DECARBONIZING MINNESOTA'S NATURAL GAS END USES

Meeting 3

February 14th, 2020

American Swedish Institute

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Meeting Goals

1. Check in and collect any feedback on the process we're following as a group.
2. Build a shared understanding of work happening on natural gas decarbonization in California and New York.
3. Better understand key considerations for assessing the potential to decarbonize natural gas end uses and identify knowledge gaps that the group would like to explore further.

Process Overview and Review from Last Meeting

- What is the process that we're following?
- How do we prioritize topics and manage the scope?
- Review notes from last meeting

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What is Transformative Scenario Planning?

"A way for people to work with complex problematic situations that they want to transform but cannot transform unilaterally or directly."

Adam Kahane, *Transformative Scenario Planning*, 2012

- **Traditional scenario planning –** create scenarios about the future and decide how to adapt, often as a single actor
- **Transformative scenario planning –** collaboratively create scenarios about the future and decide how to adapt AND how to influence the way the future plays out

When is Transformative Scenario Planning Useful?

3 Key Criteria:

1. People find themselves in a situation that is or may soon become unacceptable, unstable, or unsustainable
2. The larger system of forces (economic, social, political) creating this situation is too complex to be solved by a single actor or faction of stakeholders, requiring broad collaboration
3. The key actors are currently too polarized to collaborate towards a solution. They may disagree on the solutions, what the problem is, and even how and why the problem came to be.

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Transformative Scenario Planning
Key Process Steps

1 Convene a team from across the system

2 Observe what is happening

3 Construct stories about what could happen

4 Discover what can and must be done

5 Act to transform the system

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1 Convene a team from across the system

- Backgrounds and perspectives to SEE the whole system
- Range of positions and connections to INFLUENCE the whole system
- Have a stake in the future
- Curious, systemic, open thinkers
- Willing and able (organizationally) to reflect and speak freely
- Energetic and action-oriented
- Microcosm or faction of the whole system

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2 Observe what is happening

- Explore what has happened and is happening in and around the system, from as many perspectives as time and resources will allow
- Collect observations from across the team
- Combination of both facts (objective) and interpretations (subjective)
- Bring in outside experts/resources as needed
- Raise awareness of challenges and deepen understanding of what is happening
- GOAL: Draw conclusions about what is going on in the system that matters most for the future (certainties and uncertainties)

3 Construct stories about what could happen

- Develop 2-4 total by two methods:
  - Choose 2 key uncertainties and map them into 4 possibilities
  - Develop a long list of scenarios, then narrow down to 2-4
- Should be relevant, challenging, plausible, clear
- Should make important dynamics clear and raise questions about current thinking
- GOAL: Improve the group's wisdom around their choices as the future unfolds, not to predict the future

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4 Discover what can and must be done

- Assess each scenario from two stances:
  - Adaptive – assumes you CANNOT change the system
  - Transformative – assumes you CAN change the system
- Ask two key questions:
  - What is happening that could have an impact on me/us?
  - What impact do I/we want to have?

5 Act to transform the system

- **Discuss and decide what action(s) to take:**
  - To the extent the group has reached consensus, it can take action as a collective whole
  - To the extent the group has not reached consensus, stakeholders can go their separate ways and act individually (but with much greater knowledge than if the process hadn't occurred)
- **Open up the process:**
  - Shift from private meetings to public action
  - Disseminate the group's learnings to a broader audience
  - Inspire others to act

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Energy, Environment, and Economics Presentation

Dan Aas, Energy, Environment, and Economics (E3)

Center for Energy and Environment

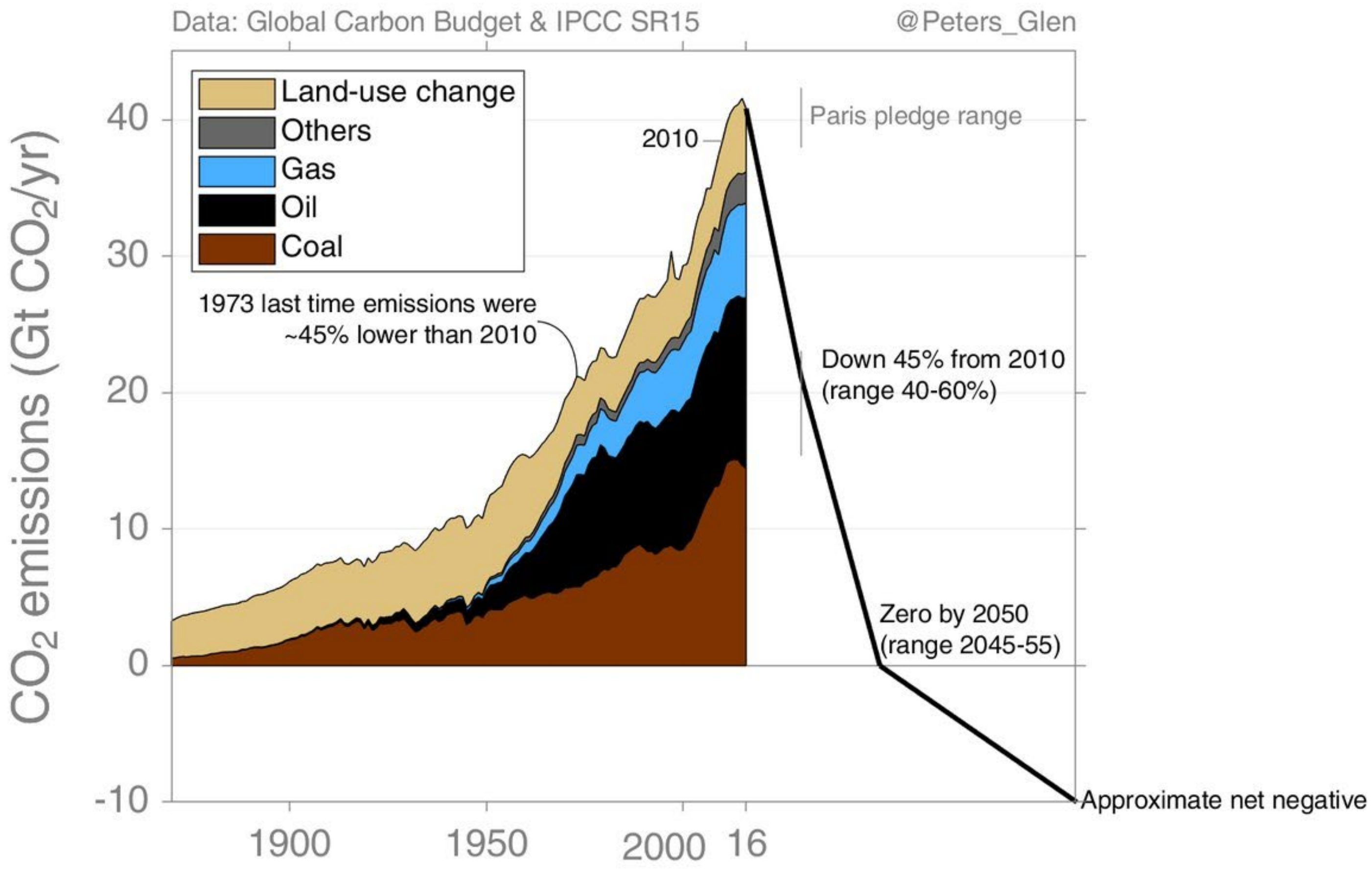
Decarbonizing natural gas end uses: Summary of recent E3 research

e21 Gas Decarbonization Workshop

February 14, 2020

Dan Aas, Managing Consultant

Motivation, 1.5C



Credit: Glen Peters, CICERO

- Carbon neutrality targets have emerged following the Paris Agreement, where parties committed to keeping global temperature rise **"well below 2 degrees Celsius" and to "pursue efforts to limit the increase to 1.5 degrees Celsius"**
- Practically, this means **carbon neutrality** must be achieved **by mid-century**, with sustained **negative** emissions beyond

Outline

- **RNG:** types, costs
- **Electrification:** opportunities, challenges
- **RNG and electrification:** in comparison

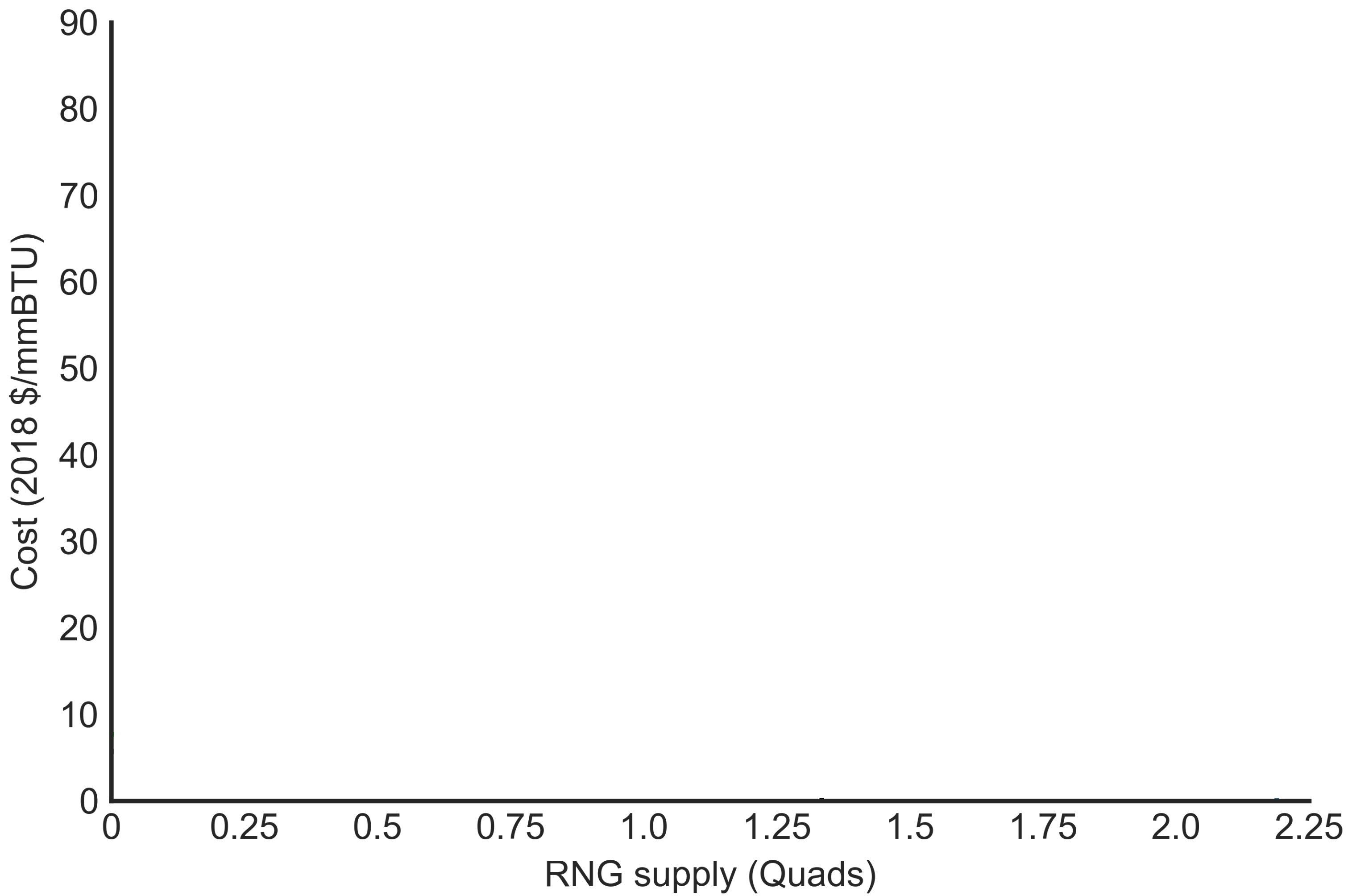
Energy+Environmental Economics

RNG

Key Takeaways

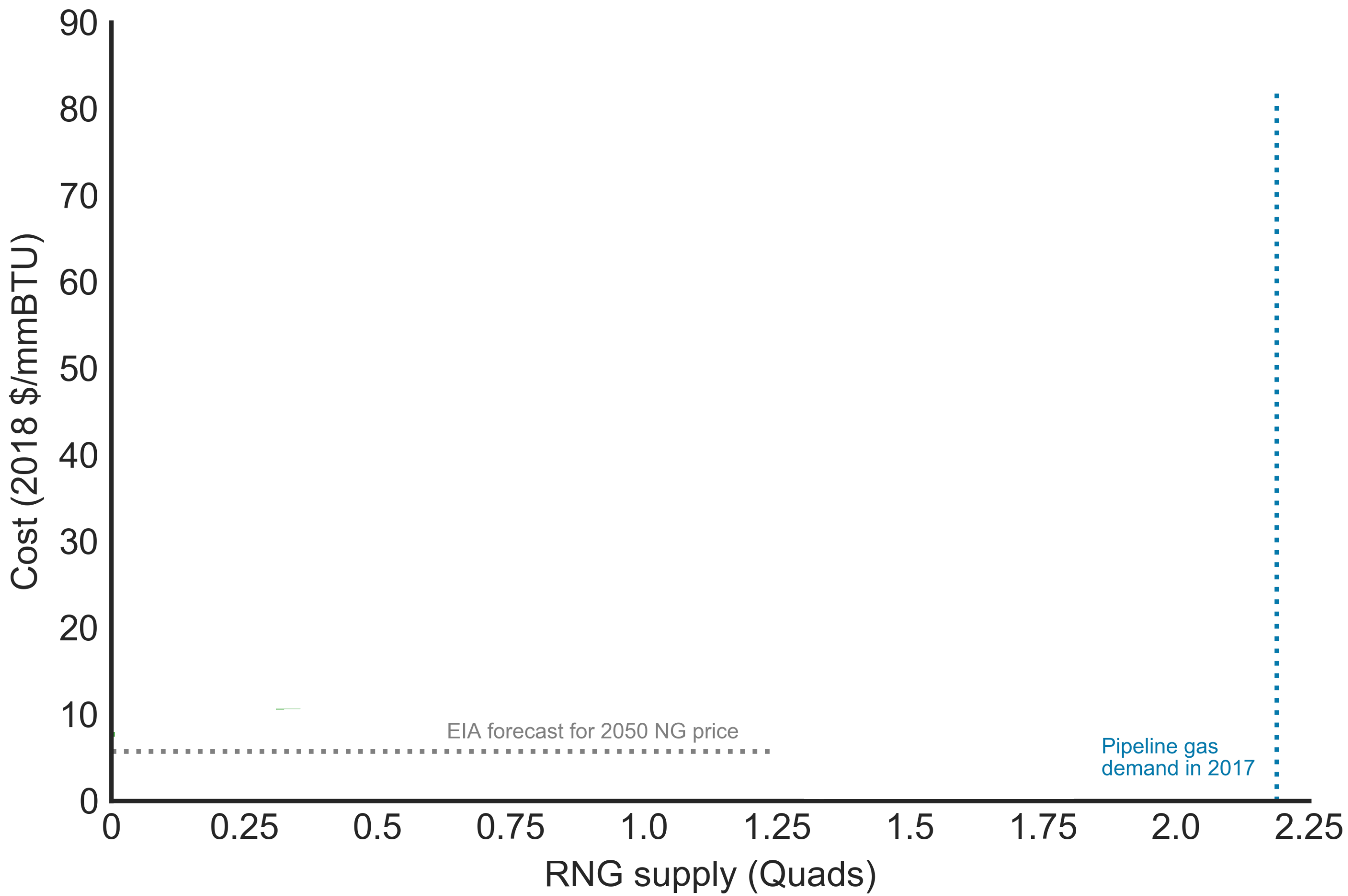
- RNG is a catch-all term that covers several different fuels
- Some varieties of RNG are very expensive and are unlikely to be competitive
- RNG and hydrogen likely have important roles to play in decarbonizing hard to electrify segments of the economy

California Renewable Natural Gas (RNG) Supply Curve



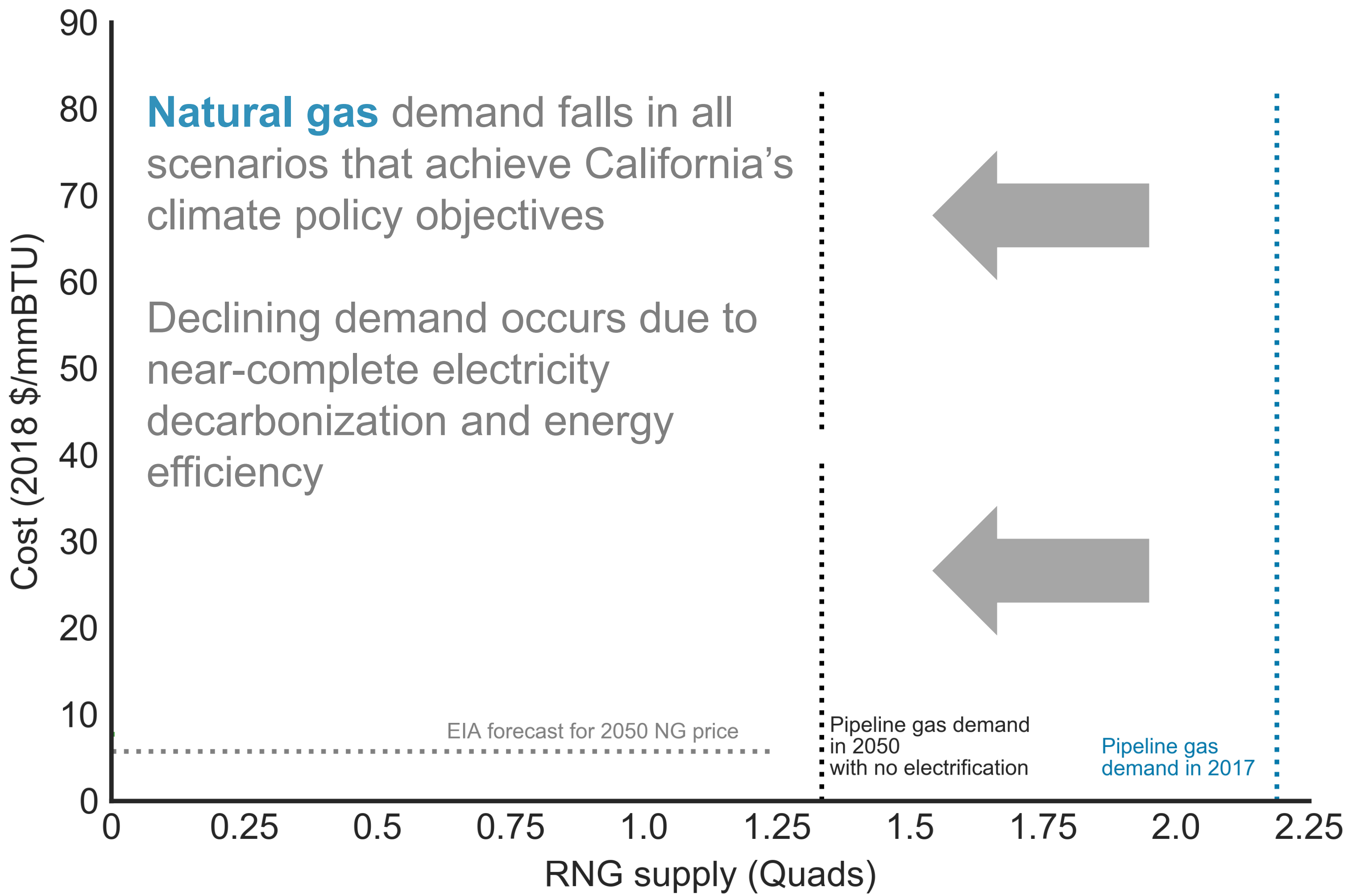
Natural gas demand and supply

California Renewable Natural Gas (RNG) Supply Curve, 2050



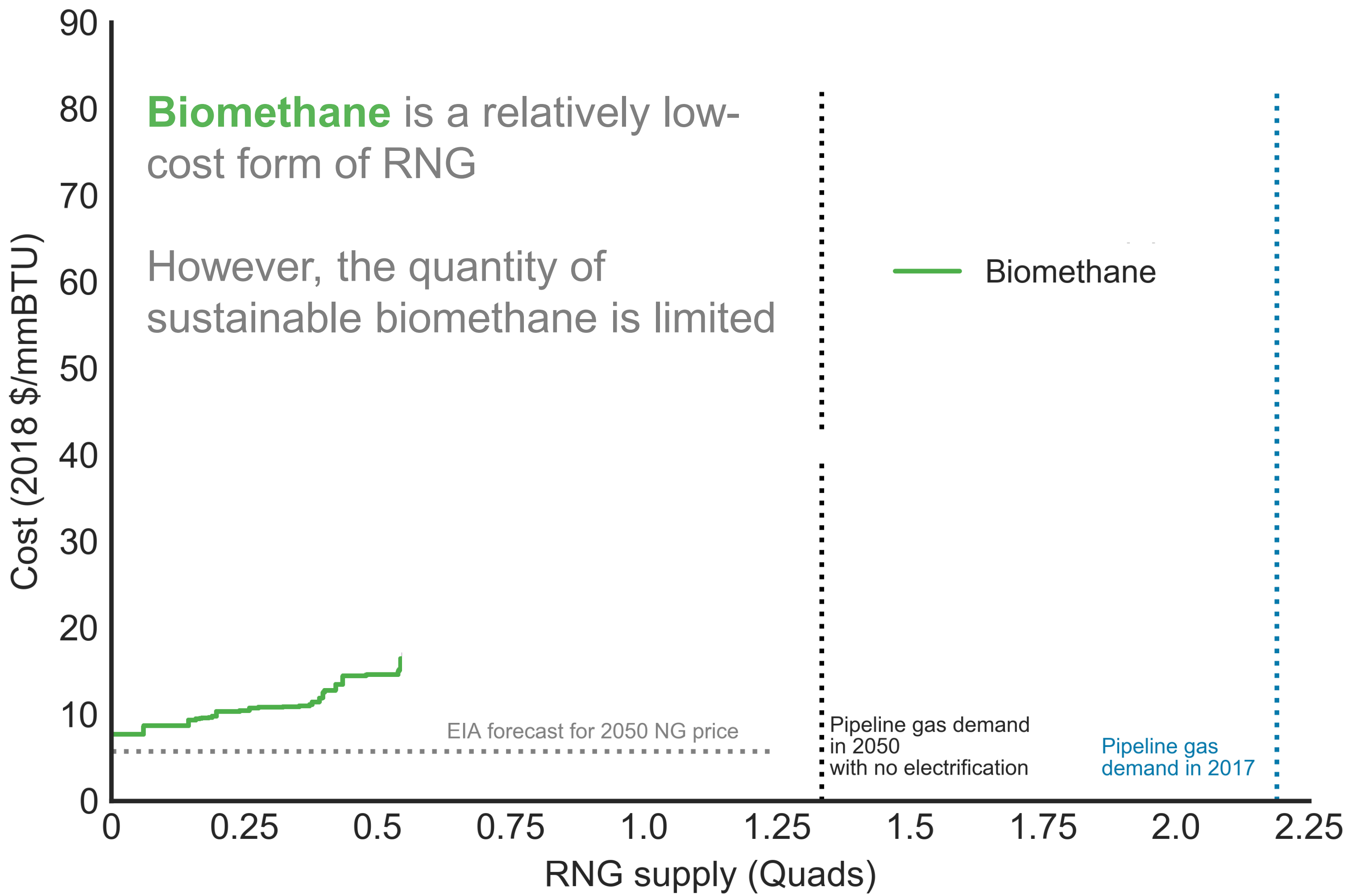
Natural gas demand in a low-carbon future

