Decarbonizing Minnesota's Natural Gas End Uses

Meeting 9 – E3 Modeling

August 14th, 2020

Via Zoom

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Agenda

9:00	Welcome, Introductions, Process Check-in
9:20	Presentation and Q&A: Scenario examples and how modeling works
10:30	BREAK
11:00	Presentation and Q&A: Possible Minnesota scenario narratives
12:00	LUNCH
1:00	Breakout group discussions (3 groups)
1:30	Full group discussion to select up to four scenarios total
2:30	ADJOURN

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Meeting Goals

1. Introduce the E3 team to this group and build a shared understanding of E3's modeling capabilities and scope for this project.
2. Discuss and seek consensus on four natural gas end-use decarbonization scenarios that the group would collectively like to see modeled and that meet the following criteria:
    a) Relevant: should be designed to provide insights to the key questions and concerns this group has been discussing.
    b) Challenging: should make important dynamics more visible and raise questions about our current thinking and assumptions.
    c) Plausible: should be logical and fact-based, while acknowledging that what's plausible may not be probable or preferable.
    d) Clear: should be accessible to the group, memorable, and distinct from one another

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Presentation and Q&A:

Scenario examples and how modeling works

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Energy+Environmental Economics

About E3

Introducing E3: consultants passionate about the clean energy transition

Technical & Strategic Consulting for ***the Clean Energy Transition***

Deep expertise in engineering, economics, mathematics & public policy

70 full-time consultants with a wide variety of backgrounds


San Francisco


New York


Boston


Calgary

250+ projects per year across a diverse client base

santee cooper
Advisory and bid evaluation services to the State of South Carolina for the potential sale of Santee Cooper (~$9 billion valuation)

Integrated Resource Planning for the CA Public Utilities Commission (CPUC) to achieve state clean energy targets (SB100)

New York Department of Public Service | NYSERDA | LIPA | NYISO | conEdison
Evaluation of gas peaker replacement and/or hybridization with energy storage in New York City and Long Island

Global Infrastructure Partners | Clearway
Price and revenue projections and due diligence for GIP acquisition of NRG renewables portfolio (~$1.4 billion)

California Air Resources Board | CALPINE
Multiple studies on costs and feasibility of high renewables integration and low-carbon transition pathways from 2020-2050

Reliability analysis of closing coastal gas-fired power plants and assessment of alternatives (transmission, storage, etc.)
LA DWP

Energy+Environmental Economics

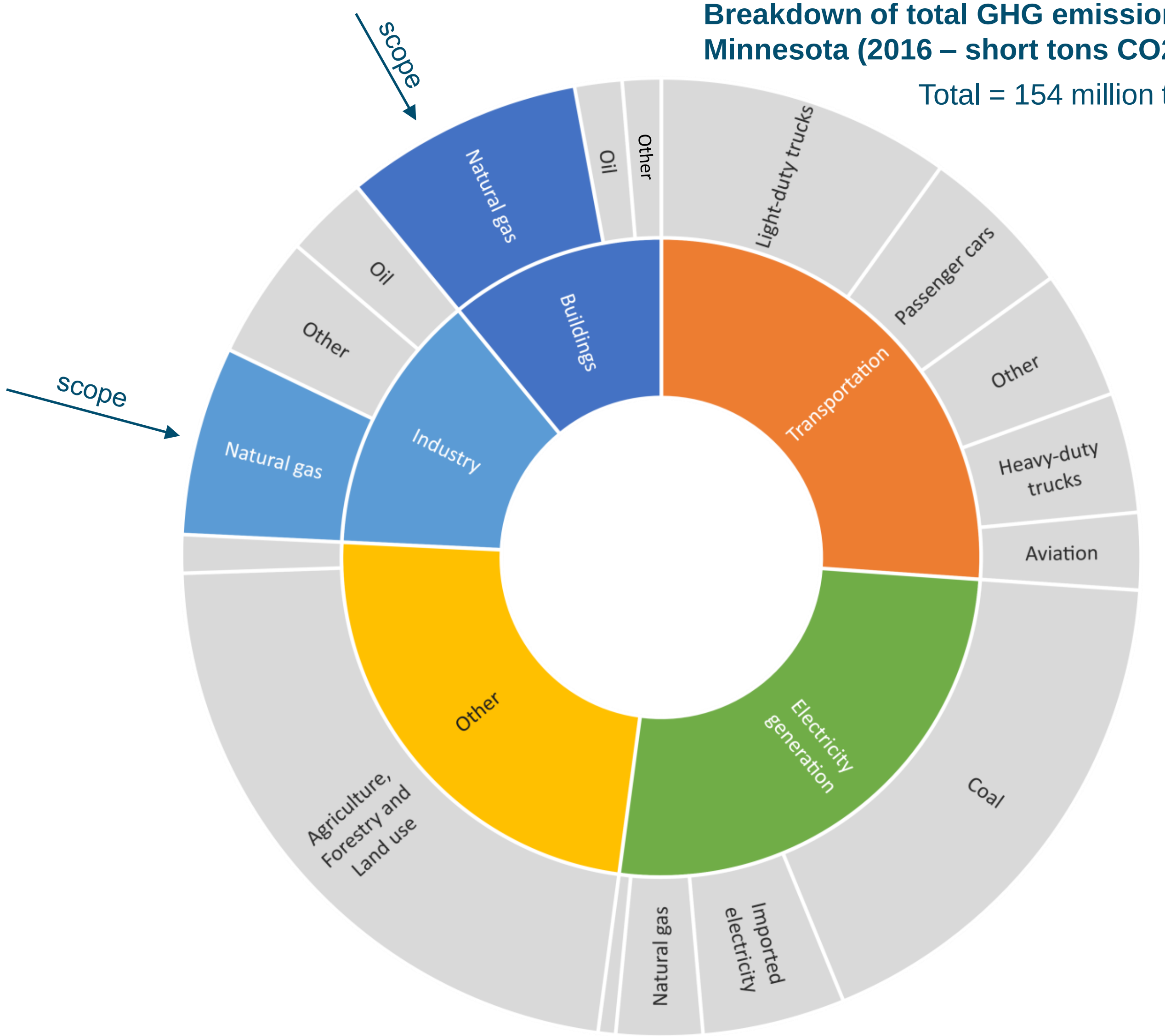
Part I: Modelling Gas End-Use Decarbonization

Project objective: a MN-specific view on reducing GHG emissions from natural gas end-uses

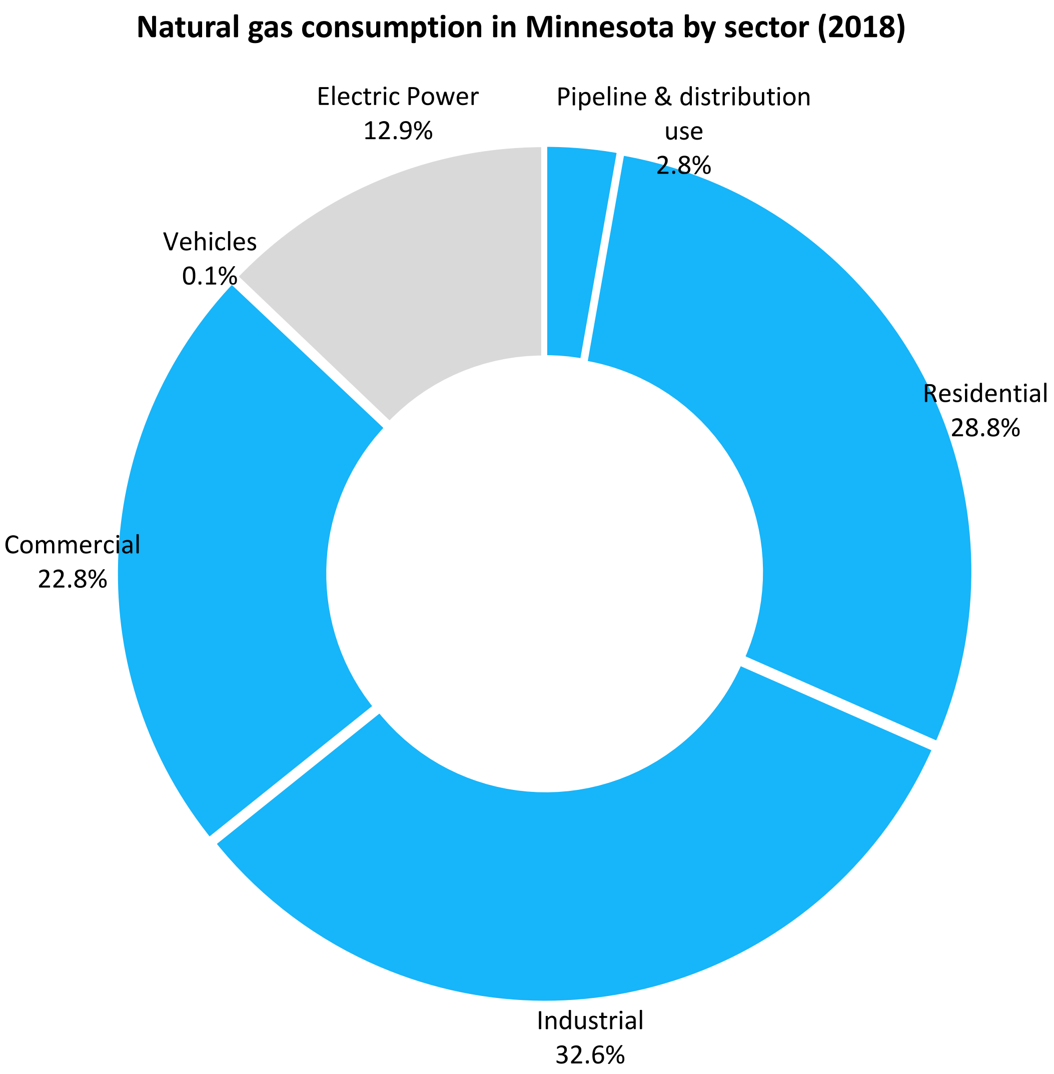
- **End-use consumption of natural gas is concentrated in Buildings (commercial & residential) and Industry**
  - Accounting for 60% of emissions in those sectors
- **Goal of this project:**
  - Develop a range of scenarios for decarbonization of gas end-uses
  - Analysis of electric infrastructure implications of those end-uses
  - Analysis of impact on customer bills
  - Inform recommendations for g21

Breakdown of total GHG emissions in Minnesota (2016 – short tons CO2eq)

