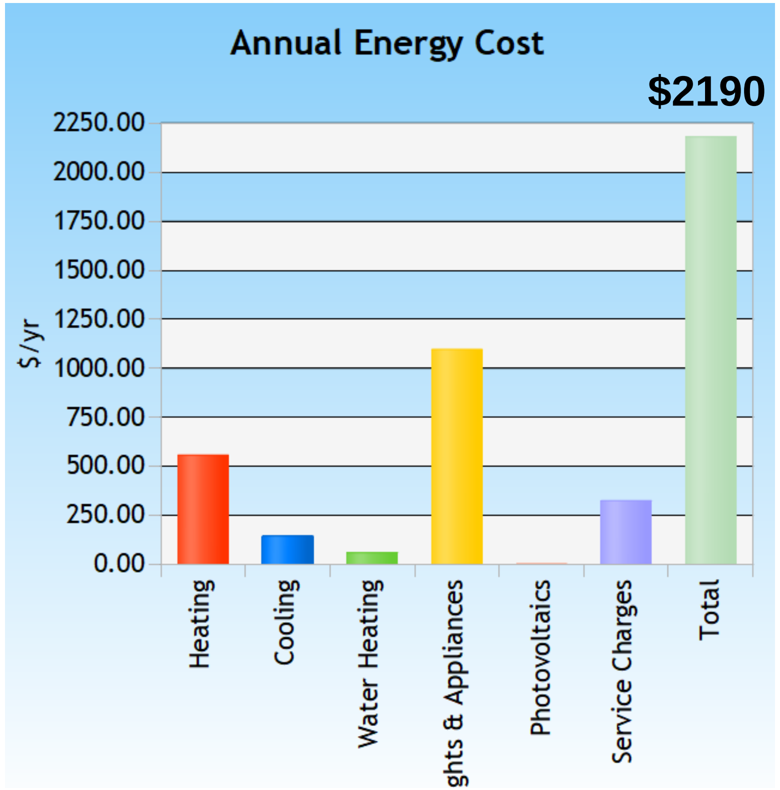
Design guidance: EHPs in Minnesota should be **> 8 HSPF** for immediate CO_2e reductions

Source: ICF Report "Implications of Policy-Driven Residential Electrification"; 2019 EPA eGRID Emission Rates for MROW

Technologies to Decarbonize Existing Homes

Existing Home Case Study: Furnace or ASHP

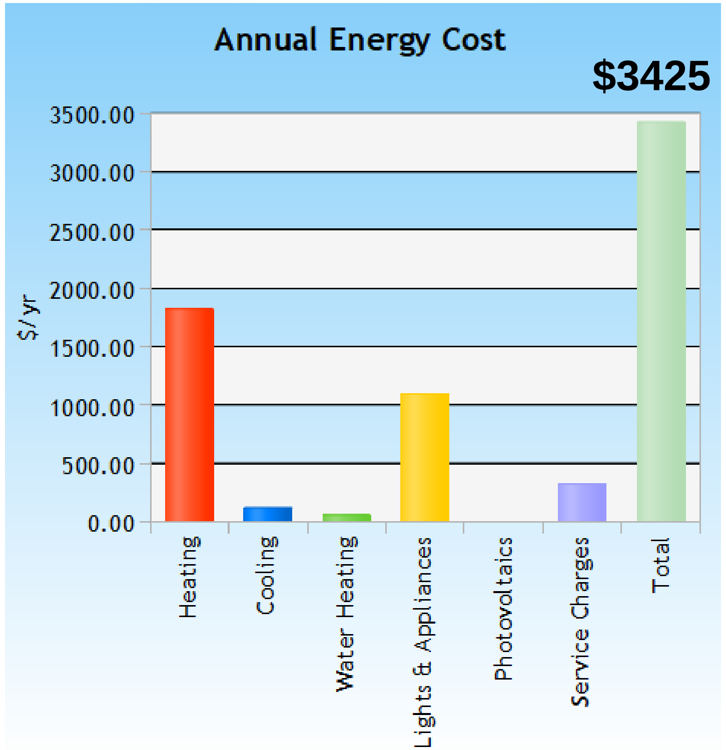
Trane S9V2 furnace



96% AFUE

HSPF: 10.0

Mitsubishi ducted VRF
PUZ-HA42NKA1 & PVA-A42AA7



Carbon Dioxide (CO_2) - tons/year

Heating	7.0
Cooling	0.8
WaterHeating	0.8
LightsAppliances	5.9
Photovoltaics	0.0
Total	**14.5**

?

CO_2e

Carbon Dioxide (CO_2) - tons/year

Heating	9.4
Cooling	0.6
WaterHeating	0.8
LightsAppliances	5.9
Photovoltaics	0.0
Total	**16.7**

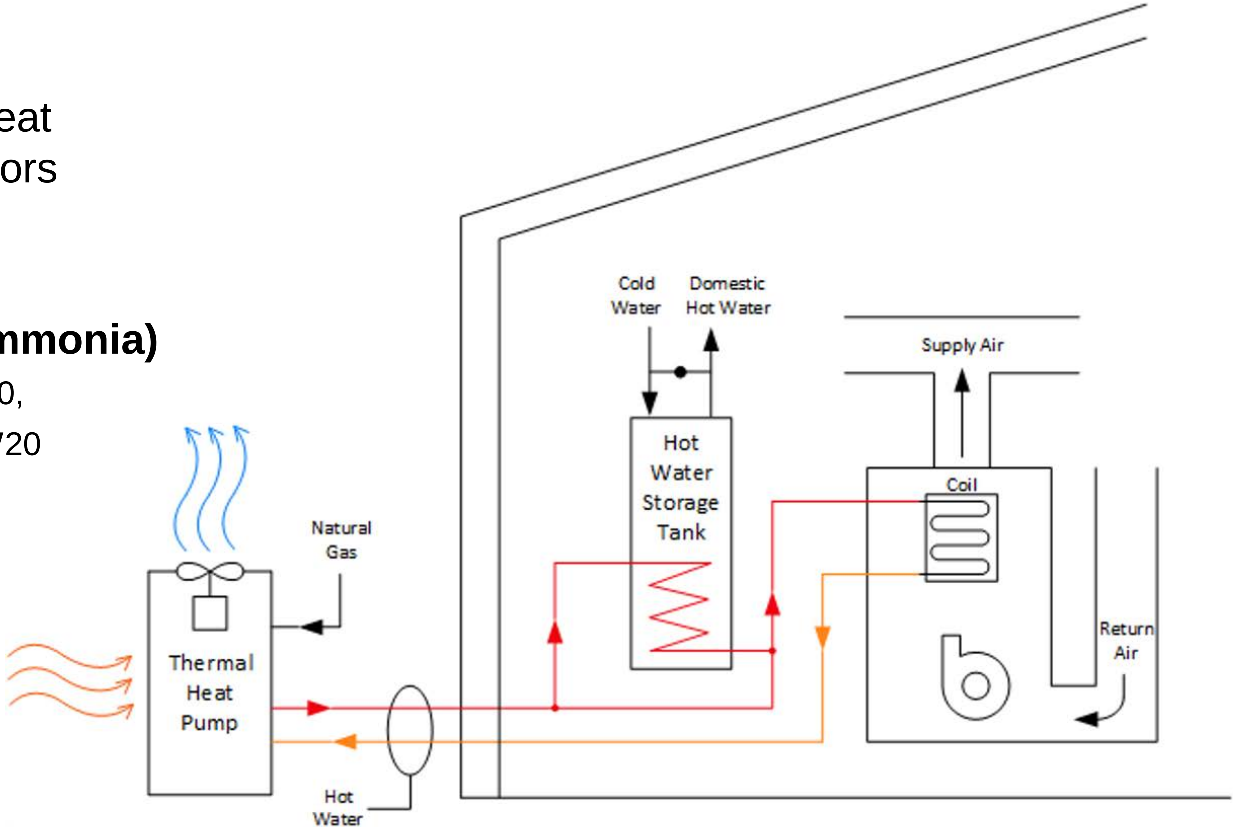
b.1963 retrofitted 2020; energy modeled using REM/Rate v.15

Or maybe.. a Gas-fired Heat Pump ?

Use natural gas efficiently and cut carbon by 1/3
1 device = 2 uses (**space and water** heating)

+140% AFUE efficient
No auxiliary / backup heat
All combustion is outdoors
4-5 year payback

Natural refrigerant (ammonia)
0 GWP20 vs 4,340 GWP20,
using methane: 84 GPW20

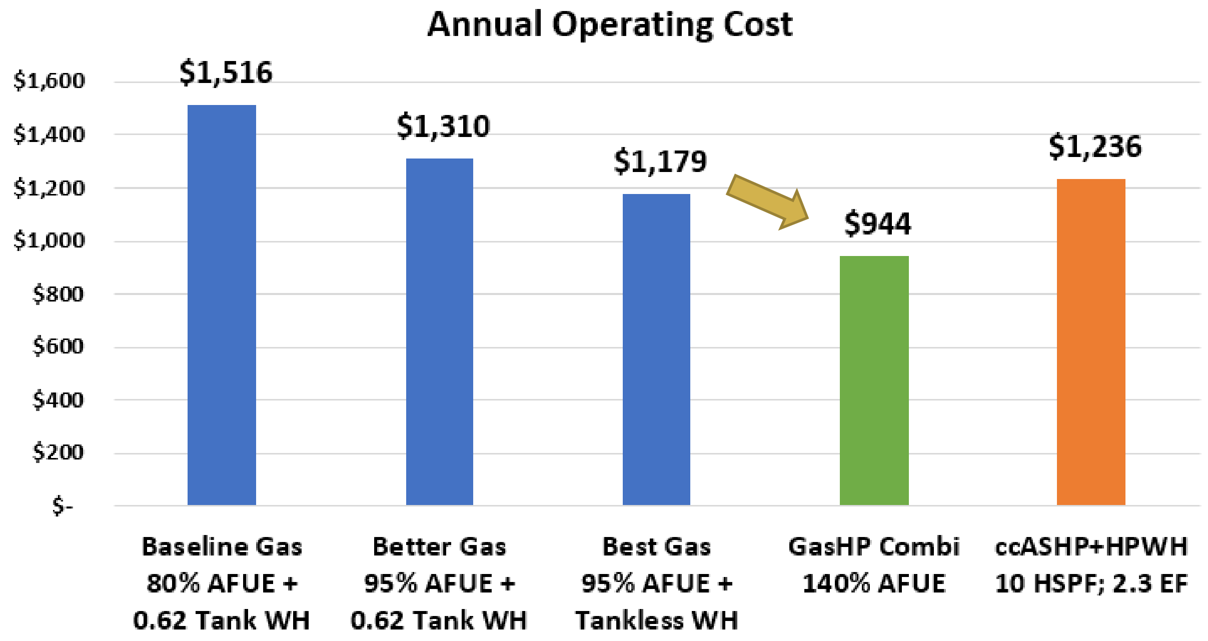


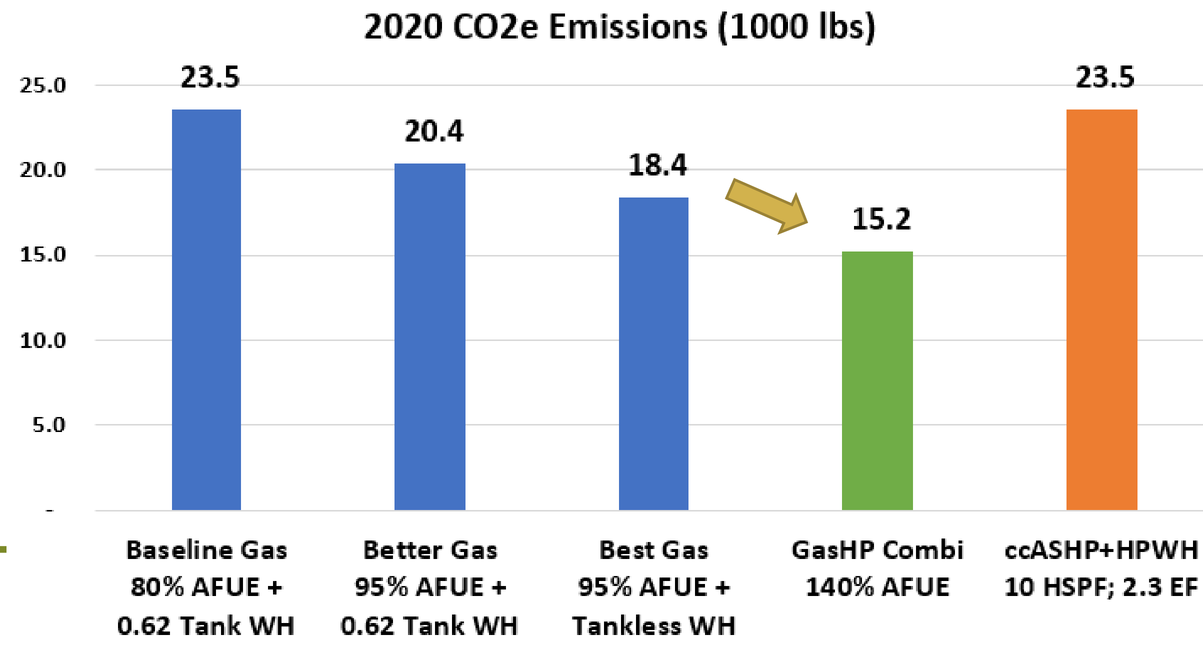
Gas Heat Pump Deployment Results

Sound Check

64-70 dB - 14 SEER A/C   60-67 dB - Gas Heat Pump

Spreadsheet analysis from EnergyPlus models





Thermally Driven Gas Heat Pump Developments

130-140% Efficiency (CoP)

Residential Heat Pump Water Heater (10 kBtu/hr)

Residential Low-Capacity Combination Space & Water Heating System (20 kBtu/hr)

Residential Large-Capacity Combination Space & Water Heating System (80 kBtu/hr)

Light Commercial Combination Space & Water Heating System (140 kBtu/hr)

Pilot programs underway across all climate zones in the U.S.