California Renewable Natural Gas (RNG) Supply Curve, 2050



Biomethane

California Renewable Natural Gas (RNG) Supply Curve, 2050



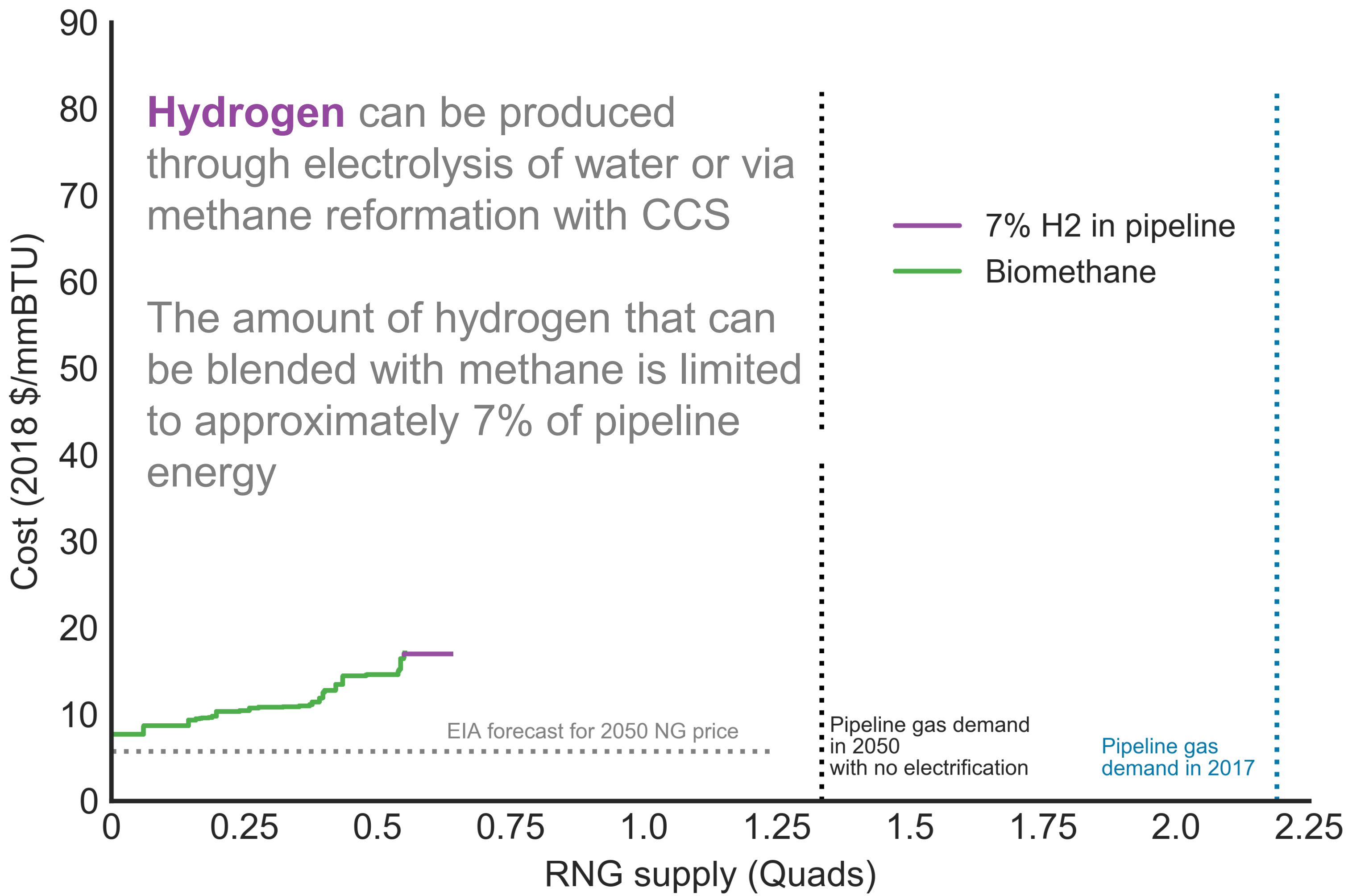
The quantity shown here assumes that biomethane feedstocks are limited to waste products (no purpose grown energy crops)

The total quantity of biomethane available is equal to California's population weighted share of U.S. feedstocks

An important caveat is that a share of those feedstocks can be used to produce liquid biofuels (e.g. renewable diesel, or renewable jet fuel)

Hydrogen

California Renewable Natural Gas (RNG) Supply Curve, 2050



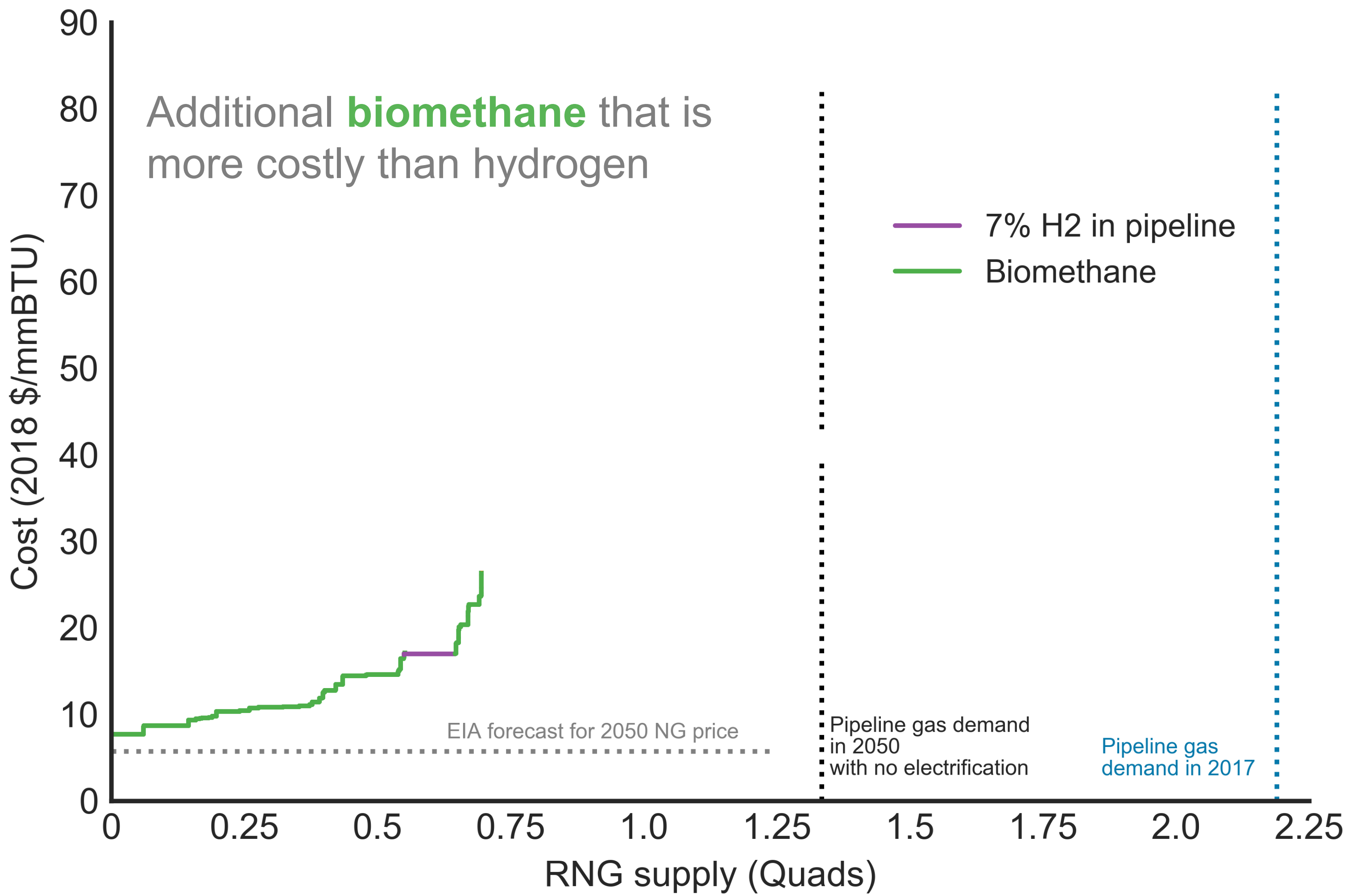
It is possible that gas systems could be converted to deliver 100% hydrogen

Such conversions would require replacement of most steel pipes used to deliver gas at high pressure and consumer equipment

Upgrades are also likely needed to gas distribution and storage infrastructure

More biomethane

California Renewable Natural Gas (RNG) Supply Curve, 2050

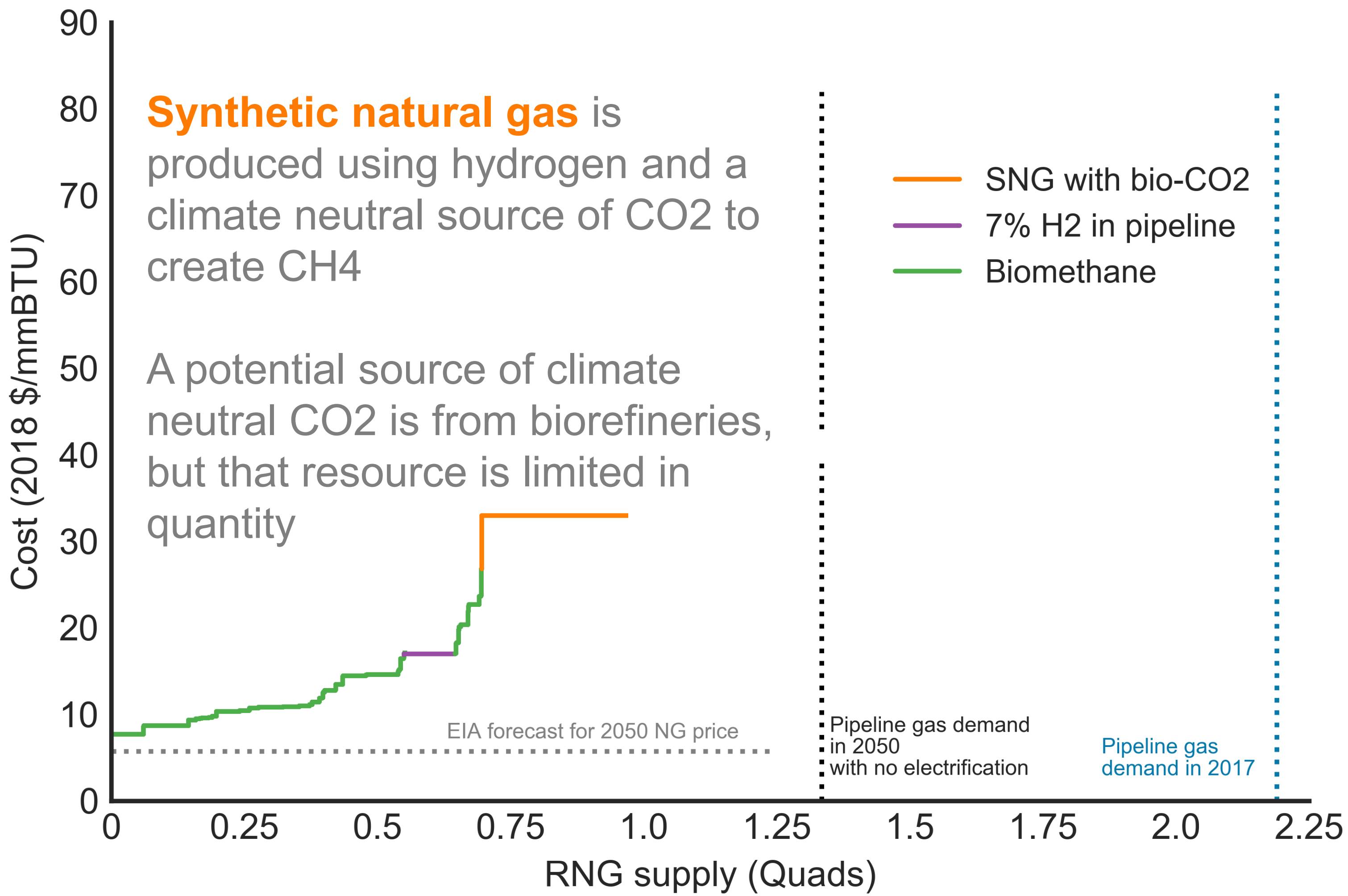


Synthetic natural gas with bio-CO2

California Renewable Natural Gas (RNG) Supply Curve, 2050

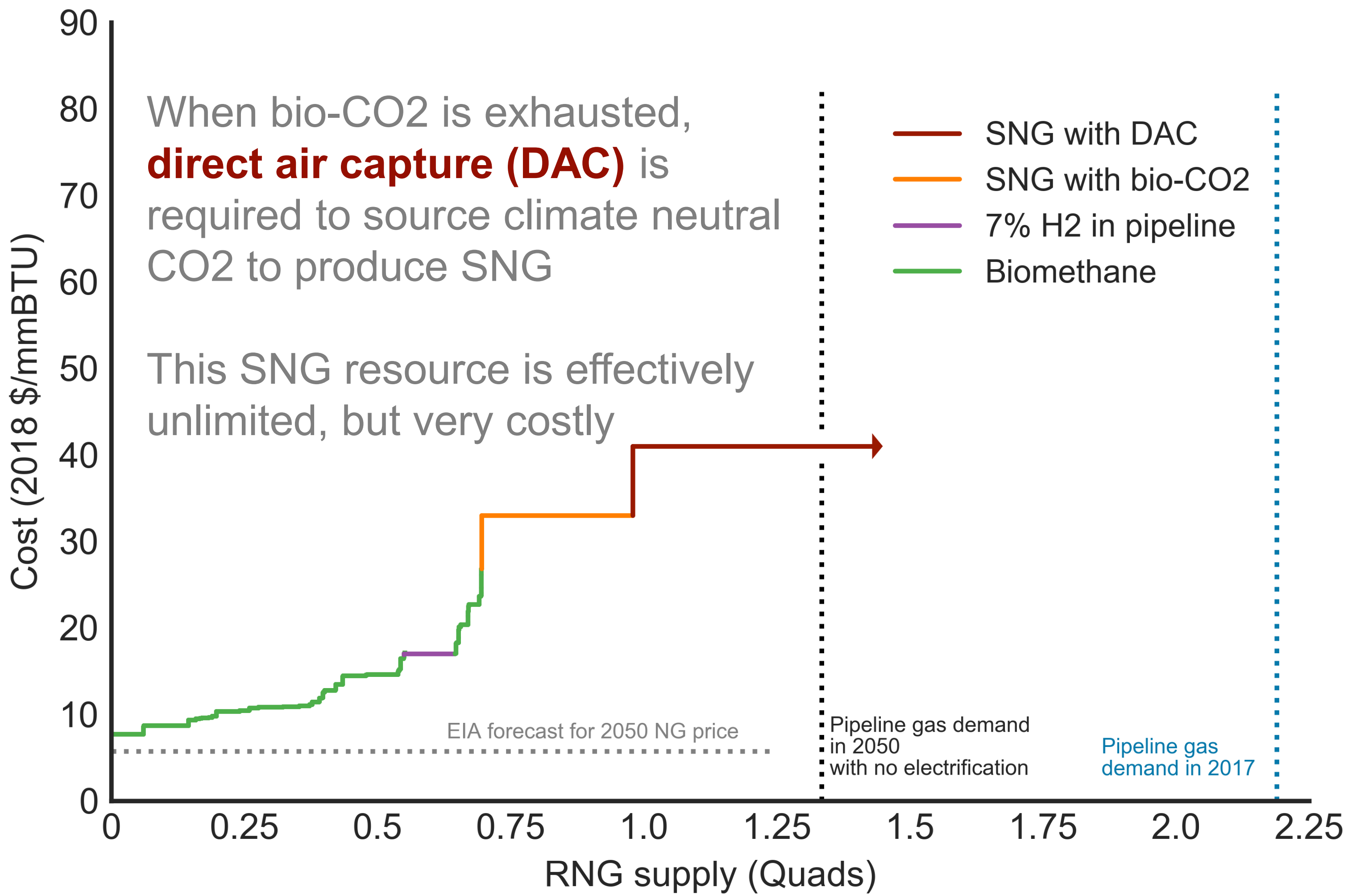
Synthetic natural gas is produced using hydrogen and a climate neutral source of CO_2 to create CH_4

A potential source of climate neutral CO_2 is from biorefineries, but that resource is limited in quantity



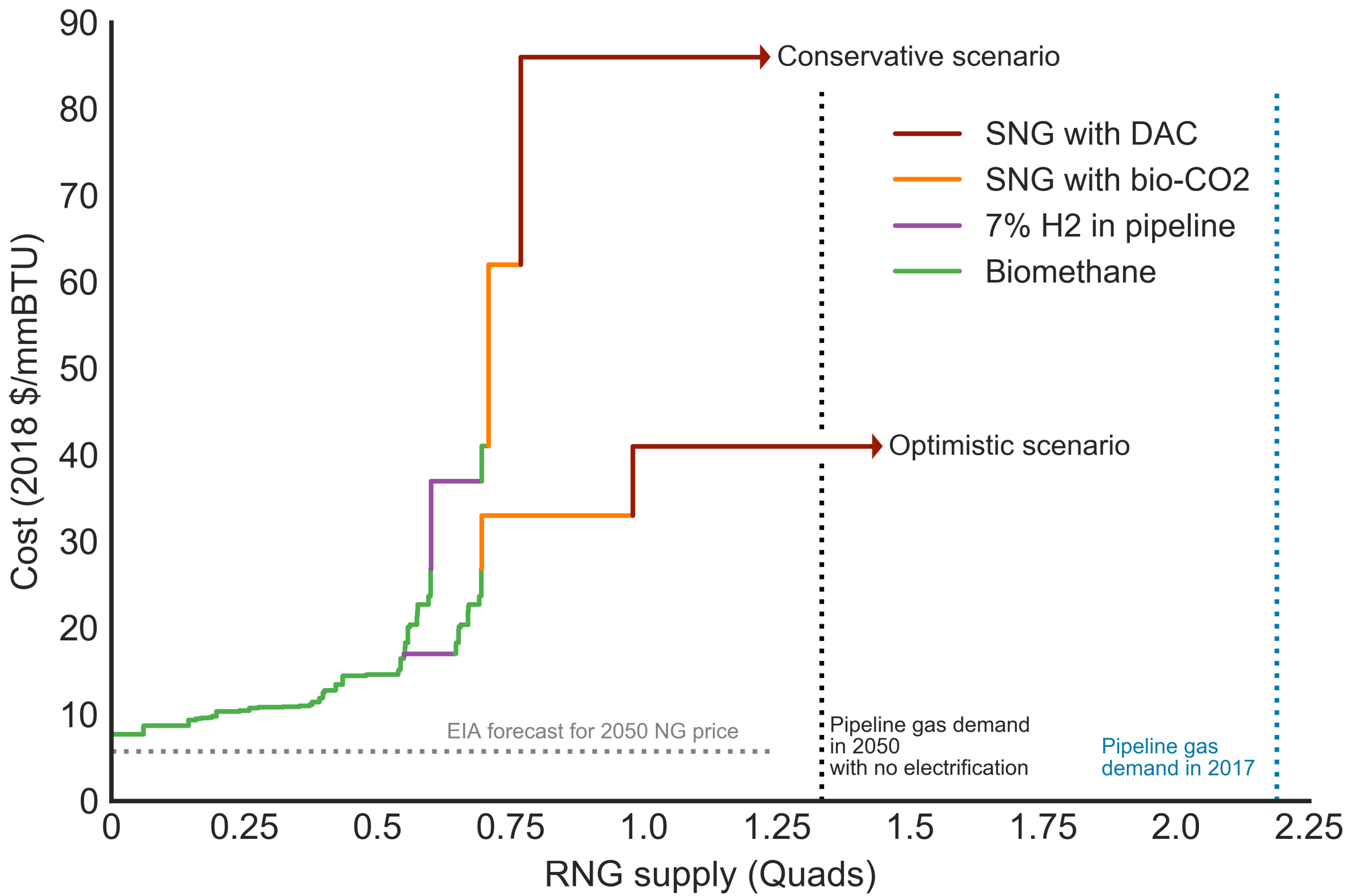
SNG with direct air capture

California Renewable Natural Gas (RNG) Supply Curve, 2050



E3 RNG Supply Curve: Conservative vs Optimistic

California Renewable Natural Gas (RNG) Supply Curve, 2050



This plot bounds a 'Conservative' and 'Optimistic' set of costs for RNG

The quantities of RNG on the x-axis will be different in MN, but the relative proportions are likely to be similar

However, it is unlikely that biomethane will be allocated on a population weighted basis, so there may be more or less available to a given state than shown here

Hydrogen could be used across multiple different applications in the economy

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Hydrogen
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Industry

- **Barriers:** Likely only under stringent carbon targets and if cheap H_2 production
- Investment in infrastructure to deliver 100% hydrogen
- **Key competitor**: Natural gas with carbon capture and storage

Power Gen

- **Barriers:** Conversion of existing generators to accommodate hydrogen
- **Key competitors**: Advanced nuclear, enhanced geothermal, … many others

Transportation

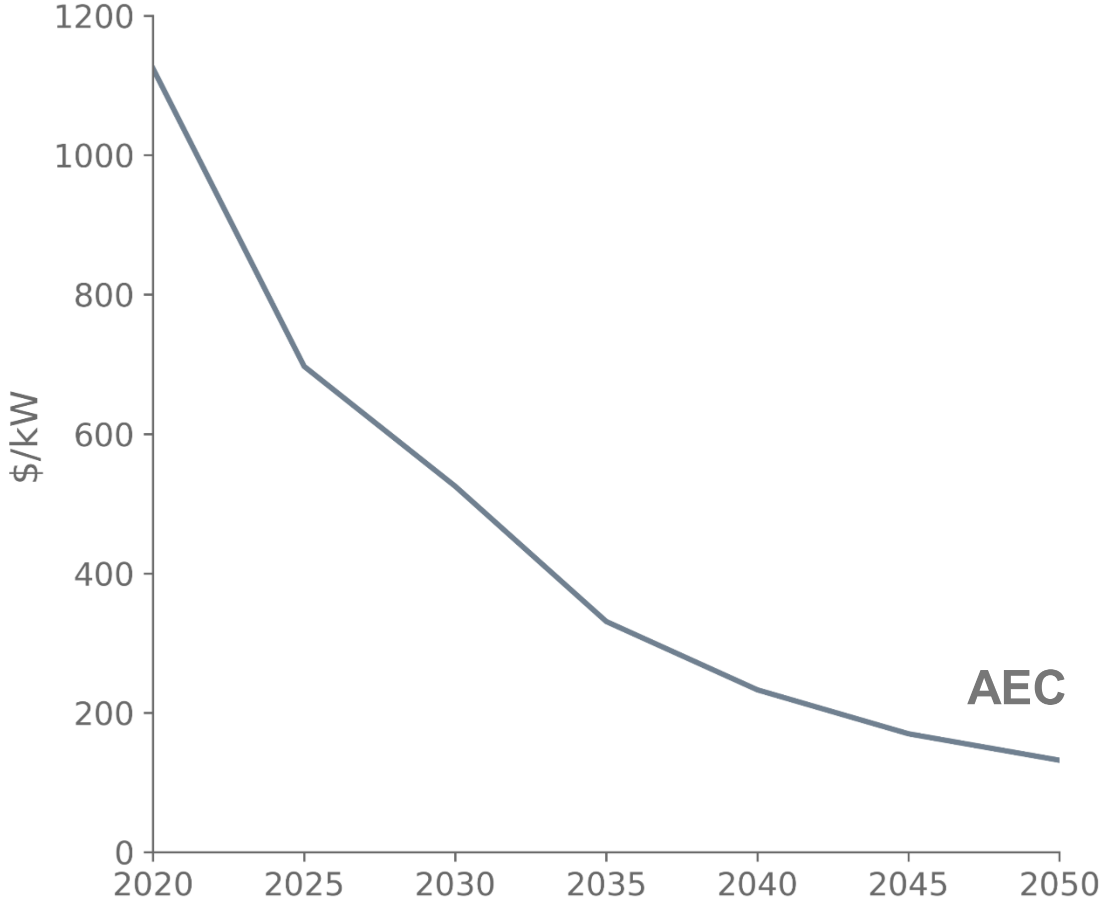
- **Barriers:** Fueling infrastructure, upfront costs of HFCVs
- **Key competitor**: BEVs, biofuels

Buildings

- **Barriers**: Likely only under stringent carbon targets and inability to electrify; requires large new industry to scale
- **Key competitor:** Electrification/heat pumps