Total = 154 million tons

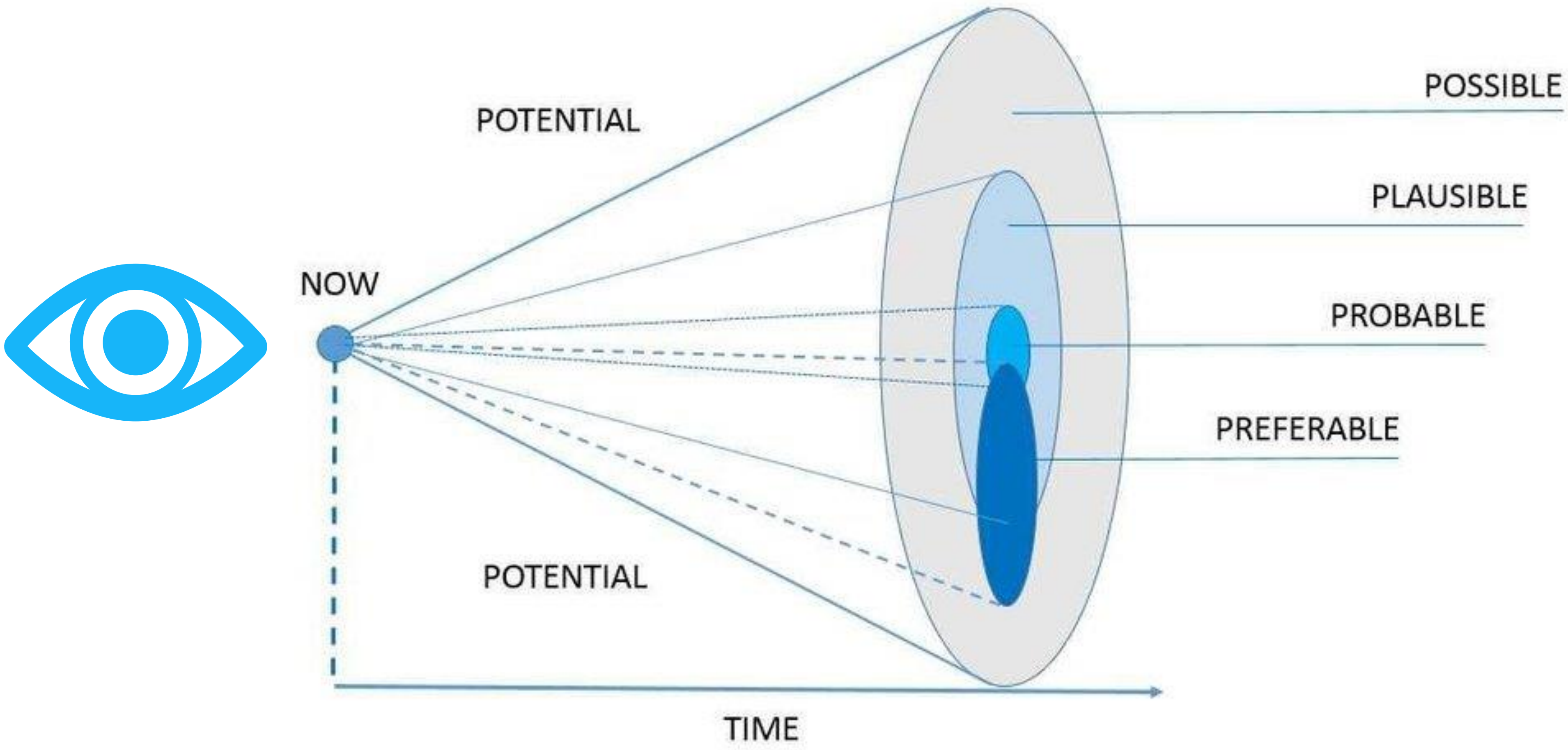


Sectoral scope includes 87% of consumption



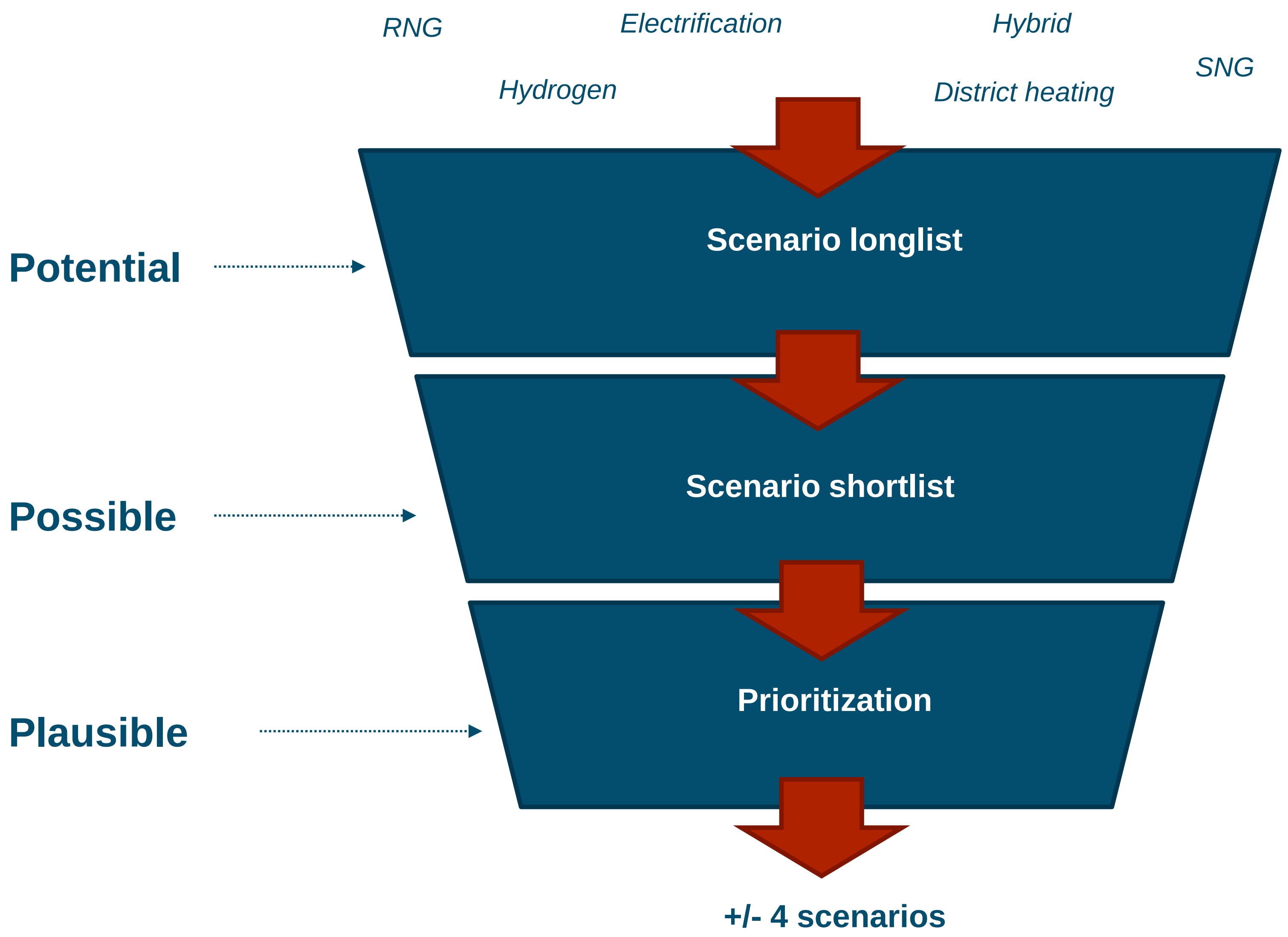
- **Sectoral scope includes 87% of MN gas consumption:**
  - Residential
  - Industrial
  - Commercial
  - Pipeline & distribution
- **Majority of natural gas consumption for buildings is for space heating purposes**

Thinking of scenario design: from possible to plausible to preferable futures

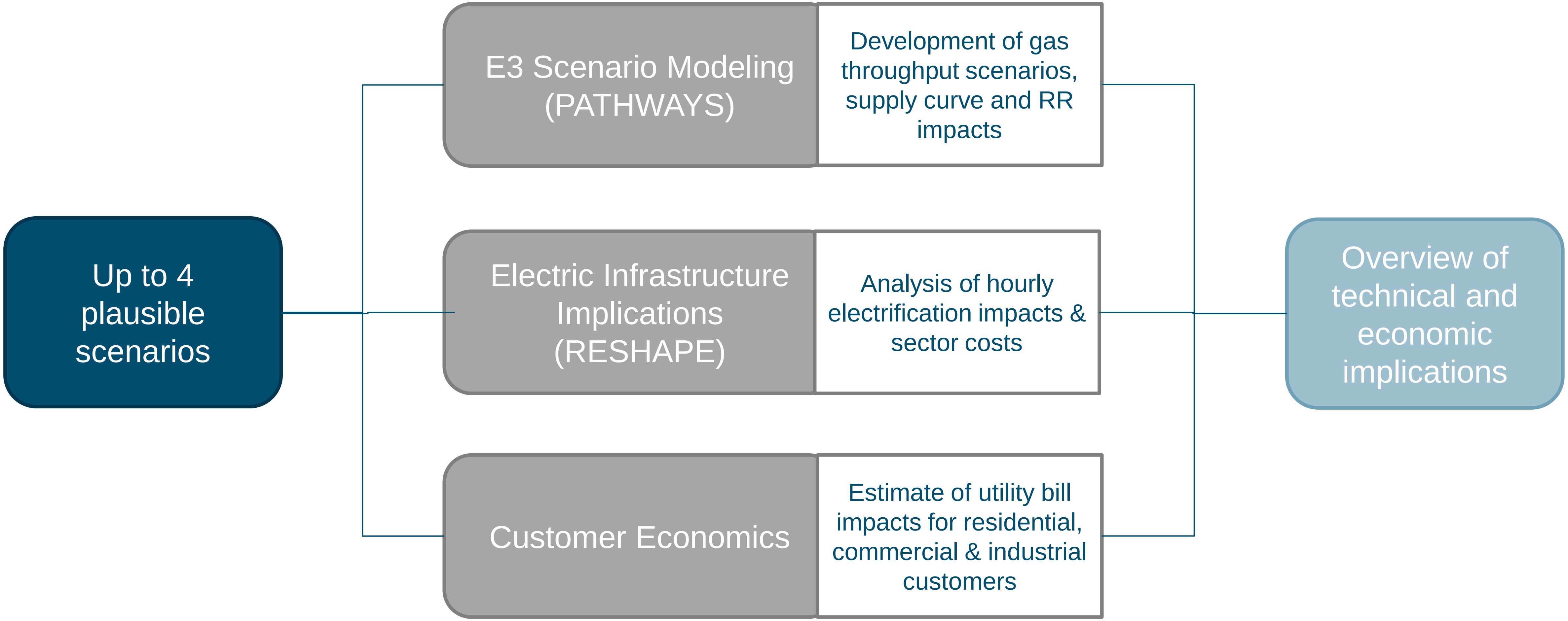


Source: Adibe, P. (2015)

Prioritizing on plausible scenario narratives for MN



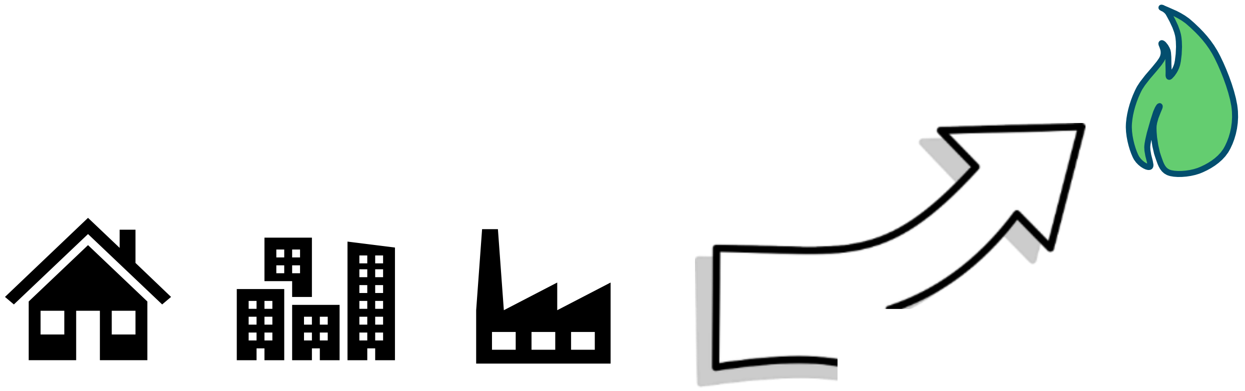
3 steps to analyze the impacts of gas end-use decarbonization scenarios



Guiding principles as defined by group

- **Affordability**
  - Keep space heating and water heating affordable for all Minnesota business & residents
- **Equity**
  - Reduces current inequities, ensure that the benefits of the transition are experienced among all Minnesotans and ensure that all Minnesotans have the ability to adopt technologies and fuels that decarbonize natural gas end uses
- **Environment**
  - Work toward practical, scalable, timely solutions to achieve reductions in GHG emissions and other pollutants while maintaining urgency
- **Economy**
  - Ensure that decarbonization of natural gas end uses in Minnesota supports economic development and innovation throughout the state & creates opportunities
- **System Considerations**
  - Consider system impacts to ensure a cost-effective transition to utilize current assets strategically and avoid unnecessary expense

Overarching scenario design directions: decarbonized gas



<u>Decarbonized gas</u>
Renewable natural gas or hydrogen

- **<u>Potential Advantages</u>: repurposes existing infrastructure, minimal consumer disruption**, also reduces non-energy emissions
- **<u>Potential Drawbacks</u>: cost, not commercial at scale**, can require extensive utility infrastructure and customer equipment retrofits

Sources of Decarbonized Gas

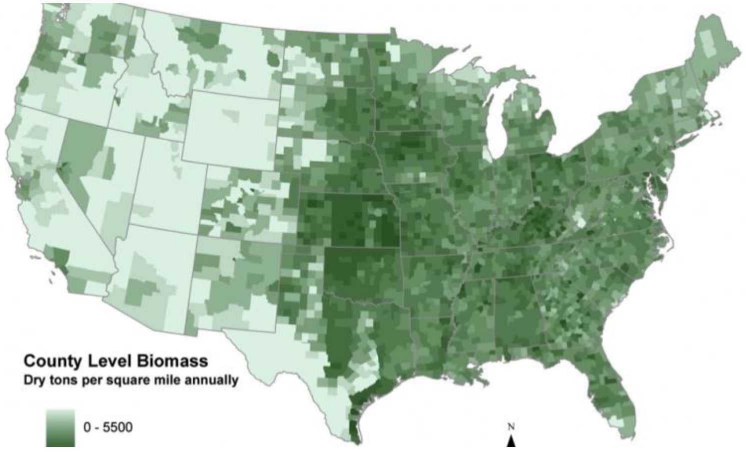
- In a "Decarbonized Gas" future, natural gas will be replaced by 2050 with zero-carbon alternatives, which are usually called Renewable Natural Gas (RNG).
- Where will the RNG come from? How much will it cost?
- E3 considers a variety of RNG sources and will compile a RNG supply curve based on estimates of the availability and costs of each source.

Waste biogas	Gasification of biomass	Hydrogen	Synthetic Natural Gas (SNG)
Sources: Municipal waste, manure	**Sources:** Agriculture and forest residues, and purpose grown crops, e.g. switchgrass;	**Sources:** Electrolysis + zero-carbon electricity or Steam Methane Reforming of natural gas with Carbon Capture and Sequestration	**Sources:** Renewable hydrogen + CO2 from biowaste (bi-product of biofuel production) and/or direct air capture (DAC)
Constraints: Very limited supply	**Constraints:** Limited supply and competing uses for biofuels	**Constraints:** Limited pipeline blends (7% by energy) without infrastructure upgrades, cost	**Constraints:** Limited commercialization, low round-trip efficiency, high cost

Biofuels Supply and Cost Estimates

- E3's Biofuels Model optimizes the allocation of scarce biomass and identifies a lowest-cost portfolio of biofuels
- The model outputs quantity of production by fuel, their production costs and a market clearing price for each fuel
- E3 derives biomass supply estimates from the US Department of Energy *Billion Ton Report*

Biomass Supply based on the DOE Billion Ton Report

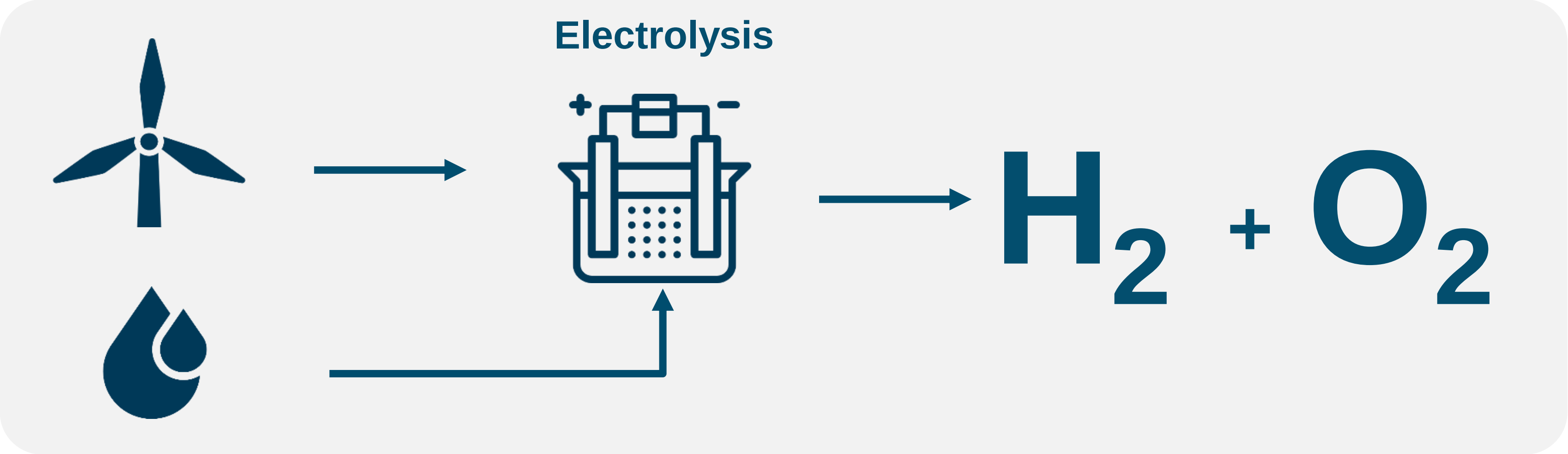


E3's Biofuels Optimization Model

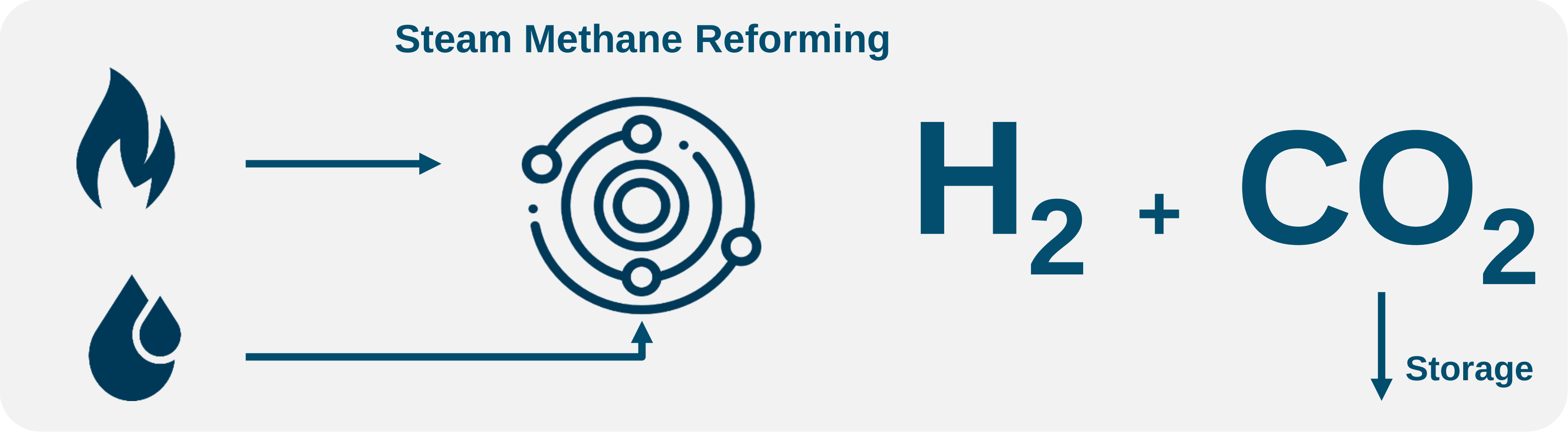
- Biofuels Supply Curve
- Biomass Feedstock Selected
- Biofuel Production and Prices

What about hydrogen?

