Puget Sound Energy (PSE) GRC Settlement Study: Regional Context

Infrastructure Analysis Update

July 2023

Energy+Environmental Economics

Summary of Updates

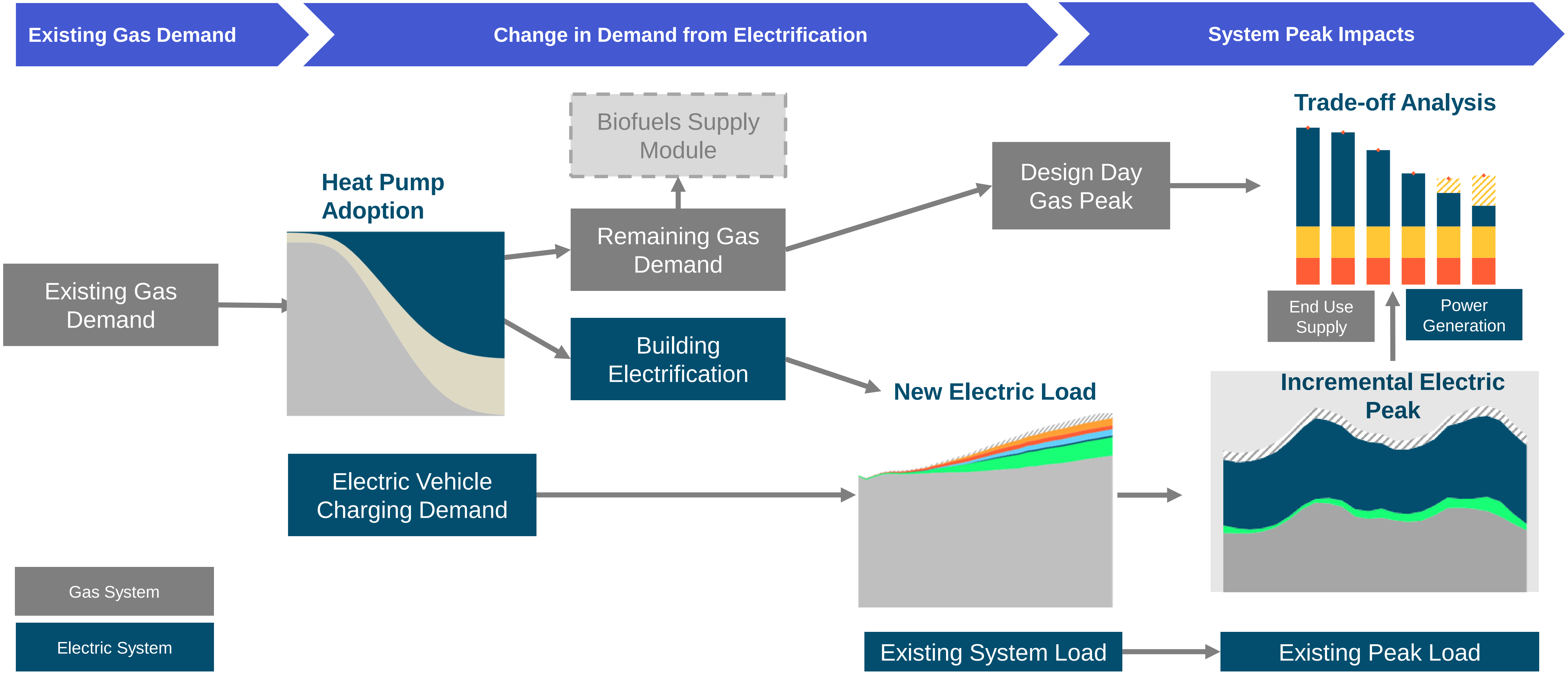
- **Climate impact is now incorporated throughout the analysis**
  - With climate impact, incremental peak demand in the State Energy Strategy Scenario is reduced from 9.2 GW to 8 GW for Western Washington
  - A description of E3's approach to climate impact is in the Appendix
- **An option to use local hydrogen-ready CT is presented as Alternative 1**
  - The local gas CT option is now presented as a Counterfactual scenario with the caveat that it may not meet the CETA requirement for 2045
- **Upfront capital cost estimates are now provided for the clean resource options**
  - Costs are presented as ranges to represent the uncertainties associated with project-specific cost to build such resources
- **Discussion around limited role for energy storage is added**
  - Both Li-ion battery and long-duration storage are discussed for their potentially limited role as options to serve the incremental peak heat