Decarbonization Options for Water Heating

Gas HPWH (Pre-commercial): As-installed $COP_{site,average} \approx 1.5$

0.35 Units Cooling (Ambient Energy)

0.65 Units Site Energy

1.0 Units Hot Water

Electric HPWH: As-installed $COP_{site,average} \approx 2.5$

0.6 Units Cooling (Ambient Energy)

0.4 Units Site Energy

1.0 Units Hot Water

For 100 Gal of Hot Water Produced (67 F Rise) – in CA

	Elec. In (kWh)	NG In (Therm)	GHG Emitted (Lbs. CO2e)		COP_{source}	
			All Plants	Non-Baseload	All Plants	Non-Baseload
Gas HPWH	0.8	0.3	5.6	6.1	1.29	1.24
Electric HPWH	6.6	N/A	4.3	8.2	1.16	0.92

Note: Excludes backup/supplemental heating

Disclaimer: Estimates are based on field data for gas-fired/electrically-driven HPWHs and do not represent certified performance

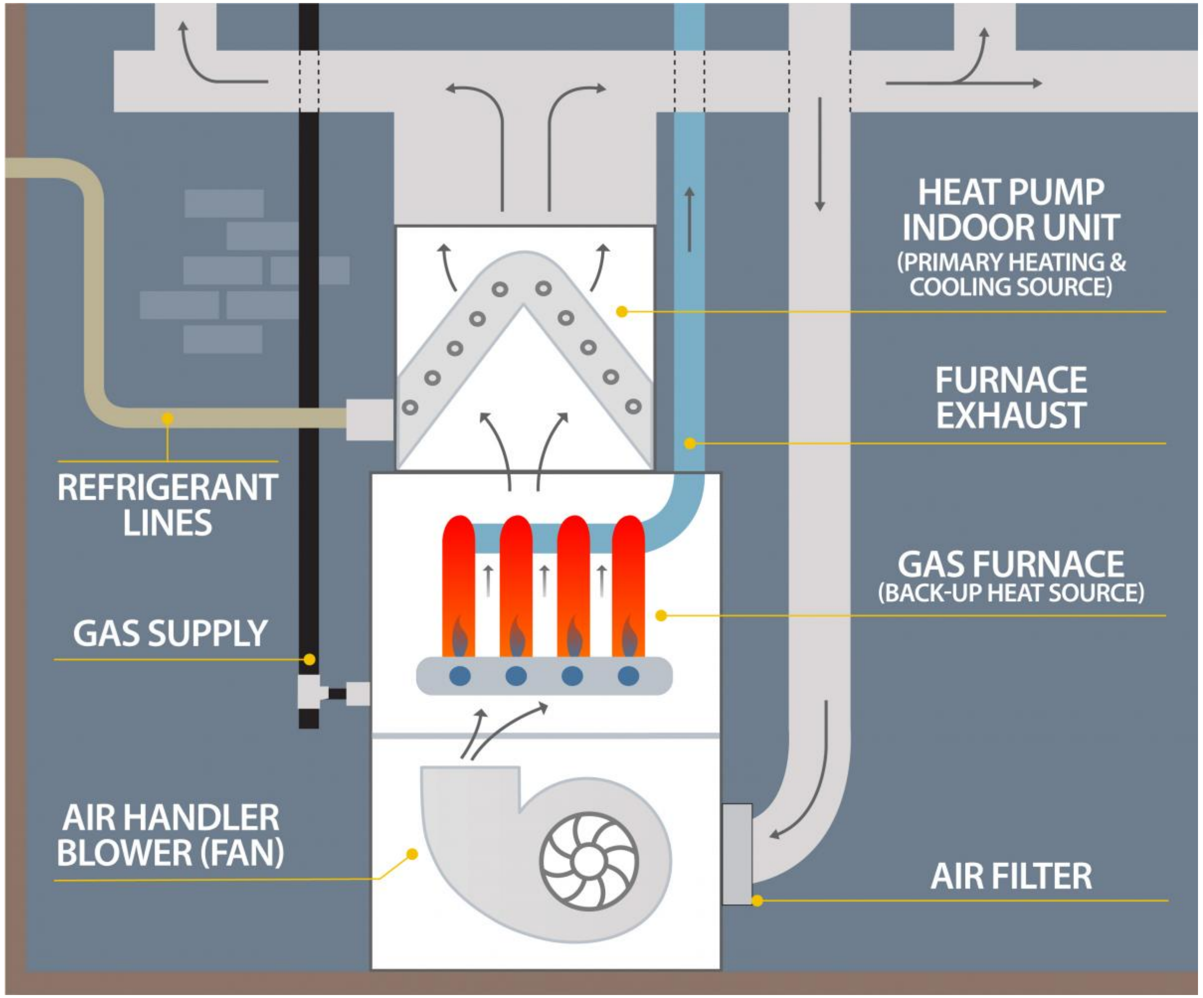
Site/Source Factors: US National 2016 eGRID Plant Level Database (CAMX), 2.12/2.68 Electricity (All/Non-baseload) & 1.09 Natural Gas; CO2e Emission Factors (Lb./MMBtu): 189.2/361.8 Electricity (All/Non-Baseload) & 149.16 Natural Gas

Data References: 1) Glanville, P., Vadnal, H., and Garrabrant, M. (2016), "Field testing of a prototype residential gas-fired heat pump water heater", Proceedings of the 2016 ASHRAE Winter Conference, Orlando, FL., 2) Shapiro, C. and Puttagunta, S. "Field Performance of Heat Pump Water Heaters in the Northeast" Report prepared for U.S. Dept. of Energy under NREL Contract No. DE-AC36-08GO28308, 2016; 3) Ecotope, Inc. 2015. Heat Pump Water Heater Model Validation Study (Report No. E15-306). Portland, OR: Northwest Energy Efficiency Alliance.

Image Sources: GHPWH photo courtesy of SMTI, EHPWH photo from A.O. Smith

Other Emerging Technology: Gas/Electric Hybrid HVAC (Furnace + Heat Pump)