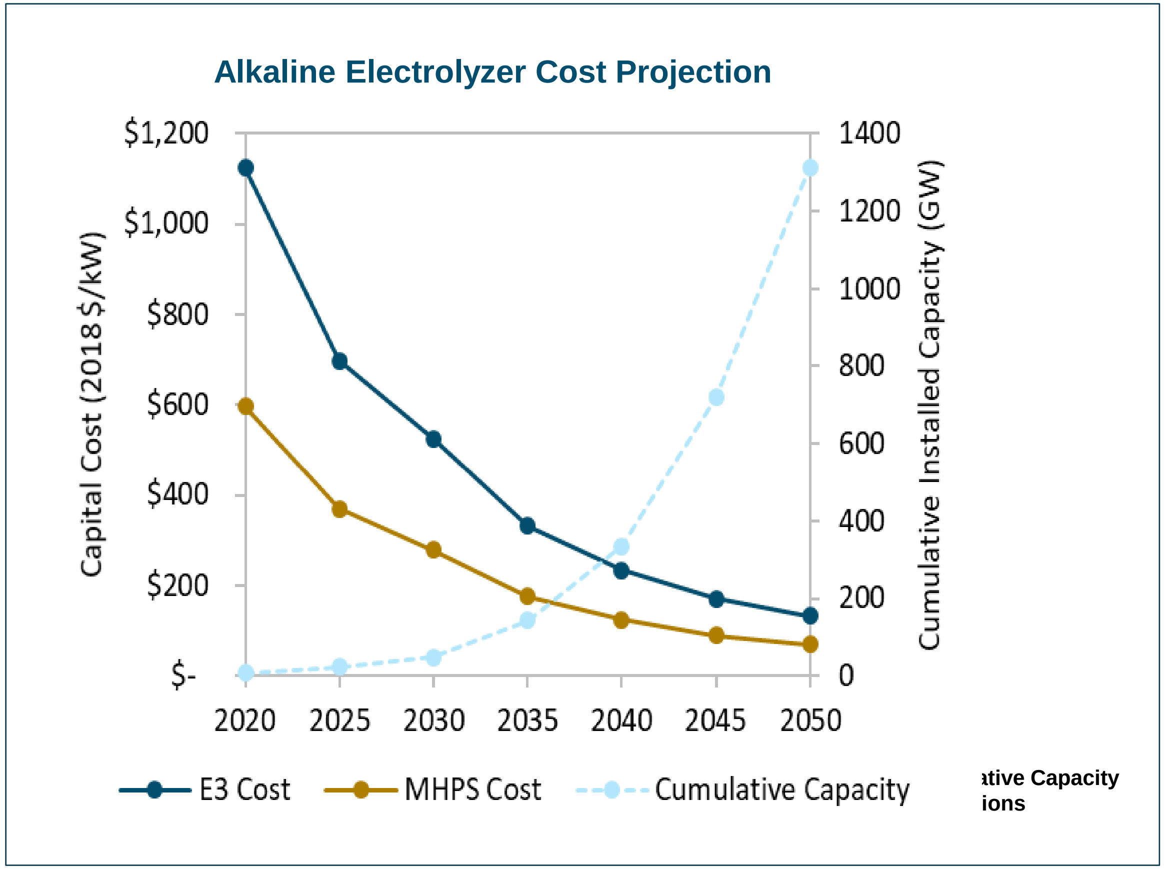
"Green" Hydrogen

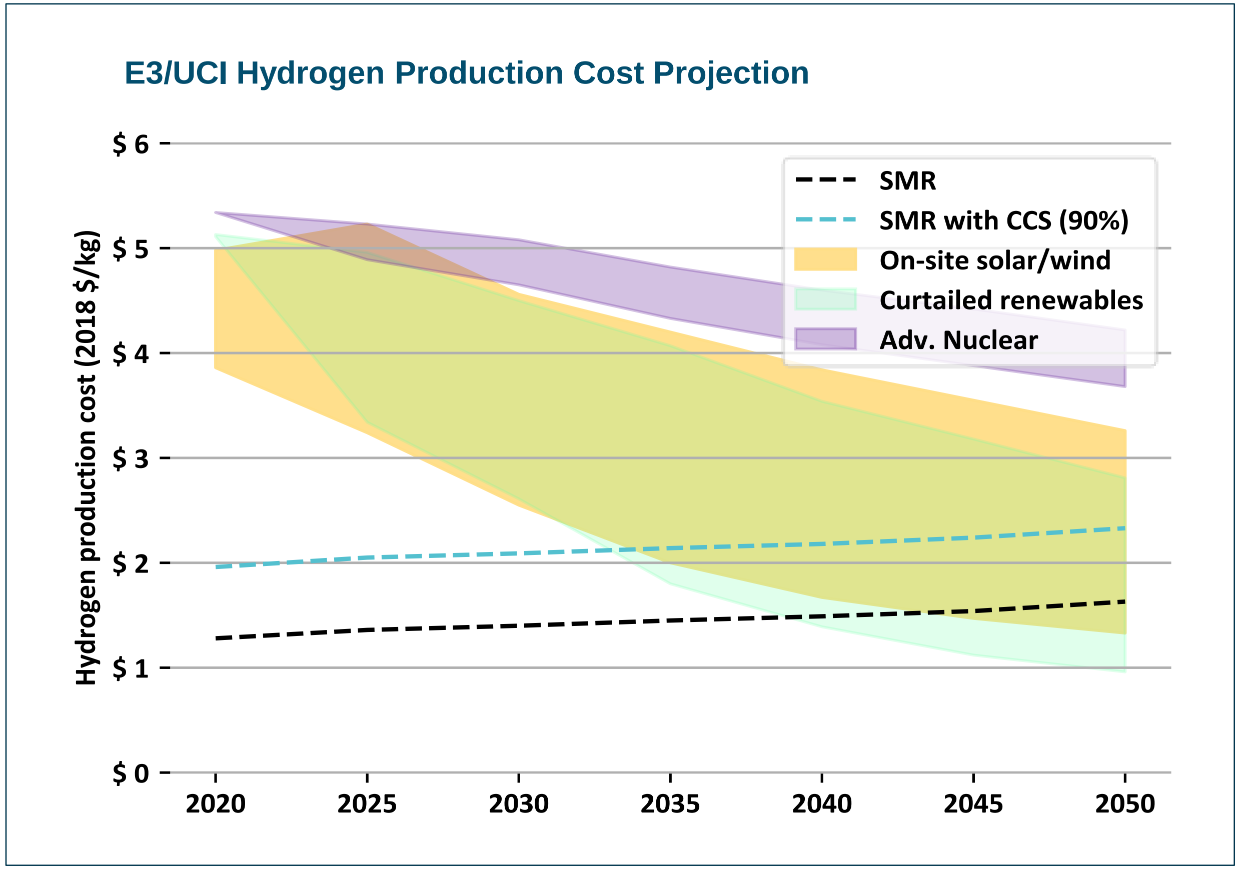


"Blue" Hydrogen



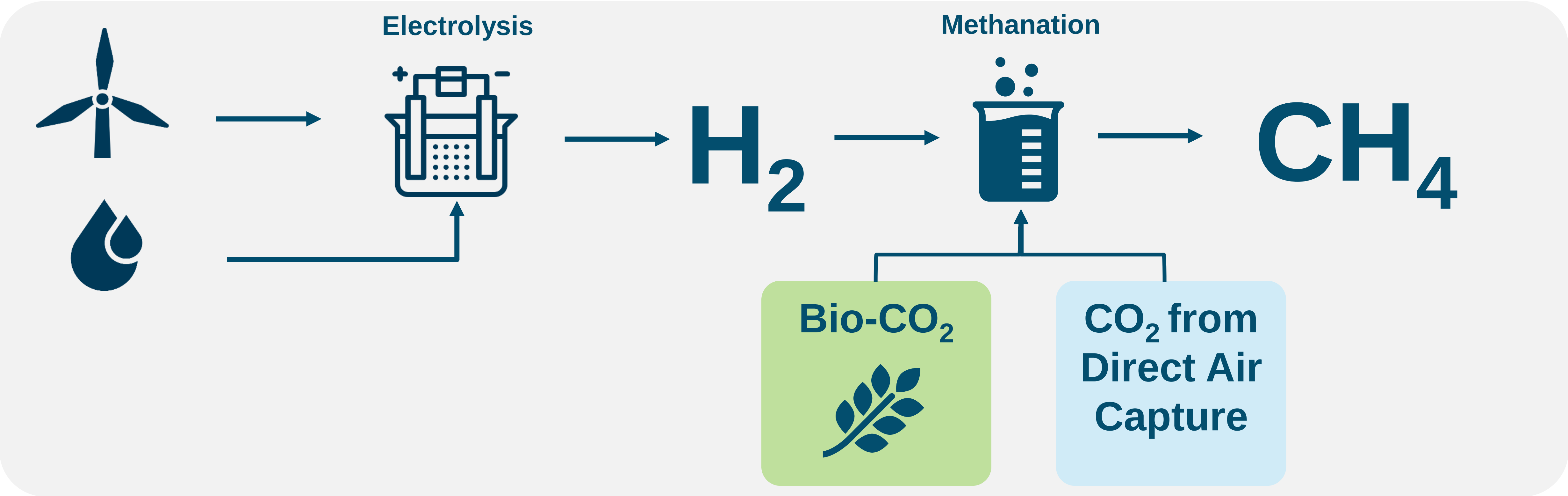
Hydrogen production costs are expected to decline





- E3 recently published a report on potential opportunity for renewable hydrogen in a deeply decarbonized future with Mitsubishi Hitachi Power Systems (MHPS)
- Electrolysis with renewable power may be more economic than SMR with CCS if electrolyzer costs fall with an aggressive learning rate of 25% and curtailed renewables are available at close to zero cost

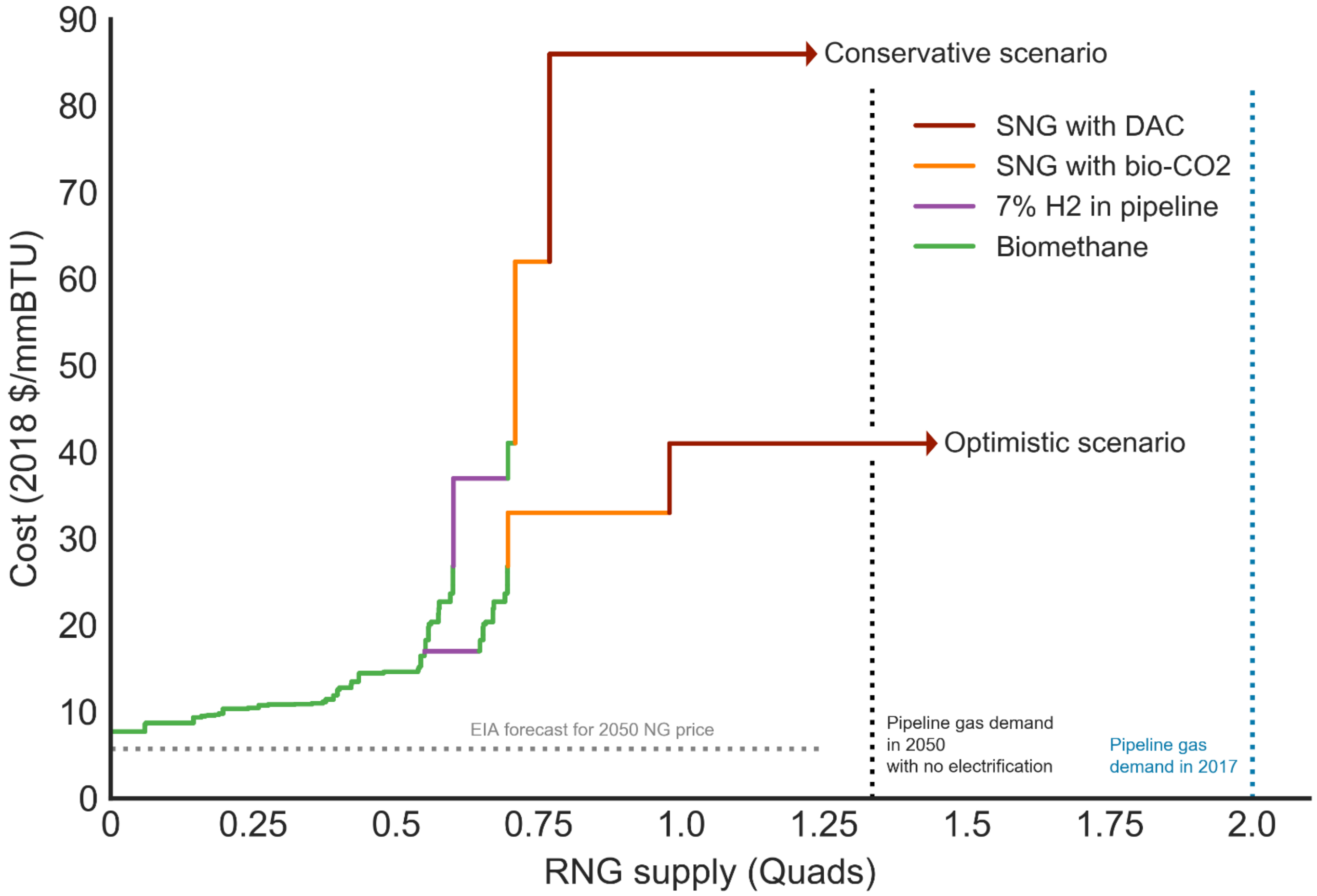
Synthetic Natural Gas (SNG) Production



- SNG production requires a combination of climate neutral hydrogen and climate neutral CO2.
- E3 considers two sources of climate neutral CO2: 1) less costly bio-CO2 from biofuels production, 2) more costly CO2 from direct air capture.