Study Description

+ **Objective: Assess the Impacts of Heating Decarbonization Pathways on Regional Electric and Gas Infrastructure**

+ **This regional infrastructure analysis is mainly focusing on:**
  1. **Assessing the ability of electric transmission systems** to deliver firm capacity during peak heat events to load pockets on the **West of the Cascades**
  2. **Estimating the impact on regional gas infrastructure requirement** considering **design day gas demand for both buildings and power generation**

Methodology



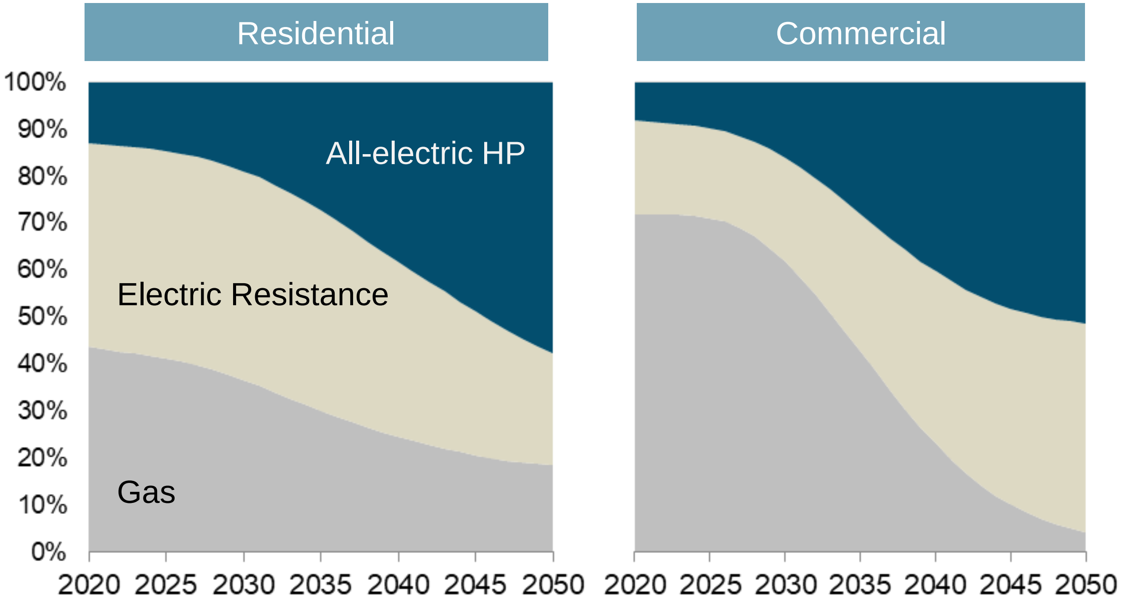
Summary of Conclusions

- **Peak electric demand in Western Washington will increase by 8 GW in 2045, mainly driven by heating electrification, if the state follows or goes beyond the electrification trajectory envisioned in the 2021 State Energy Strategy.**
- **To serve the incremental peak and meet 100% clean electricity by 2045 under CETA, Western Washington could (1) build local hydrogen-ready combustion turbines, (2) expand transmission capacity to access firm resources outside of the region, or (3) build local clean resources such as small-modular nuclear or offshore wind**
  - Relying on one solution alone comes with its own unique challenges including costs or feasibility to build such large amount of resources and infrastructure
- **A hybrid electrification approach using dual-fuel heat pumps will significantly alleviate the peak impact on the electric system by largely utilizing the existing gas distribution system as backups for serving peak heat need**
  - However, hybrid electrification largely maintains CO2 emissions in gas system during peak hours compared to hydrogen peakers
- **Energy storage will likely have a limited role for serving peak heat need during multi-day cold snaps**
  - Long-duration energy storage with up to 100-hr duration will likely be needed, but it is still an expensive option with limited commercial application today