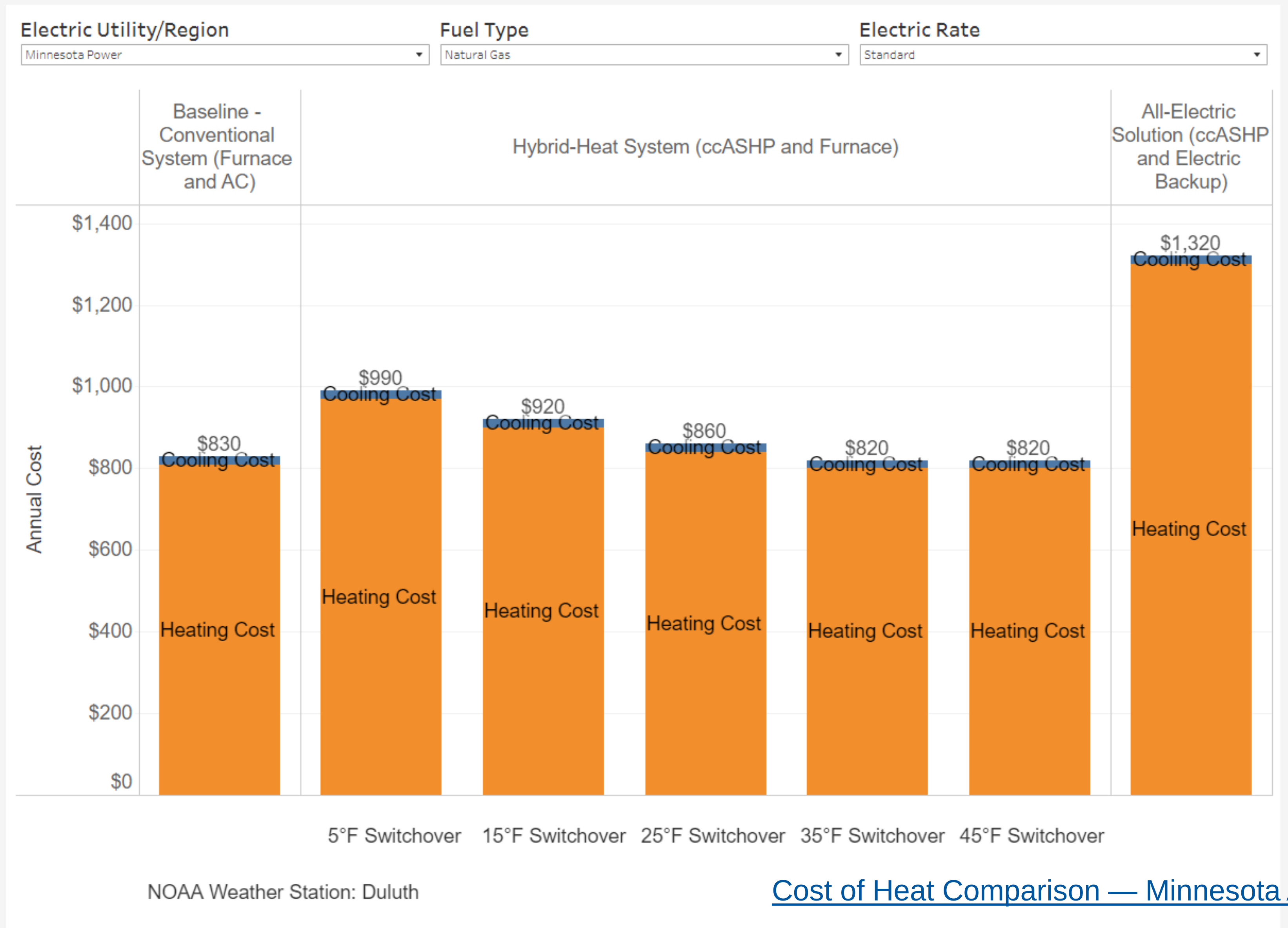
Right-Sized Electric Heat Pump



Low-Capacity Gas Furnace

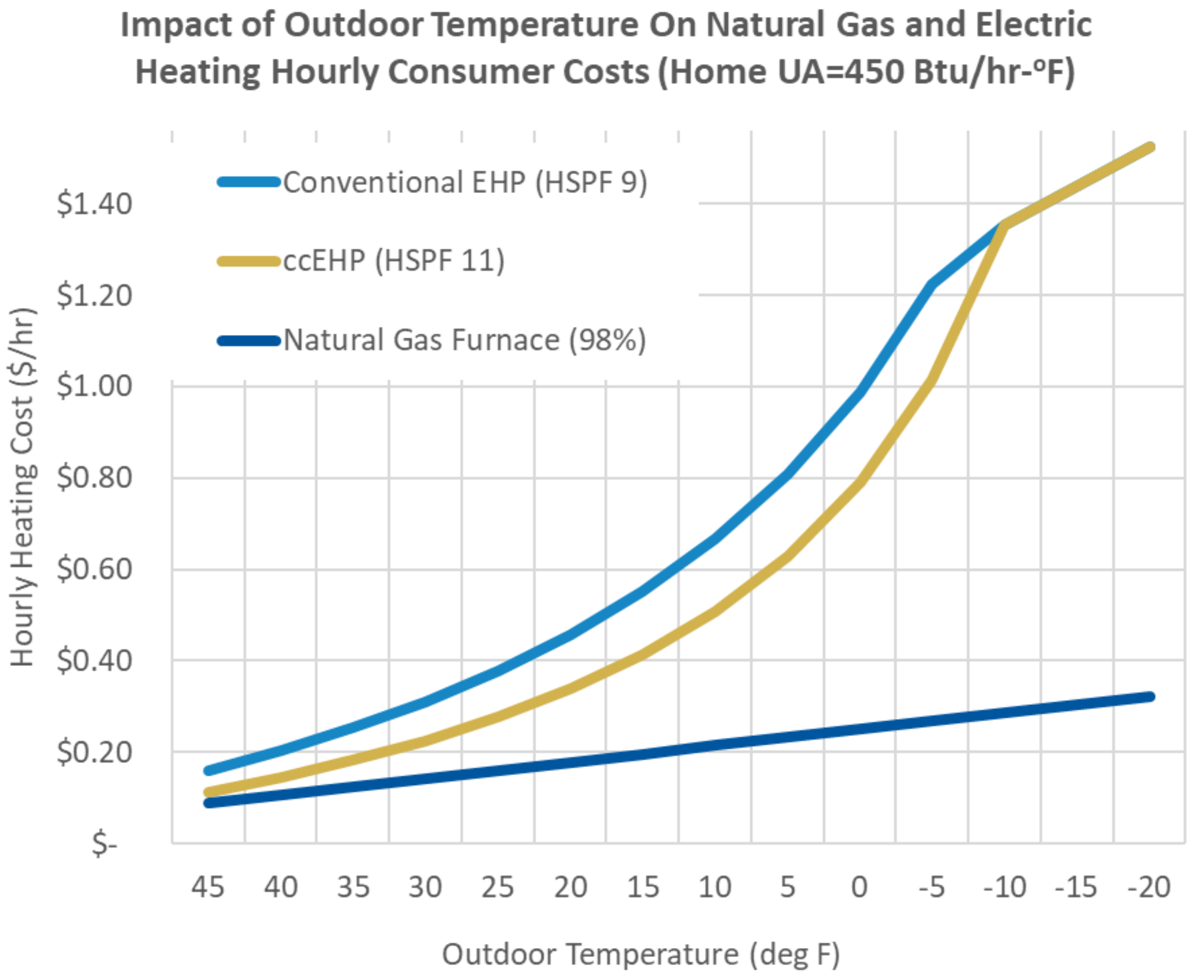
Key Concept: Balance Point (BP) for energy supply crossover

Hybrid HVAC Analysis – Cost of Heat Comparison



[Cost of Heat Comparison — Minnesota ASHP Collaborative (mnashp.org)]

Hybrid Systems: Consumer Value



At mild temperatures (e.g., 40ºF and above), electric heat pumps have hourly space heating costs slightly higher than natural gas.

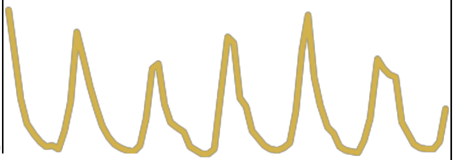
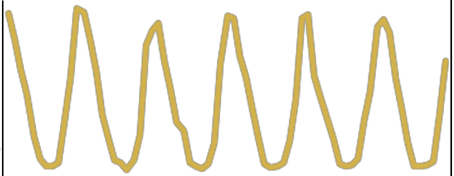
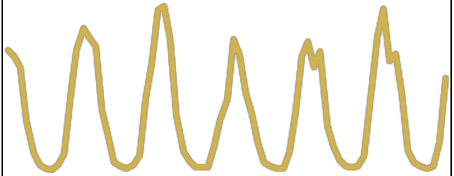
At colder temperatures, electric demand increases and electric heat pump efficiency decreases, leading to non-linear increases and much higher hourly electric space heating costs.

Temperature (ºF)	Electric/Gas Heating Cost Ratio
20	1.9
10	2.4
0	3.2

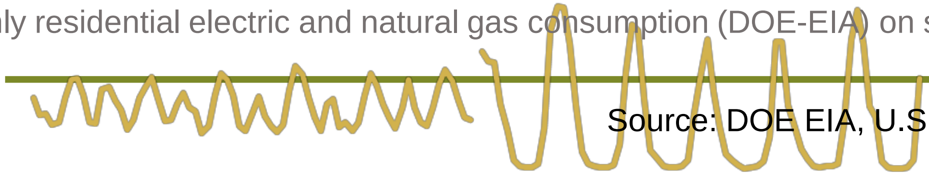
UA Value of 450 is typical for single-family homes in GTI analysis of select Nicor Gas homes. UA accounts for home size and insulation level. Prices based on DOE-EIA average 2020 residential natural gas ($7.78/MMBtu) and electric ($0.1284/kWh) in Illinois.

Winter Natural Gas Winter Peaks >>Summer Electric Peaks

Monthly Energy Consumption In Residential Sector (Six Years)

2013 - 2018	Residential Electric	Residential Natural Gas	Peak Natural Gas: Peak Electric Ratio	% Gas Heating	% Electric Heating
CA			2.2	64	27
CO			3.4	70	22
IL			5.6	78	16
NY			4.6	58	11

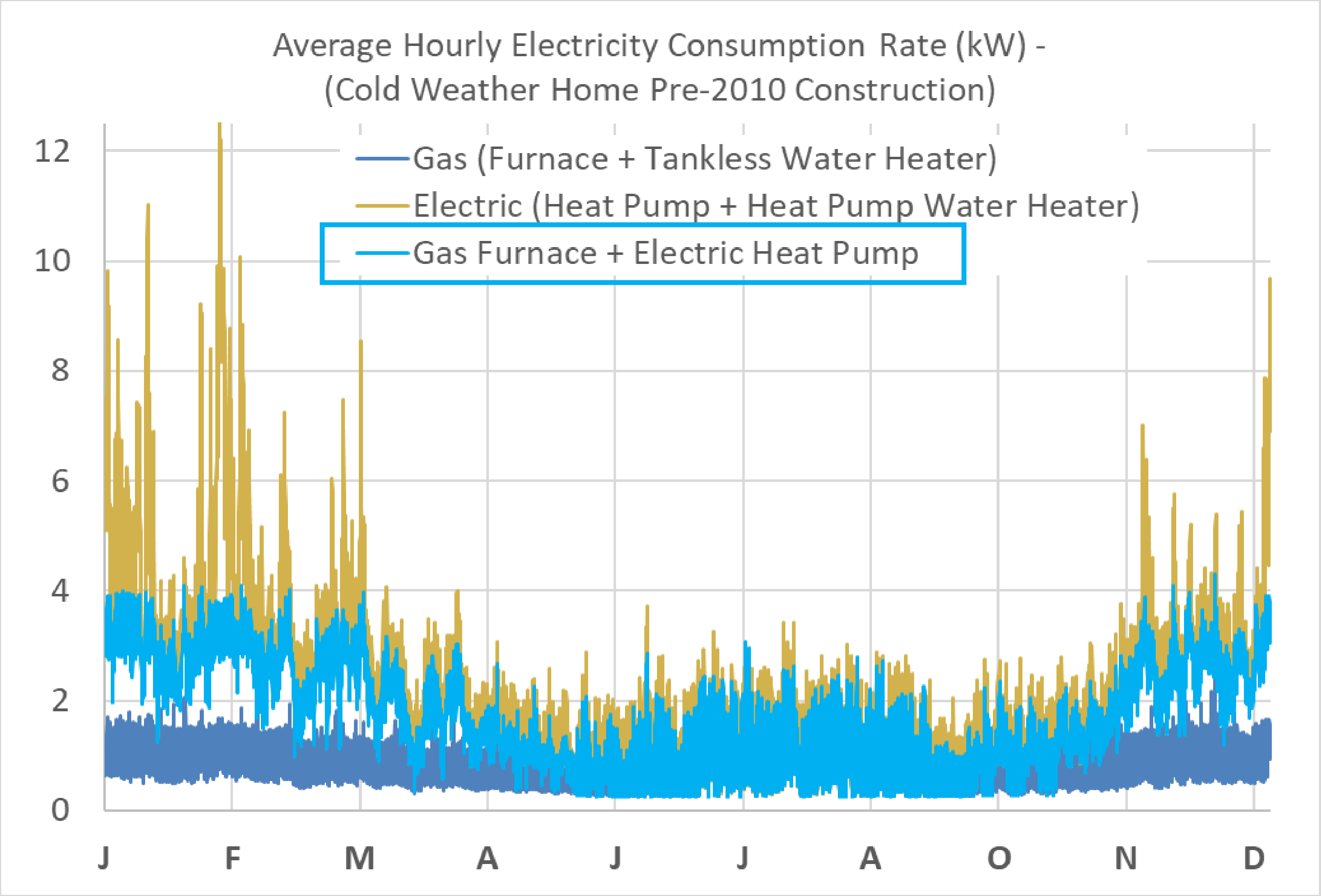
Monthly residential electric and natural gas consumption (DOE-EIA) on same energy scales. Six years of data.



Substantially more natural gas is delivered in a peak month to residential users than electricity. Heating loads are very intense.

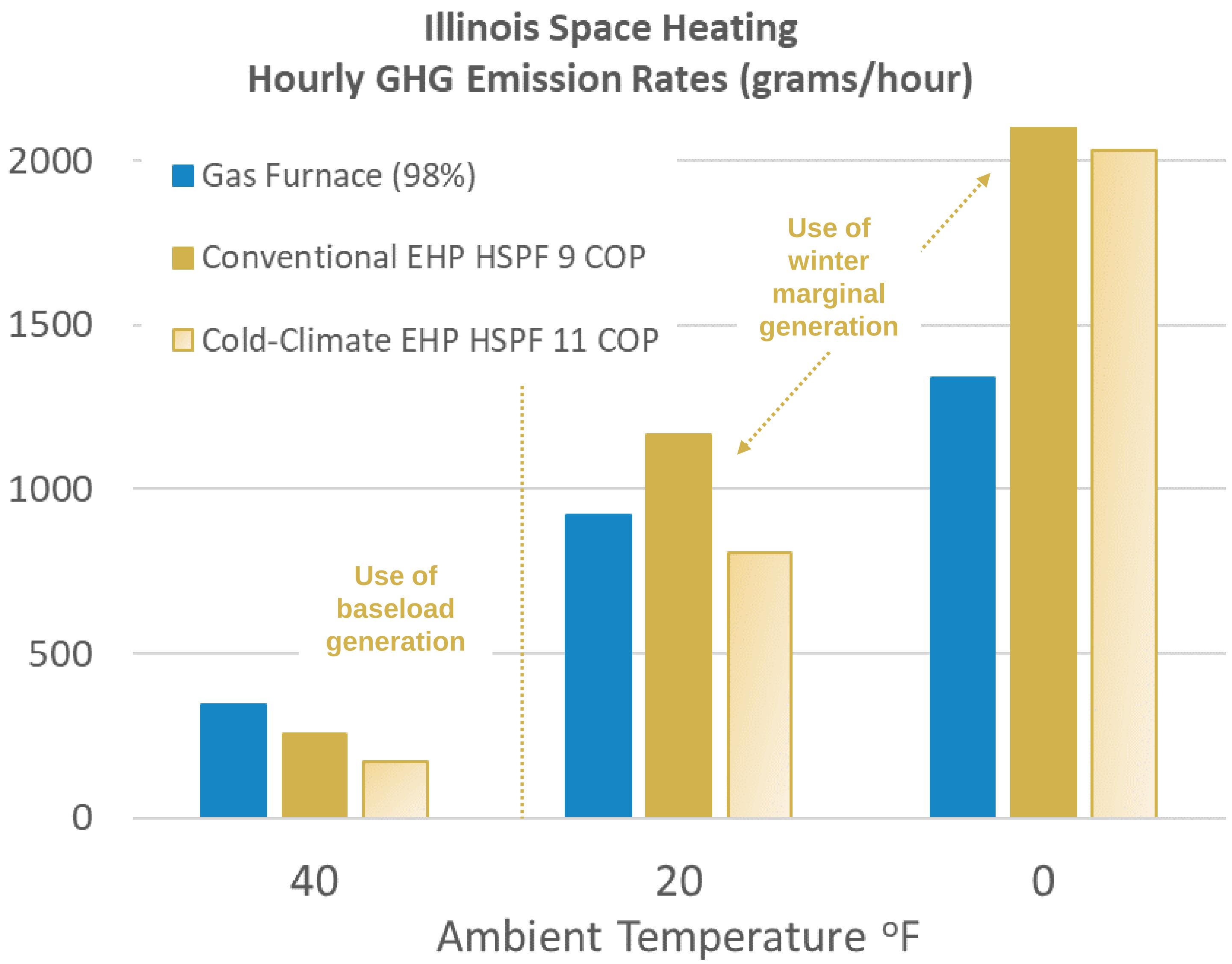
Source: DOE EIA, U.S. Census

Hybrid HVAC: Reducing Peak Electric Demand



In example 8,760-hour residential home energy model, all-electric home space heating results in large increases in peak winter demand.