Example RNG Supply Curve from E3's work in California

California Renewable Natural Gas Technical Potential Supply Curve in 2050, Assuming All Biomass Is Directed to Renewable Natural Gas



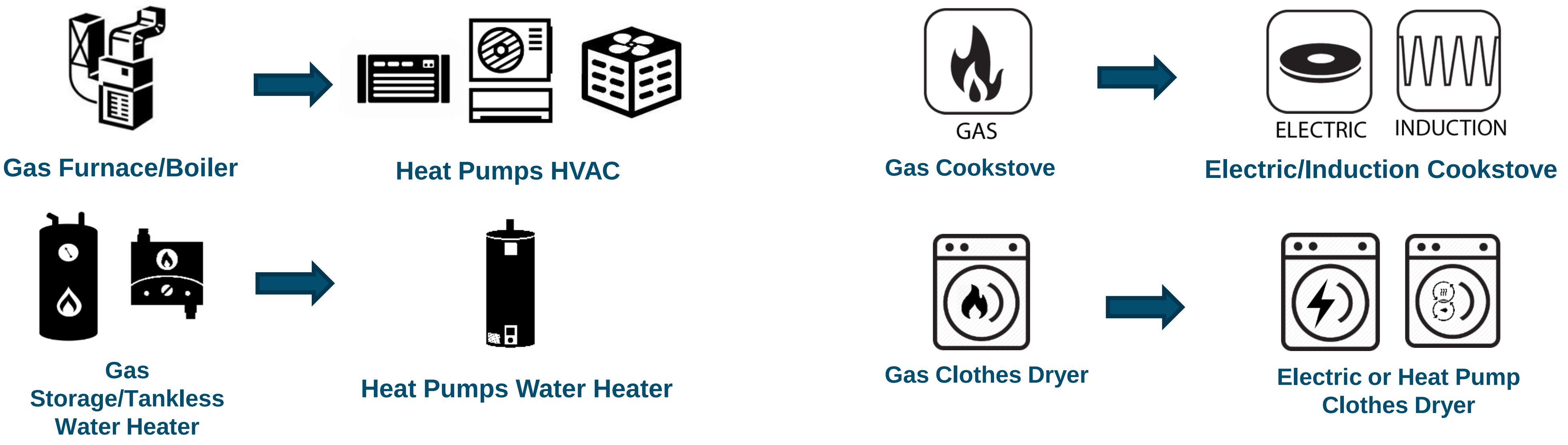
- **The example here shows two RNG supply curves E3 developed for California from our recently published report.**
- **One important question regarding biomethane supply is**
  - How much biomass will be used for liquid fuels to displace petroleum consumption in transportation and industry?
- **In this study, we will develop two separate biomethane supply curves (green) based on the assumption whether biomass feedstock will be restricted to local markets or open to the national markets.**

Overarching scenario design directions: electrification

- **Potential Advantages**: **commercially available** products, **complementary to decarbonized electricity**, assists with climate adaptation
- **Potential Drawbacks**: requires building retrofits, **upfront consumer costs**, electric peak load impacts, potential for **stranded assets** and **workforce reductions**

Electrification Scenario Assumptions

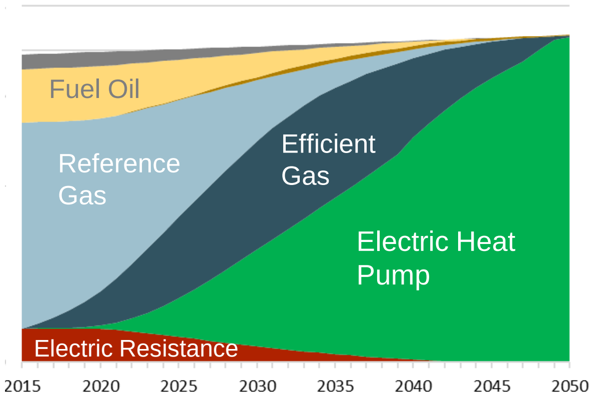
+ In an “Electrification” scenario, we assume that most of natural gas end-uses will be electrified by 2050.
+ Residential and commercial end-uses studied include space heating, water heating, cooking and clothes drying



+ Industrial electrification will include technologies for (mostly) low-temperature end-uses, such as electric boilers for steam supply, heat pumps for low/medium temperature heat and electric furnaces

Methodology for the Electrification Scenario

End-use Electrification Trajectory from PATHWAYS (space heating as an example)

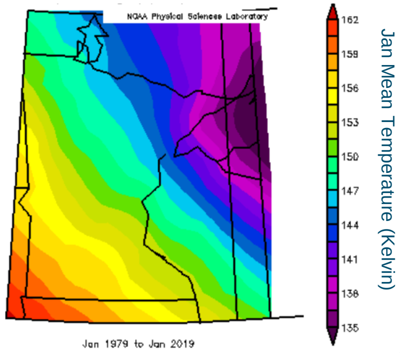


E3's RESHAPE Model

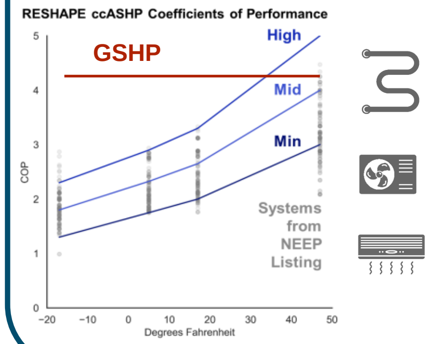
- Incremental Annual Load by End-use
- Incremental Hourly Load by End-use
- Peak Load Impact

Region-specific Diversified Building Stock

Spatially and Temporally Granular Historical Weather

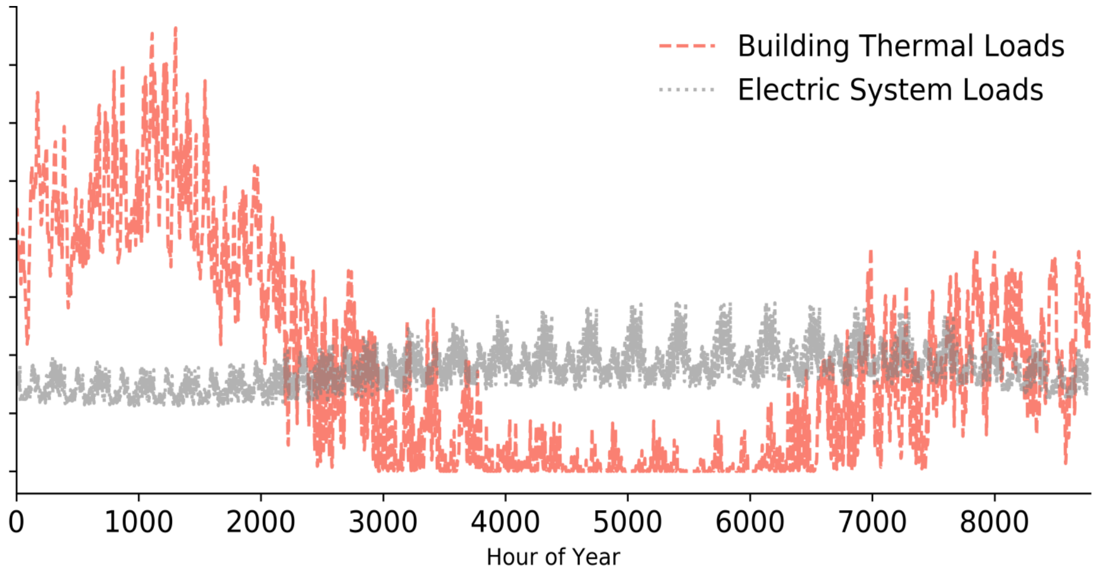


Distinct Heat Pump Technology Options

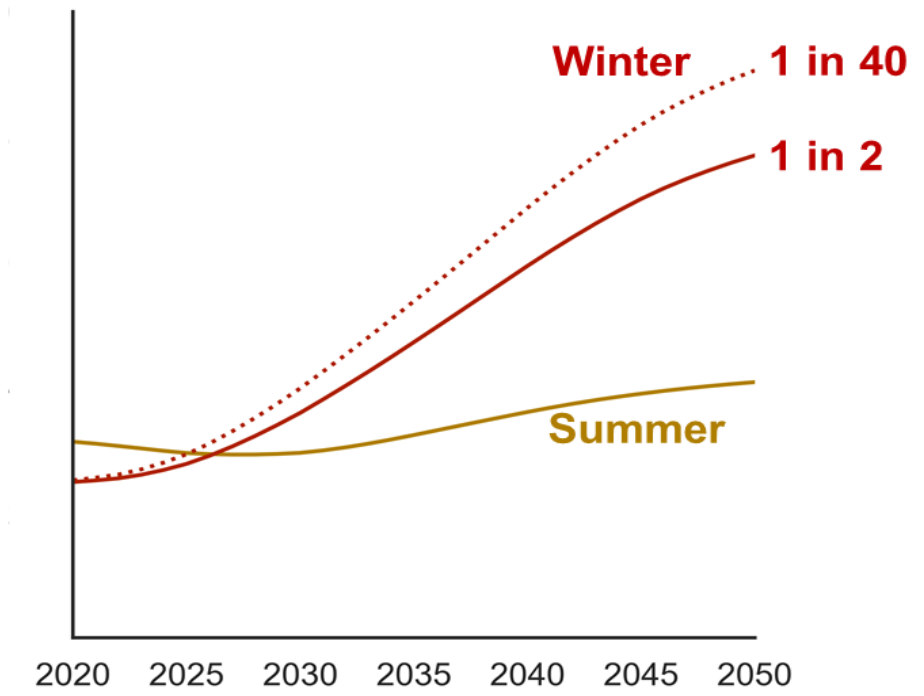


Example Output for the Electrification Scenario

Example Building Heat Demand compared to Current Electric System Loads in some states on the East Coast

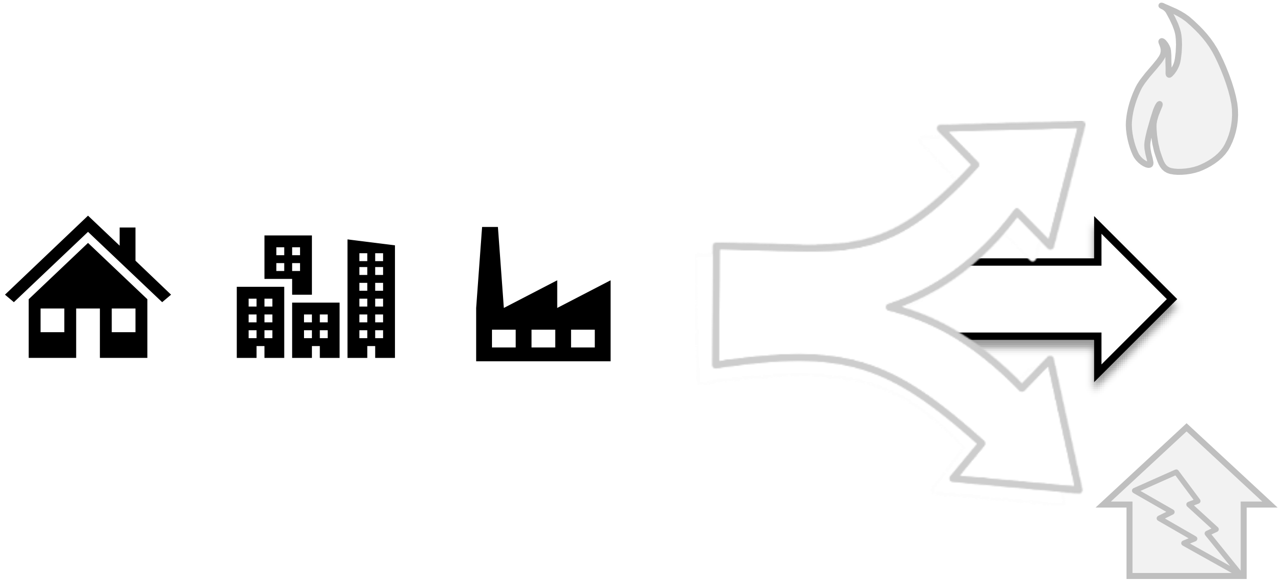


Example Projected Change of Summer and Winter Peak Electric Loads due to building electrification



- Building thermal loads in Minnesota will likely outweigh the current electric system loads
- Using heat pumps to efficiently meet the thermal loads can reduce the peak heat requirement, but the Minnesota electric system will likely still become winter peaking if all end-uses are electrified.
- A smart electrification strategy including energy efficiency measures can reduce the peak impact and delay the transition to winter peaking.

Overarching scenario design directions: hybrid



Decarbonized gas
Renewable natural gas or hydrogen

Hybrid
Heat pumps paired with gas

Electrification
Heat pumps, induction stoves

+ **Potential Advantages:** reduces consumer disruption, **utilizes existing infrastructure**, reduces demand for more expensive varieties of decarbonized gas, **mitigates grid impacts**
+ **Potential Drawbacks**: this approach is **not well studied** in the U.S., though it is **an emerging strategy in Europe**

Hybrid Scenario Assumptions

- In the "Hybrid" scenario, E3 will model at least half of the heat pump HVACs with fuel backup
- Heat pump sizing determines when backup heat is needed

An Illustrative Example of the Hybrid Heat Pump Assumptions

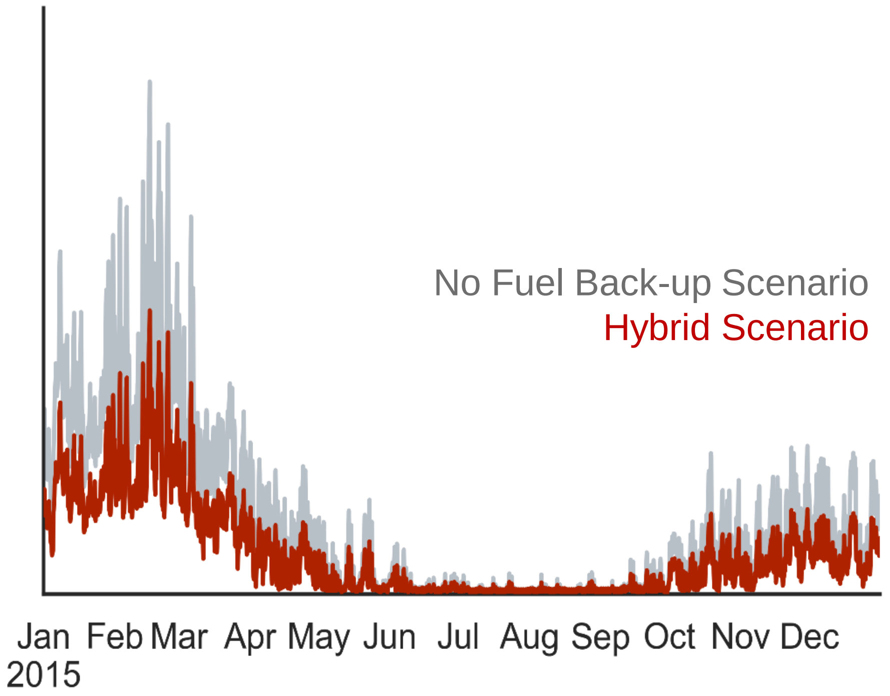
Air Source Heat Pump with Electric Backup (32%)	Ground Source Heat Pump (16%)	Air Source Heat Pump with Fuel Backup (32%)		Fuel Heating (20%)
		Central Air	Minisplit	
		Fuel backup heat in 5% of coldest hours	*Fuel backup heat in 20% of coldest hours*	

Increasing peak load impact ←

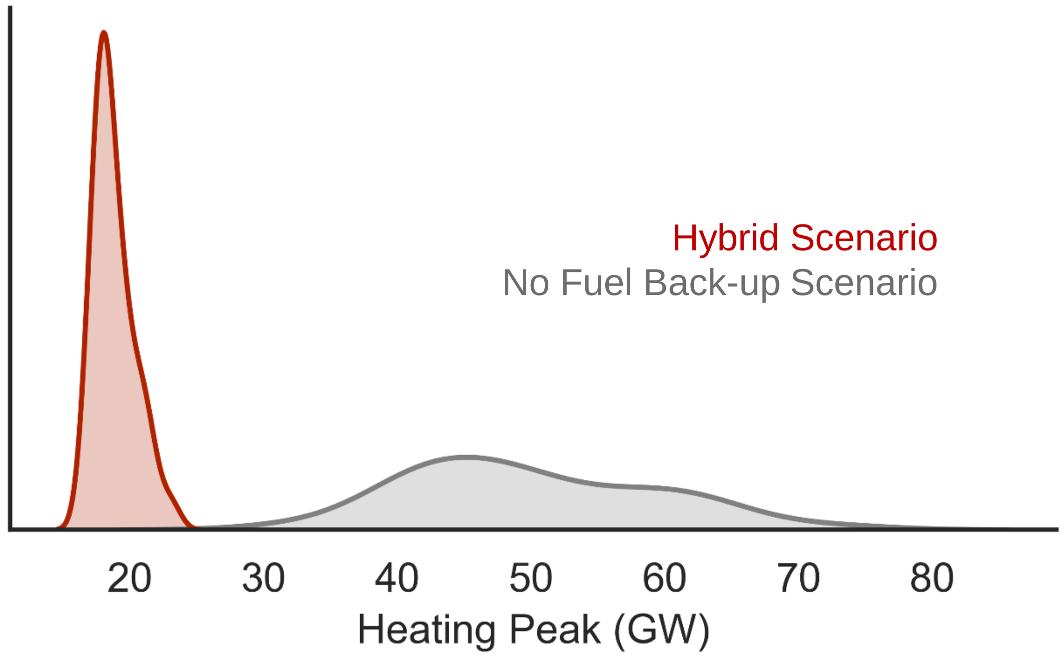
Electric backup heat for ASHP in coldest 1% of hours leads to ***significant*** *peak load impacts*	*Stable ground temperature for GSHP mitigates need for backup electric heat and leads to* ***medium*** *peak load impacts*	*Fuel backup heat for ASHP mitigates needs for electric backup and leads to* ***small*** *peak load impacts*	*Fuel heating leads to* ***no*** *peak load impacts*