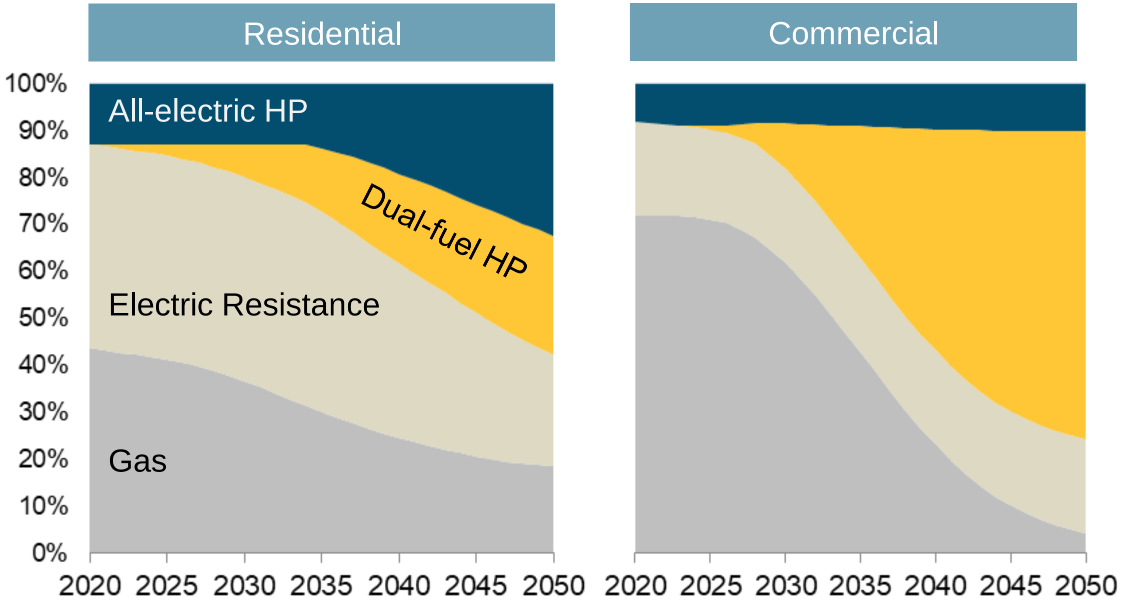
Electrification Scenarios

Scenario Name	Design
State Energy Strategy (SES)	Pace of electrification for buildings and transportation envisioned in the Electrification Scenario from the **2021 WA State Energy Strategy**, which maximizes electrification with potential large impact on electric system
Hybrid	Modified SES scenario assuming existing gas heating that switched to electric heating in the SES all adopt **dual-fuel heat pumps**, aiming at achieving similar emissions reduction but at a lower cost