Hybrid gas/electric systems combining natural gas heating on colder days with an electric heat pump on milder winter days dramatically lowers peak electric demand and host of related negative consequences.



At mild temperatures (e.g., 40°F and above), electric heat pumps have lower GHG emission rates.

With colder temperatures, electric demand increases and marginal winter generation plants are brought online.

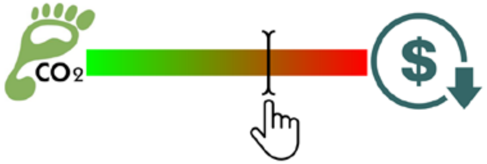
Under colder winter conditions, electric heat pumps likely to produce higher full-cycle GHG emissions than gas heating.

Uses baseload power at 40°F (367.4 g/kWh) and 100% natural gas marginal generation at colder temperatures (468 g/kWh). Excludes house fan power. Absolute values will vary depending on house size and degree of weatherization.

Smart(er) Hybrid HVAC Control

Smart (Connected)

Smarter (AI)

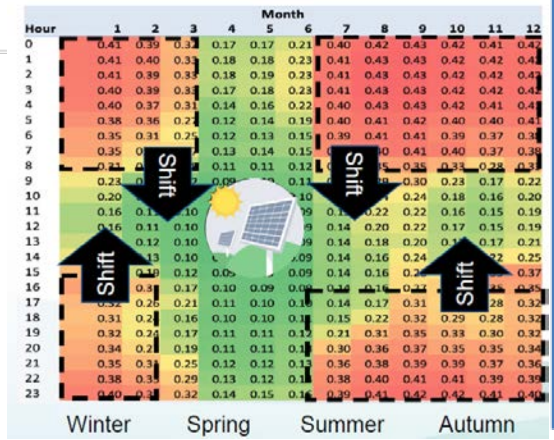


Weather

Grid DR Signals

Work with any connected thermostat to make it smarter

Environmental Perspective



Customer Perspective

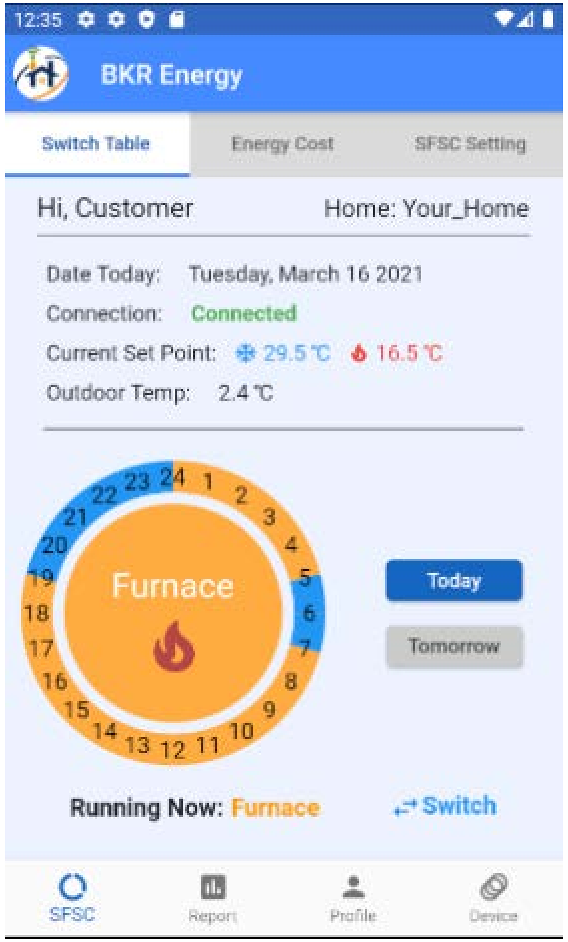
Utilities

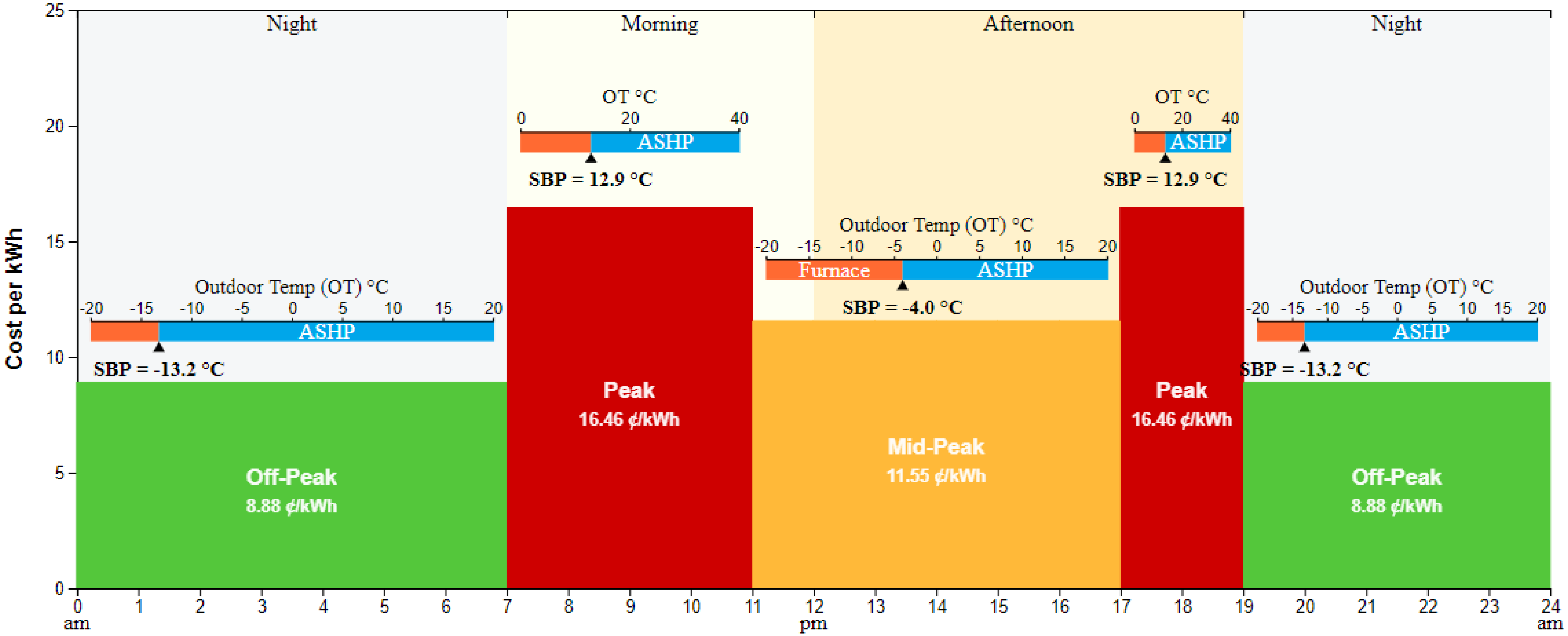
Real time pricing

2021 Hourly Marginal Emissions Intensity (MT/ CO_2)

Source: Angela Tanghetti, CEC

One example: BKR Energy day-ahead forecast

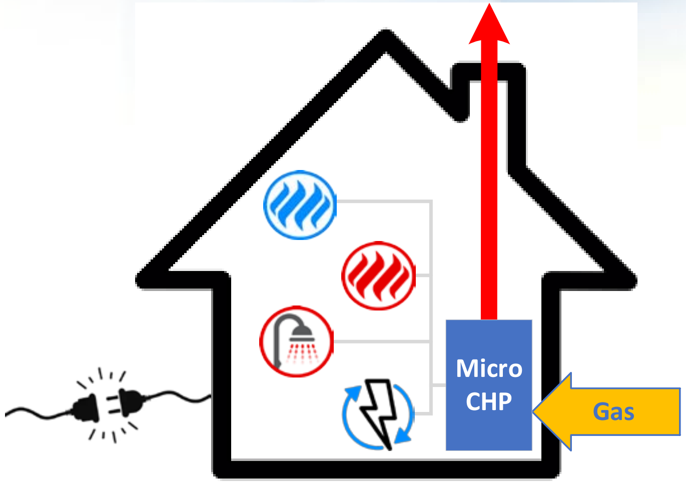




Small-scale Micro-CHP (≤ 50kW) are also on the near-term horizon

Key Driver: Affordable Resilience

- Major weather and non-weather interruptions are on the rise
- LBNL found electric outages very expensive for commercial sector (~$6,000 per 8-hr outage)
- Low natural gas prices, high CHP efficiency, capital costs coming down
- Dozens of manufacturers entering North American Res/Com market
- Can bring fuel-fired site energy COP > 1.0



Actionable Gas Technologies by 2030

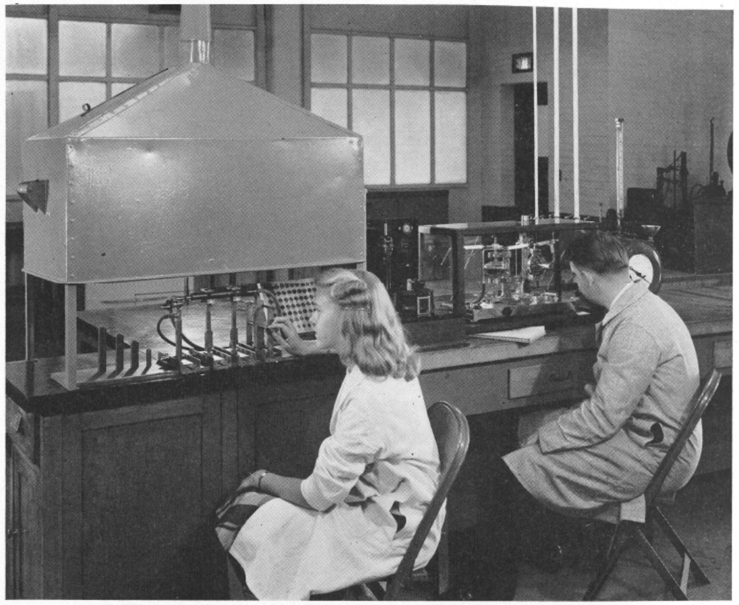
- Renewable Natural Gas
- Hydrogen
- Decarbonized future