Example Hybrid Scenario Results

Example Hourly Load Impact Comparison

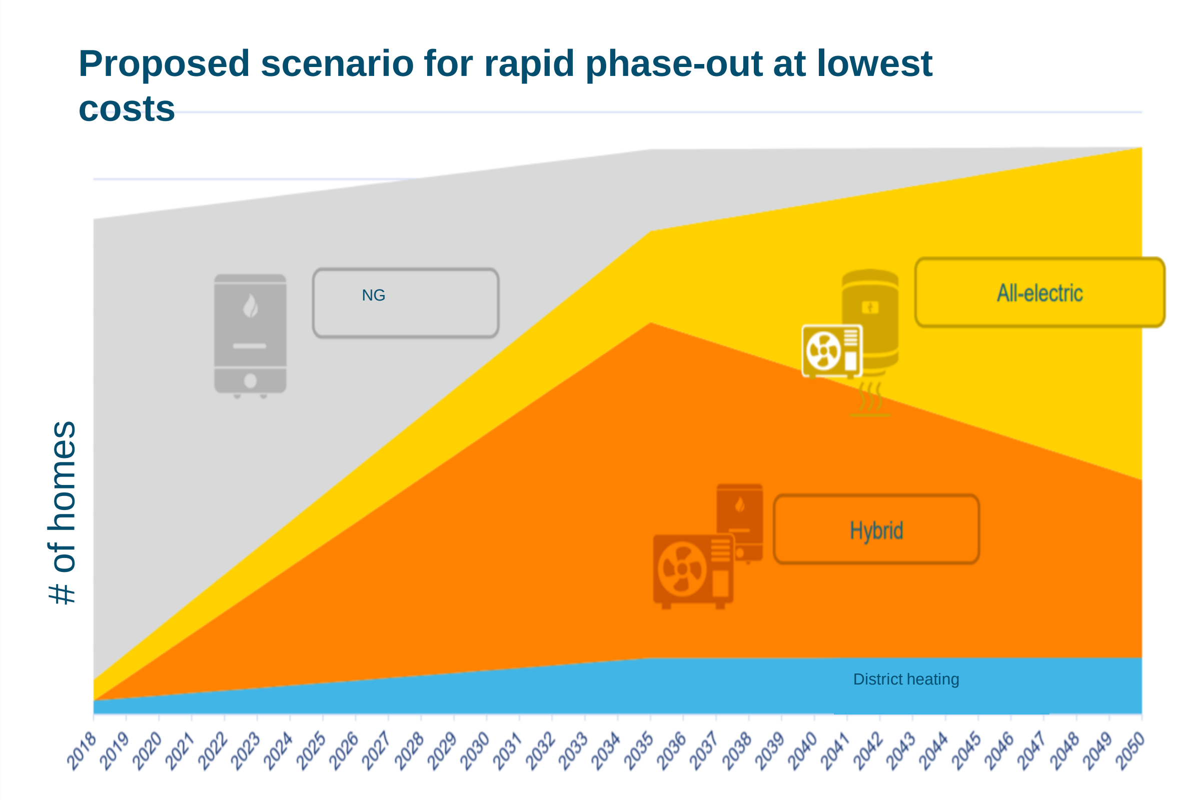


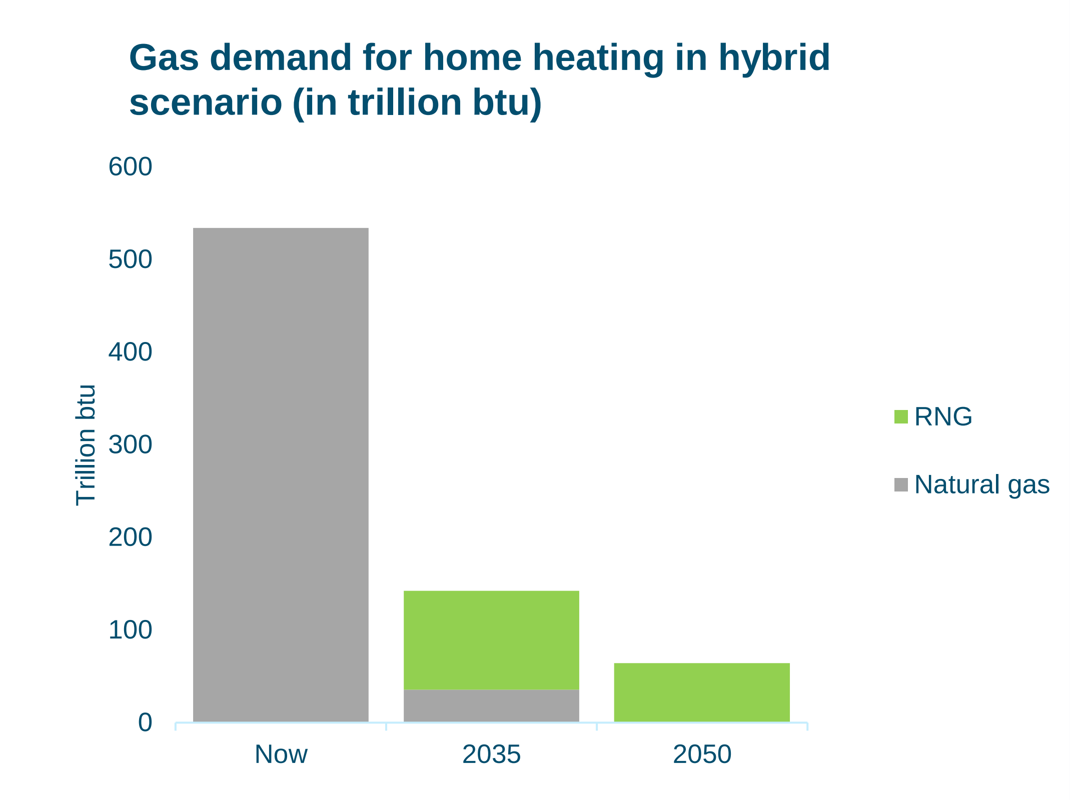
Example Peak-hour Heat Distribution Comparison
Using 40-year Historical Weather Data



- The Hybrid scenario will likely see a reduced peak load impact compared to the electrification scenario without fuel back-up
- The peak load will likely have less variation under different weather conditions due to the use of fuel back-up systems

Using a Dutch example: hybrid scenario enables cost-effective deployment of RNG

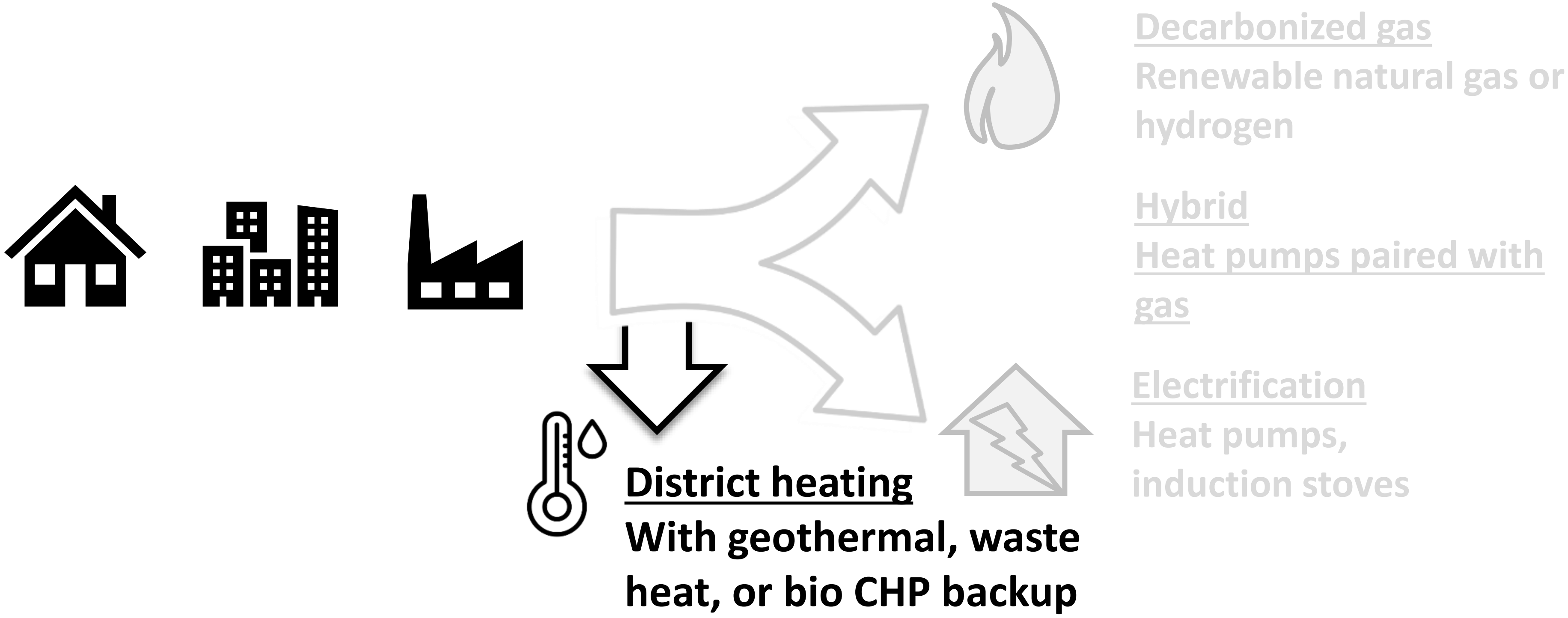




- The hybrid scenario **drastically reduces natural gas** demand by 2035. Remaining gas demand in 2035 and 2050 is low enough to be supplied by biogas
- This scenario reduces both **home owner costs** and **peak load capacity** by 50% compared to an all-electric scenario

Source: Berenschot (2018): Verduurzaming Gebouwde Omgeving

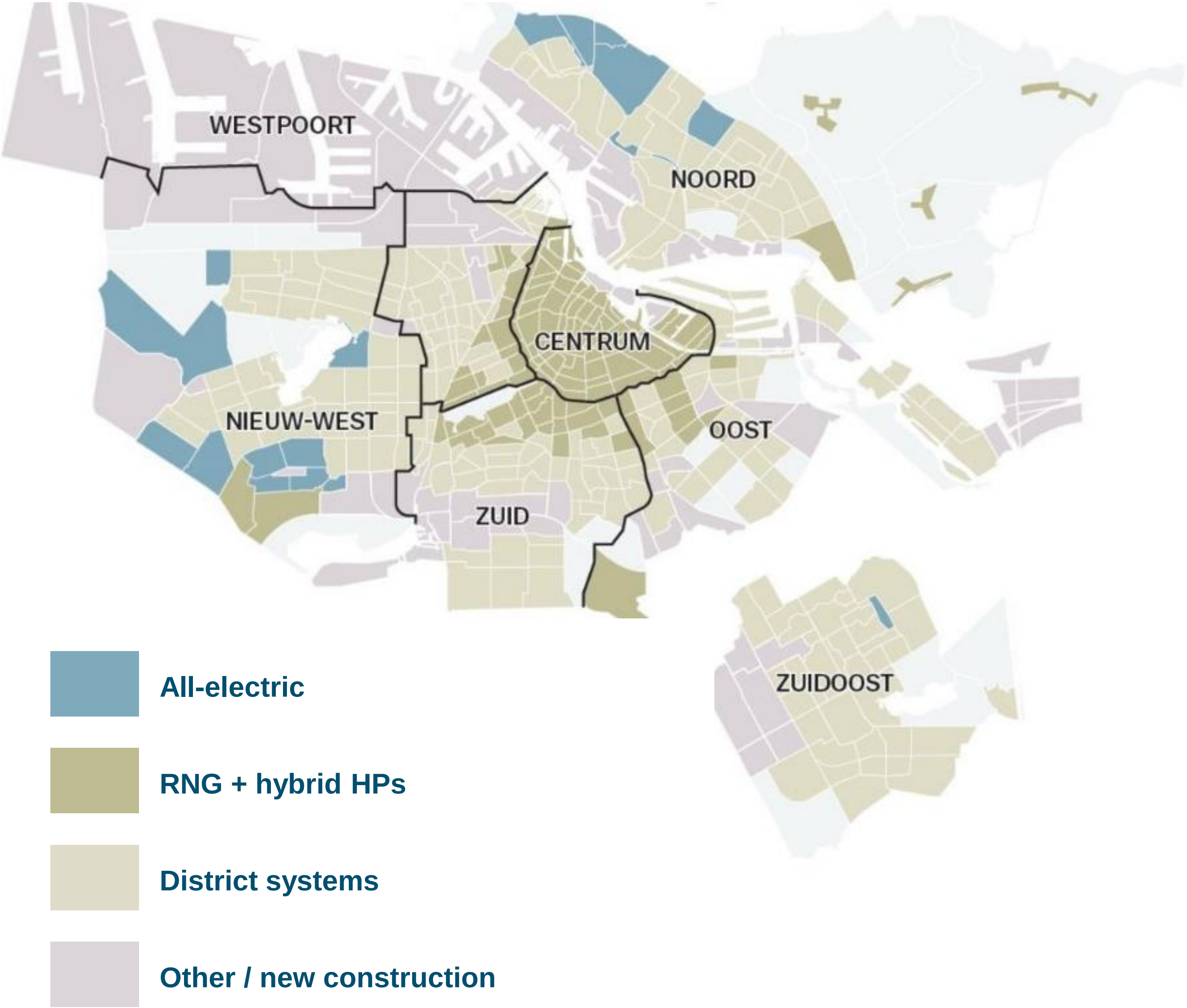
Overarching scenario design directions: district heating



- **Potential Advantages:** multiple input sources enable a diversified decarbonization approach
- **Potential Drawbacks**: partly requires new infrastructure, expansion is **not well studied** in the U.S., though it is **an emerging strategy in Europe**