HVAC Stocks by Technology – SES



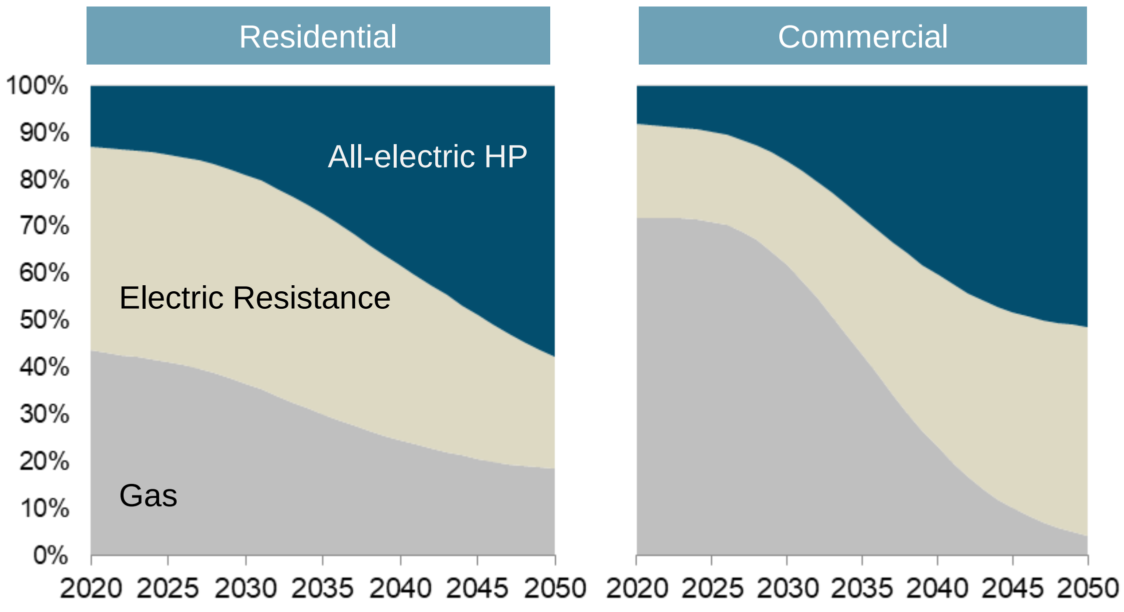
HVAC Stocks by Technology - Hybrid



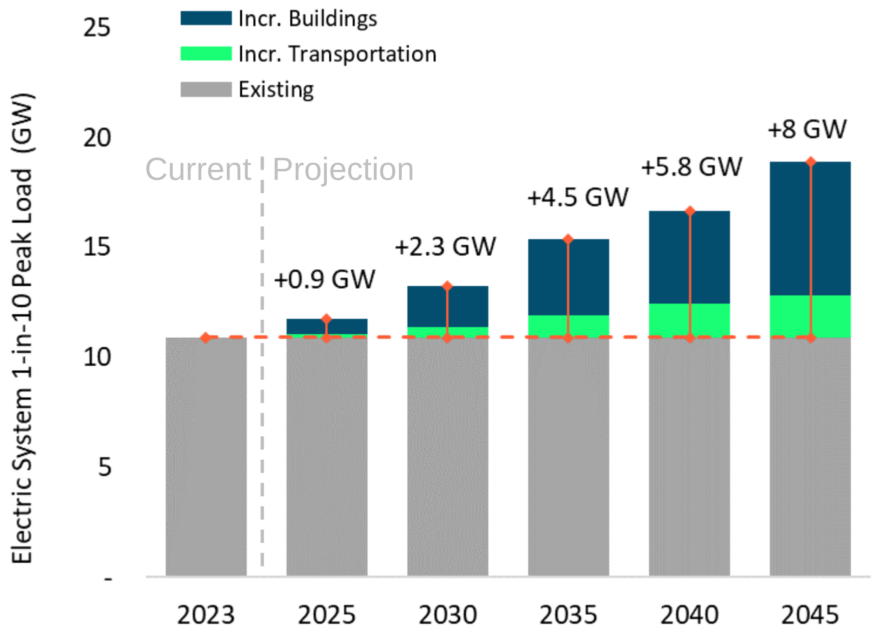
The State Energy Strategy envisions a transition towards electric heating

- The State Energy Strategy envisions a rapid transition towards all-electric heating.
- E3 estimates that the heating transition envisioned in the SES will increase peak demands by 2.3 GW in 2030 and 8 GW in 2045 if current cold-climate air source heat pump technologies are used.