Decarbonized Fuels: A Historical Perspective

Blending H_2 with delivered fuels is not new…

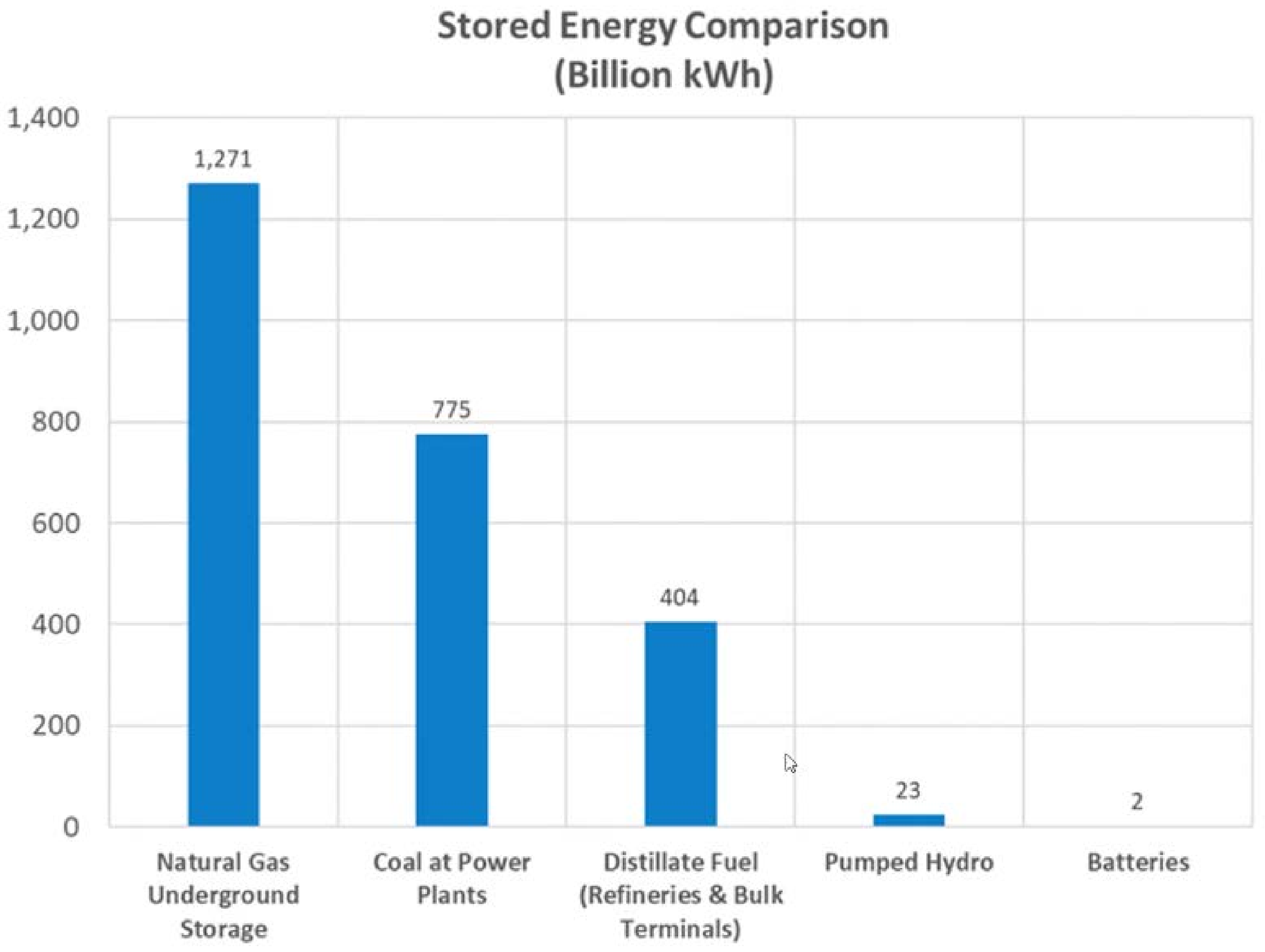
- Before “Natural Gas” there was “Town Gas”*
  - ~50% H2, balance CH4, CO, light HCs, etc.
  - Commonly gasified coal, for lighting, then indoor uses (cooking, heating, refrigeration, etc.)
- Manufactured gases phased out as Natural Gas grew post-WWII, though use continues
  - Hawaii Gas Co. delivers syngas, via refining oil, with ~15% H_2 since 1970s to ~30k customers
  - Design guidance (still used!), based on data from ~50s from AGA Labs (pic.), include mfr’d gases
  - Many appliance standards also permit mfr’d gases in addition to propane, etc.
- European appliances are certified with 23% H_2 to assure performance with wider range of gas qualities

Gas Works Park – Seattle (Decomm. 1956)



*Illuminating Gas, City Gas, Manufactured Gas, etc.

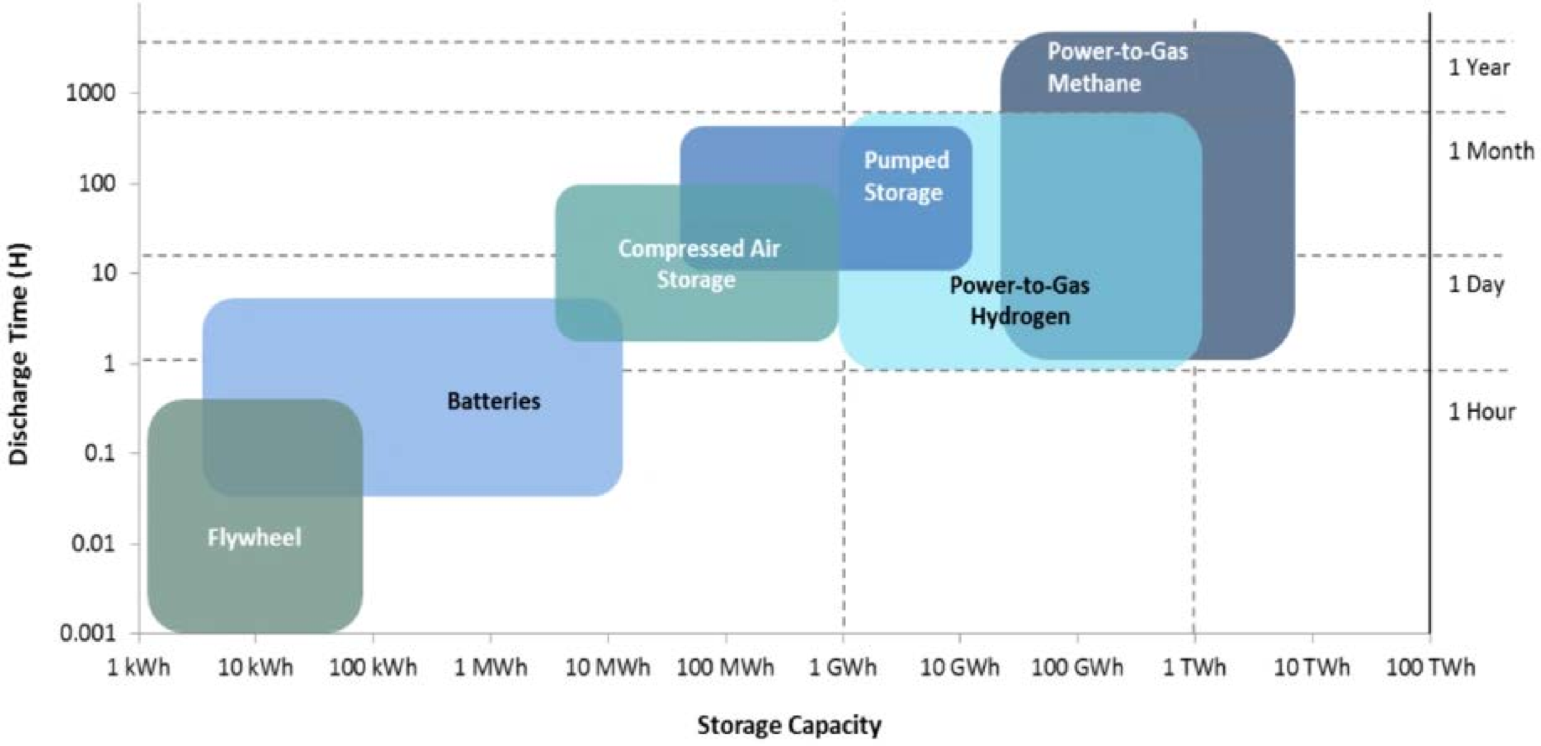
Where Do We Store Energy Now?



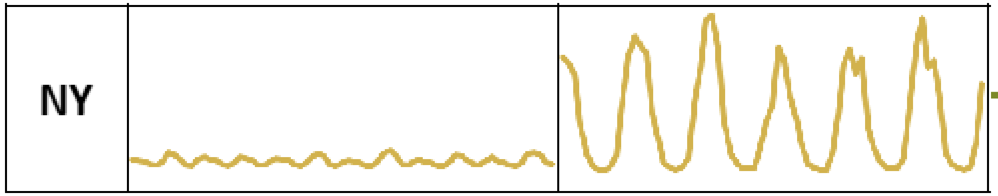
Source: DOE-EIA; includes thermal energy equivalent values.

Solving seasonal energy storage challenges

Electrons → Molecules

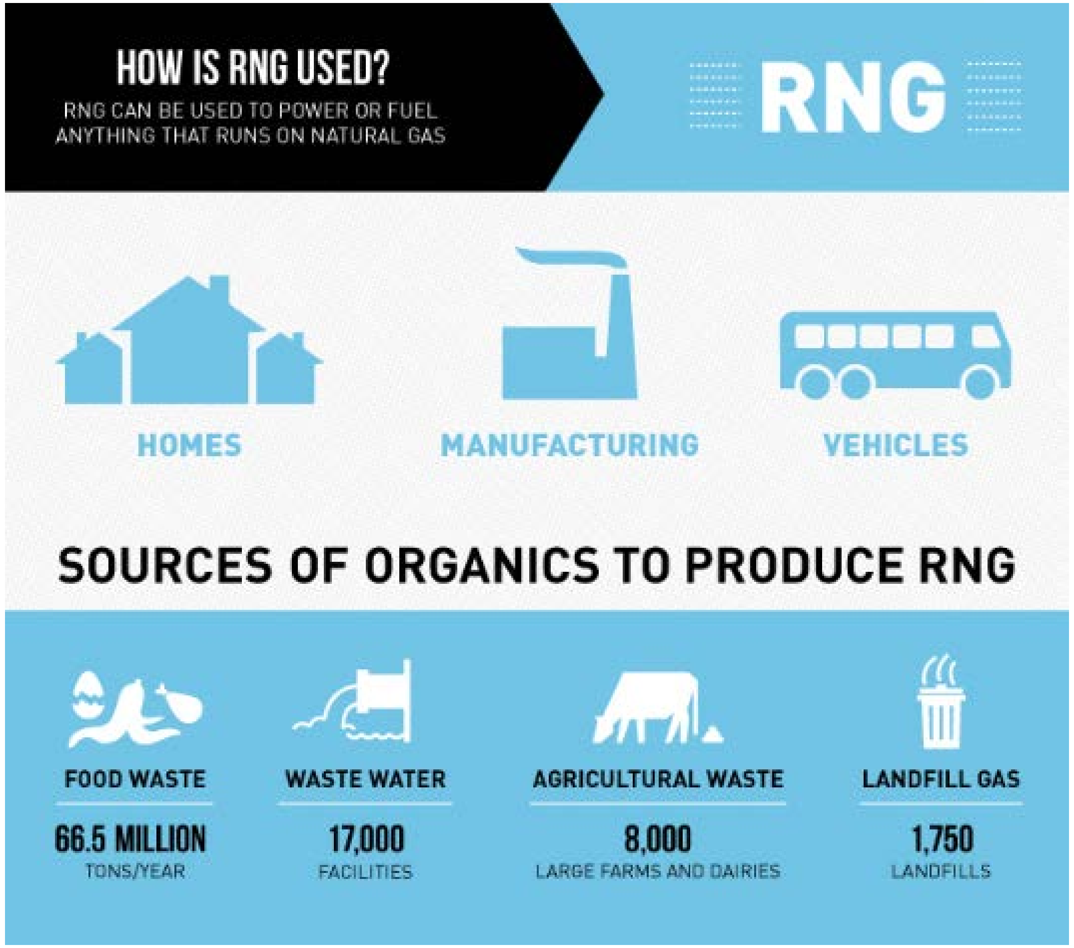


californiahydrogen.org



What is Renewable Natural Gas?

- **Biogas** that has been processed to remove carbon dioxide and other trace constituents, resulting gas is typically >90% methane
- Methane produced from **digesters**
  - Animal manure (dairy cows, swine)
  - Wastewater treatment facilities
  - Food processing plants
- Methane from Landfills
- RNG produced from **renewable feed-stocks** including forest residues and agricultural wastes.