Hydrogen production cost are expected to fall

Example Electrolyzer Cost Forecast

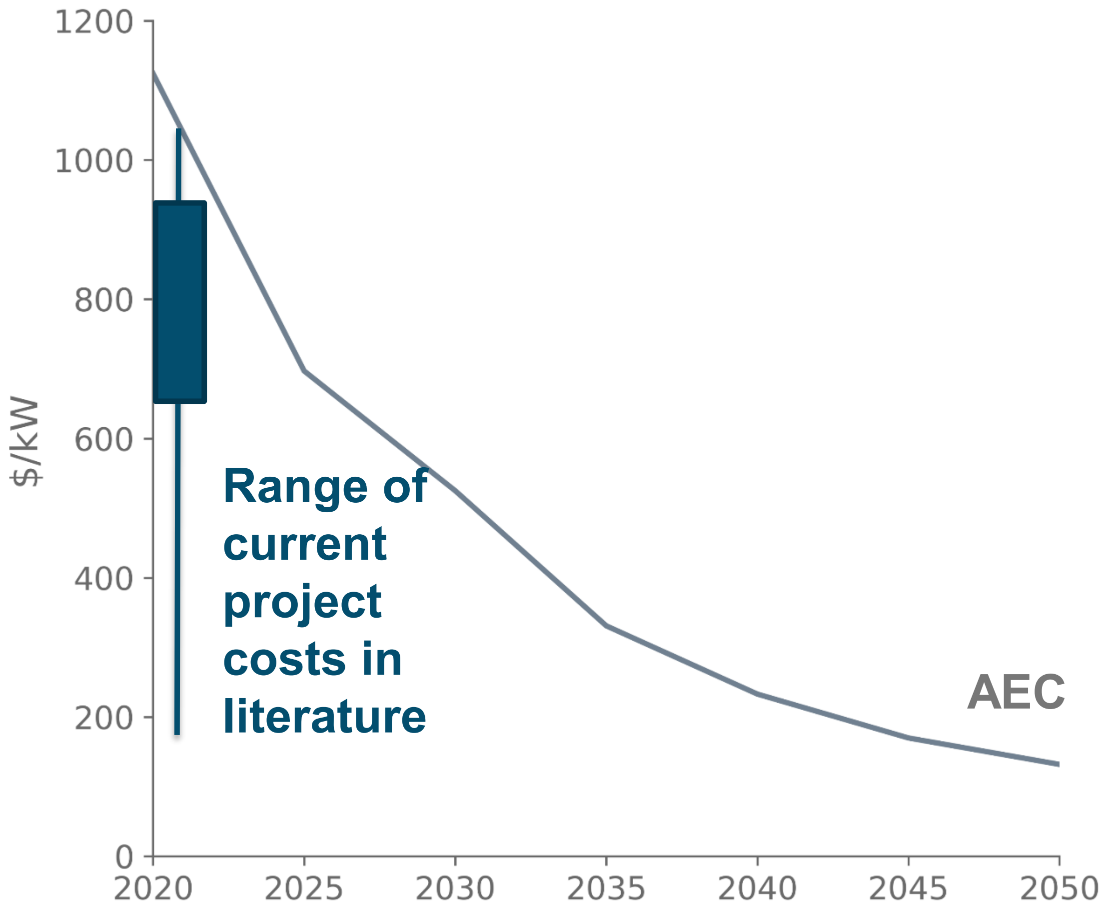


E3 recently worked with experts at the UC Irvine Advanced Power and Energy Program to evaluate long-term cost and performance trajectories for hydrogen costs

UC Irvine forecasted steep declines in electrolyzer costs driven by experience curves and learning by doing

Hydrogen costs may already have fallen

Electrolyzer Cost Forecast



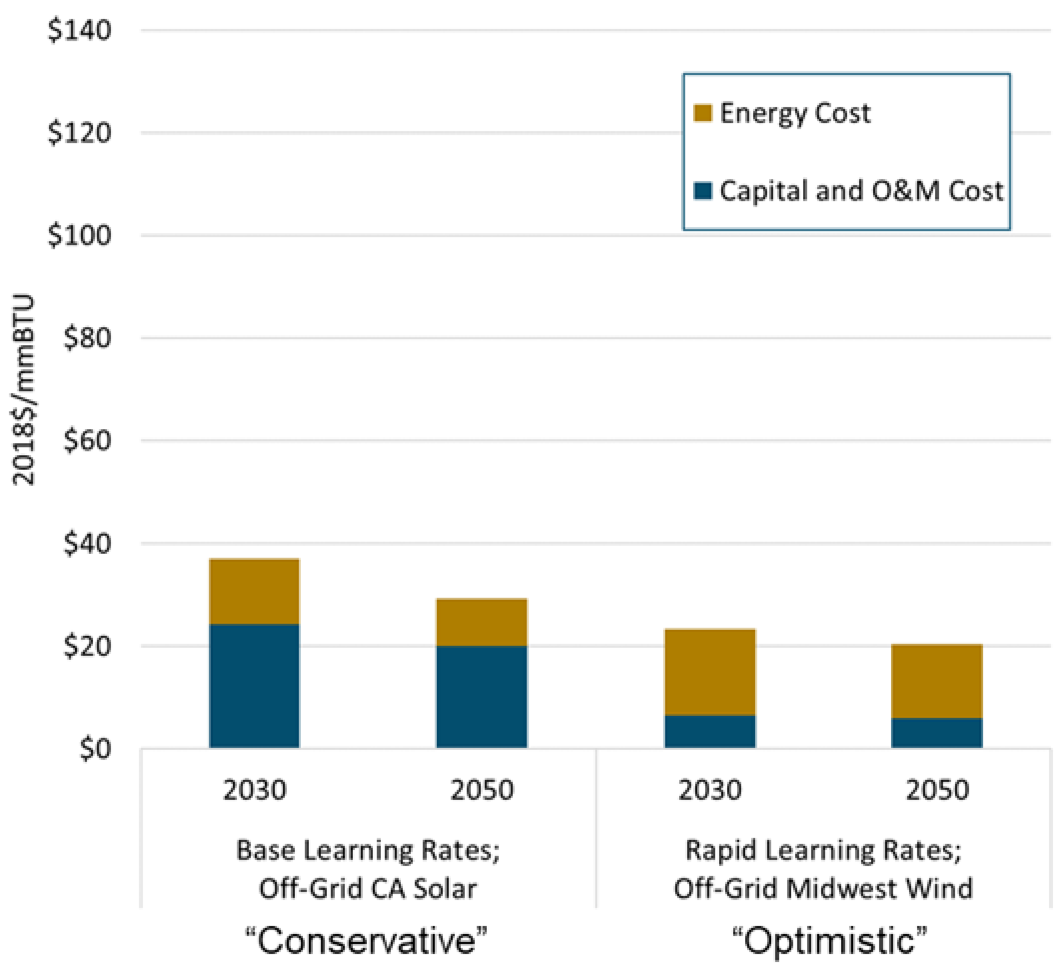
In 2017, E3 worked with experts at the UC Irvine Advanced Power and Energy Program to evaluate long-term cost and performance trajectories for hydrogen costs

UC Irvine forecasted steep declines in electrolyzer costs driven by experience curves and learning by doing

Since that research, there have been several reports of actual projects that are well below of UC Irvine's cost projections

Hydrogen production costs are dominated by energy input when electrolyzer costs are low

2050 hydrogen costs, decomposed



Today, electrolyzers are expensive from a capital investment perspective

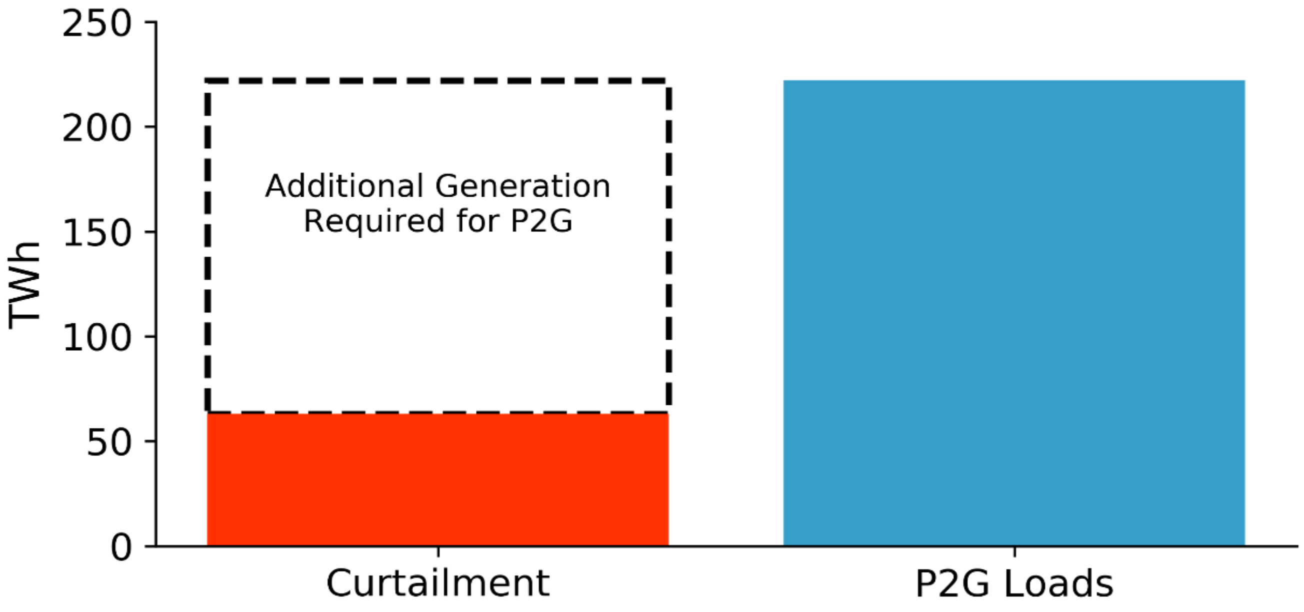
This means they are most economical when they can be used at high capacity factors

However, if electrolyzer costs are low then the largest driver of hydrogen commodity costs is the source of electricity used

This cost-structure raises the prospect that off-grid renewables could be the preferred electricity source to produce hydrogen

“Power to Gas” loads compared to curtailment

2050 Curtailment versus P2G loads in California



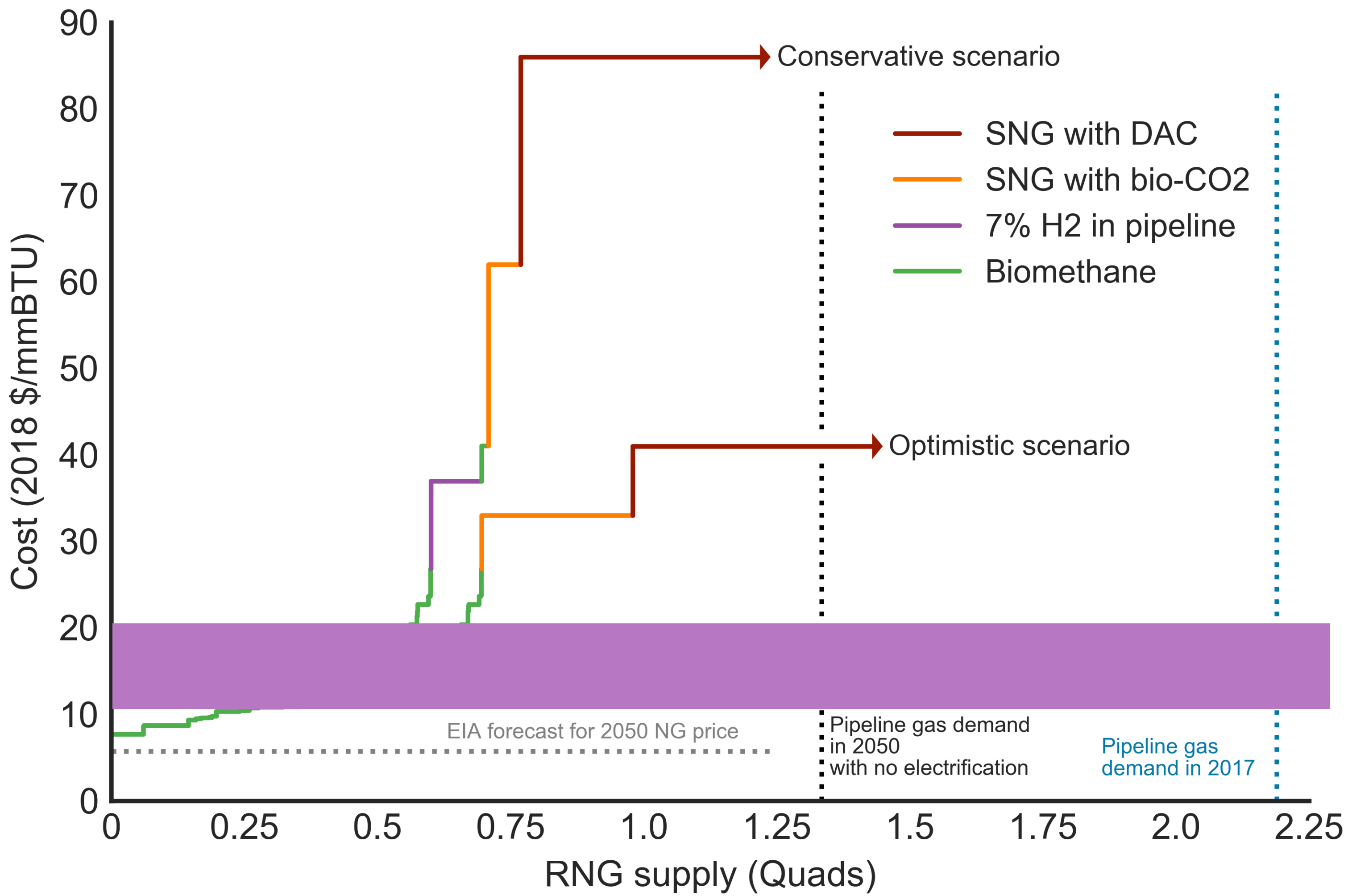
“Power to Gas” is a catch-all term for hydrogen and SNG. Some analyses show low P2G costs resulting from use of ‘free’ electricity that would be otherwise be curtailed

In our work in California, we find that P2G loads far exceed the amount of curtailment that can be expected in a future decarbonized electricity system.

In this example, P2G loads in 2050 nearly equal CA electric loads today

100% hydrogen commodity cost

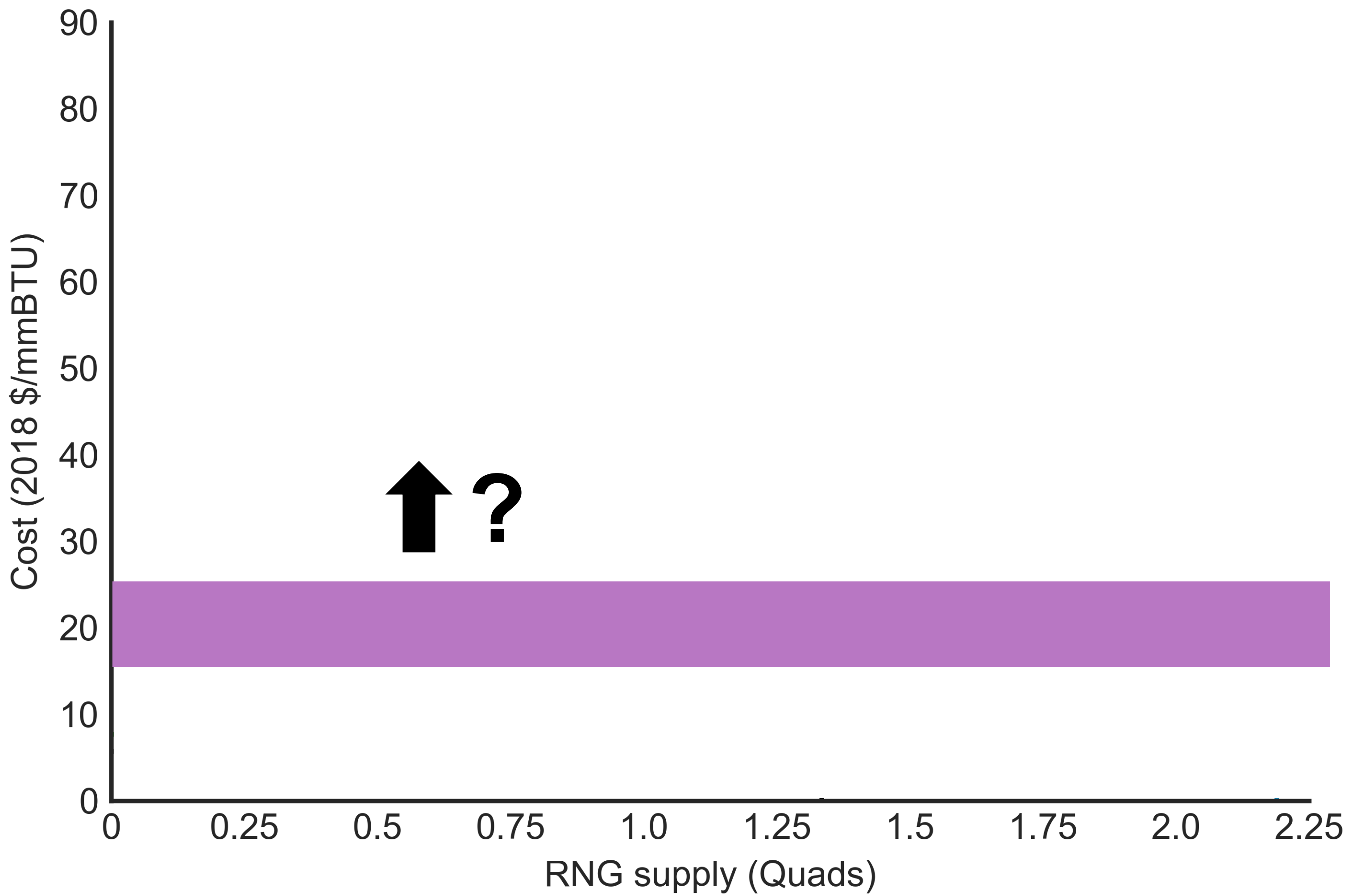
California Renewable Natural Gas (RNG) Supply Curve



100% hydrogen may be far more economical than a 100% RNG blend

100% hydrogen, commodity + hypothetical incremental delivery cost

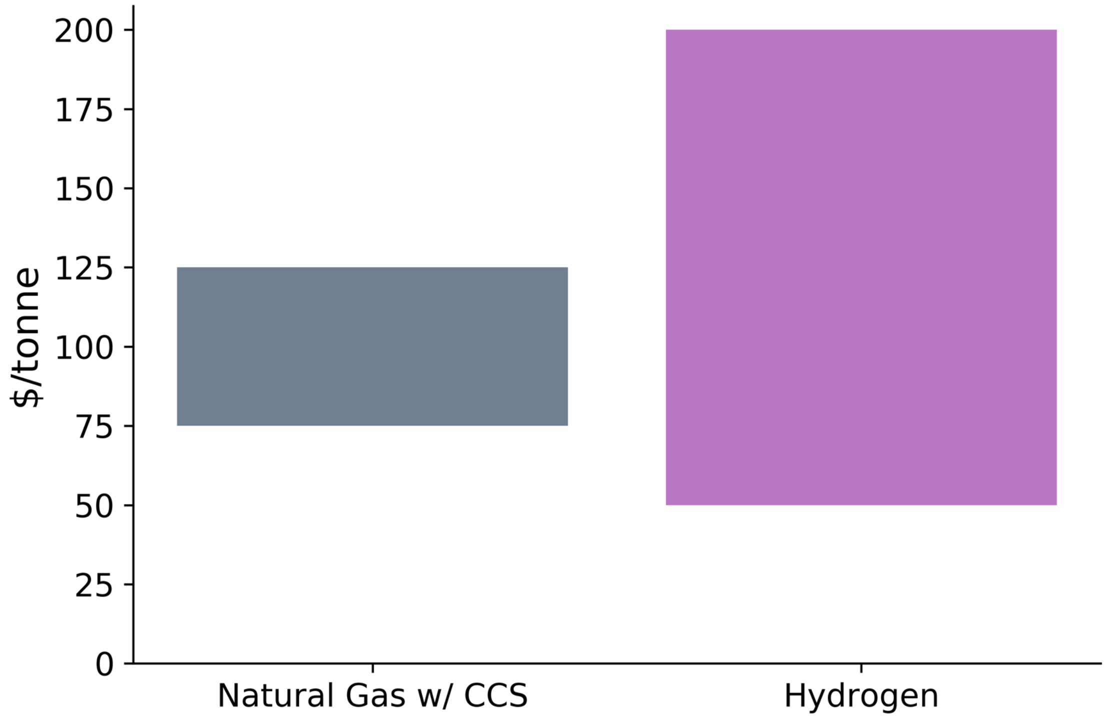
California Renewable Natural Gas (RNG) Supply Curve



However, there will be incremental costs beyond just the commodity cost of hydrogen that are difficult to account for

Hydrogen in industry

Example GHG abatement cost ranges

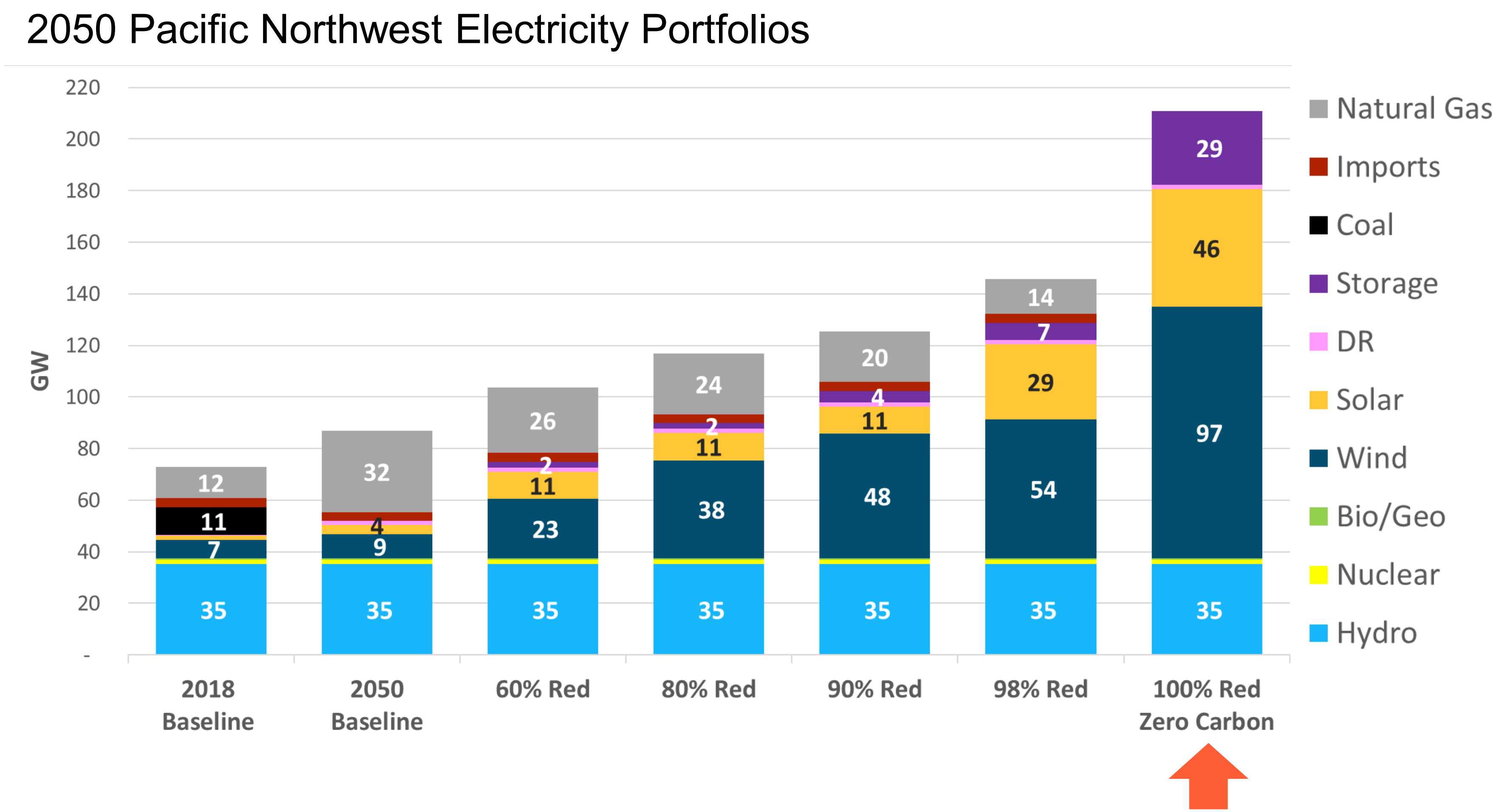


A promising use for hydrogen could be used to displace natural gas use in industry

The primary alternative is natural gas paired with carbon capture and sequestration

Hydrogen is likely to be a more economic option in cases where natural gas is expensive, while CCS is more cost-effective when natural gas is low-cost