HVAC Stocks by Technology – SES



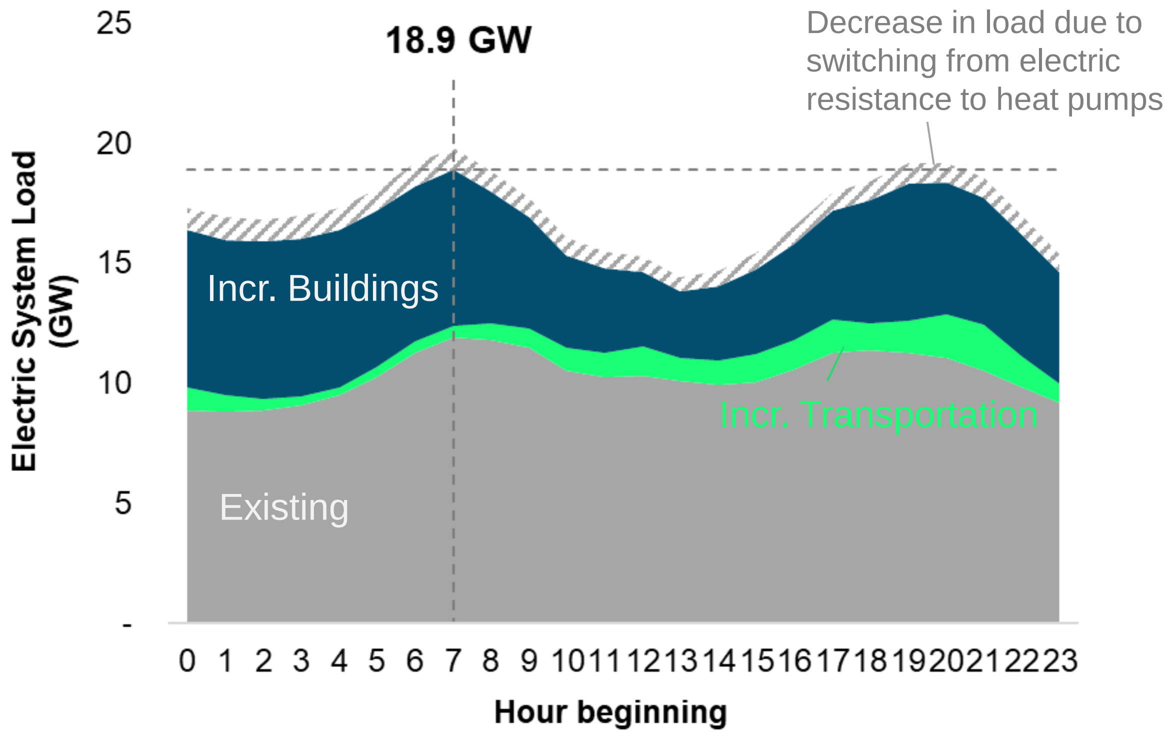
Electric System 1-in-10 Peak Demand – Western WA



Heating electrification peak demands are sustained over a multi-day periods and could be challenging to serve

Hourly Load on the 1-in-10 Peak Day

State Energy Strategy Scenario (2045)



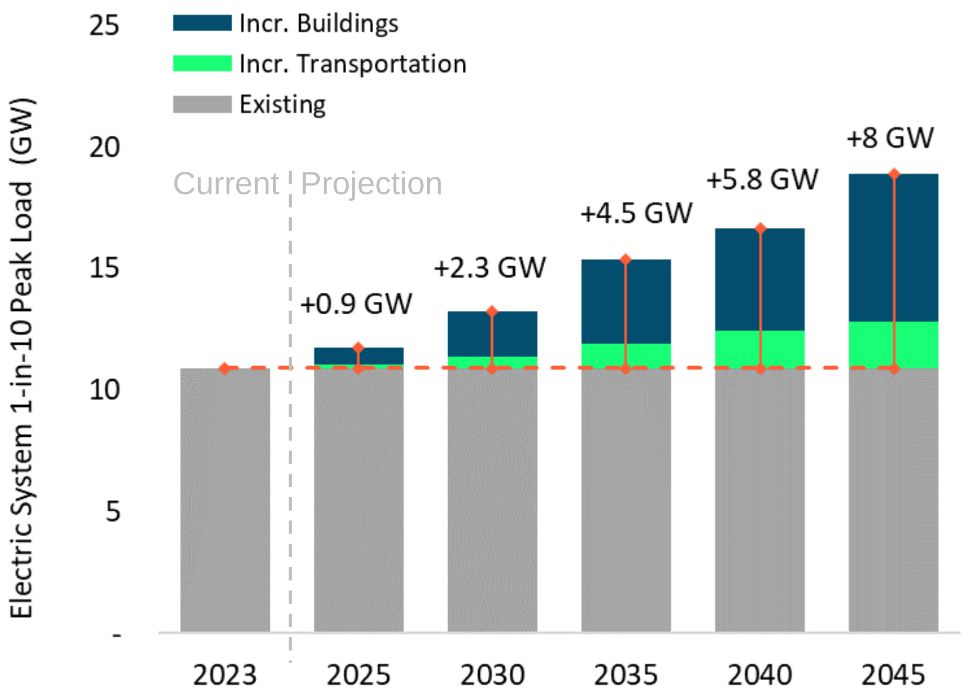
- Heating loads are highest during mornings and evenings, but are also a sustained overnight.
- Given the sustained nature of these loads, opportunities to meet peak demands via commercialized energy storage or load flexibility may be limited.
- An additional challenge is meeting sustained heating loads during periods of low renewable generation.