Benefits and Challenges of Renewable Natural Gas

Benefits

- Decarbonization (pipelines, transportation, power generation)
- Reduced (or negative) GHG emissions
- Improved air quality
- Diversity in energy portfolio
- Value added product for customers
- Financial Incentives

Challenges

- Costs 4x-7x more than fossil gas
- Supply Stability: Variability in composition & supply
- Impact on Infrastructure / Pipeline integrity: CO_2, water, H_2 sulfur compounds, NH_3, bacteria, etc.
- Impact on end use applications:
  - CO_2, CO, H_2 all impact flame stability, engine knock
- Safety – Odorization/leak detection

Renewable Natural Gas

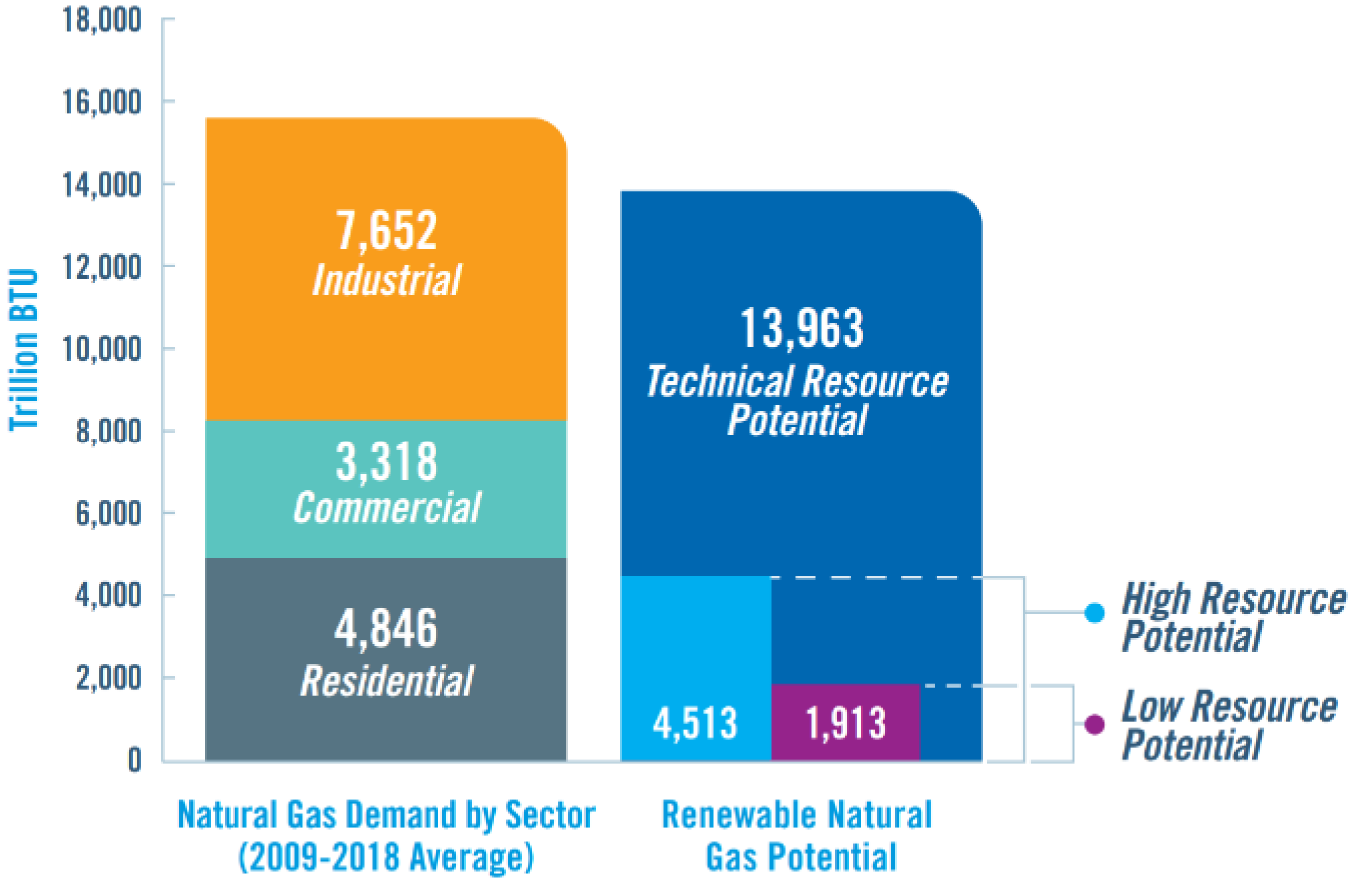
Sizable Emission Reductions

Greenhouse gas emissions (GHG) reduction potential in the low and high resource scenarios ranges between 101-235 Million Metric Tons (MMT) of GHG emission reductions, respectively. Comparatively, the ten year average annual natural gas emissions from the residential sector total 248 MMT.

RNG Could **Reduce Emissions from Natural Gas 95%** in the Residential Sector.[1]

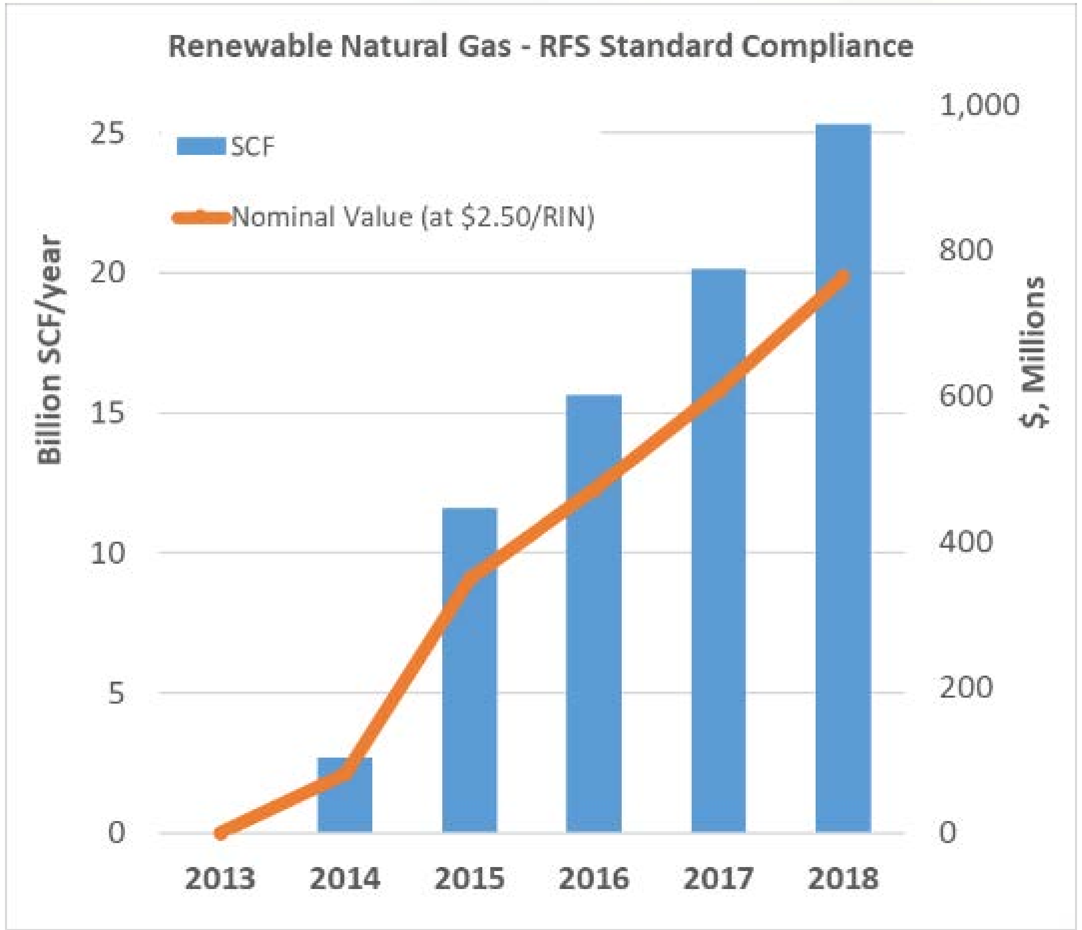
1 *Percentage calculated using ten year average, 2009-2018, EIA natural gas emissions from residential sector consumption.*

RNG Resource Potential



RNG Market is a Direct Response to Incentives

- Market has grown rapidly due to credits
  - US Renewable Fuel Standard (RINS)
  - California Low Carbon Fuel Standard (LCFS)
- 95 RNG sites operational in North America (39 in development)
- RNG production over 25 BCF/yr (over 225 million GGE) in 2018 and about $800 million in value
- How might gas industry formulate incentives for stationary natural gas markets (e.g., residential)? At what price?



Actionable Gas Technologies by 2030

Hydrogen

These homes near Newcastle, UK built by Northern Gas Networks are powered by hydrogen, which burns yellow.

Hydrogen: Where Does It Fit In?

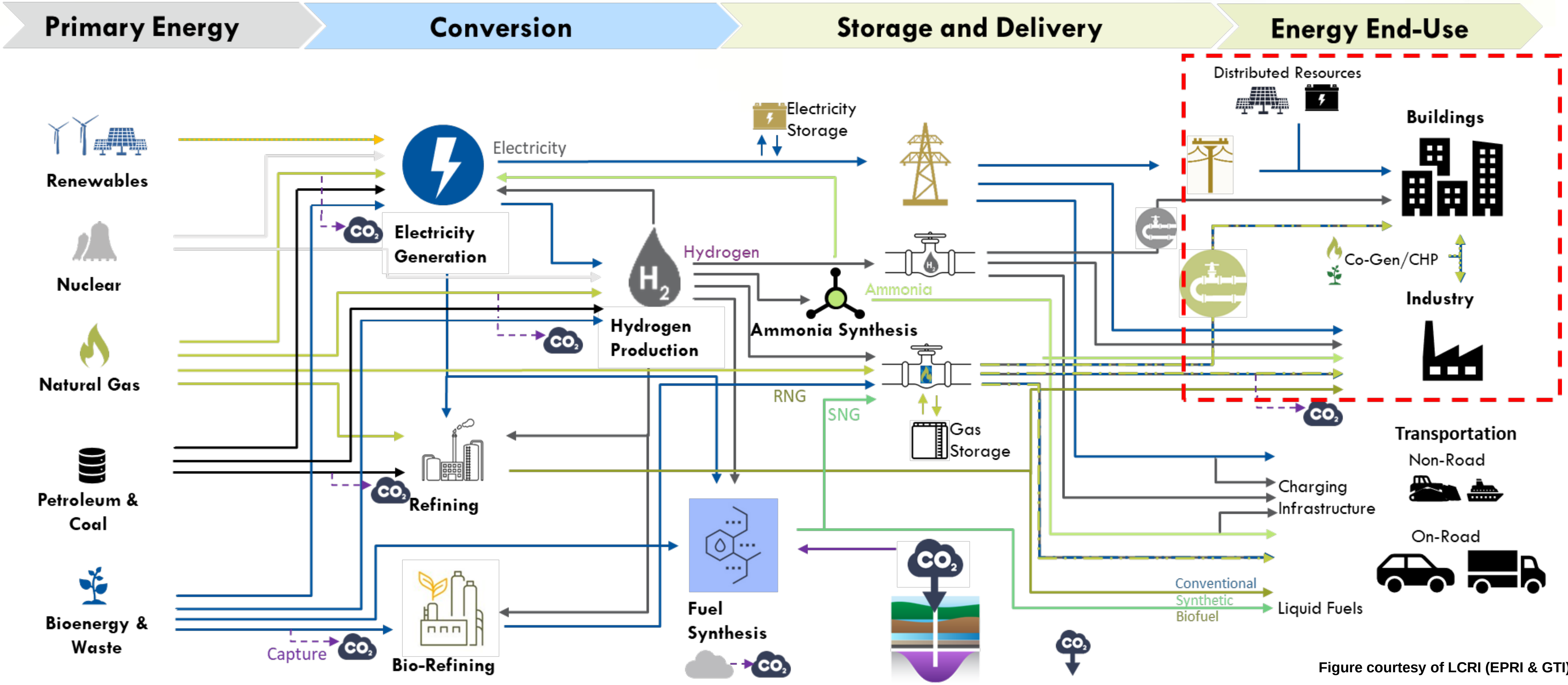


Figure courtesy of LCRI (EPRI & GTI)

Hydrogen is envisioned to play an important role in economy-wide decarbonization, per the **Low-Carbon Resources Initiative** (LCRI), a five-year R&D effort to accelerate the deployment of low-carbon technologies, jointly led by **EPRI and GTI**.