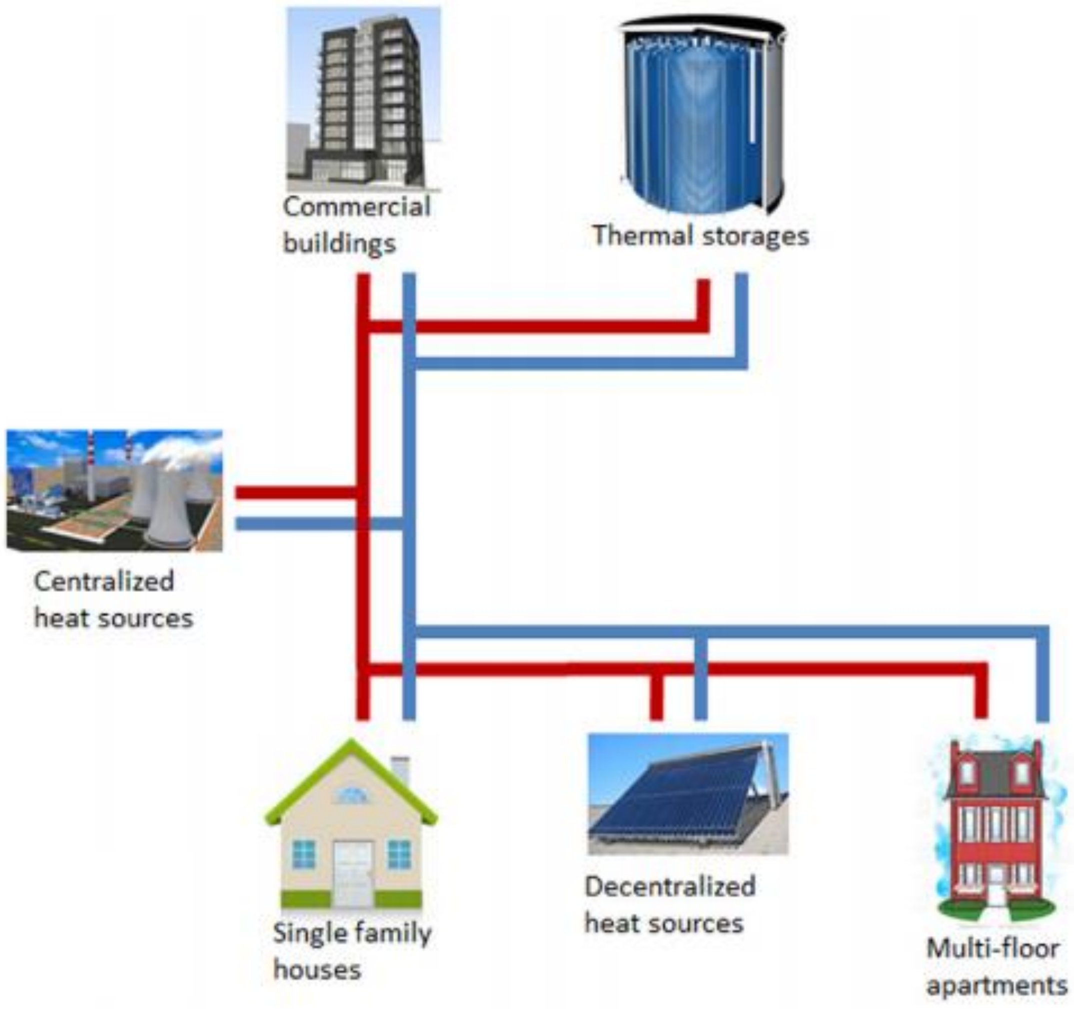
Colder cities in Europe are converting to collective district heating systems

City of Amsterdam: natural gas phase out by 2040



Multiple heat sources enable flexibility of supply

- **Centralized (collective) heating system distributing hot water or steam**
- **Combines centralized heat sources:**
  - Waste incineration
  - Biomass plants
  - Geothermal plants
  - (bio)-CHPs
  - Industrial waste heat
- **With small-scale decentralized sources**
  - Solar panels
  - Micro CHPs
  - Individual HPs



Source: Mahzar et. al (2018). A state of art review on the district heating systems

No-regret efficiency options apply in all scenario types

+ **A variety of efficiency measures will be considered to reduce demand**

High-Efficiency Cold-Climate Air Source Heat Pumps (ccASHP)

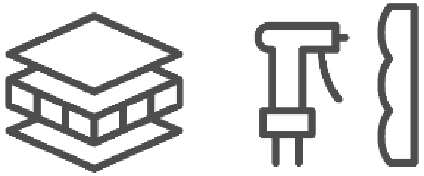
- Best-in-class ccASHPs on the market operates at COP of 2-3 even at -20 F
- Reduces peak heat demand in buildings

Ground Source Heat Pumps (GSHP)

- Efficiency does not vary with the outdoor air temperature
- Higher penetration of GSHP will greatly reduce both annual and peak heat demand in buildings

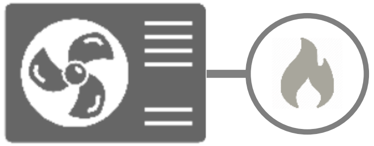
Building Shell Improvements (Shell)

- Includes multiple measures like air sealing, insulation, etc..
- Reduces both annual and peak heat demand in buildings

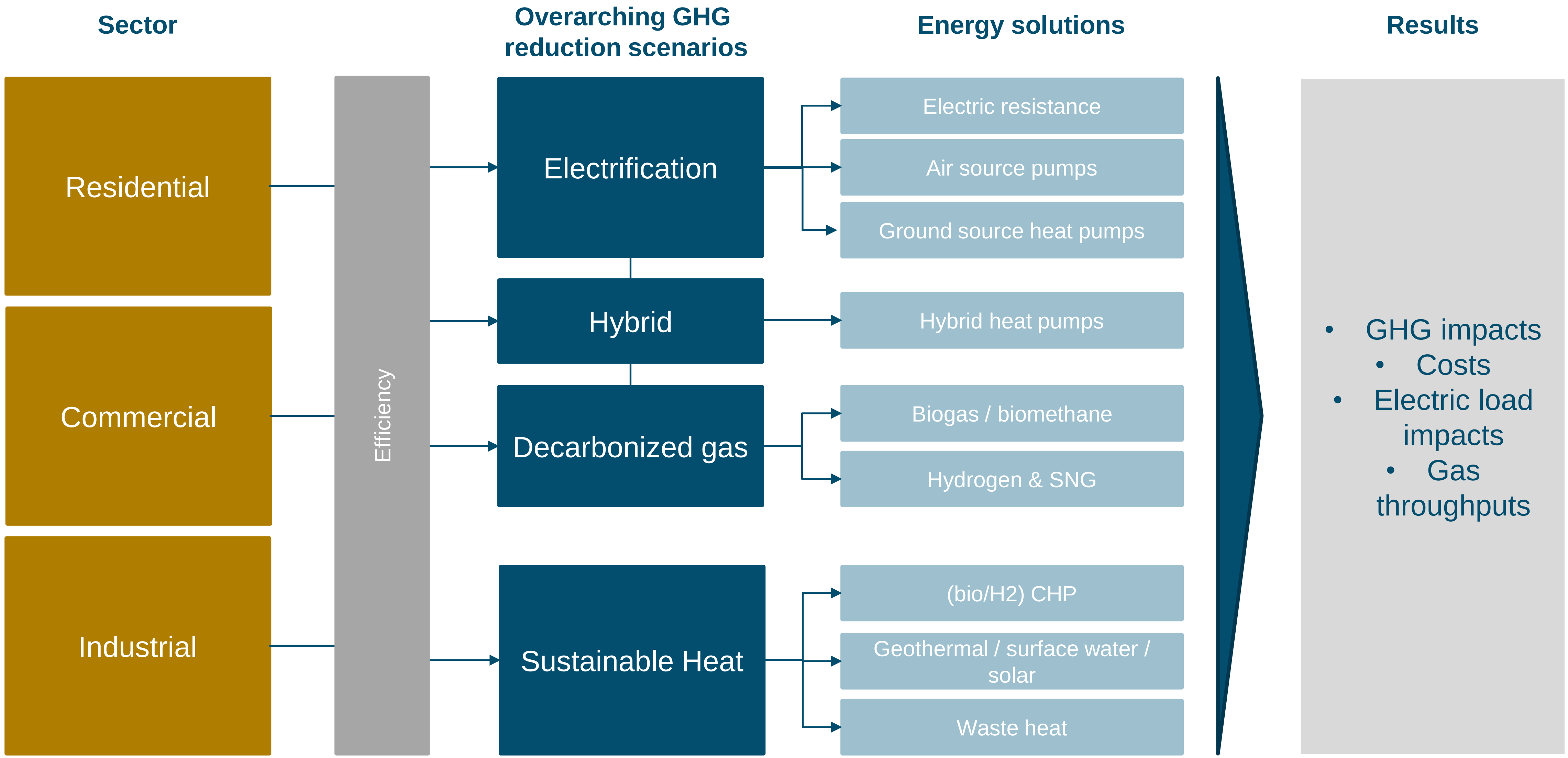


Natural Gas Heat Pumps

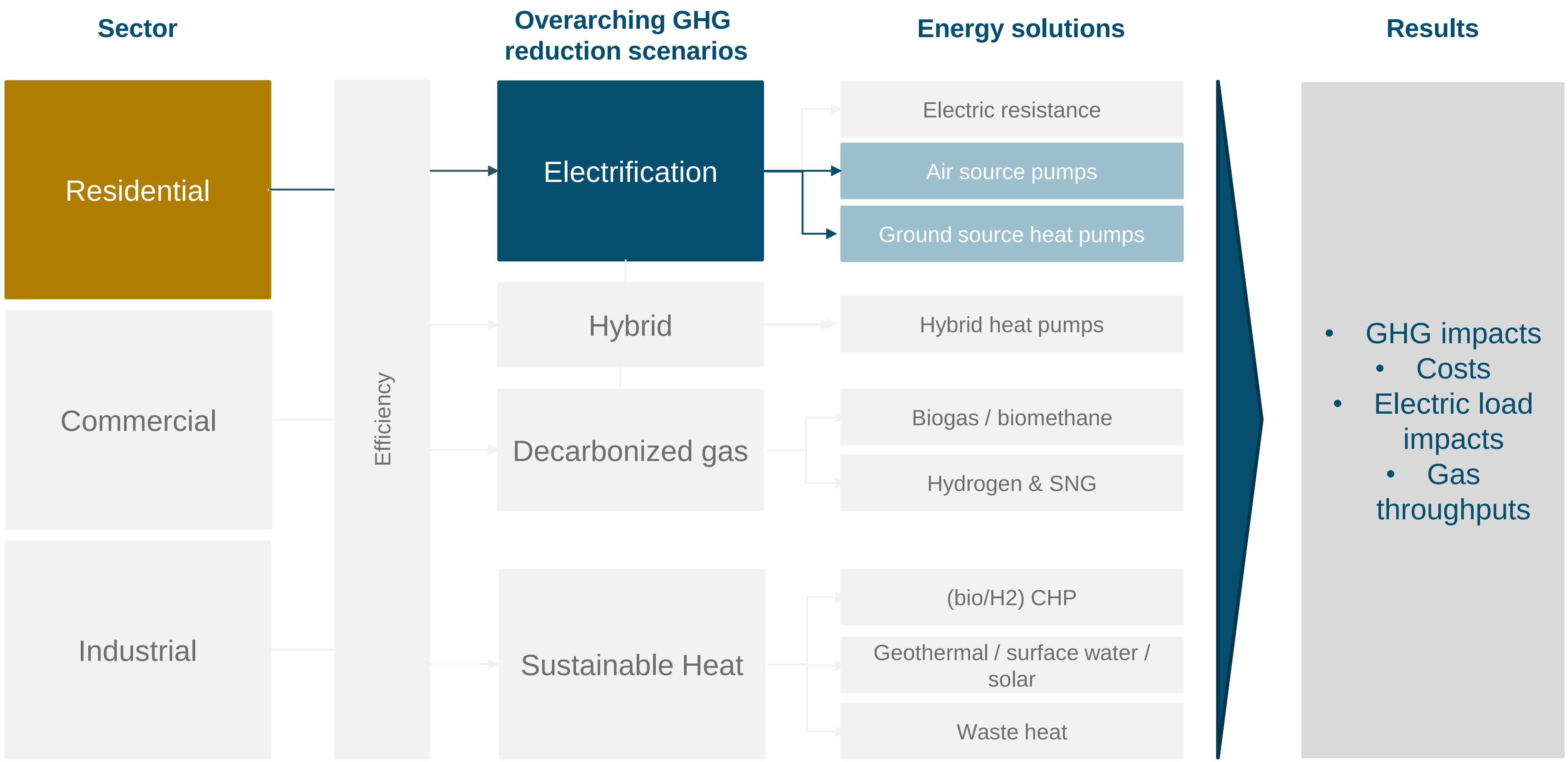
- Reduces demand for natural gas while providing efficient heating



Overview of technology 'flavors'