There are multiple ways to serve the incremental peak electric demand driven by heating electrification in Western Washington

- **Our results show that the State Energy Strategy Scenario is projected to have peak electric demand in Western WA increase by 8 GW by 2045**
- **There are multiple ways to serve the incremental peak electric demand:**
  1. **Local hydrogen-ready combustion turbines (CTs)**
  2. **Transmission expansion** to connect to gas CTs located on east side of the Cascades where gas capacity is less constrained
  3. **Clean resources** that provide capacity values during the peak day, such as **small modular nuclear reactors** (**SMRs**, as a clean firm resource) or **offshore wind** (as a potential high-capacity-value renewable resource)
- The next few slides will show results of **three "bookend" alternatives** , i.e. what if incremental peak were served entirely with one resource type. In practice, a portfolio of options could be deployed.

State Energy Strategy Scenario

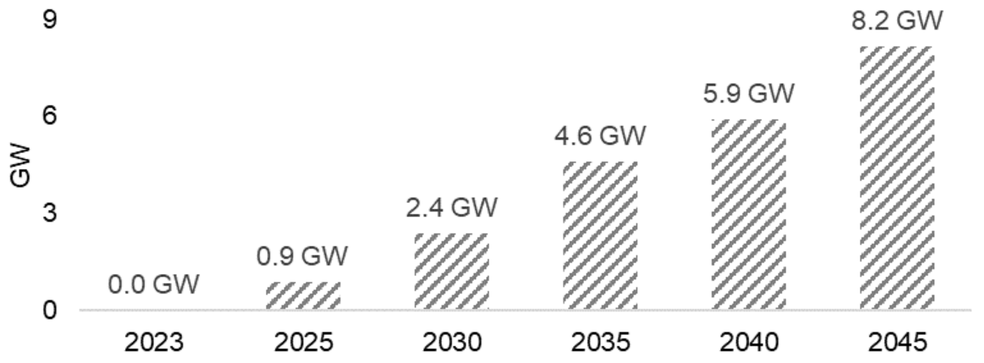
Electric System 1-in-10 Peak Demand – Western WA



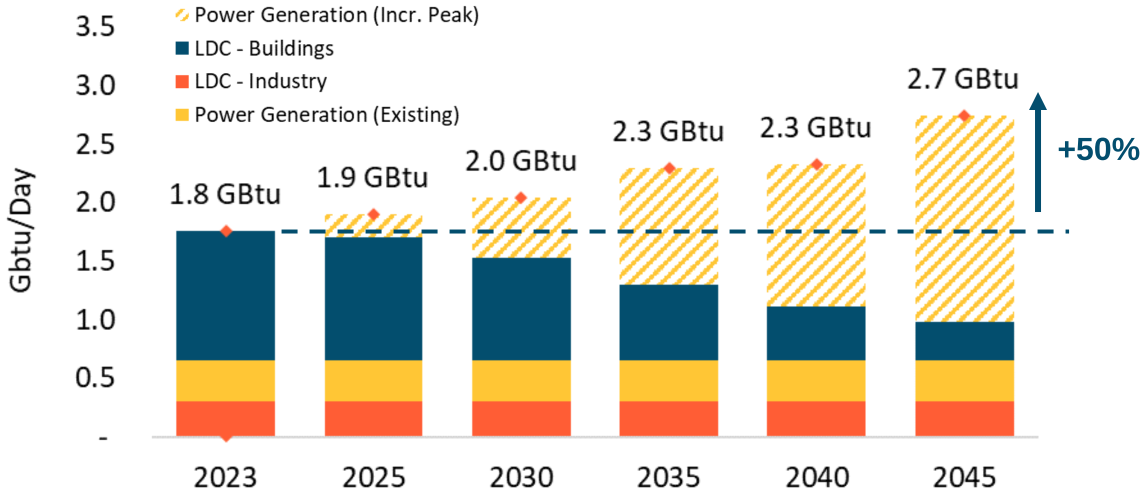
Counterfactual: Building local gas CTs in Western WA