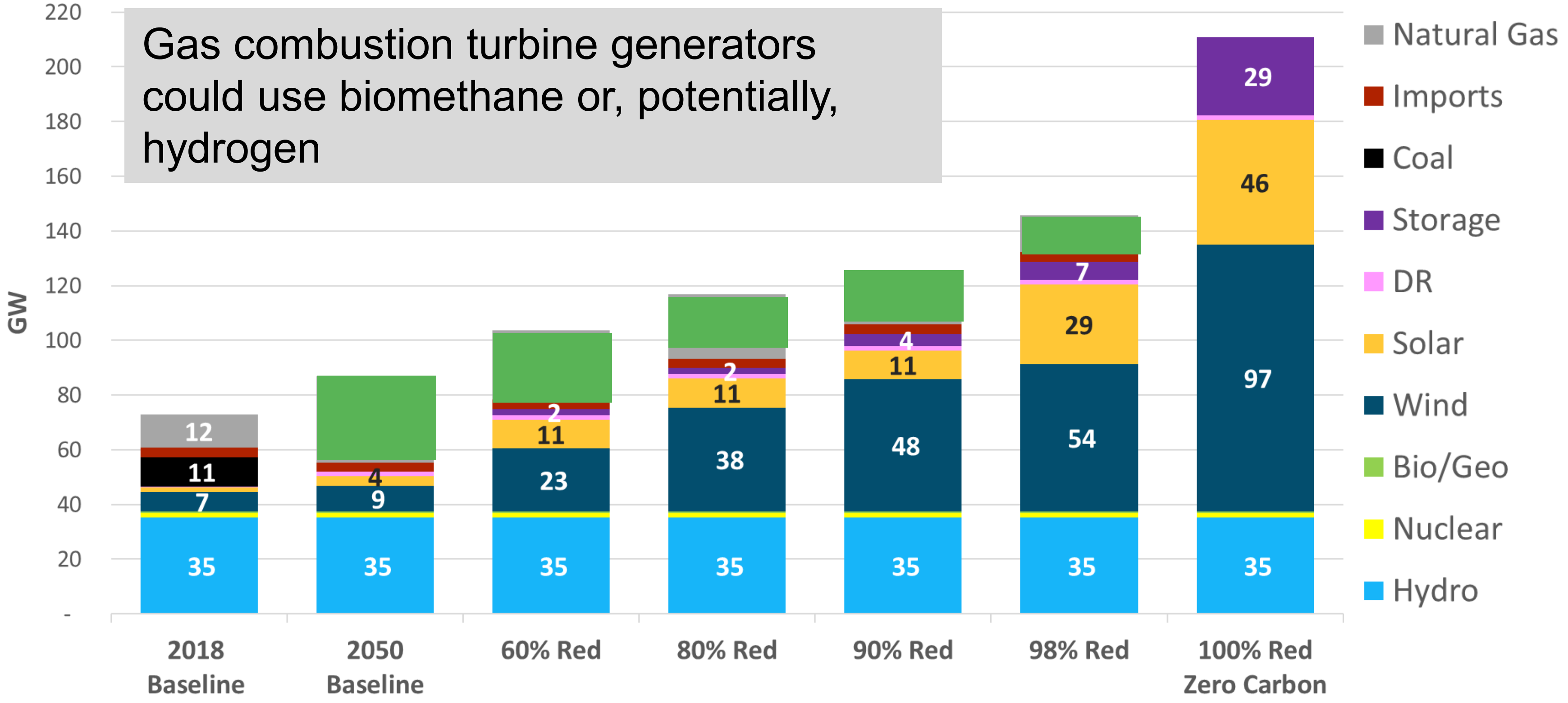
The importance of firm capacity in a low-carbon future



Removing final 1% of carbon requires additional $100b to $170b of investment

RNG and hydrogen may have a role in achieving a 100% decarbonized electric system

2050 Pacific Northwest Electricity Portfolios, zero-GHG firm



Key Takeaways

- RNG is a catch-all term that covers several different fuels
- Some varieties of RNG are very expensive and are unlikely to be competitive
- RNG and hydrogen will likely have important roles to play in decarbonizing hard to electrify segments of the economy

Energy+Environmental Economics

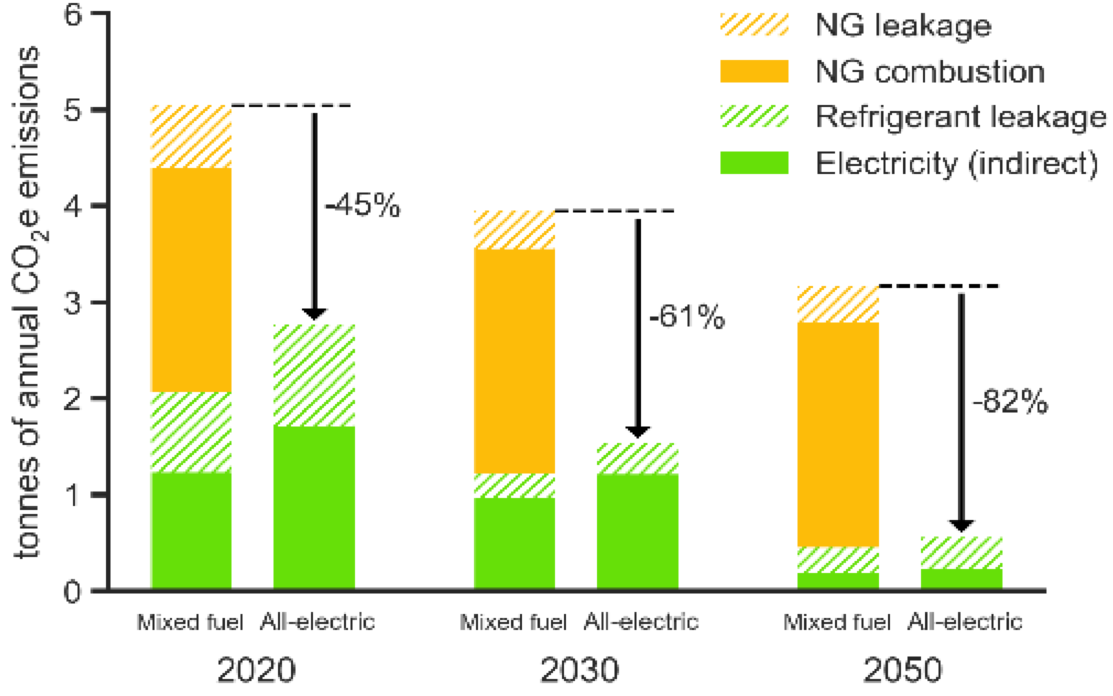
Part 2: Electrification

Key Takeaways

+ Electrification is a promising strategy to almost completely eliminate emissions from buildings using commercially available products
+ In cold climates, building electrification will put upward pressure on winter peak loads. At scale, building electrification may require a substantial expansion of electricity systems
+ Hybrid systems may be a promising strategy to balance the benefits of RNG and electrification in cold-climates

Why building electrification?

GHG Benefits of Building Electrification in CA

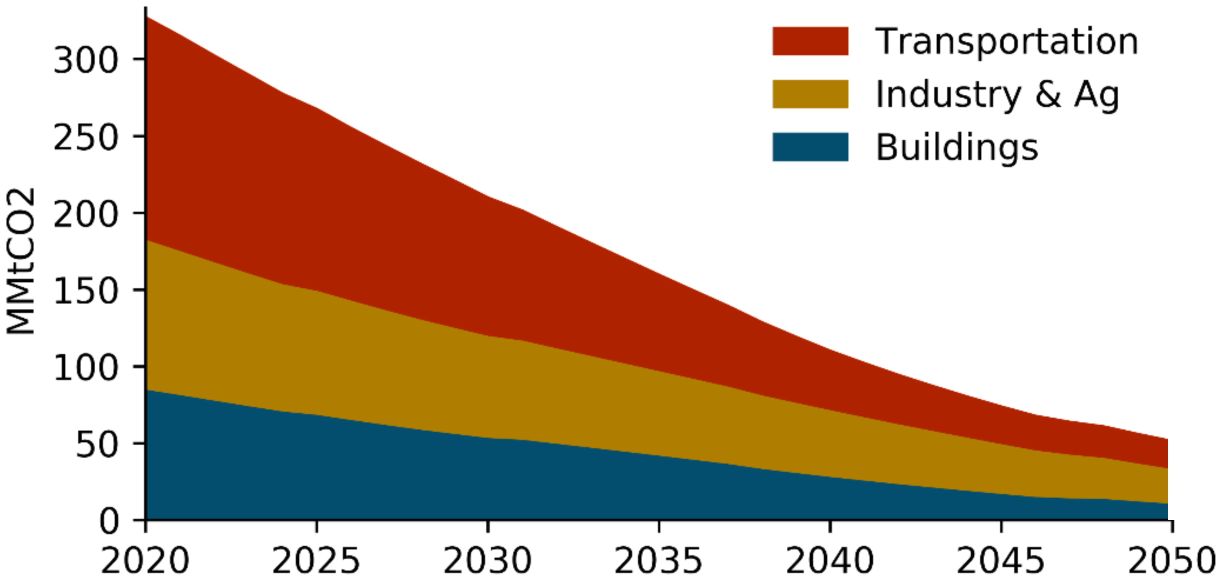


The value proposition of building electrification is that – paired with electric sector decarbonization – it can nearly eliminate GHG emissions from buildings

Building electrification can be accomplished using existing technologies that are widely commercialized today

Buildings have an important role in economy-wide decarbonization

Buildings in the context of economy-wide decarbonization



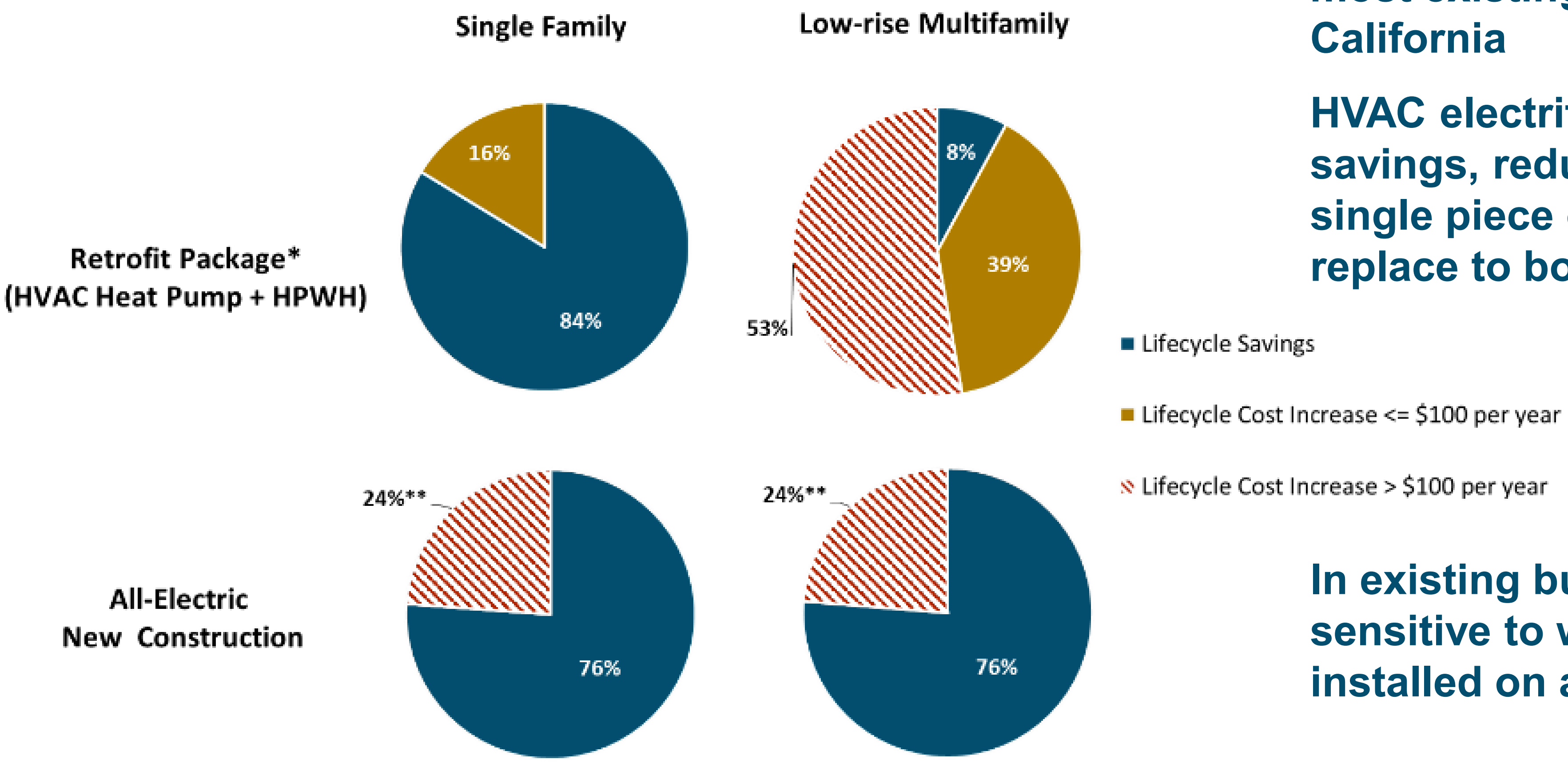
In most jurisdictions, buildings have lower total emissions than the transportation and industrial sectors.

However, most building emissions can be addressed via known technologies, while emissions reductions strategies in industry, freight and aviation are much less mature.

Electrifying buildings allows limited biomass to be allocated to produce biofuels for those hard to electrify end-uses

Building electrification saves consumers costs … in California

Lifecycle Costs and Savings of Building Electrification



Building electrification is cost-effective in most existing and new buildings in California

HVAC electrification is the largest source of savings, reducing bills and allowing for a single piece of equipment (a heat pump) to replace to both a furnace and AC

In existing buildings, this finding is sensitive to whether heat pumps are installed on a natural replacement basis

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Grid Impacts

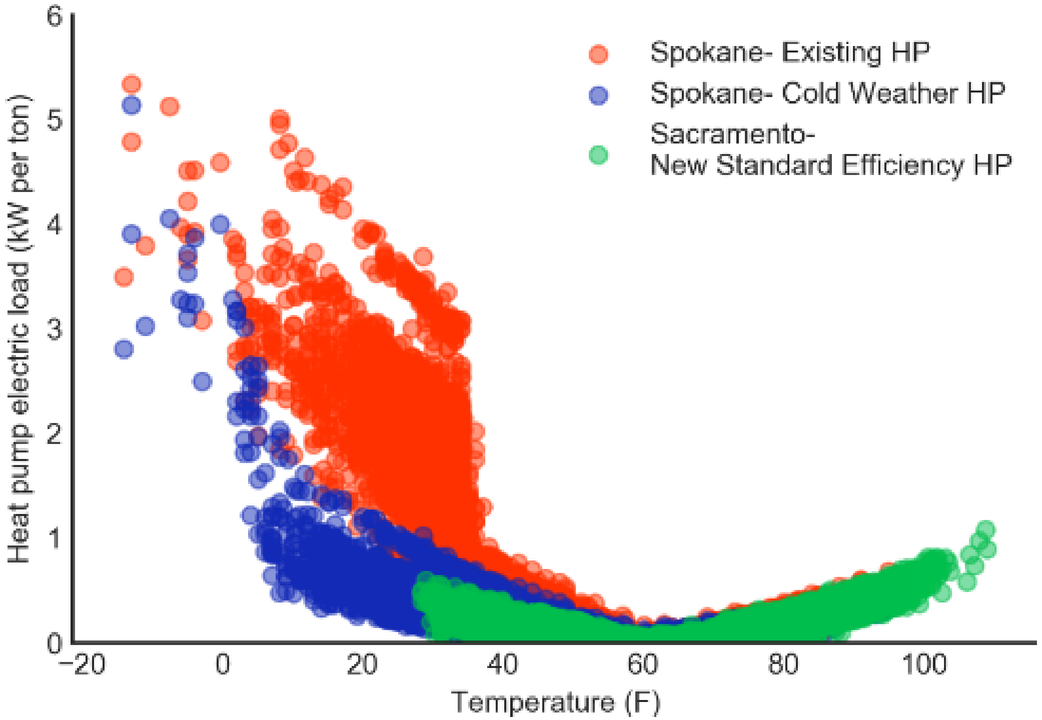
Defining the ‘Peak Heat’ challenge

Building electrification will cause large new peak loads on most electricity systems, particularly on the coldest days of the year.

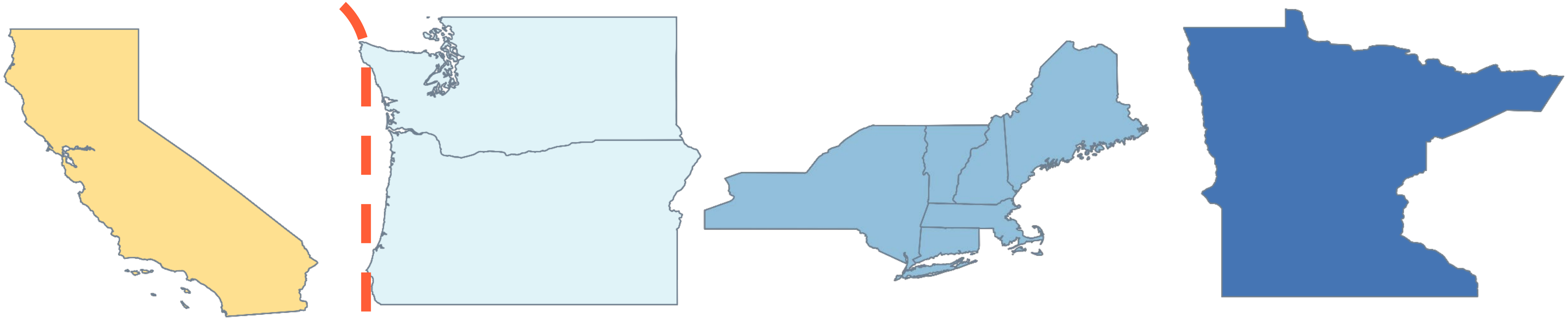
An emerging body of literature suggests that full electrification of heating will cause most electricity systems to be winter peaking

These studies suggest that bulk system peak loads could increase by 50% to 125%, driven by very cold weather events

Heat pump loads by temperature and type



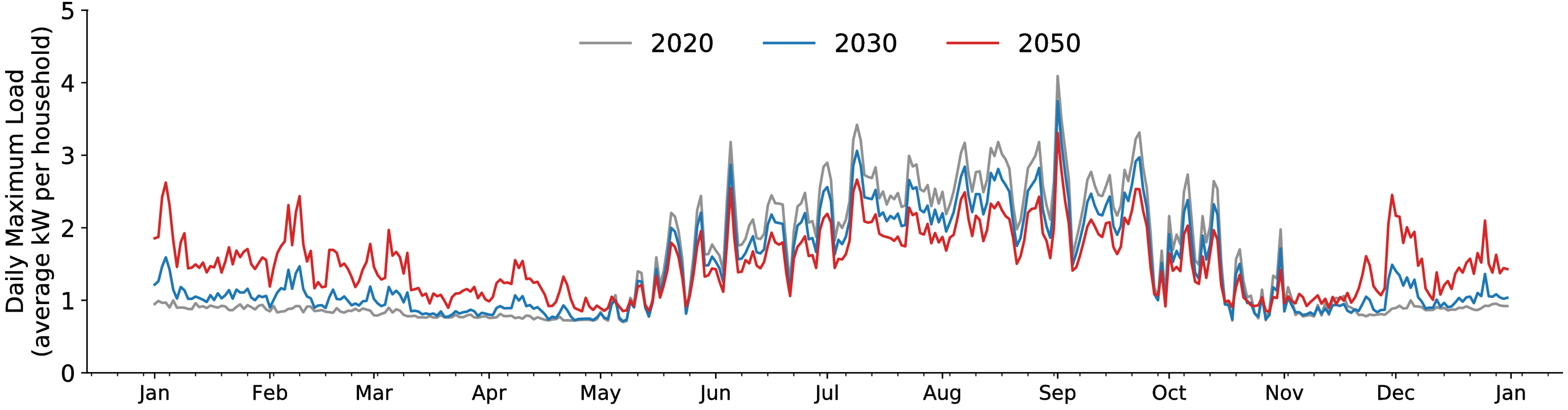
E3 has examined the grid impacts of building electrification in distinct settings



	California	Northwest	Northeast	Minnesota
Cold Day Temp	35F	10F	-5F	-20F or lower
Heating Fuels	Mostly Gas	Gas and Electric	Gas and Fuel Oil	Mostly Gas
Electric Peak	Summer	Winter	Summer	Summer

California's warm summers and mild winters mean that 'Peak Heat' is unlikely to be an issue there

Household hourly load impacts in California during a typical meteorological year



* The average load per household reflects a changing share of natural gas-fueled vs. all-electric homes

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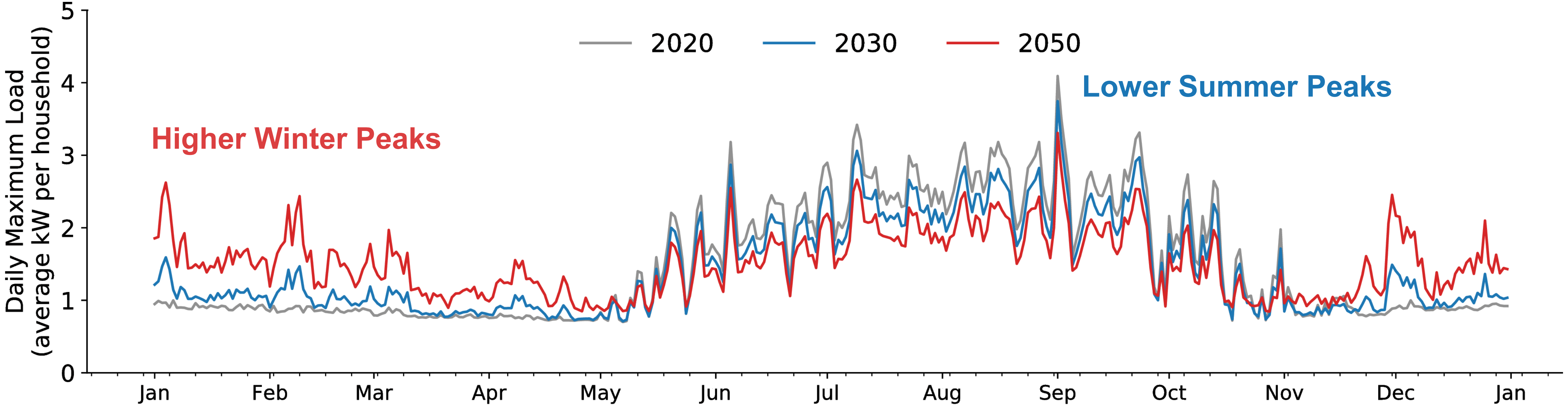