Results in a large number of possible futures



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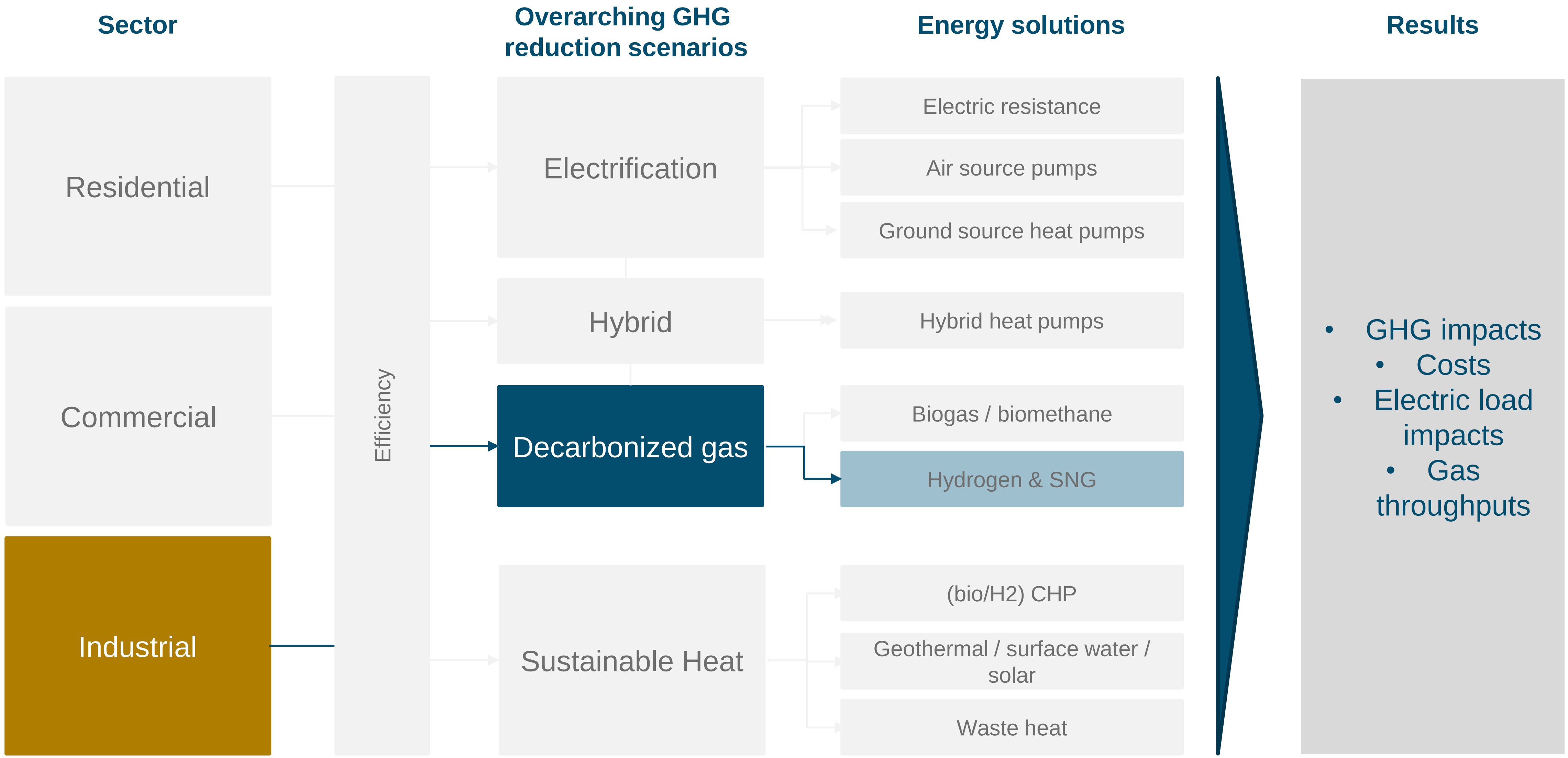
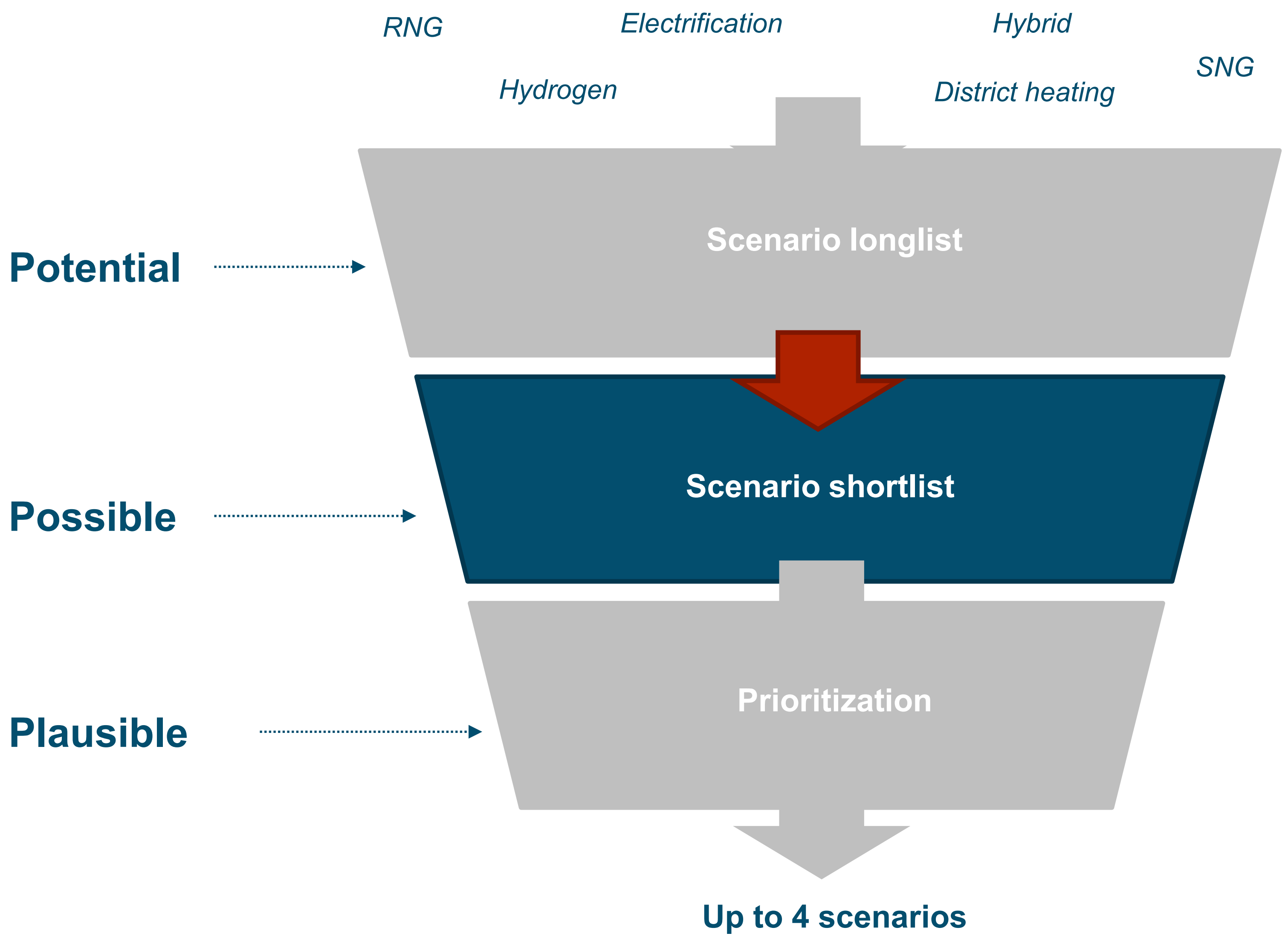


Key questions we aim to answer for MN

+ What options are technically feasible in each sector?
+ What options are most cost-effective given Minnesota's cold climate?
+ How can we make use of the available resources in the state?
+ How do the choices we make affect electricity supply?
+ How do the choices we make affect customer bills?

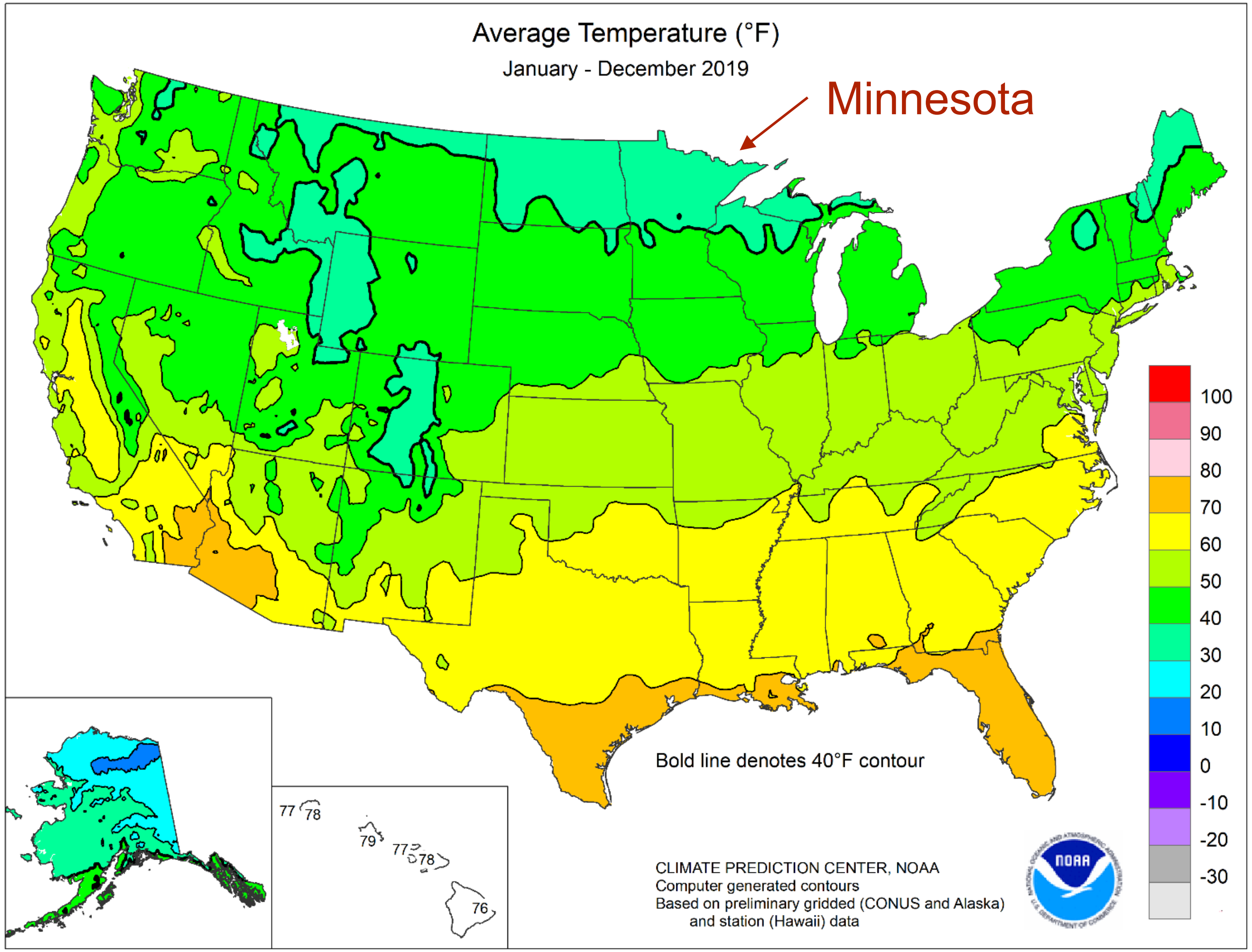
Part II: MN Narratives – Bookends & Plausible Futures

Prioritizing on plausible scenario narratives for MN



Shaping scenarios around the Minnesota context

- Cold winter climate requiring back-up heating solutions
- Good wind resources
- Large agricultural sector with biomass opportunities
- Income disparities raise importance of affordability
- Existing district systems and expertise around district systems



Source: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/12cavg0.png

Example scenarios: mix of two 'bookend' scenarios plus 1-2 intermediate options

Technology focus

High Fuels (bookend)	Mix of options	High Electrification (bookend)
1 high decarbonized gas scenario	1-2 intermediate scenarios	1 high electrification scenario

High Fuels (bookend) — 1 high decarbonized gas scenario

- *Higher consumer disruption (hydrogen focused)*
- *Lower consumer disruption (biomethane, potential H2 blend)*

Mix of options — 1-2 intermediate scenarios

- *Focus on hybrid electrification*
- *Focus on partial electrification (50-50 on electrification vs. decarb gas)*
- *Focus on sustainable heat (district heating, geothermal)*

High Electrification (bookend) — 1 high electrification scenario

- *Focus on retrofits + ASHP/GSHP*

Each narrative has different focus areas

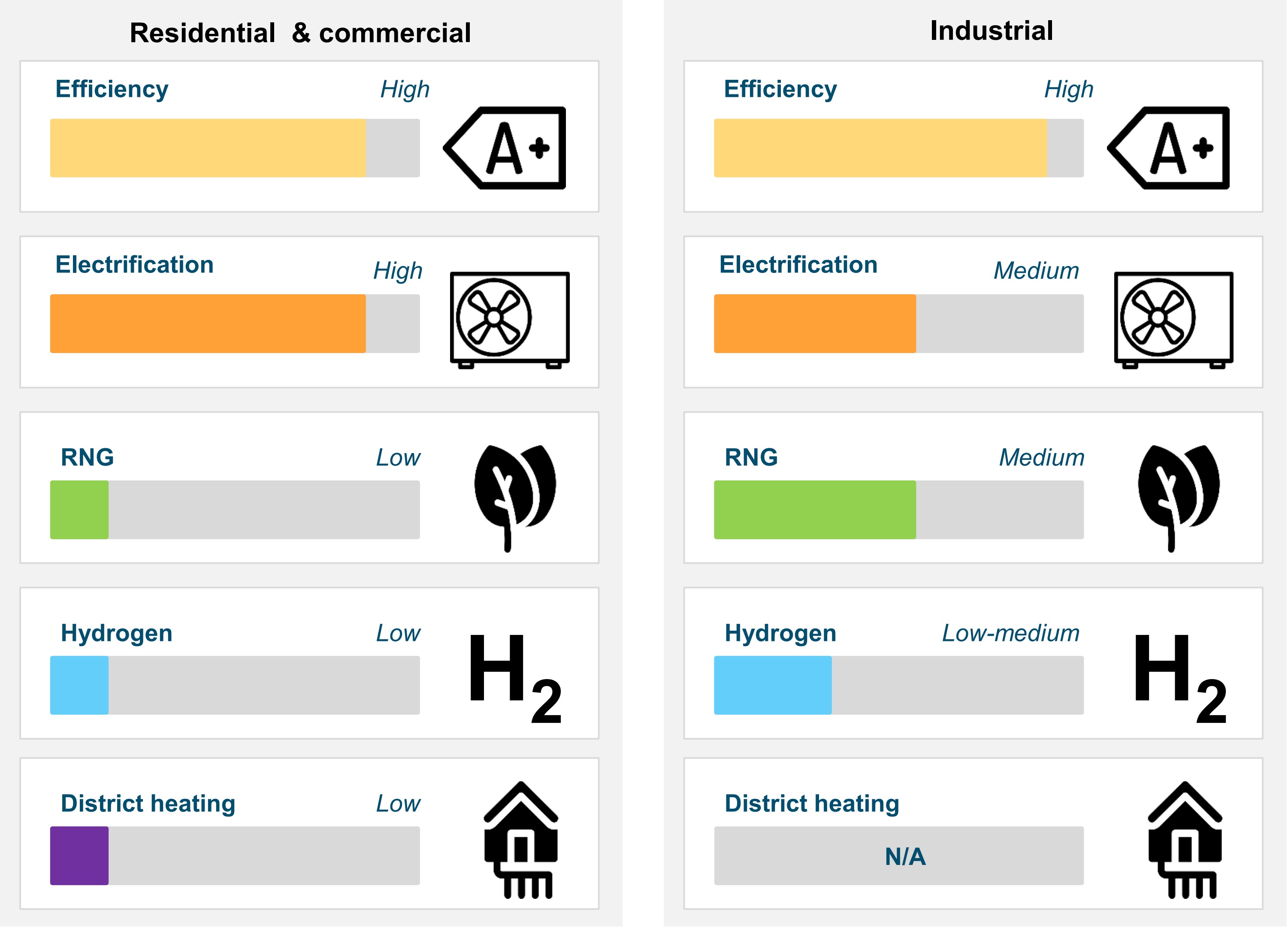
	Efficiency	Electrification	RNG	Hydrogen	District systems
High Electrification	*High*	*High*			
High Decarbonized Gas (I)			*High*		
High Decarbonized Gas (II)				*High*	
Hybrid Electrification		*Medium-high*	*Low-medium*		
Partial Electrification		*Medium*	*Medium*		
Geothermal (district) systems					*Medium*

Bookend narrative: high electrification

+ **In a High Electrification future, most homes switch to ASHPs and GSHPs. The gas system is almost completely replaced by wires. Some features:**
  - All-electric for new construction
  - Industrial electrification where technically viable
  - High efficiency through retrofits

Trade-offs

+ Capex vs. Opex: higher upfront consumer investments, lower fuel costs
+ Relatively high consumer disruption levels through retrofits
+ Large electric back-up necessary, high peak demands with low COPs in cold winters