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Hydrogen - A Path Towards Decarbonization

Research and Technology Development to Enable the Hydrogen Economy

Low-carbon Production

- Compact Hydrogen Generator
- Biomass gasification
- Hydrogen power generation

Compatibility with Natural Gas Delivery Infrastructure

- Material impacts of blending
- Operational impacts
- Blending technology and standards

Use in Industry and Buildings

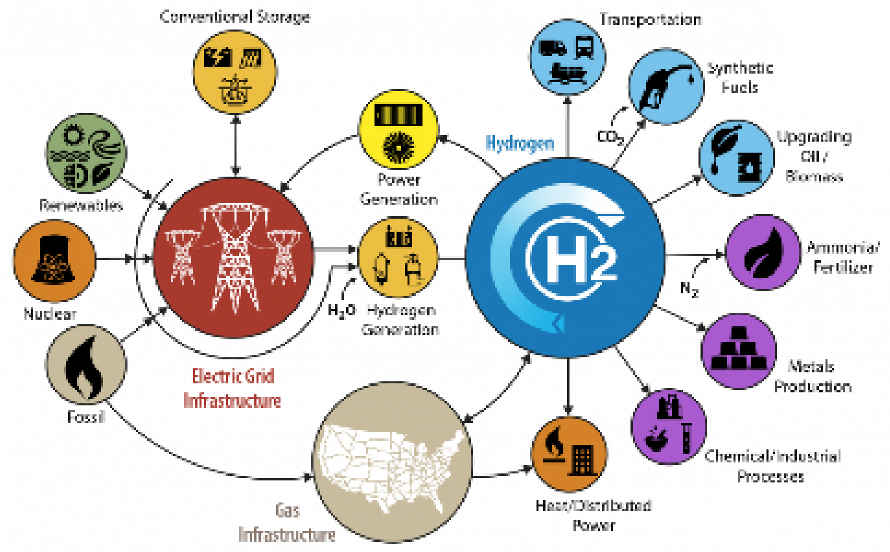
- End-use equipment testing
- Codes and standards

Use in Transportation

- California Fuel Cell Partnership
- Fueling station technology
- RNG-to-hydrogen fueling

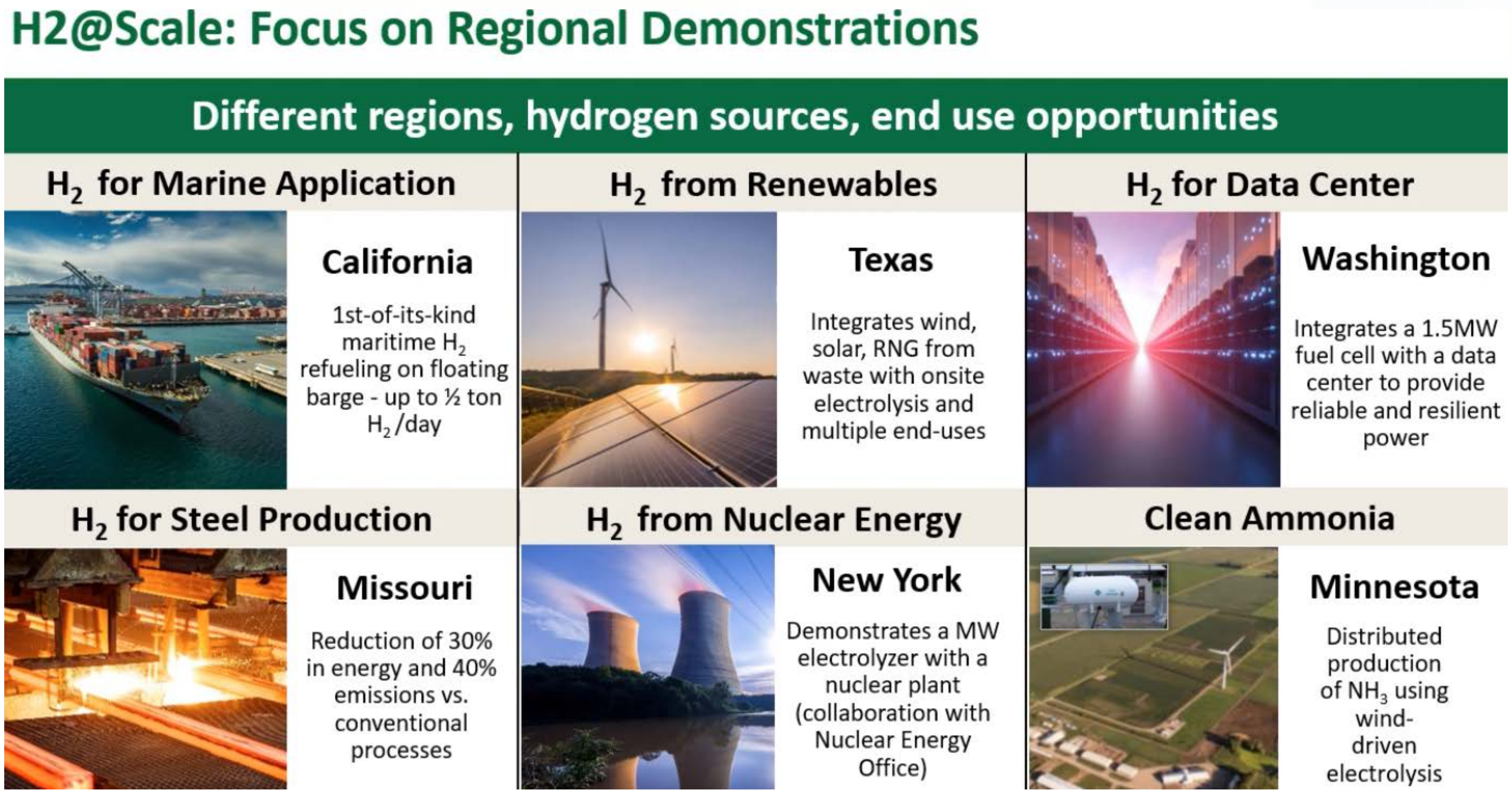
Hydrogen: Large-Scale Demonstrations in N. America

- Enbridge/Cummins Blending/Power-to-Gas Pilot – Ontario
- ATCO Fort Saskatchewan Blending Pilot – Alberta
- H2@Scale with UT-Austin, Green H2 Generation, Storage, and Utilization Demo – Texas
- Sempra Hydrogen Blending Demonstration Program & SoCalGas *Hydrogen Home* – California
- CenterPoint Green H2 Demo – Minnesota
- NW Natural 10 MW Green H2 Demo – Oregon
- Dominion Blending/Methanation Demo – Utah
- ACES – Coal-to-NG-to-H2 Power Plant – Utah
- And more in preparation/planning stages…



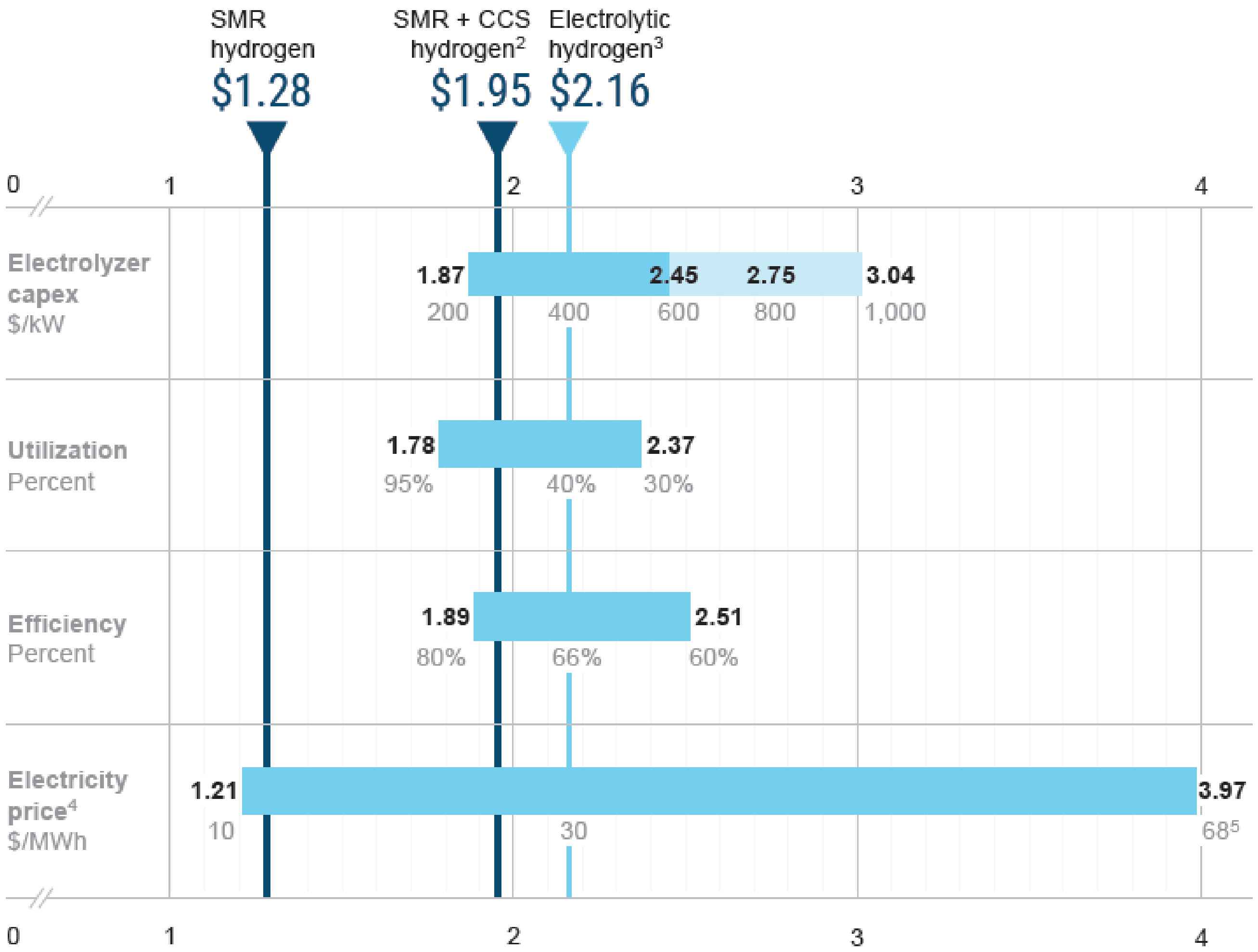
Source: SoCalGas, DOE

DOE clean hydrogen initiative



Infrastructure Bill has **$9.5B** set aside for clean H2, including power-to-gas

Projected 2030 Hydrogen Production Costs for Different Technology Options



1-Natural gas price of $4.59/MMBTU in 2030

2-Capture cost –$66/ton of CO2, storage cost –$20/ton of CO2, transportation cost –$6/ton of CO2

3-For electrolytic hydrogen: 20,000 Nm3/h electrolyzer assumed (~43,000 kg/day); electrolyzer capex includes the electrolyzer stack and balance of plant (e.g., valves, DI water system, pipes, rectifiers, heat exchangers), additional costs of 25% of capex assumed for installation costs, buildings, civil works, water purification system, high-purity dryer system, and thermal control unit

4-If grid-connected, electricity price is assumed to incorporate applicable transmission and distribution charges

5-2030 EIA Industrial Electricity Price Outlook

Source: FCHEA/McKinsey, 2020

Enabling Hydrogen Use for Residential/Commercial Applications

Efforts underway:

- Demonstrate solutions to utilize high hydrogen blends in residential and commercial combustion equipment
- Performance testing of appliances with varying hydrogen blends
- Quantify the ability of appliances to retain normal operations (emissions, efficiency, cycling)
- Hydrogen sensor development for "behind the meter" applications and in-situ sensing