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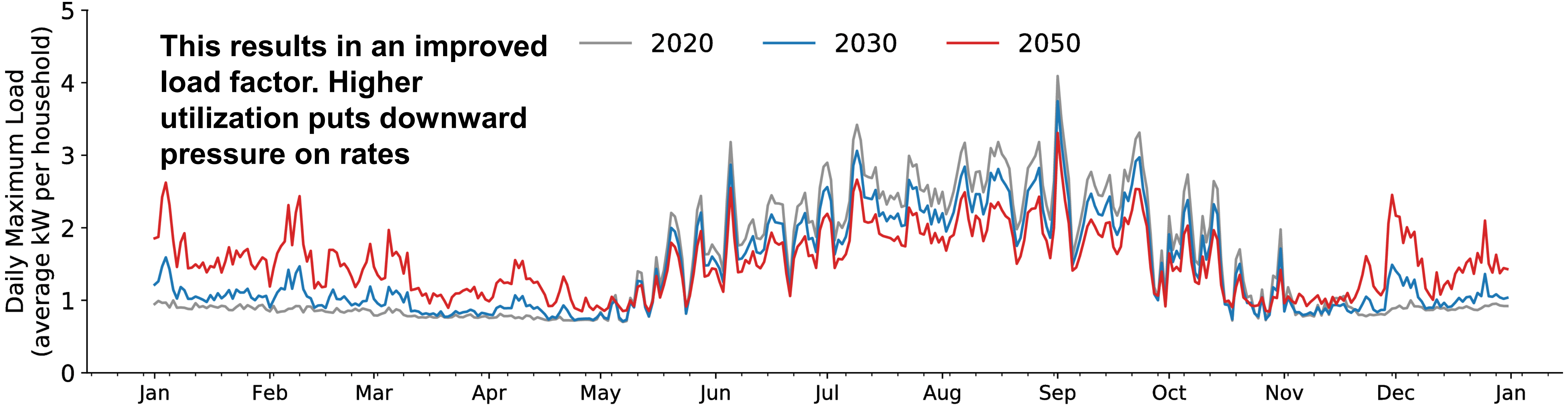
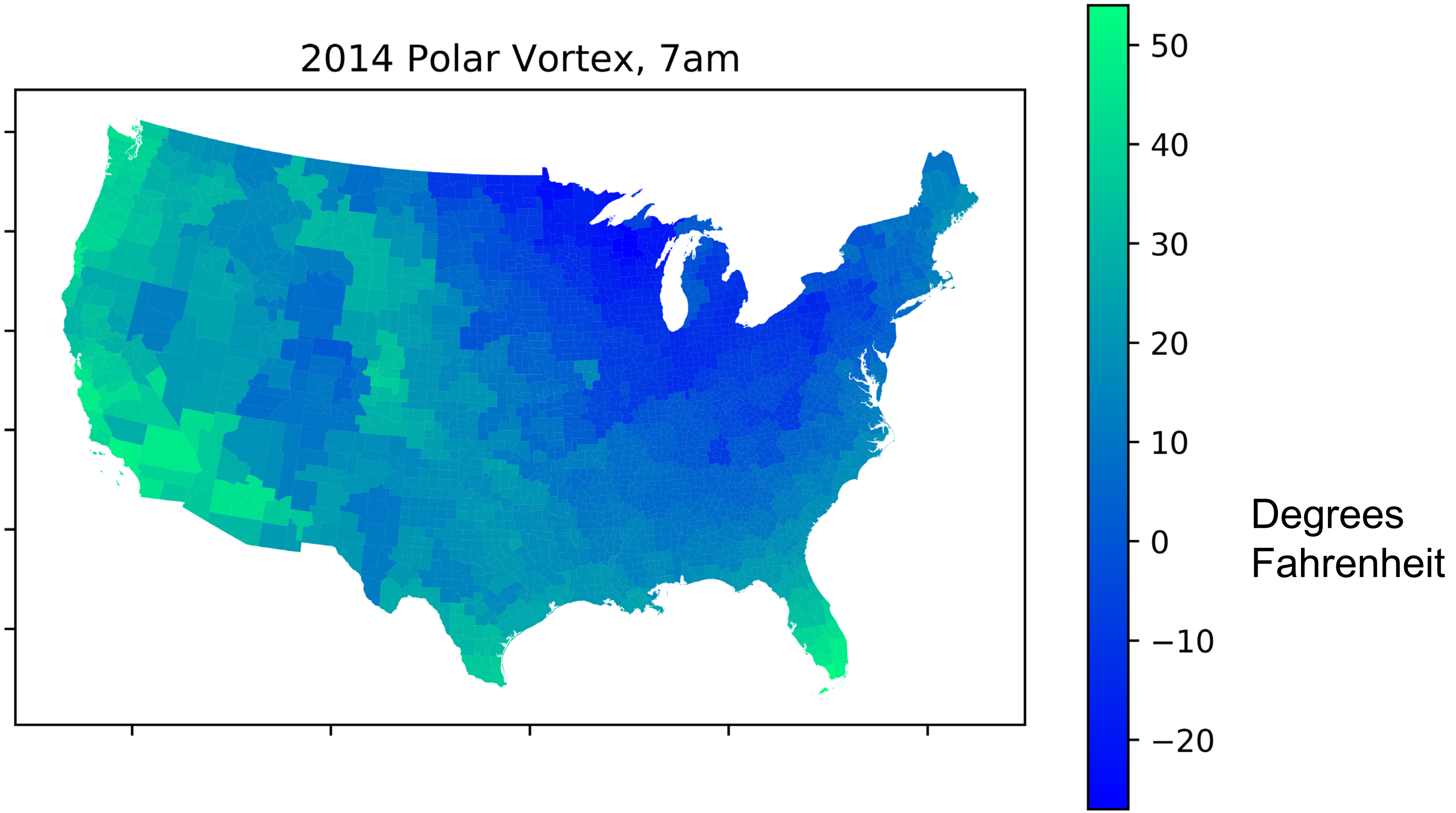


* The average load per household reflects a changing share of natural gas-fueled vs. all-electric homes

California has a very different climate compared to most of the United States!



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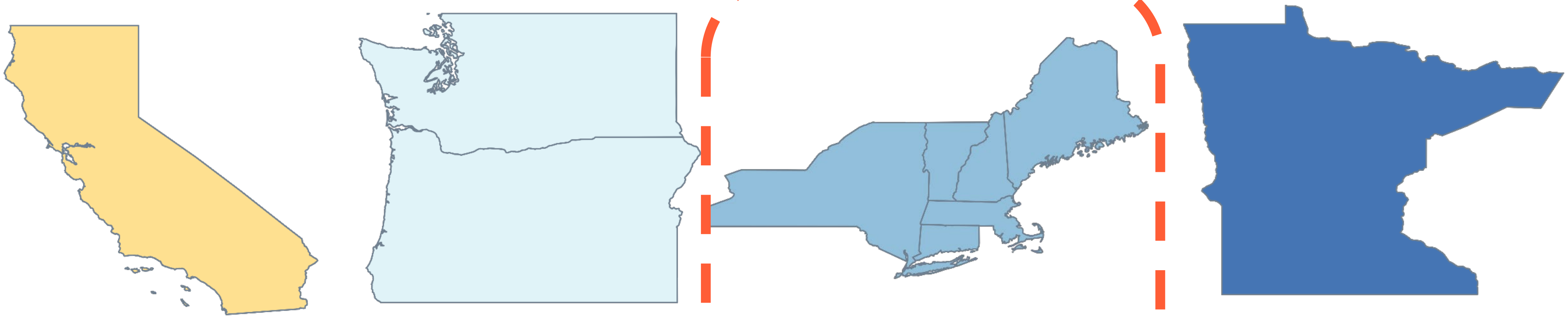

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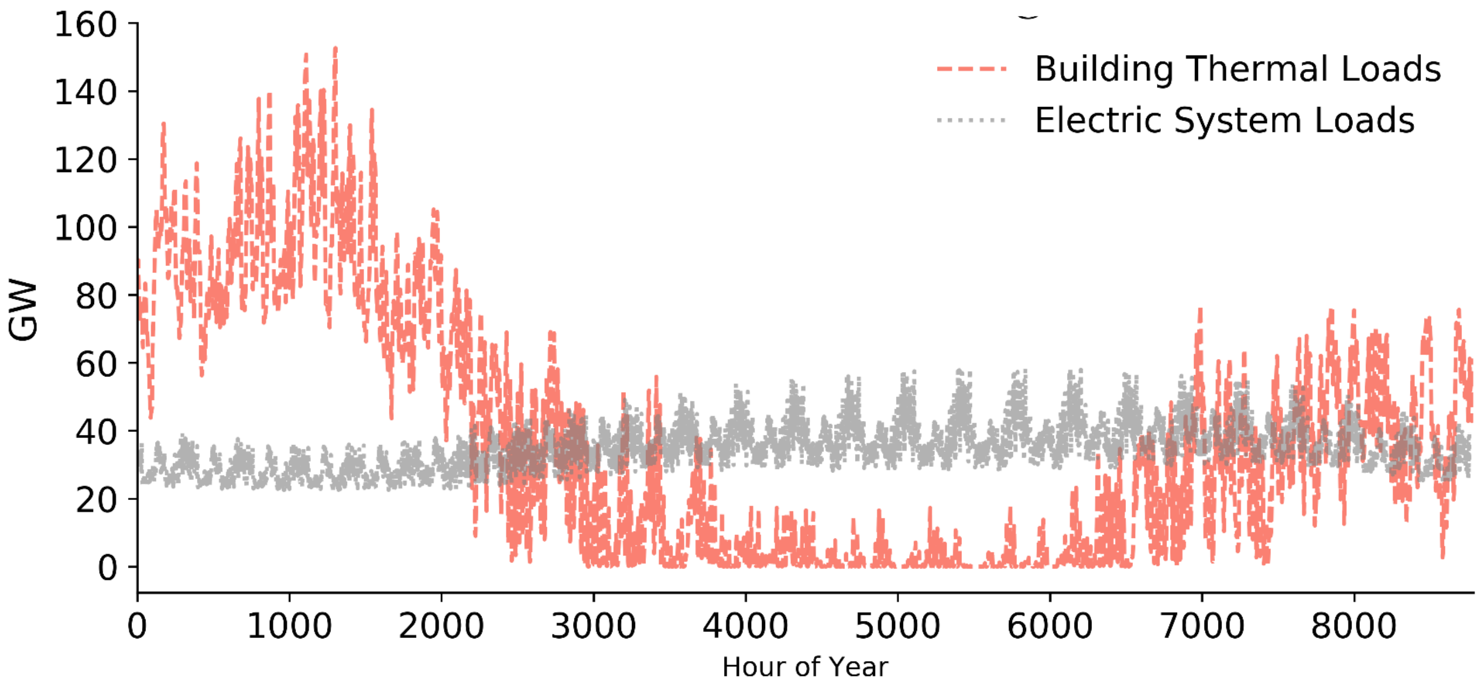
Northeast

Building heating loads are large and peaky

Thermal vs electric loads: NY + NE, 2050



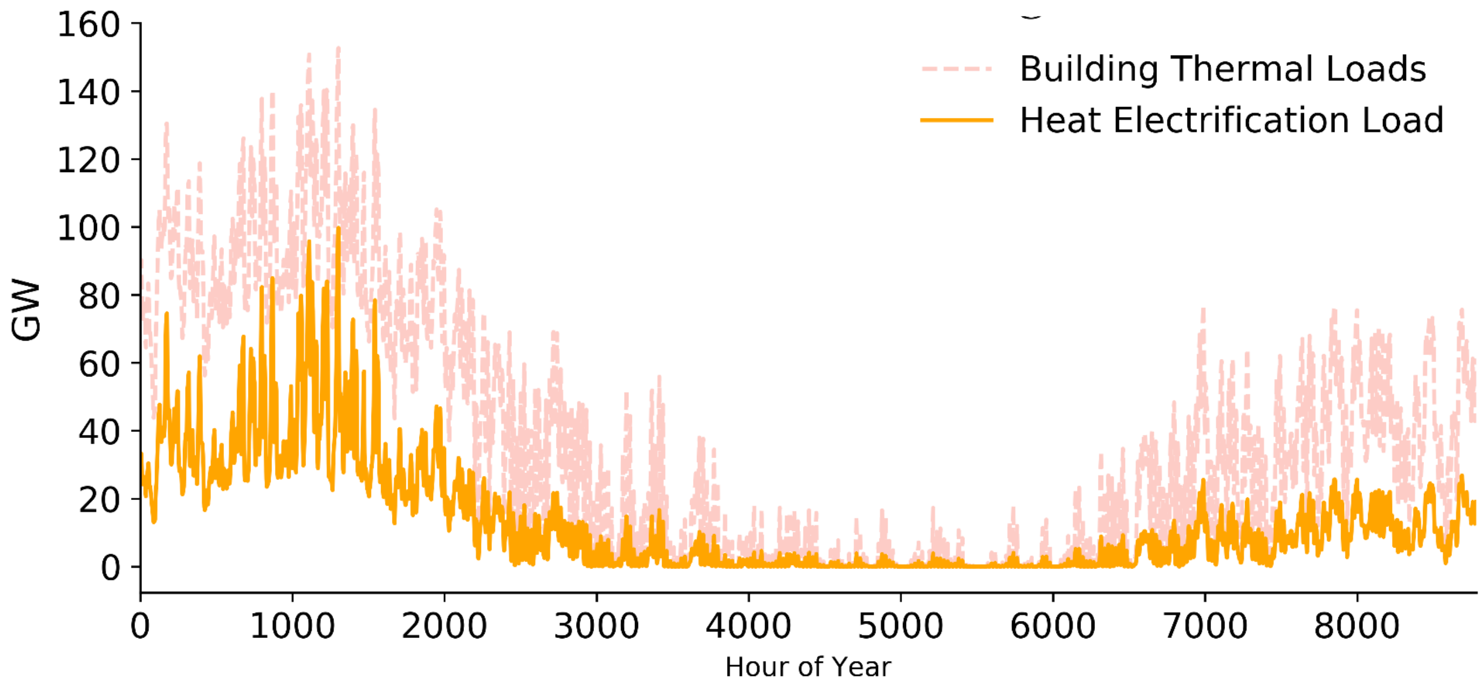
Peak heat loads in the Northeast are currently served by natural gas and fuel oil energy systems

This example assumes:

- A cold-year
- The region's existing building stock

Heat pumps can heat efficiently, even in cold weather

Hourly Space-Heating Electric Loads: NY + NE, 2050



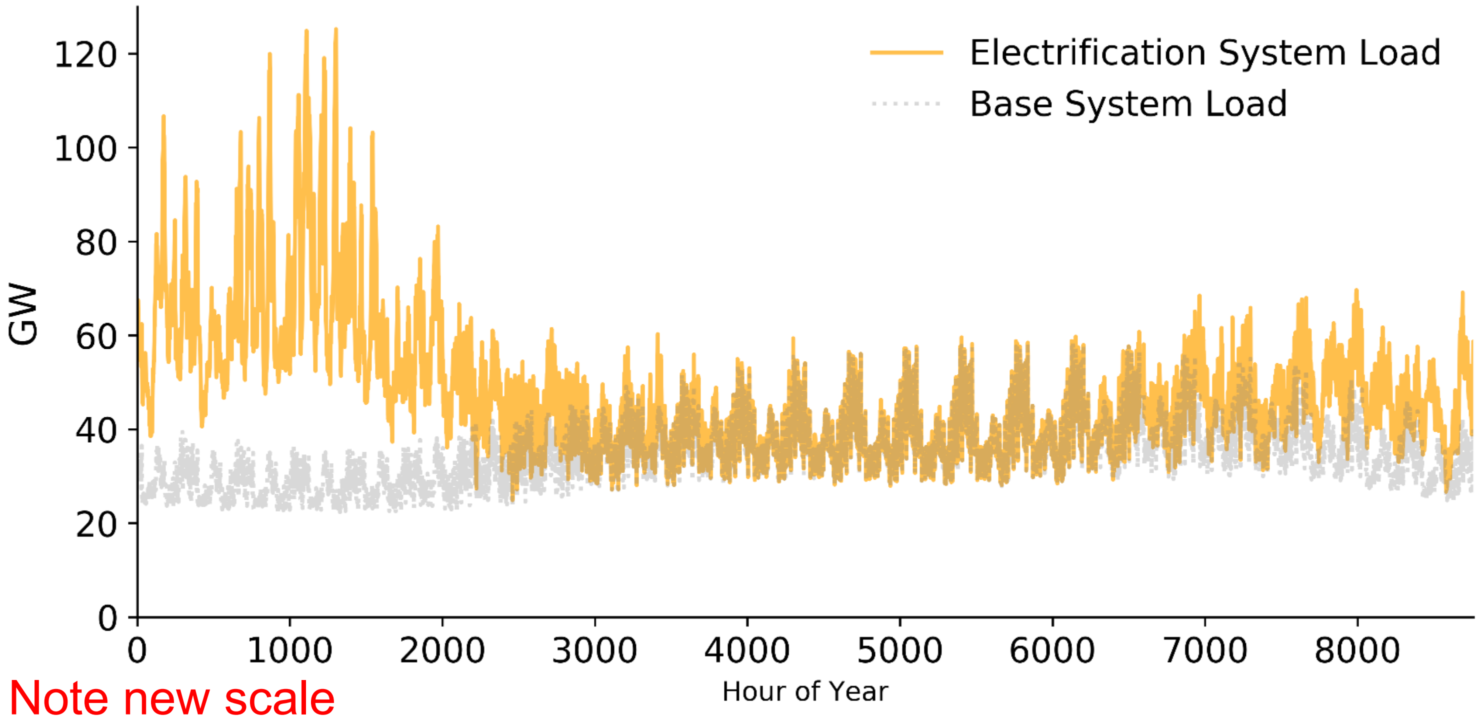
Even relatively efficient heat pumps (COP = 1.5 at -5F) imply large new electric loads

This example assumes:

- A cold-year
- ASHPs that meet the NEEP cold-climate standard
- All supplemental heat delivered is electric
- There are no building shell upgrades

The Northeast's electricity sector becomes strongly winter peaking

Hourly Space-Heating Electric Loads: NY + NE, 2050



Note new scale

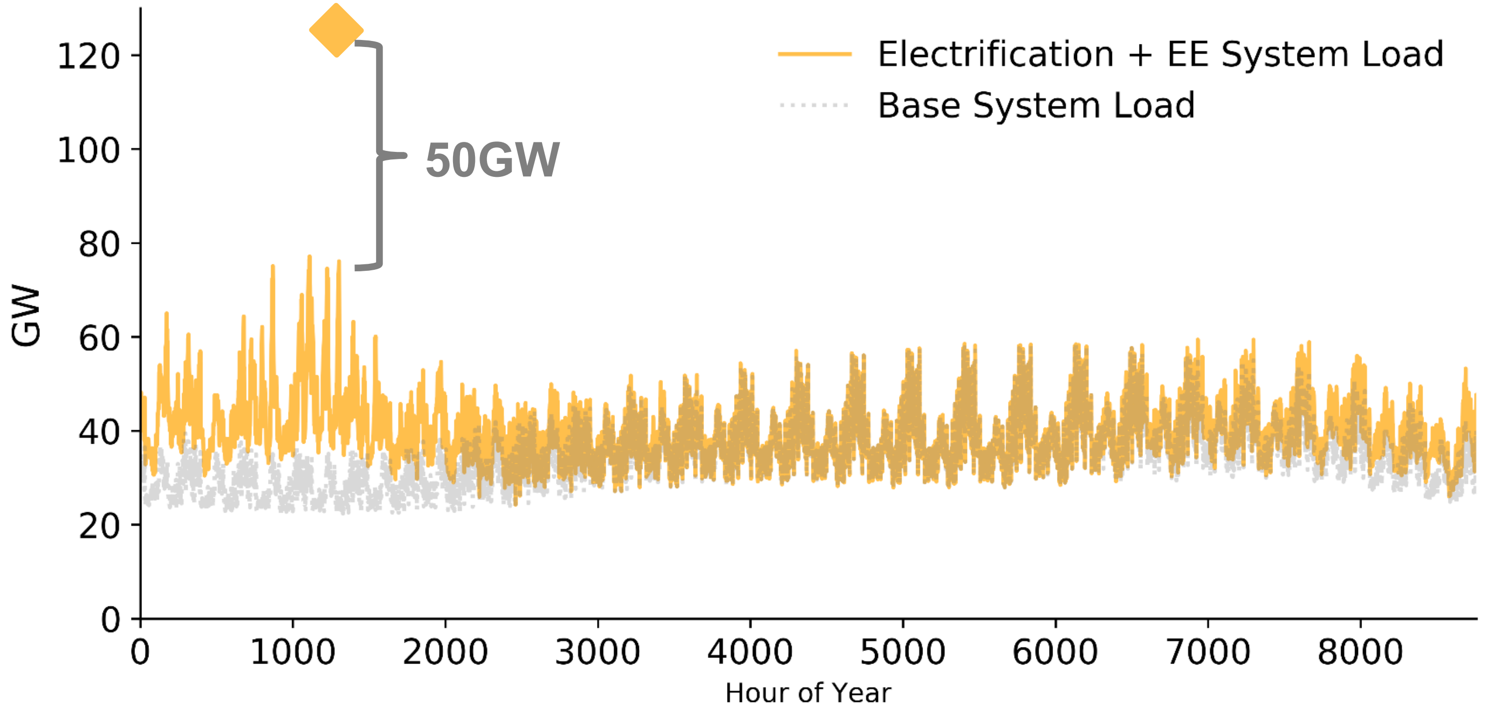
The peak load of the Northeast's electricity system doubles, requiring 60 GW of new firm capacity

This example assumes:

- A cold-year
- ASHPs that just meet the NEEP cold-climate standard
- All supplemental heat delivered is electric
- There are no building shell upgrades

New peak loads might be managed with EE

Hourly Space-Heating Electric Loads: NY + NE, 2050



Electric grid impacts could be mitigated if aggressive energy efficiency measures are pursued

Assuming avoided generation and T&D costs of $220/kW-yr, electric system capacity costs are reduced by <u>$11 billion per year</u>

This example assumes:

- A cold-year
- Best available ASHPs today (COP > 2.5 on peak)
- All supplemental heat delivered is electric
- A 30% reduction in heating demands via weatherization measures

Back-of-the-envelope capacity cost calculations

Indicative Single-Family Home Capacity Costs

	Base Case
Capacity Cost $/kW-yr	$220
Peak HP Load (kW)	7
Annualized Capacity Cost Per Home	$1,540
NPV Savings	N/A

Peak electric space-heating loads could cause substantial electric infrastructure costs

Consider a home with a 45 kbtu/hr design load and a heat pump that has a 1.5 COP on peak

In a winter peaking system, over $1,500 per year in capacity costs would be incurred to serve that load

How much extra budget might we have to implement multiple measures?