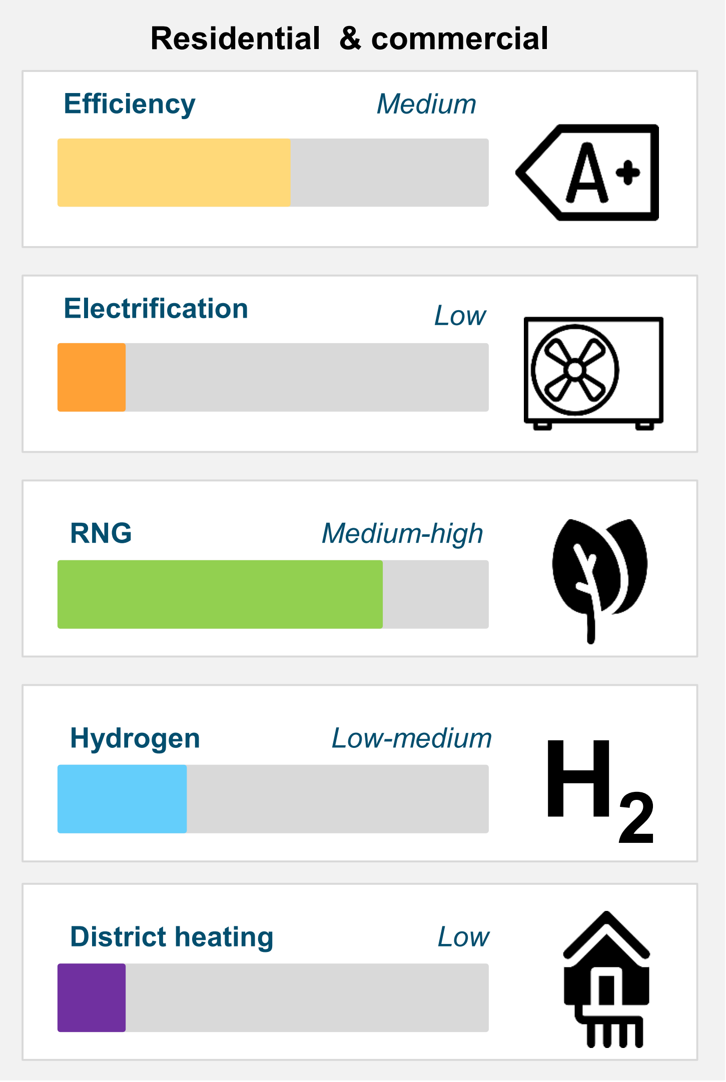


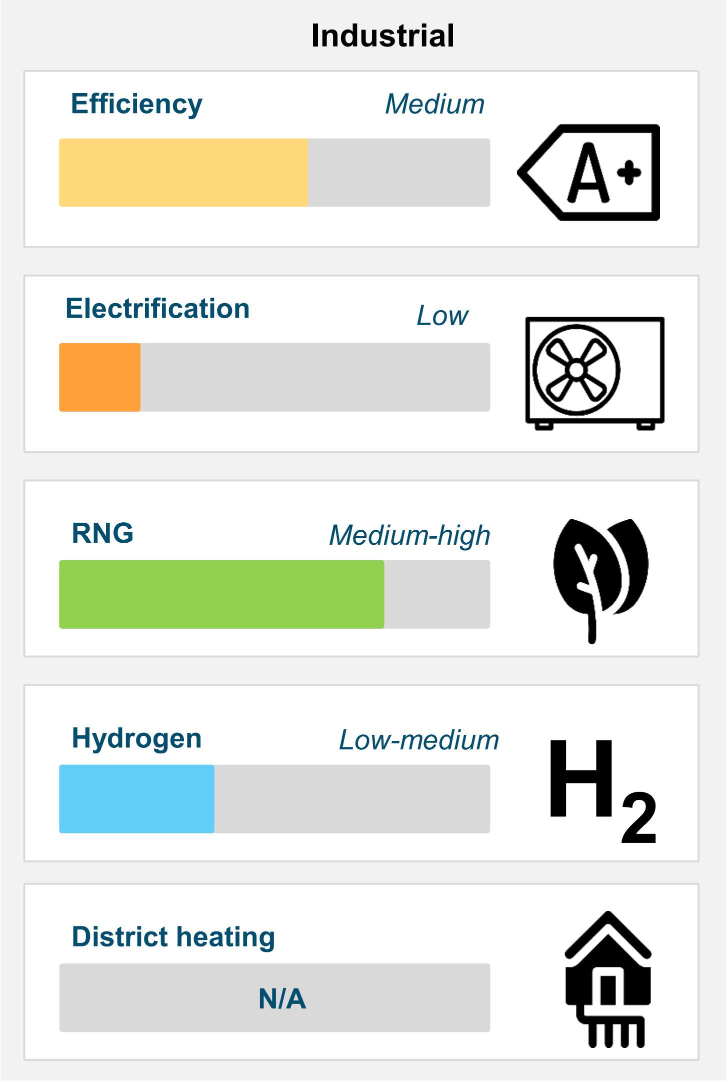
Bookend narrative: high decarbonized gas (I)

+ **In this high decarbonized gas future, most homes get to keep their gas connection. Gas supply consists of biomethane & hydrogen. Some features:**
  - Hydrogen blend in pipelines (~ 7%)
  - RNG from mix of in-state and out-of-state biomass
  - Efficiency through gas-fired HPs

Trade-offs

+ Capex vs. Opex: lower upfront consumer investments, higher fuel costs
+ Low consumer disruption levels
+ Large gas supply from sustainable sources necessary, potential (inter)national competition





Bookend narrative: high decarbonized gas (II)

In this high decarbonized gas future, most homes get to keep their gas connection. Gas supply consists of dedicated hydrogen pipelines combined with RNG. Some features:

- Dedicated H2 pipelines where viable
- Combined with RNG from mix of in-state and out-of-state biomass

Trade-offs

- Capex vs. Opex: lower upfront consumer investments, higher fuel costs
- Higher consumer disruption levels compared to previous scenario (in-house adjustments necessary)
- Large (currently expensive) hydrogen supply from electrolysis or SMR necessary, potential expensive pipeline adjustments

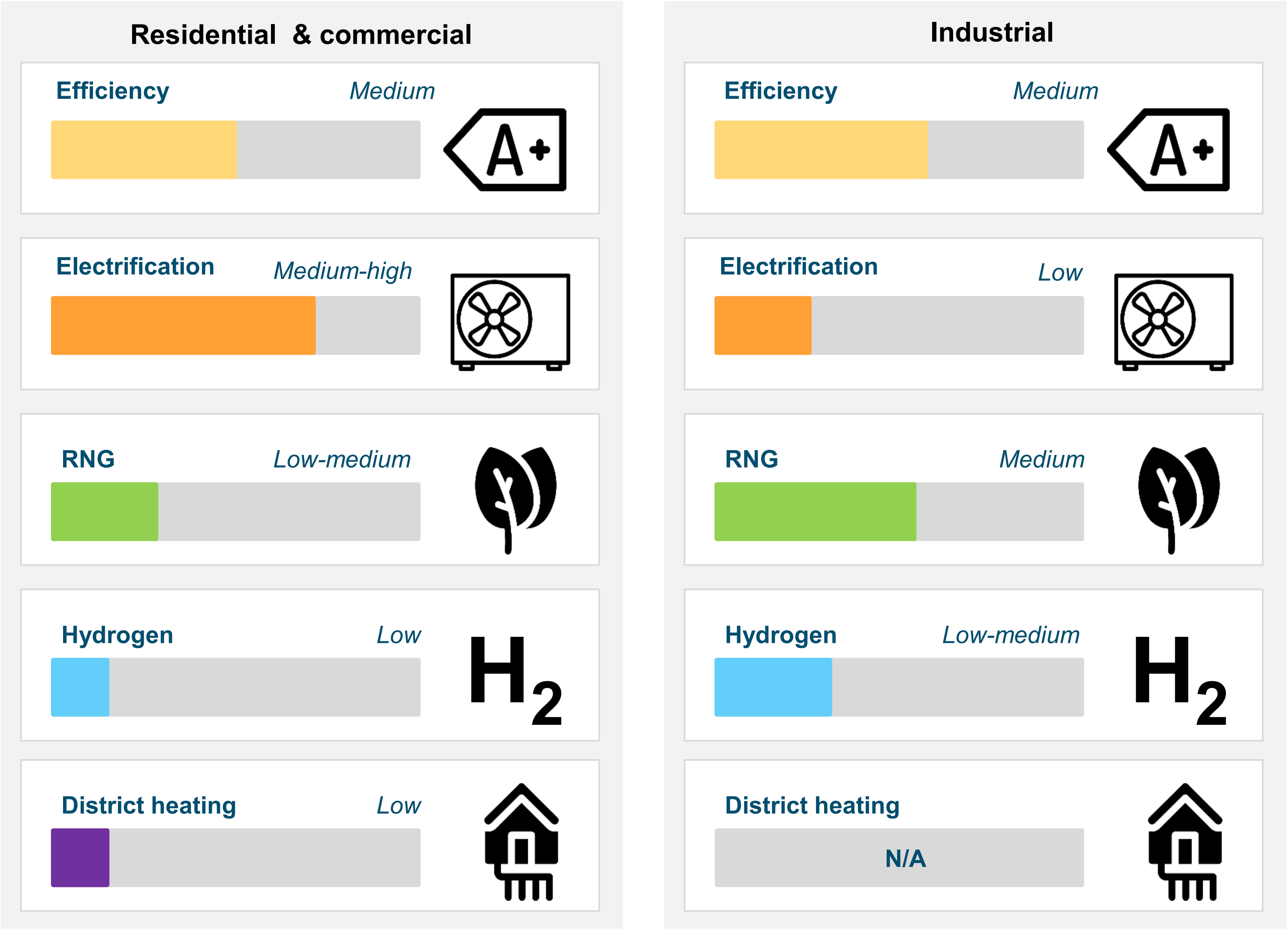
	Residential & commercial	Industrial
Efficiency	*Medium*	*Medium*
Electrification	*Low*	*Low*
RNG	*Low*	*Low*
Hydrogen	*High*	*High*
District heating	*Low*	N/A

Intermediate narrative: hybrid systems

- **In a hybrid future, most homes get to keep their gas connection. Homes are supplied with hybrid HPs, where gas is used in the coldest days of the year. Some features:**
  - All-electric for new construction
  - Hybrid HPs with RNG backup
  - Relatively high retrofits

Trade-offs

- Capex vs. Opex: higher upfront consumer investments, lower fuel costs
- Relatively high consumer disruption levels
- Electric peak demand reduced to a large extent, though low gas system utilization potentially drives up costs



Intermediate narrative: partial electrification

+ **With partial electrification, 50% of homes converts to HPs, while 50% remains connected to the gas grid. Some features:**
  - All-electric for new construction and other most suitable homes (better shell levels)
  - RNG for older buildings

Trade-offs

+ Transition needs to be structured (per neighborhood instead of per household approach) in order for scenario to make economic sense
+ Still relatively high electric winter peak

	Residential & commercial	Industrial
Efficiency	Medium	Medium
Electrification	Medium	Medium
RNG	Medium	Medium
Hydrogen	Low	Low-medium
District heating	Low	N/A

Intermediate narrative: geothermal (district) systems

- **In this scenario, the existing district systems convert and expand to collective geothermal/bio CHP systems Some features:**
  - Expansion of collective heat networks where possible
  - Emphasis on GSHPs for electrification

Trade-offs

- Capex vs. Opex: higher upfront consumer investments, lower fuel costs
- New infrastructure investments necessary
- Local vs. collective district systems, dependent on building type/geography

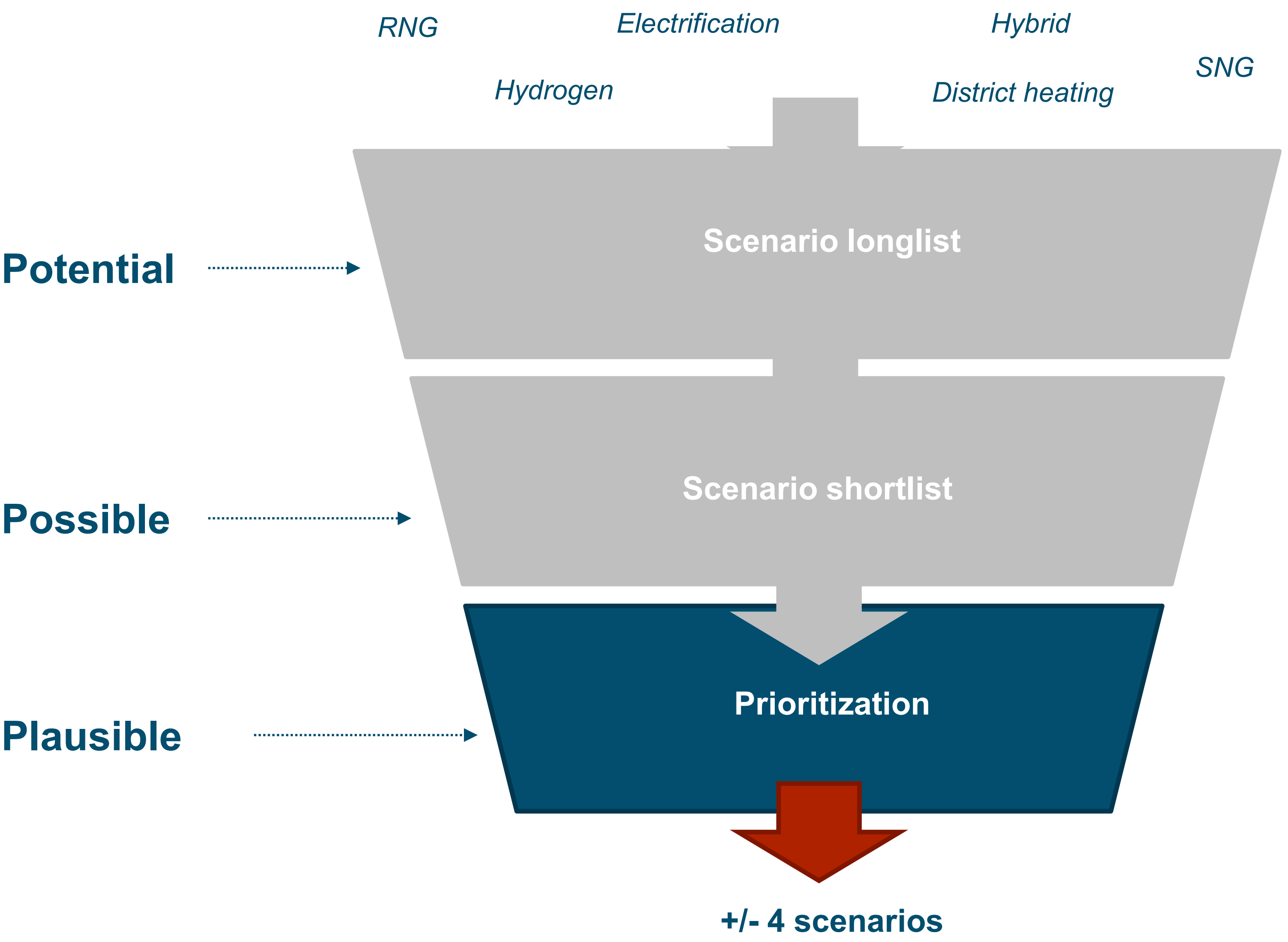
	Residential & commercial	Industrial
Efficiency	*Medium*	*Medium*
Electrification	*Medium*	*Medium*
RNG	*Low*	*Medium*
Hydrogen	*Low*	*Low-medium*
District heating	*Medium*	N/A

Summary of narratives

	Efficiency	Electrification	RNG	Hydrogen	District systems
High Electrification	High	High	Low	Low	Low
High Decarbonized Gas (I)	Medium	Low	Medium-high	Low-medium	Low
High Decarbonized Gas (II)	Medium	Low	Low	High	Low
Hybrid Electrification	Medium	Medium-high	Low-medium	Low	Low
Partial Electrification	Medium	Medium	Medium	Low	Low
Geothermal (district) systems	Medium	Medium	Low	Low	Medium

Part III: Breakouts & prioritization

Prioritizing on plausible scenario narratives for MN



Goal & logistics of break out rooms

+ **Goal of the break out rooms:** Clarifying scenario narratives where needed & selecting **<u>your collective top 3</u>**

+ **Questions in selecting your top 3:**
  - Which of these scenario narratives seem most plausible for Minnesota?
  - Which of these scenario narratives will challenge our thinking & assumptions most?
  - How would you tweak these scenarios to better fit the Minnesota context?

+ **Logistics & facilitation:**
  - Break-out in 3 Zoom groups – up to 10 participants per group
  - Each group is facilitated by E3 and GPI

Final Discussion and Wrap Up

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cee Center for Energy and Environment

Decarbonizing Minnesota’s Natural Gas End Uses

Next Meeting:

Wednesday, September 16, 2020

Via Zoom

*Note, meeting was rescheduled to avoid meeting on 9/11.

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