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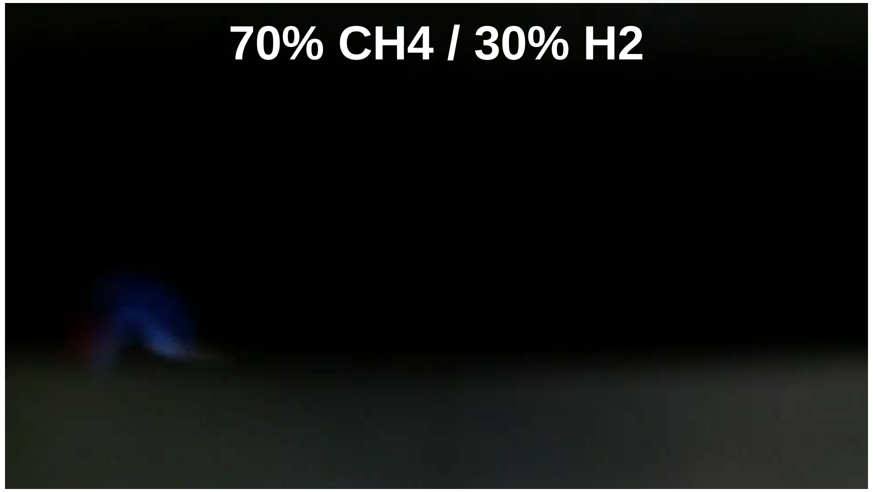
Feature	Possible Equipment Issues
Flame Temperature	Flame burns hotter, can lead to uneven heat transfer and material degradation
Flame Speed	Can lead to flame stability issues, ignition problems and flashback
Flammability Range	H_2 portion can ignite prematurely in rich pockets of fuel/air mixture, leading to pre-ignition
By Products	Flue gas dew point will be higher, leading to unwanted condensation/corrosion, also many products are calibrated to stack CO_2 which will be off
Visibility / Ionization	Safety equipment to detect flame (flame rod, etc.) and technicians/operators will updating/training

Energy Efficiency + Decarbonized Fuels

- **Energy efficiency** coupled with **decarbonized fuels** can drive GHG reductions
- As a fuel, Hydrogen (H_2) emits no CO_2 and can be blended with natural gas or **biomethane** for standard products, or utilized directly (100% H_2) by **specially-designed equipment**
  - Used for **long duration**, mega-scale storage of renewable energy

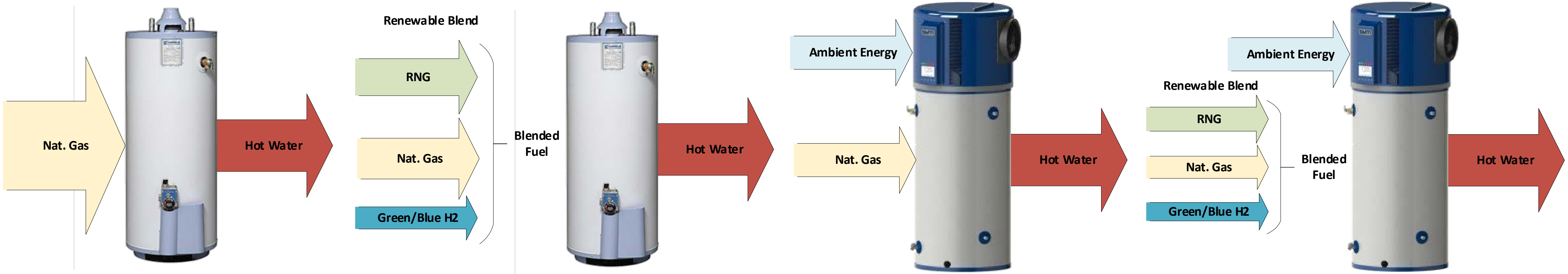


Baseline

Baseline + Decarb. Fuel*
~50% Fossil Reduction

High-Efficiency**
~60% Fossil Reduction

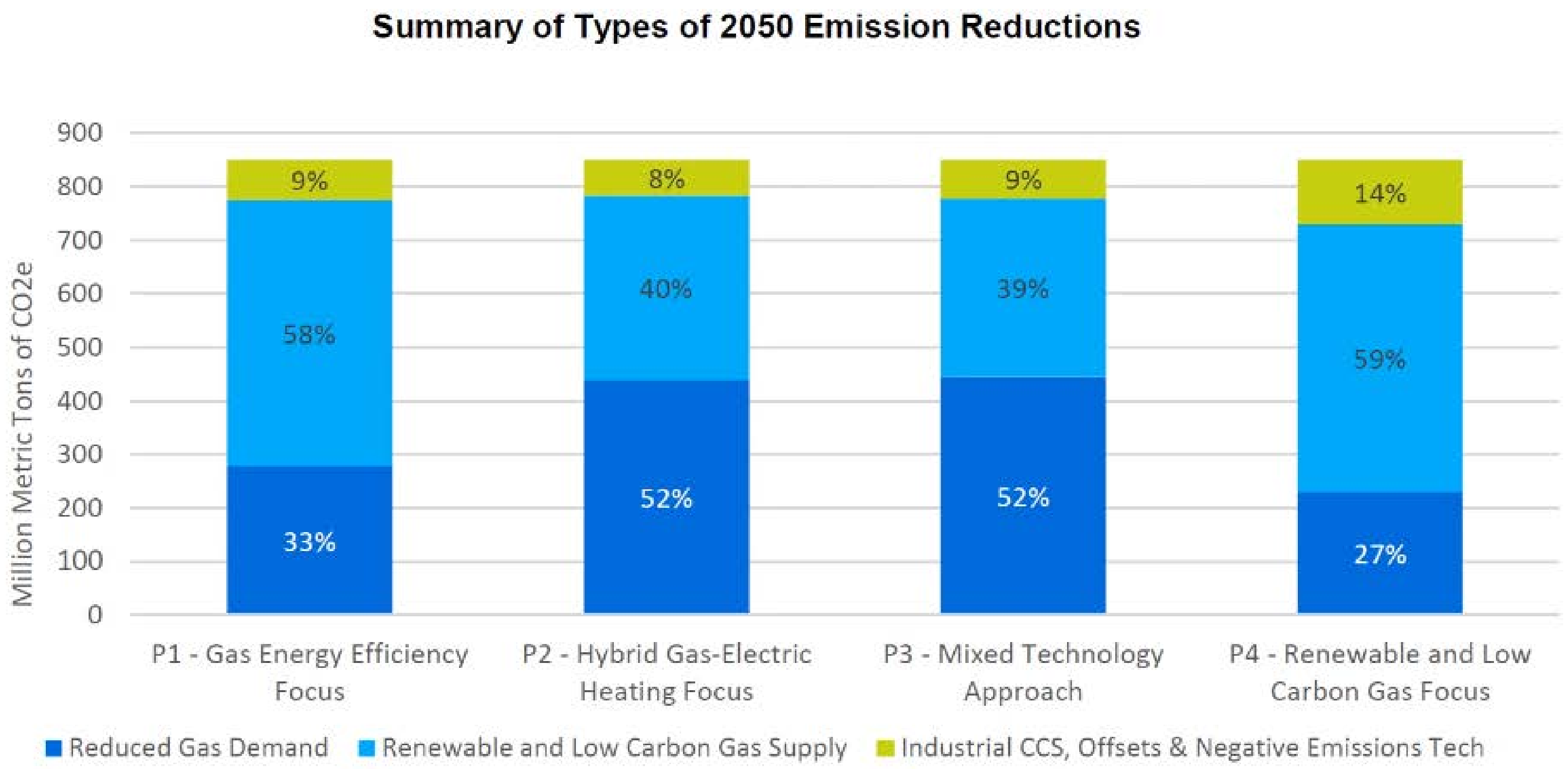
High-Efficiency + Decarb. Fuel**
~80% Fossil Reduction



*Assumes near-term achievable targets of H2 & RNG blending / ** Fuel-fired GHPWH performance assumptions from *Glanville, P., Fridlyand, A., Mensinger, M., Sweeney, M., Keinath, C. (2020) Integrated Gas-fired Heat Pump Water Heaters for Homes: Results of Field Demonstrations and System Modeling, ASHRAE Transactions; Vol. 126 325-332,* image source: SMTI.

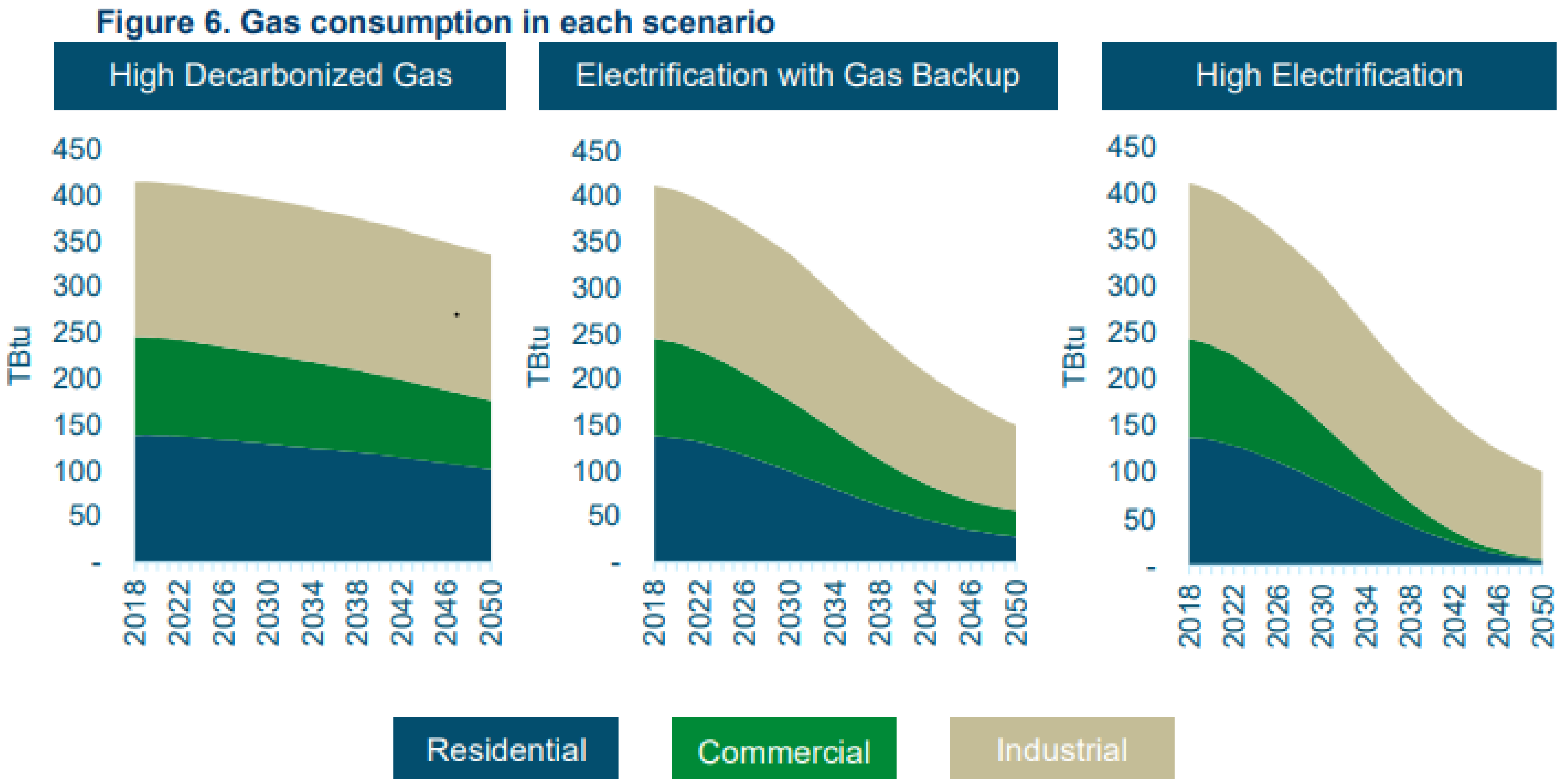
Multiple paths for fuel-fired net zero emissions

The relative contribution of measures varies by pathway, showcasing a diversity of potential approaches



Source: AGA Net-Zero Emissions Opportunities for Gas Utilities (2022)

Multiple paths for fuel-fired net zero emissions: MN



In all scenarios, geological natural gas is phased out by 2050, replaced by a combination of carbon-neutral or carbon-free hydrogen, biogenic methane, and synthetic methane

Source: Decarbonizing Minnesota's Natural Gas End Uses (2021)

Pulling it All Together:

The pathway to a carbon-neutral vision

A decarbonized network:

- Deep energy efficiency
- Renewable natural gas
- Renewable hydrogen
- Blended and dedicated hydrogen systems

Source: NW Natural

Questions? Feedback?

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