Indicative Single-Family Home Capacity Costs

	Base Case	Improved Heat Pump	Improved Heat Pump & Shell
Capacity Cost $/kW-yr			$220
Peak HP Load (kW)	7	3.5	2
Annualized Capacity Cost Per Home	$1,540	$770	$440
NPV Savings	N/A	($8,000)	($12,500)

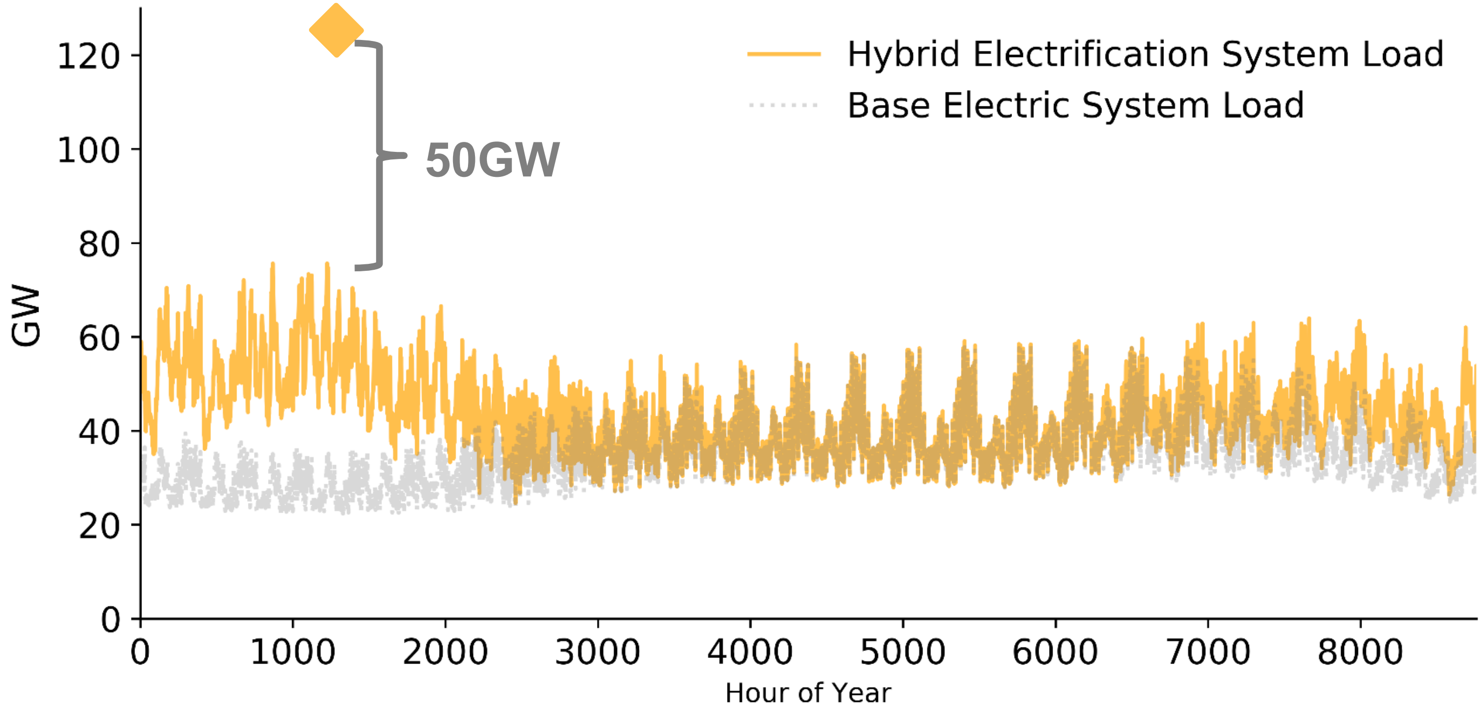
EE measures have the potential to deliver substantial 'peak heat' capacity savings

A key question will be how much it costs to realize those savings

****This figure does not include other values like annual energy savings or NEBs****

Hybrid heat pumps could be an alternative strategy

Hourly Space-Heating Electric Loads: NY + NE, 2050



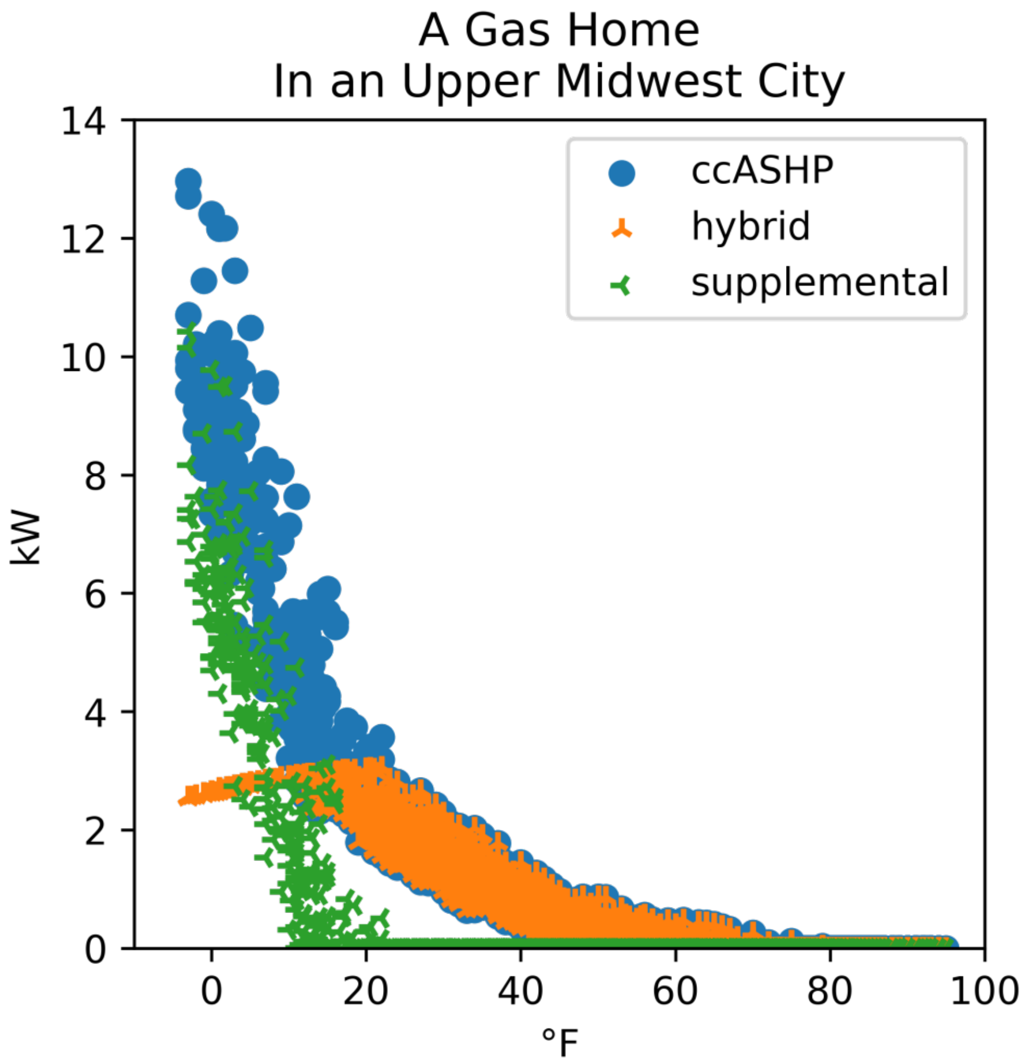
+ This example assumes:

- A cold-year
- Moderate efficiency ASHP
- **75% of supplemental heat demands are delivered by natural gas or fuel oil**
- No building shell improvements

The same magnitude of electric sector savings could be achieved using hybrid heat pumps

An important question is how the costs of these two approaches compare, as well as their respective GHG emissions impacts

More on hybrid heat pumps



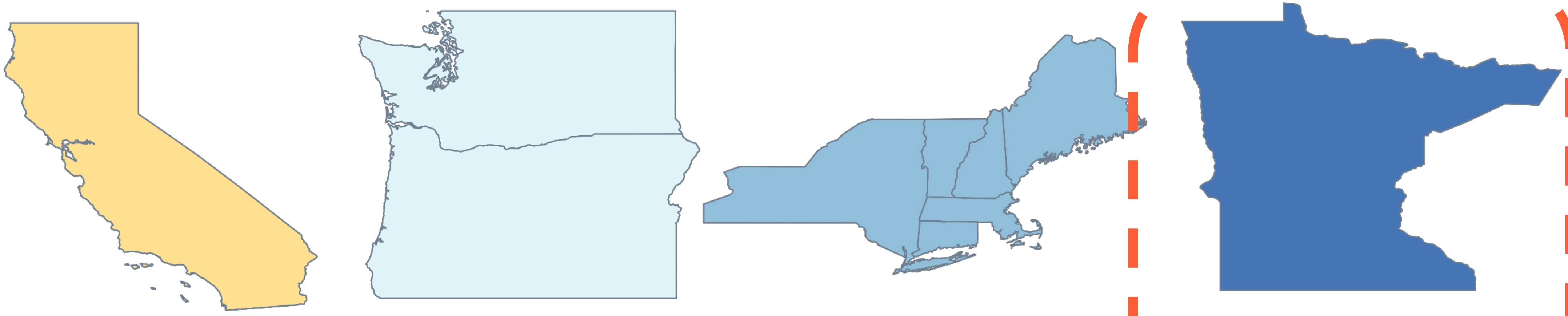
Instead of electric resistance, hybrids use a furnace for supplemental heat

Lower gas throughput will decrease demand for the most expensive tranches of RNG

Depending on jurisdiction, the capacity of heat delivered by gas on peak could be similar to today

But there is uncertainty about the business model and operational implications, as well as alternative approaches

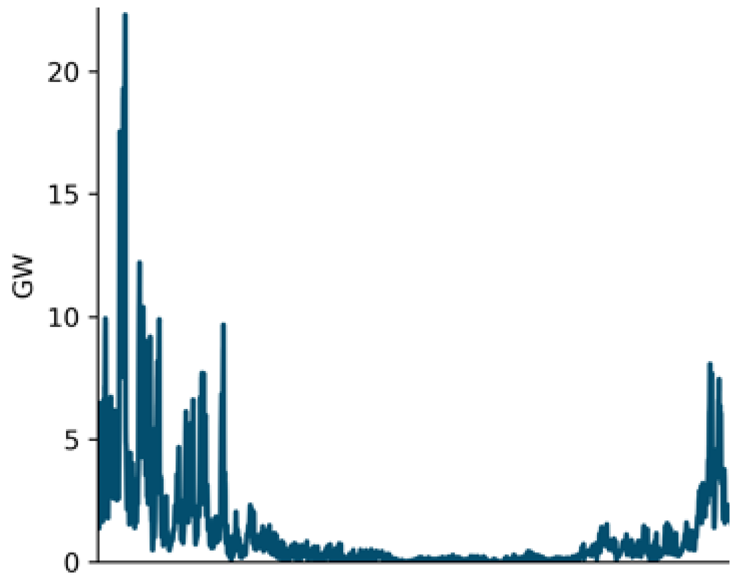
E3 has examined the grid impacts of building electrification in distinct settings



	California	Northwest	Northeast	Minnesota
Cold Day Temp	35F	10F	-5F	-20F or lower
Heating Fuels	Mostly Gas	Gas and Electric	Gas and Fuel Oil	Mostly Gas
Electric Peak	Summer	Winter	Summer	Summer

E3's "High Electrification Sensitivity" in the Xcel IRP

Hourly annual space-heating loads 2009

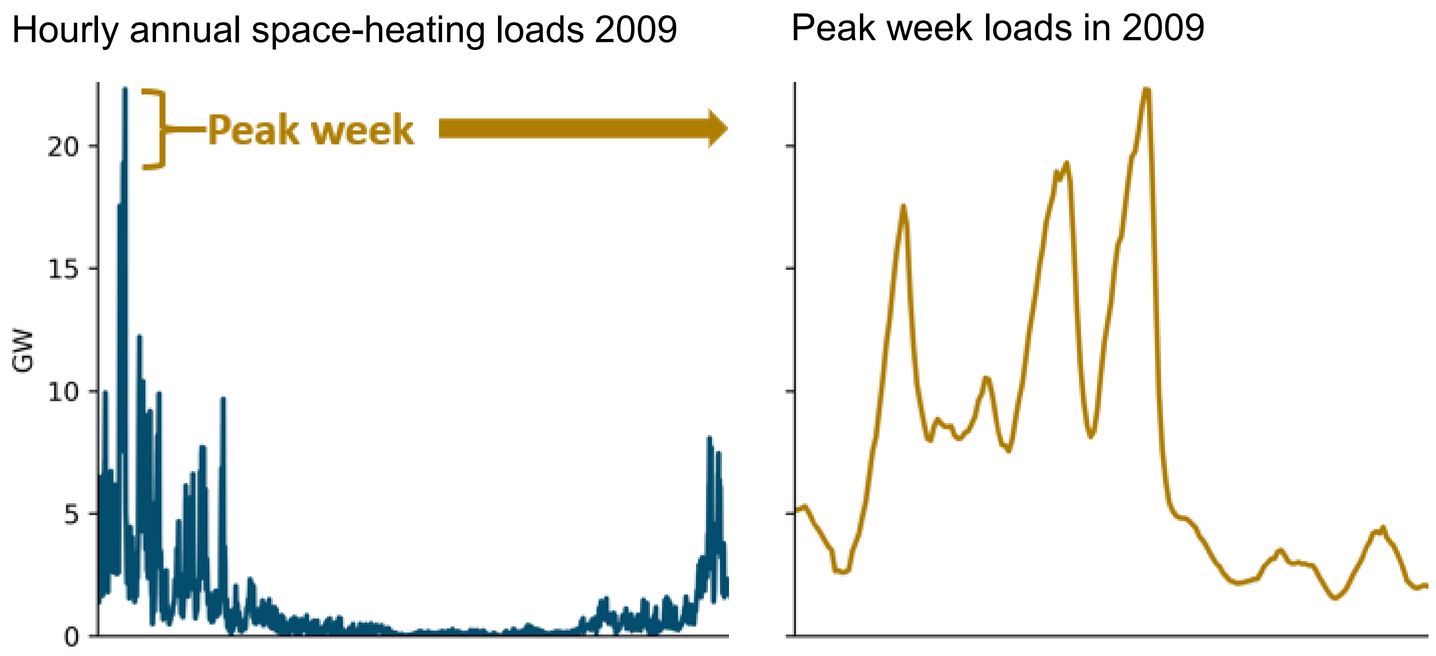


E3 recently conducted both economy-wide and electric sector analyses in support of Xcel's Integrated Resource Plan

E3 developed a High Electrification Sensitivity case that assumed 100% electrification of buildings in the state

E3 calculated that peak heating loads in Minnesota would exceed 20 GWs, while space-heating peak loads in the Xcel Energy – Upper Midwest service territory would be over 14 GW

The most challenging peak loads occur during multi-day cold-snaps



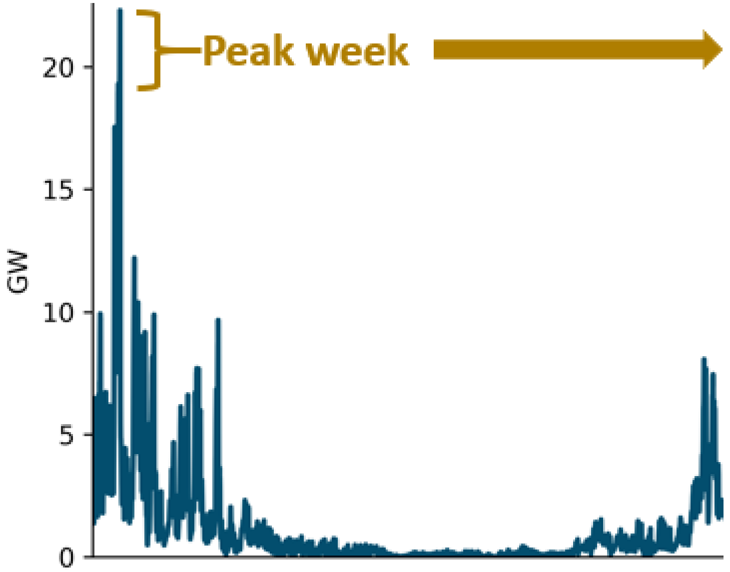
This example assumes wide-spread adoption of cold-climate heat pumps and building weatherization measures

The heat pump is assumed to cover the full load of a building until 0F, at which point electric resistance elements provide supplemental heat

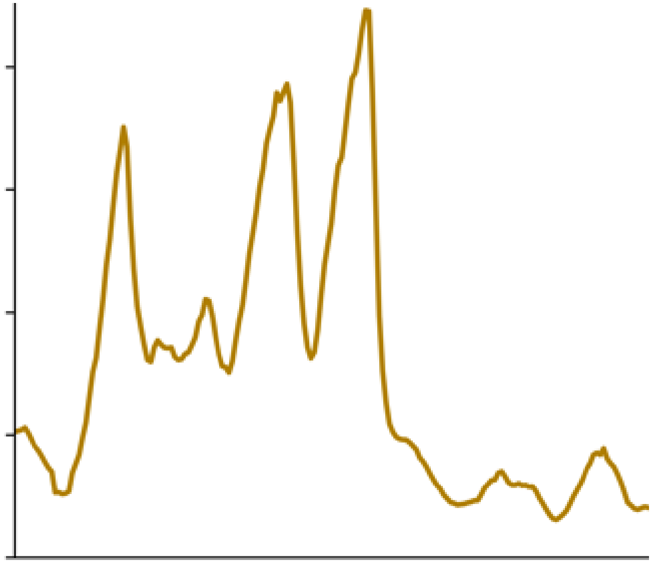
The share of heat provided by electric resistance increases as the temperature drops below 0F, until -25F when we assume all heat is assumed to be resistance

These peak loads will tend to occur in morning hours

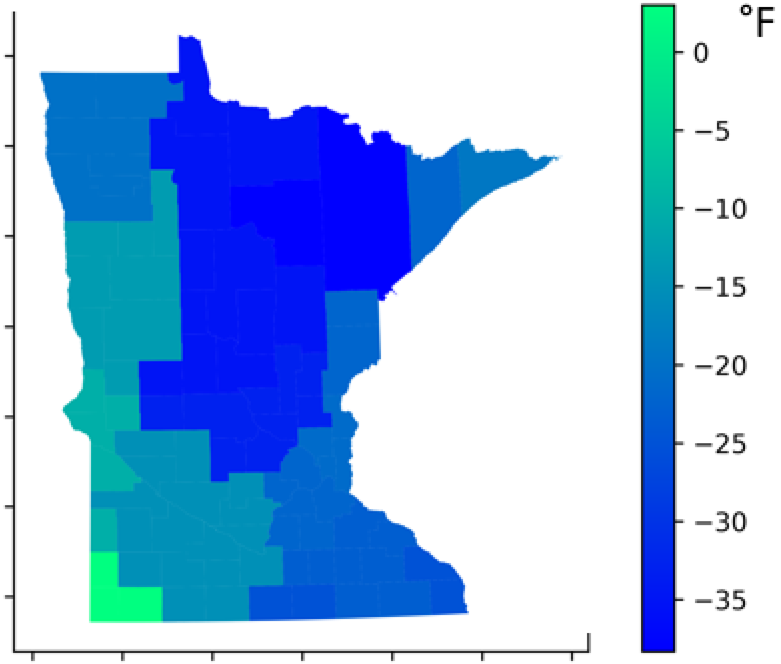
Hourly annual space-heating loads 2009



Peak week loads in 2009



Temperatures at 6am on January 16, 2009



Key Takeaways

- Building electrification is a promising strategy to almost completely eliminate emissions from buildings using commercially available products
- In cold climates, building electrification will put upward pressure on winter peak loads. At scale, building electrification may require a substantial expansion of electricity systems
- Hybrid systems may be a promising strategy to balance the benefits of RNG and electrification in cold-climates

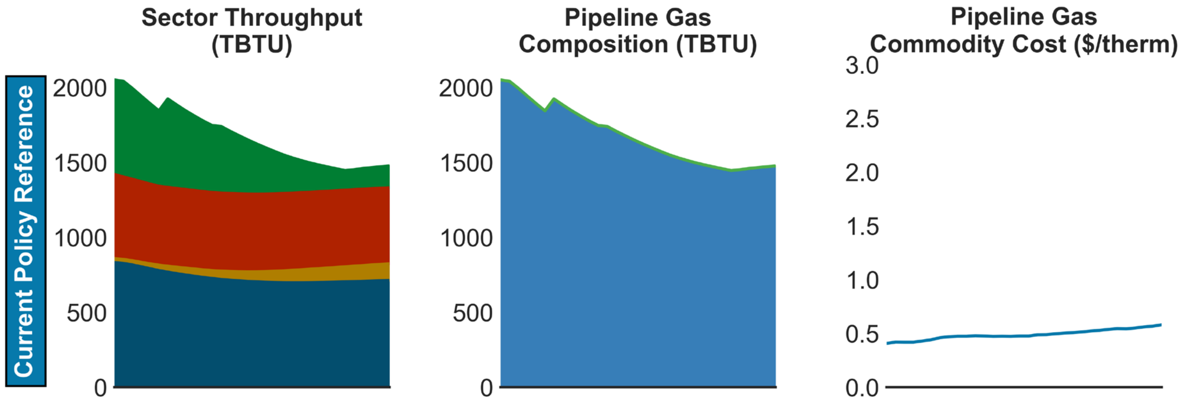
Energy+Environmental Economics

Bringing it all together

Key Takeaways

- Scenarios that achieve deep decarbonization see upward pressure on either gas delivery or commodity costs
- Increasing gas rates improve the economics of building electrification, potentially leading to a feedback effect
- These feature motivate the need for a considered gas transition strategy

"Future of Retail Gas" study in California

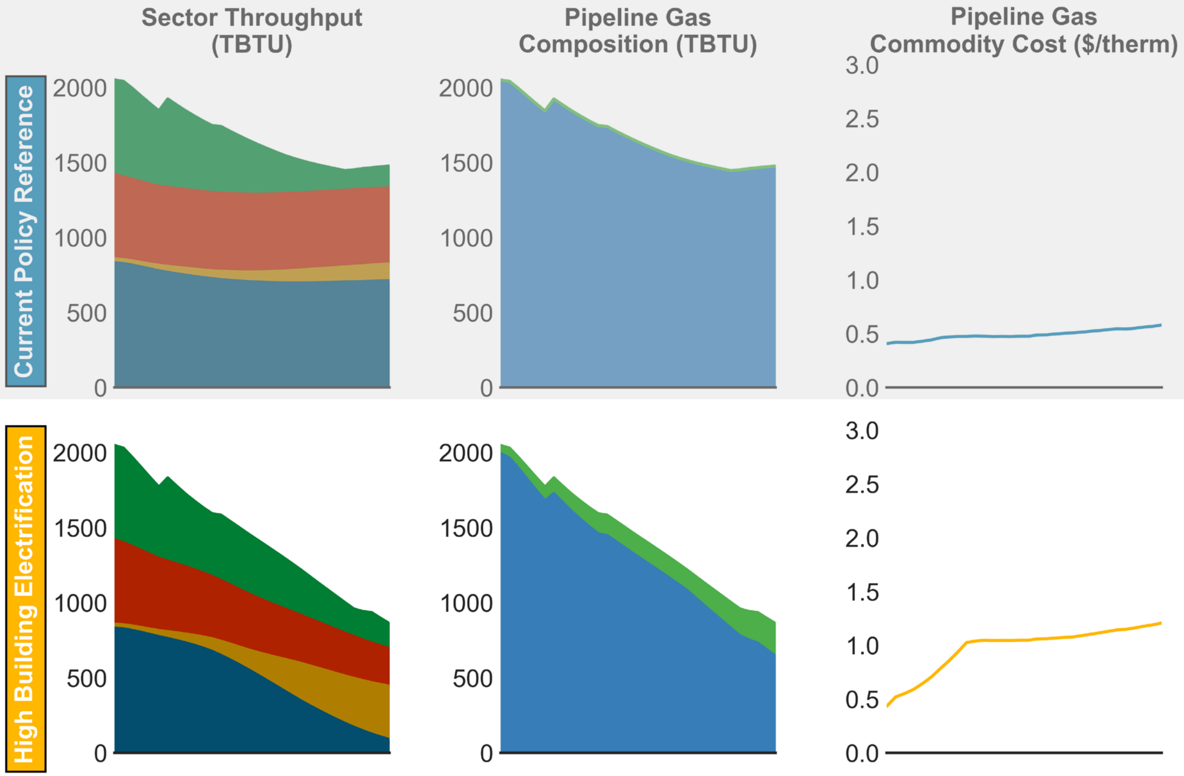


Total gas demand falls due to electricity decarbonization.

Direct use gas demand is flat.

The pipeline nearly 100% fossil gas

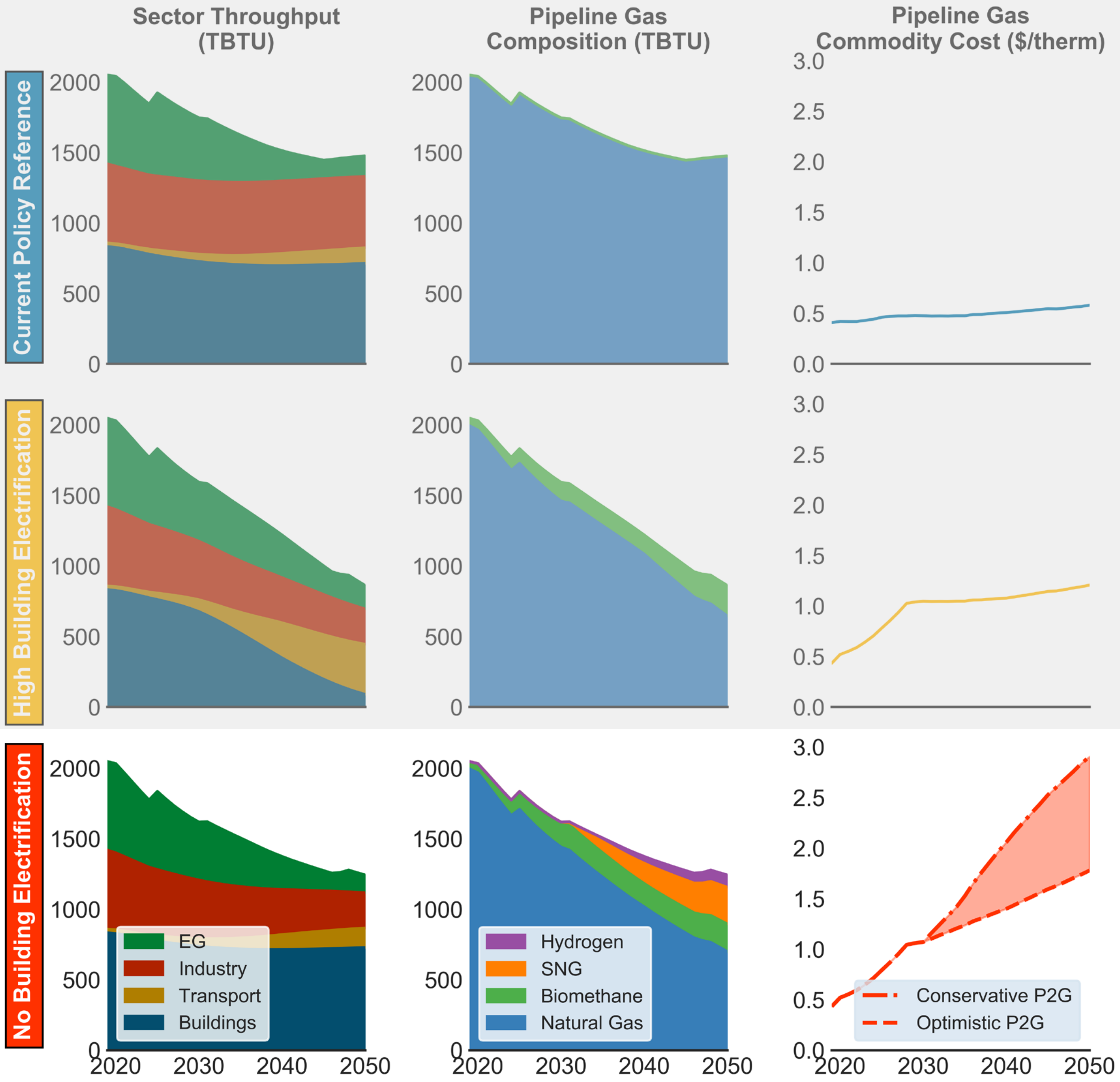
High Building Electrification scenario



In the High Building Electrification scenario, gas demand falls sharply in the buildings sector.

20% of remaining pipeline gas is served by biomethane by 2050

No Building Electrification Scenario

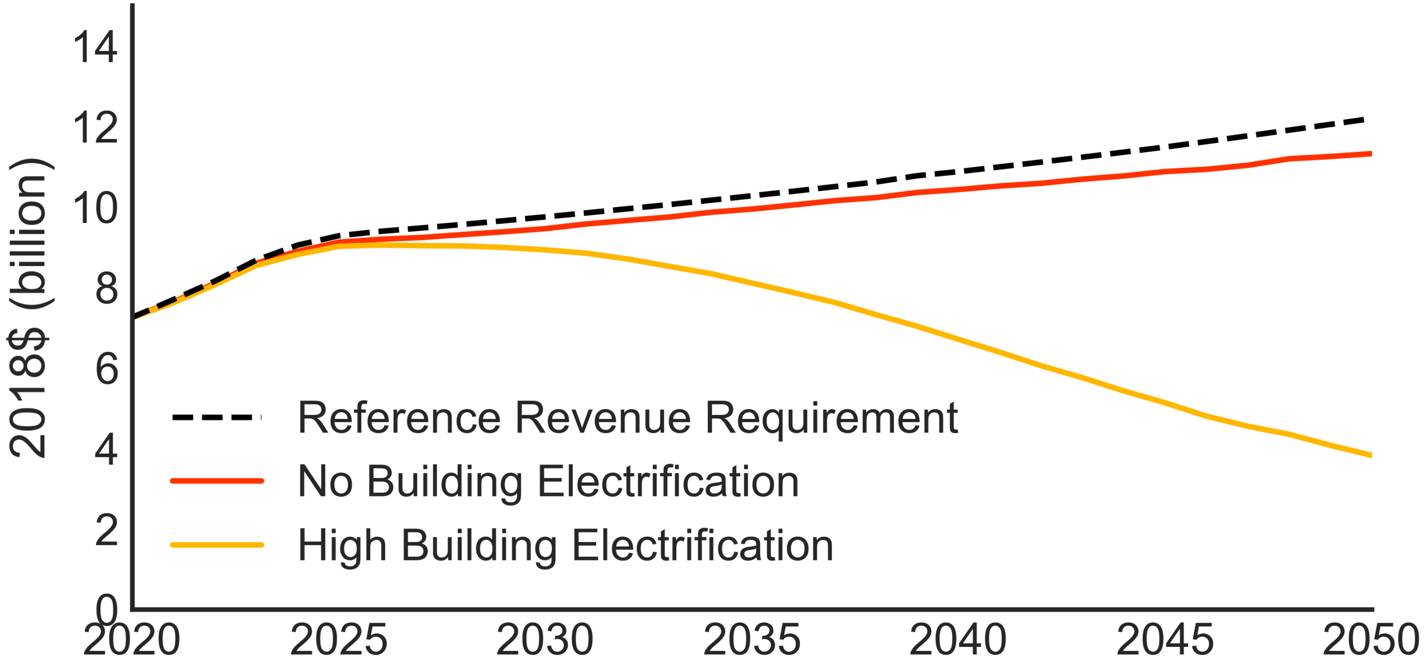


The No Building Electrification scenario has similar throughput as Reference

The pipeline is 45% decarbonized, with a blend of biomethane, hydrogen and SNG

E3 modelled California gas utilities’ revenue requirements

California Gas Revenue Requirement and Revenues by Scenario



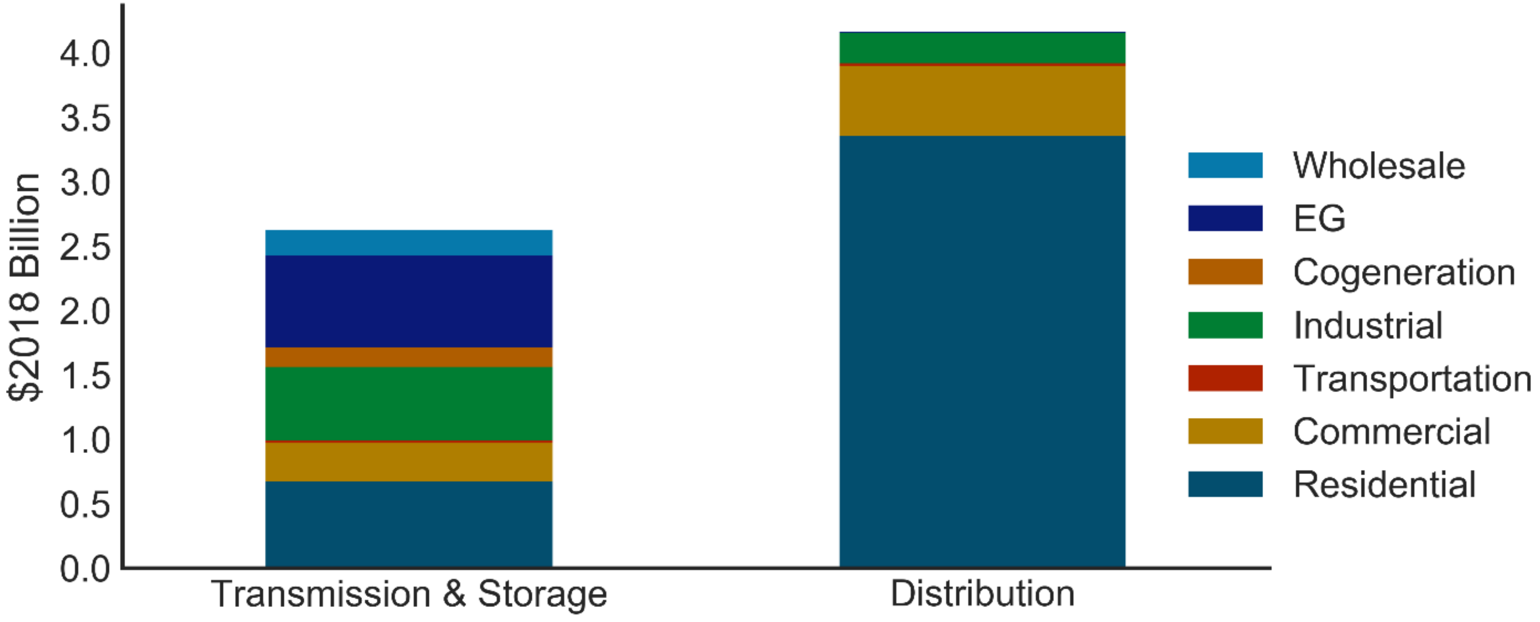
Gas delivery systems require reinvestment to ensure safety and reliability

In California, utilities are in the midst of large safety related investments following high profile, fatal incidents

To illustrate the magnitude of cost recovery challenge in each scenario we froze customer rates at 2019 levels and identified a revenue requirement ‘gap’ for each scenario

A brief digression on the cost structure of gas utilities

Monthly utility bills in High Building Electrification Scenario



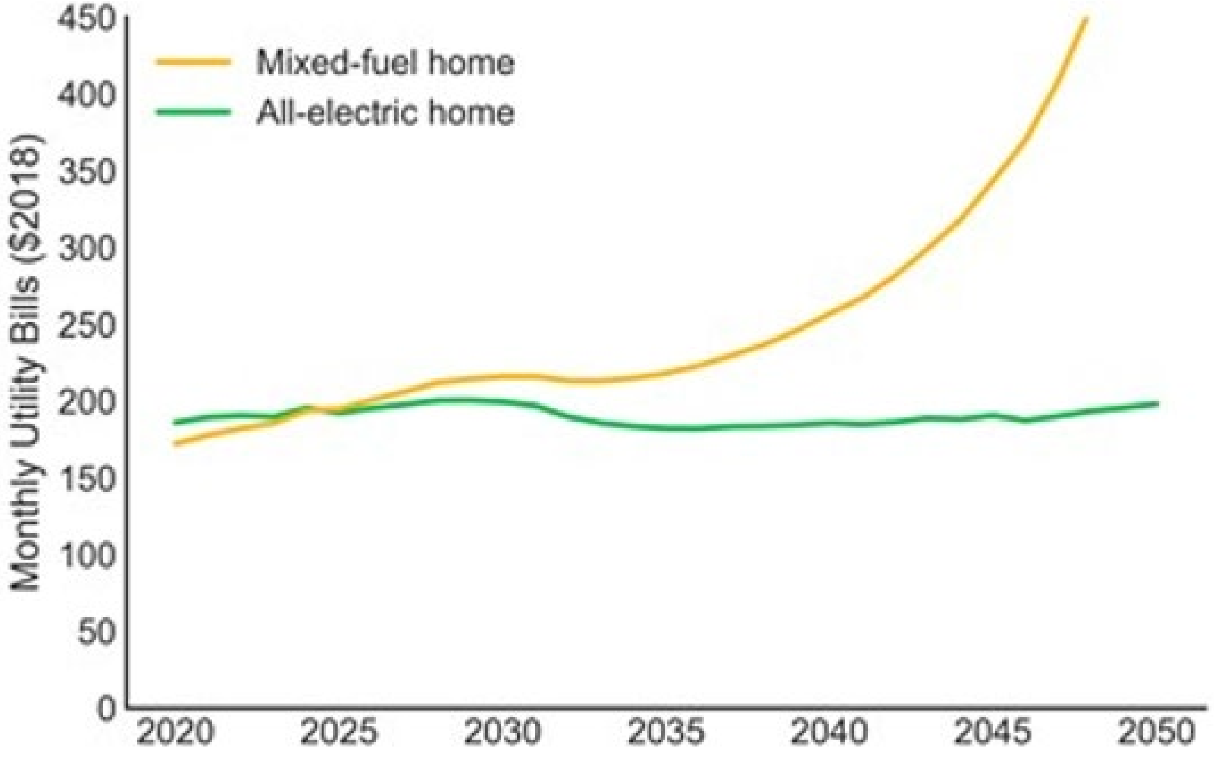
The bulk of gas distribution utilities' rate base tends to be in their distribution system. That is the lower pressure system that serves homes and businesses

The vast majority of revenues that cover distribution system costs are collected from residential customers

If residential throughput or customer counts fall, rates for remaining customer rise

Example impacts of large-scale electrification on residential customers

Monthly utility bills in High Building Electrification Scenario



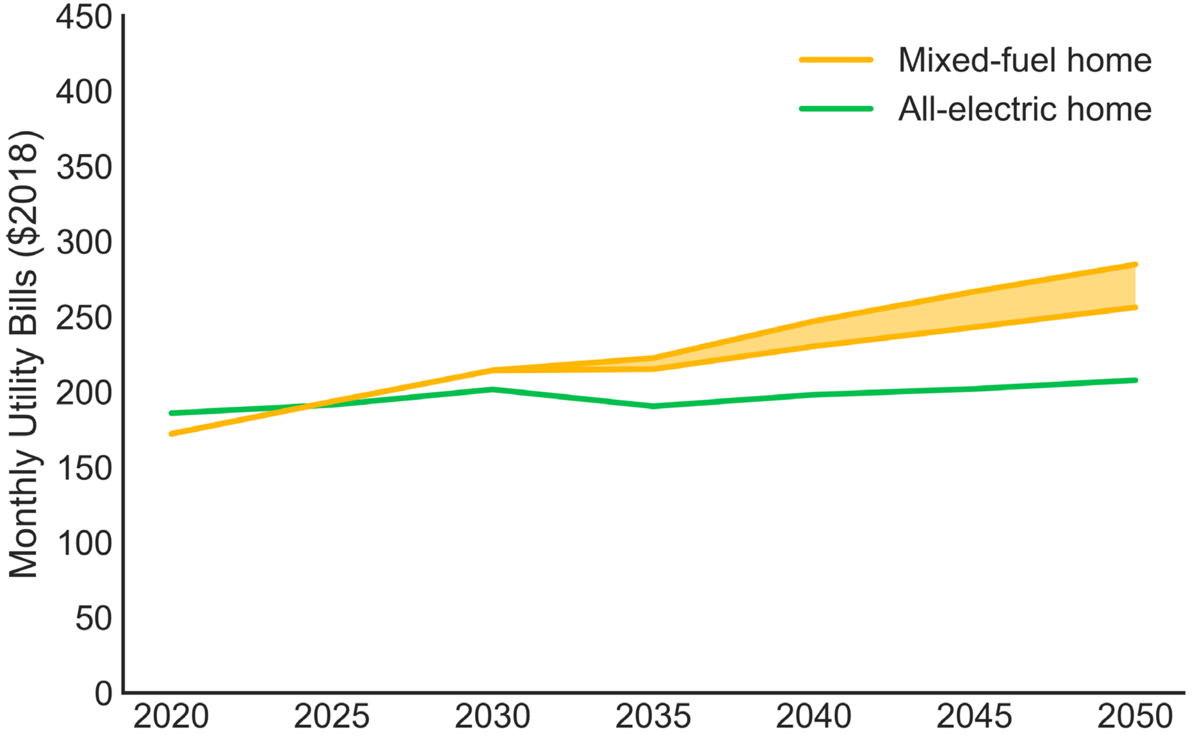
We modelled a case where residential customers pay the same proportion of the distribution revenue requirement, regardless of remaining customer counts or throughput

Bills for remaining residential mixed fuel customers exhibit a 'hockey stick' increase that starts in the mid-2030s

This outcome raises troubling equity issues. Those with means are more likely to be able to electrify and insulate themselves from high costs.

The No Building Electrification scenario has its own issues

Monthly utility bills in No Building Electrification Scenario



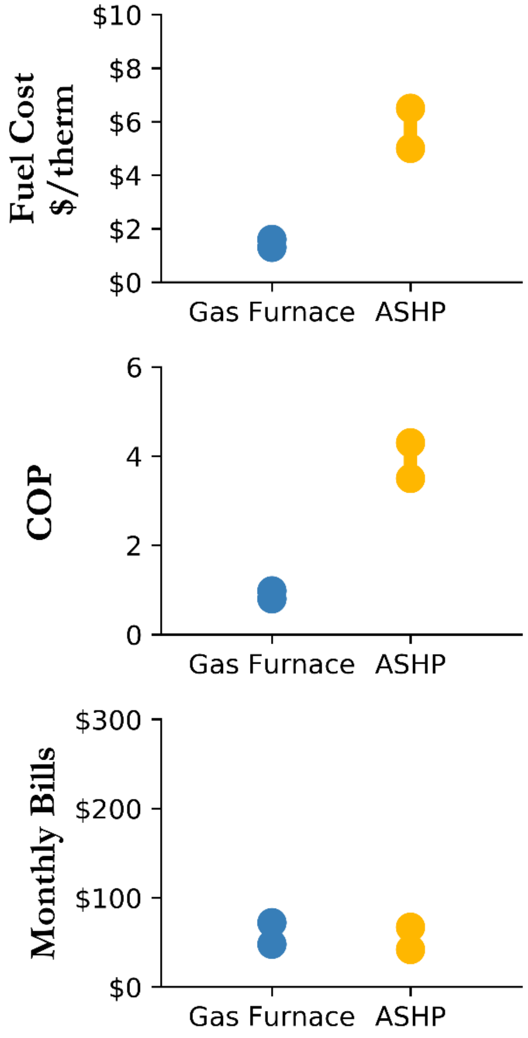
The increasing commodity costs associated with increasing RNG blends mean that all-electric customers have lower bills in both scenarios

This scenario also has a major assumption that there is no economic electrification, an unlikely outcome given the difference in bills

One notable point, mixed-fuel bills stay mostly flat over time. Why? Load growth and load factor improvements mean that increasing electric sector costs are spread over more KWh

Digging one layer deeper into the economics of building electrification versus RNG in California

2020 - 100% Fossil Gas

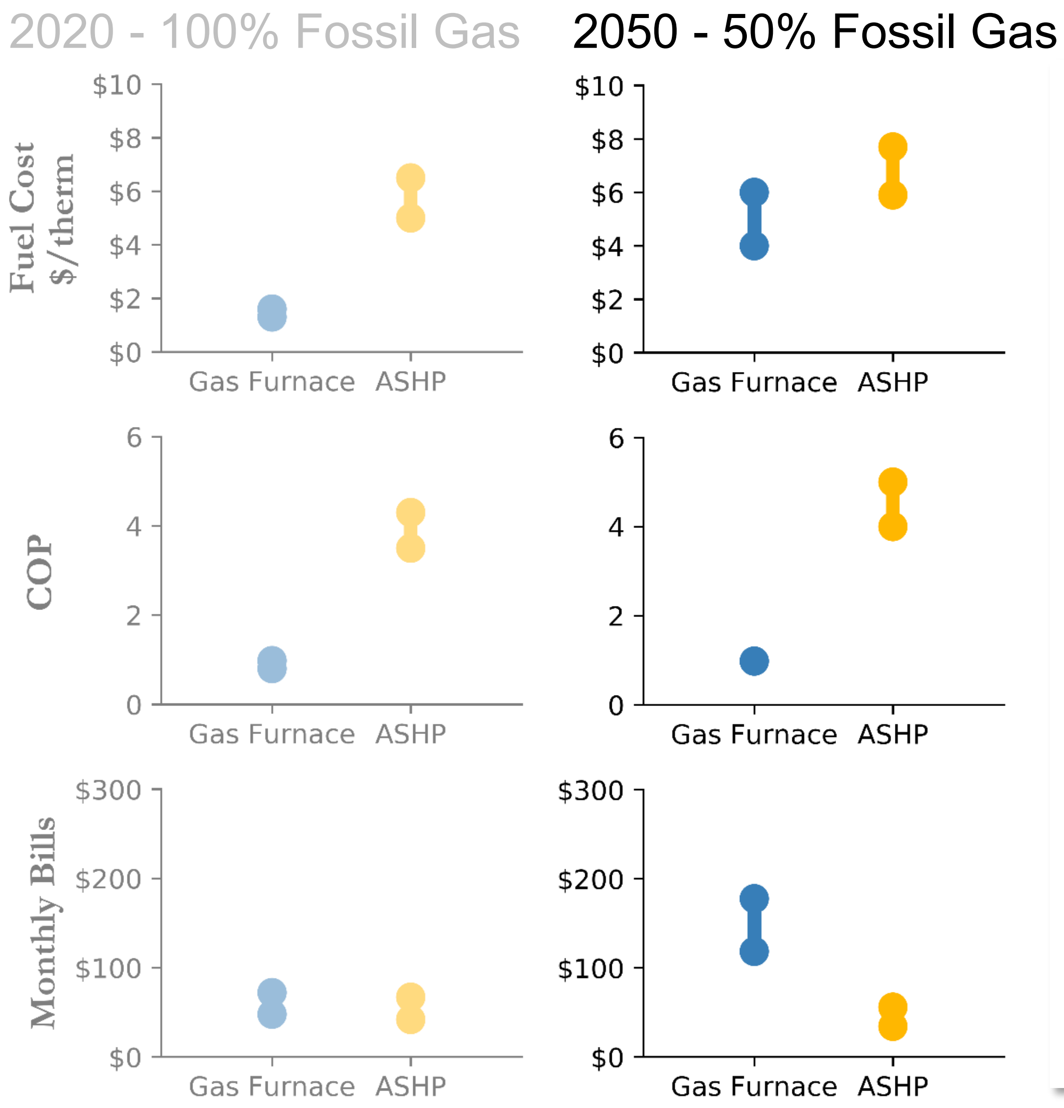


Residential natural gas rates are less than electric rates when compared on a like-for-like basis (in this case $/therm)

But heat pumps are more efficient on a site energy basis than gas furnaces

This means that the monthly cost of space-heating for gas and electric customers are similar today

A 50% decarbonized pipeline blend changes the economics

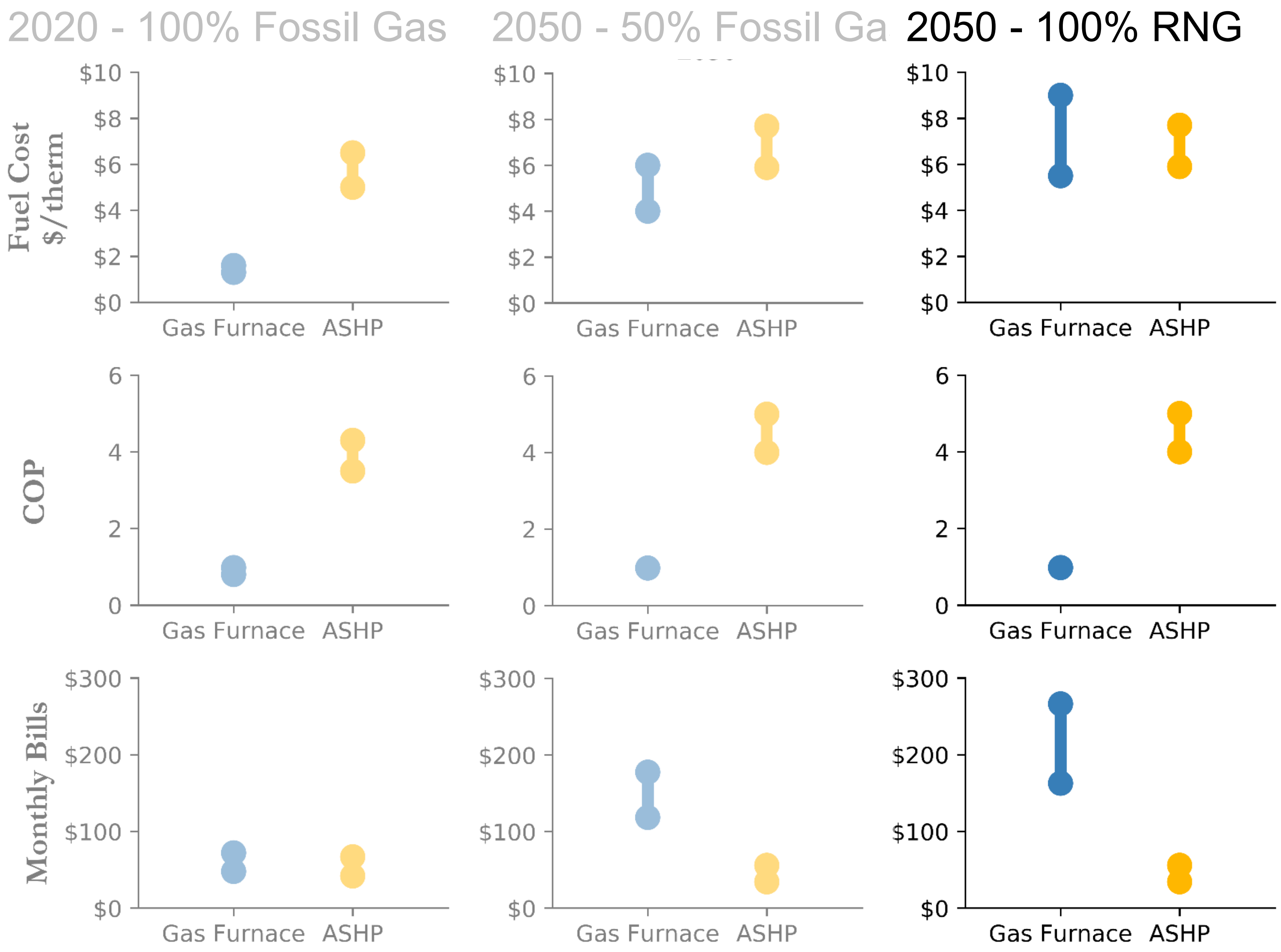


Gas rates become <u>similar to</u> electric rates at 50% RNG blends

Heat pumps have more room for improvement on COP than gas furnaces

At 50% RNG, the consumers with electric space-heating incur <u>lower costs</u> than customers with gas space-heating

The choice is fairly clear at 100% blends



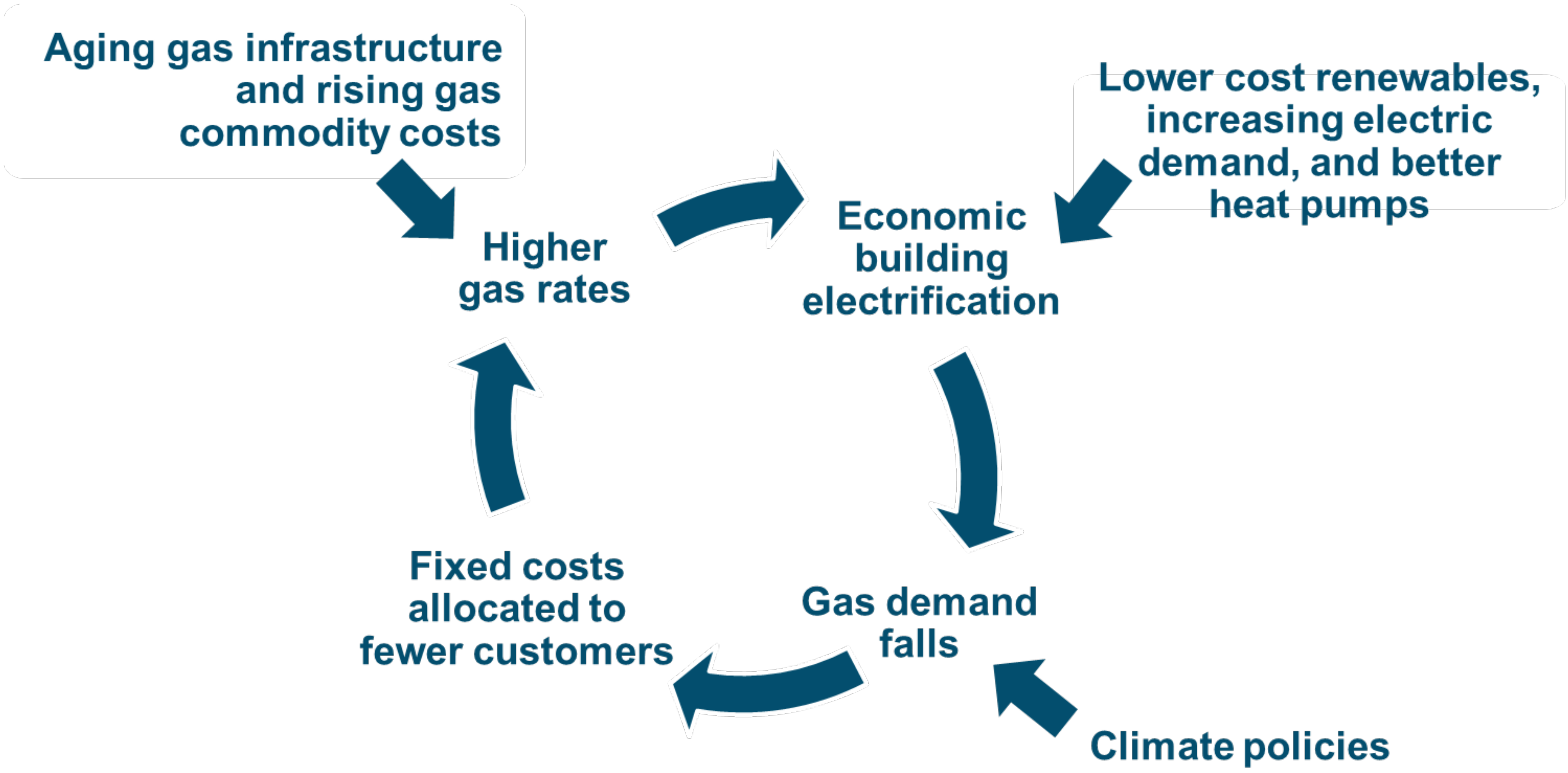
In a 100% decarbonized pipeline case

Gas rates ≈ Electric rates

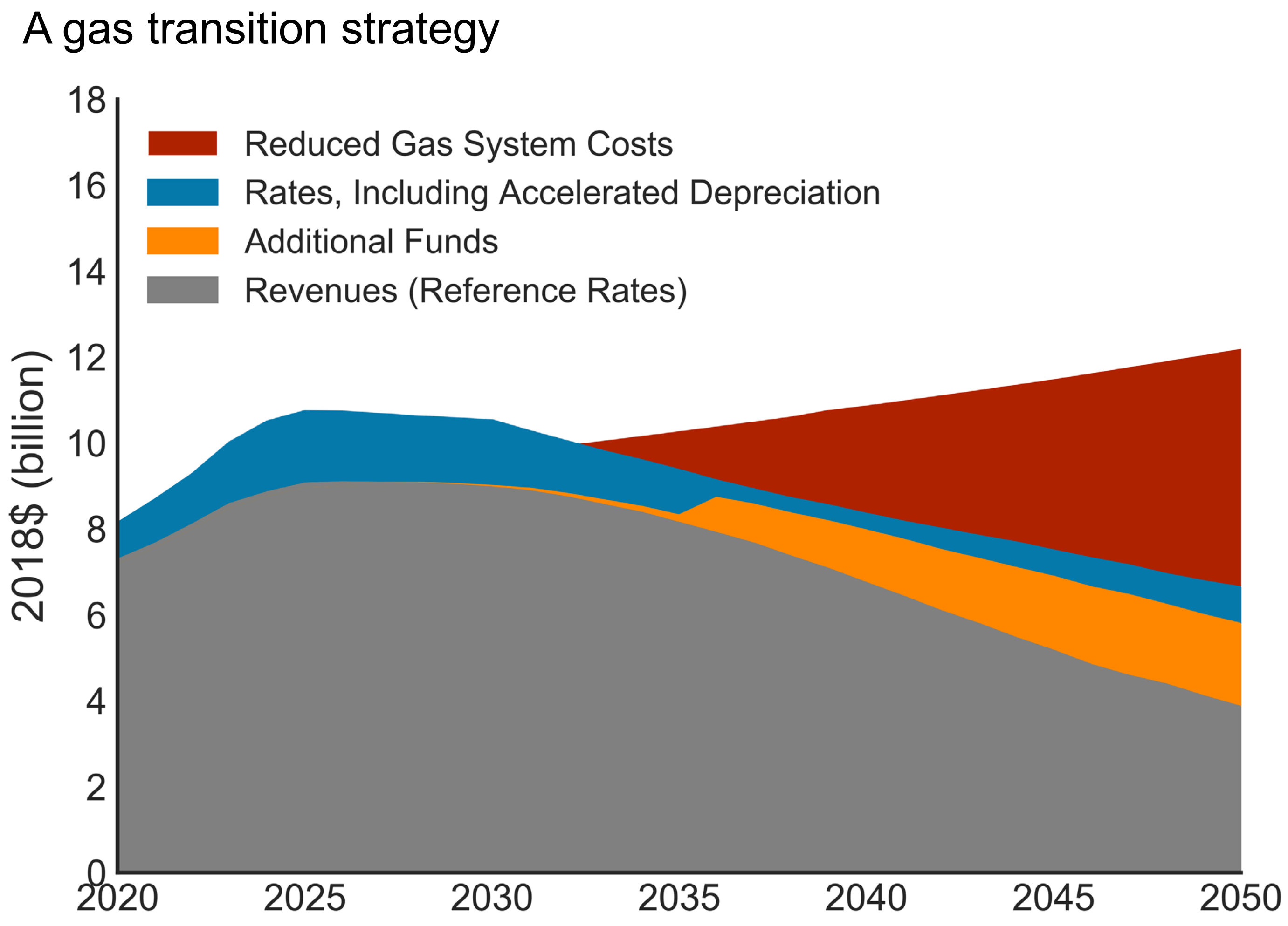
But

Gas bills >> Electric bills

The fundamental challenge for gas utilities in California



Gas Transition Strategy



Our work in California identified a need for the state to start exploring gas transition strategies. Strategies might include

- **Gas system cost reductions**
- **Accelerated deprecation and other changes to rates**
- **Infusion of funds from either electric ratepayers or the state general fund**

There have already been initial steps in considering such a plan via a stakeholder process managed by Gridworks and a new CPUC proceeding

Key Takeaways

- Scenarios that achieve deep decarbonization see upward pressure on either gas delivery or commodity costs
- Increasing gas rates improve the economics of building electrification, potentially leading to a feedback effect
- These feature motivate the need for a considered gas transition strategy

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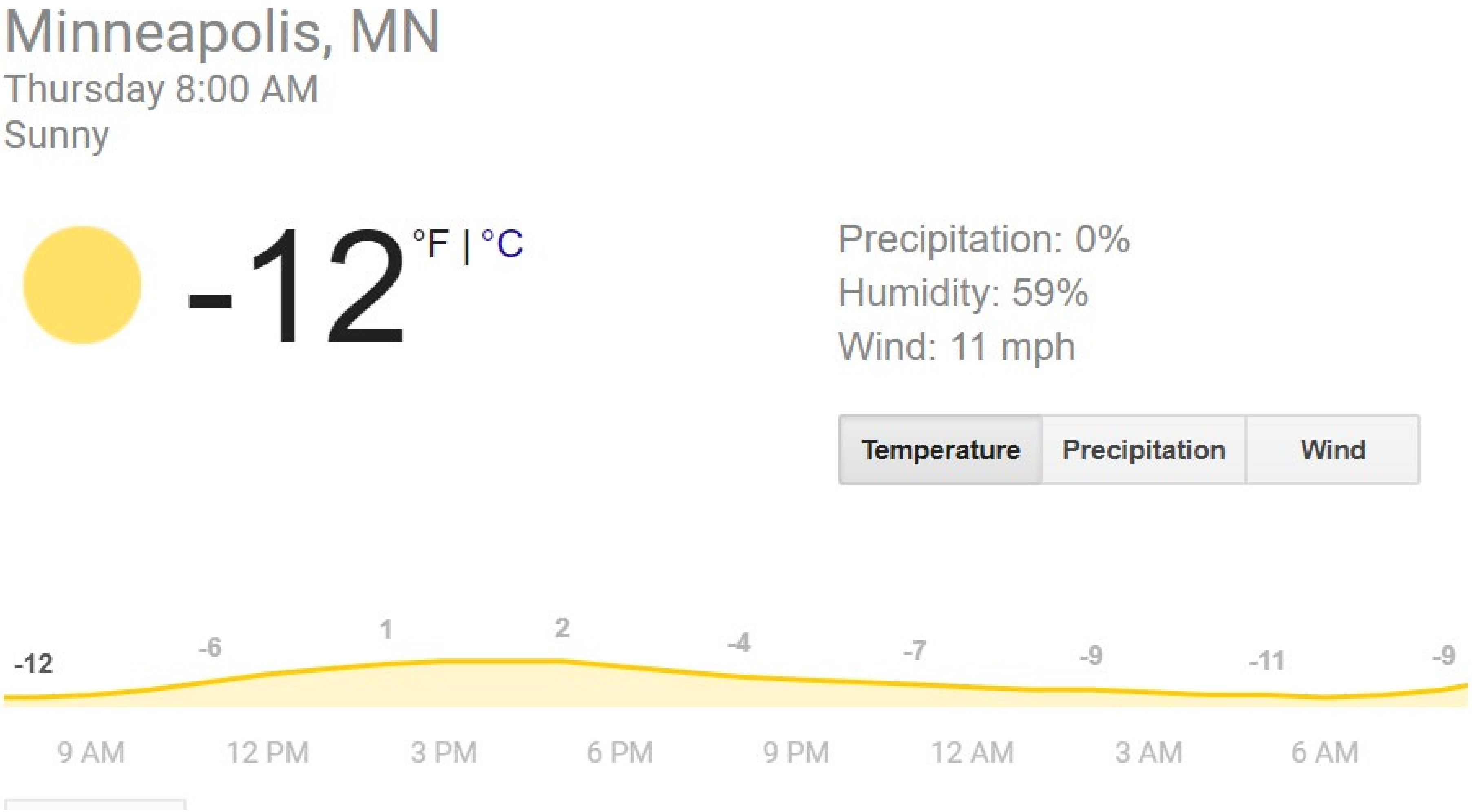
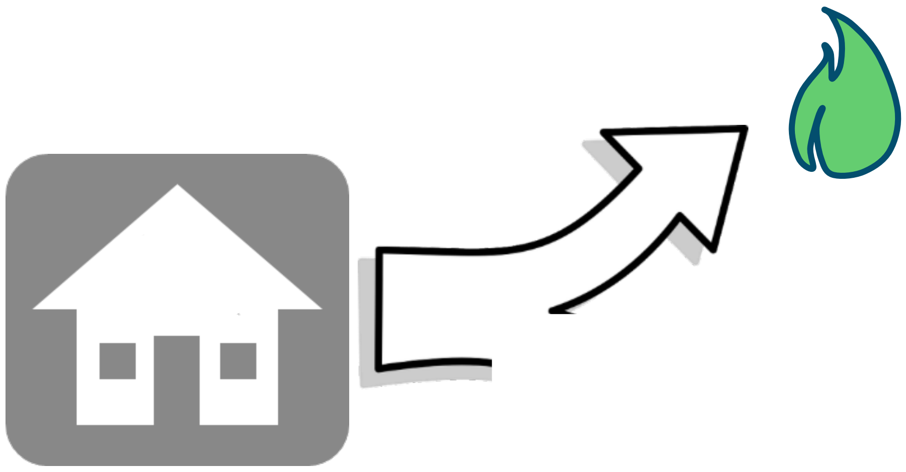
Bringing it all together, MN version

For reasons already described, decarbonizing gas end-uses is a much more challenging problem in MN



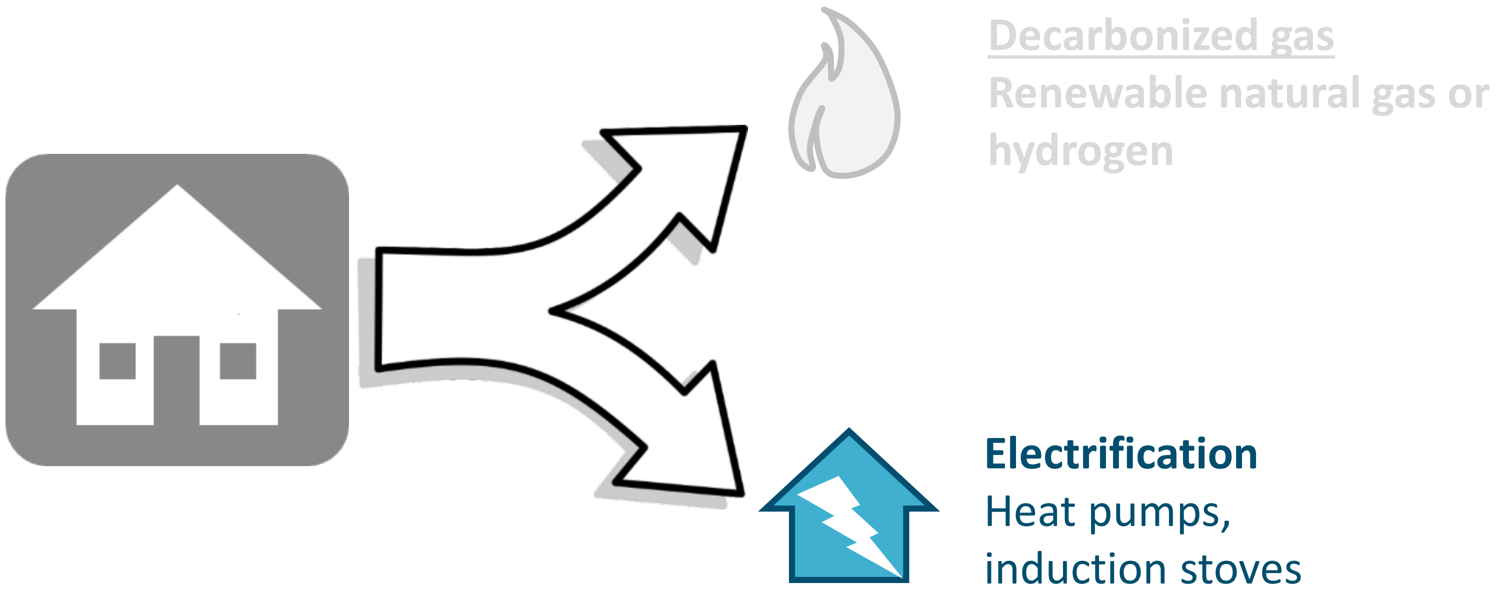
How will we heat our buildings?



Decarbonized gas
Renewable natural gas or hydrogen

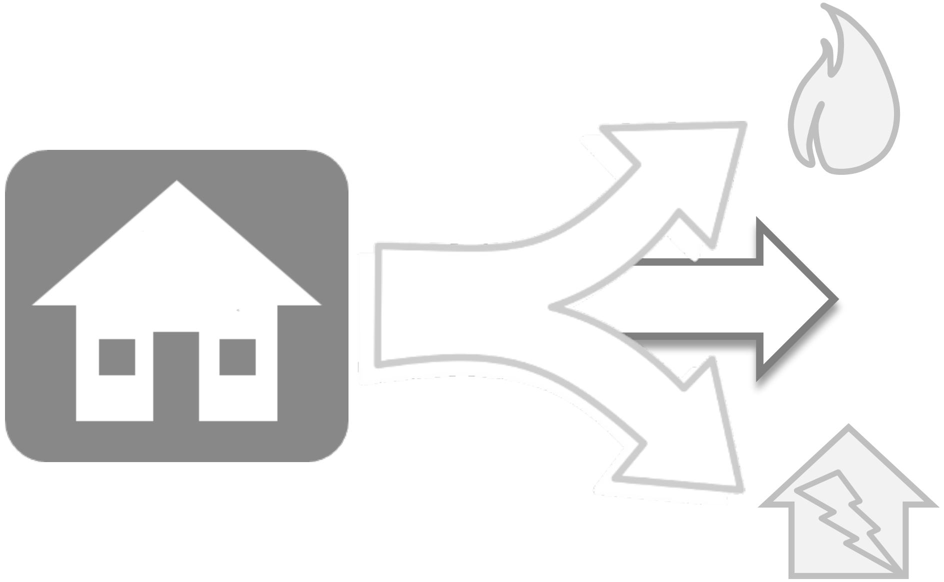
- Key Advantages: **repurposes existing infrastructure, minimal consumer disruption**, also reduces non-energy emissions
- Key Drawbacks: **cost, not commercial**, can require extensive utility infrastructure and customer equipment retrofits

How will we heat our buildings?



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

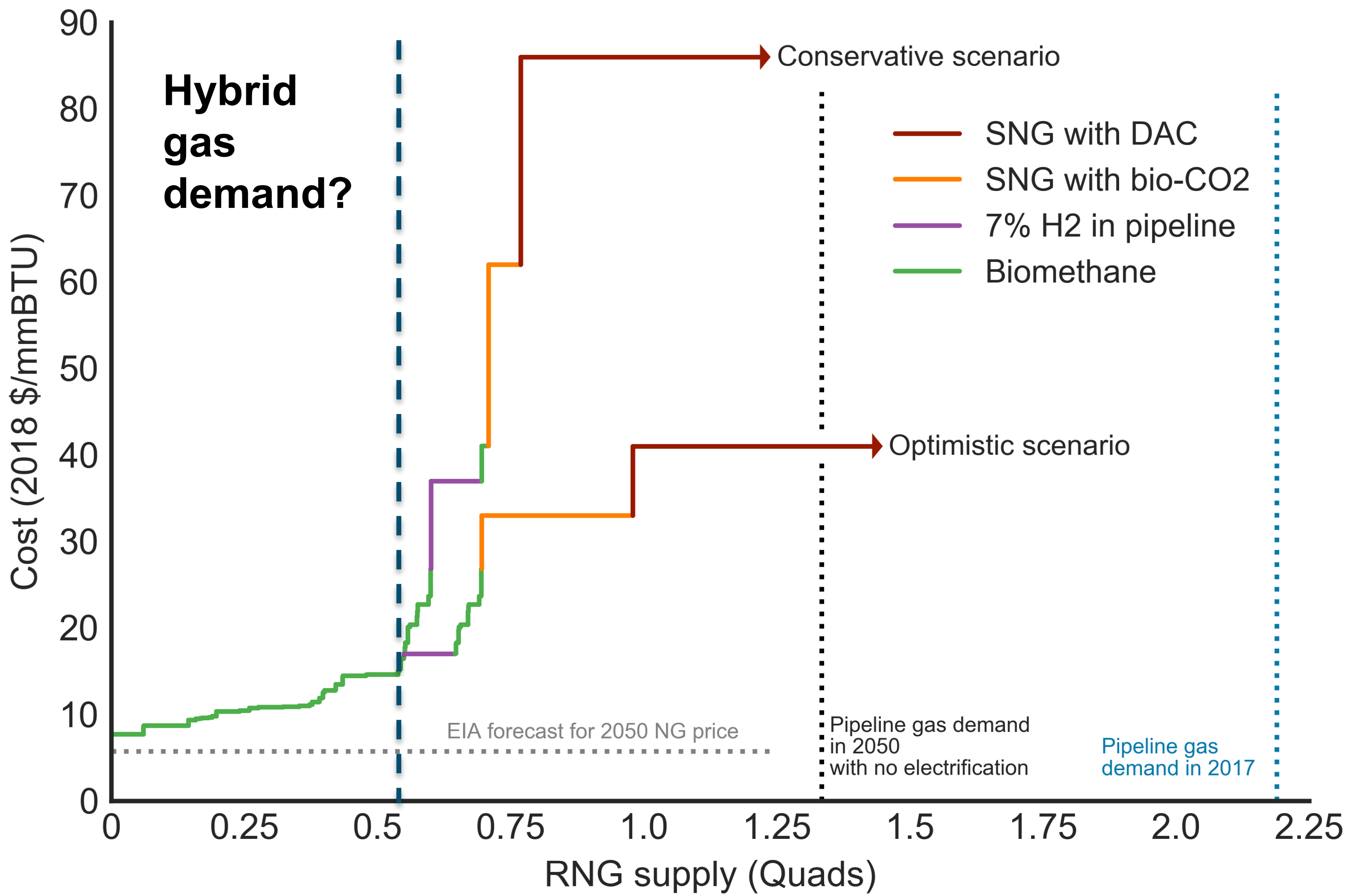
How will we heat our buildings?



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

E3 RNG Supply Curve: Hybrids

California Renewable Natural Gas (RNG) Supply Curve, 2050



Use of hybrids may allow for a larger percentage of gas throughput to be decarbonized

Lower throughput means that the more expensive forms of RNG could be avoided altogether

Conclusions for MN

Hypotheses on decarbonizing heat in MN:

- **Electrification will have a role:** electrification is a great strategy to efficiently deliver decarbonized energy for much of the year, but there are major challenges with peaks
- **Climate neutral fuels will have a role:** At a minimum, hydrogen and RNG will be important fuels to decarbonize hard to electrify sectors; they may also play an important role in buildings
- **There will be "no regrets" near-term actions:** They might include pilots focused on hybrid electrification, hydrogen, RNG, or deep energy efficiency retrofits
- **But there may be forks in the road**: Some strategies could lead to stranded assets or negative long-term equity impacts
- **A robust long-term planning framework is needed**: Key insights can be drawn from best available information today, but a long-term strategy must be able incorporate new information and learnings

Many questions remain, more work is needed

Research needs and gaps include:

- **Internally consistent and comprehensive cost data:** The all-in equipment cost of HVAC equipment and efficiency retrofits dominate the consumer economics of building electrification. There is not great comparative data available.
- **Long-run view on the impact of building decarb strategies on rates and bills:** Consumers will ultimately determine what building decarbonization strategies are adopted. Starting with the consumer perspective in mind clarifies what is possible.
- **Cost of conversion of portions or all gas systems to hydrogen:** 100% hydrogen gas blends appear to be far less costly from a commodity cost perspective than 100% RNG, but the difference in delivery costs is not well identified.
- **Business models for hybrid heat pumps**: Could a gas distribution utility function primarily as a peak capacity resource? And if so, how would they be compensated? Could hybrids be used to increase the flexibility of electric loads?

Energy+Environmental Economics

Thank You

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DECARBONIZING MINNESOTA'S NATURAL GAS END USES

Meeting 3

February 14th, 2020

American Swedish Institute

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Discussion:

- What insights from work in California and New York seem important for our work in Minnesota?
- What opportunities and challenges does this raise for you?
- What issues/topics do you think we need to dig into more to build the group's problem-solving abilities?

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DECARBONIZING MINNESOTA'S NATURAL GAS END USES

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