- Serving the incremental peak with local hydrogen-ready CTs would require 8.2 GW additional capacity installed
- The new local hydrogen-ready CTs will result in (1) design day gas throughput increase by 50%, and (2) design day net GHG emissions increase by 52 kTCO2e
- *CAVEAT: Counterfactual scenario may meet the CETA requirement to achieve 100% clean power generation by 2045 if the CTs were powered by zero-carbon fuels*

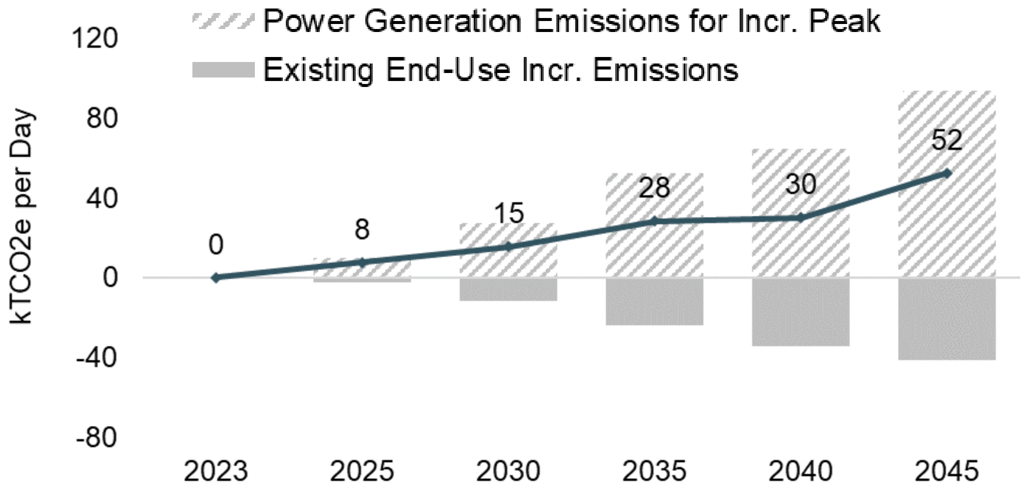
Local Gas CT Capacity to Serve Western WA



Design Day* Gas Throughput in Western WA



Design Day Net Emissions to Serve Western WA

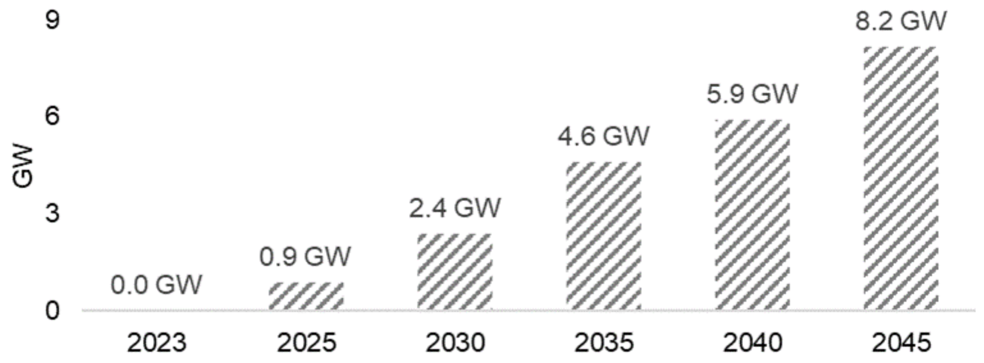


* The gas design day in this analysis is defined based on the most conservative design criteria among gas LDCs in Western Washington. E3 models it as the coldest day with the highest heating degree days (HDDs) from 1979-2019.

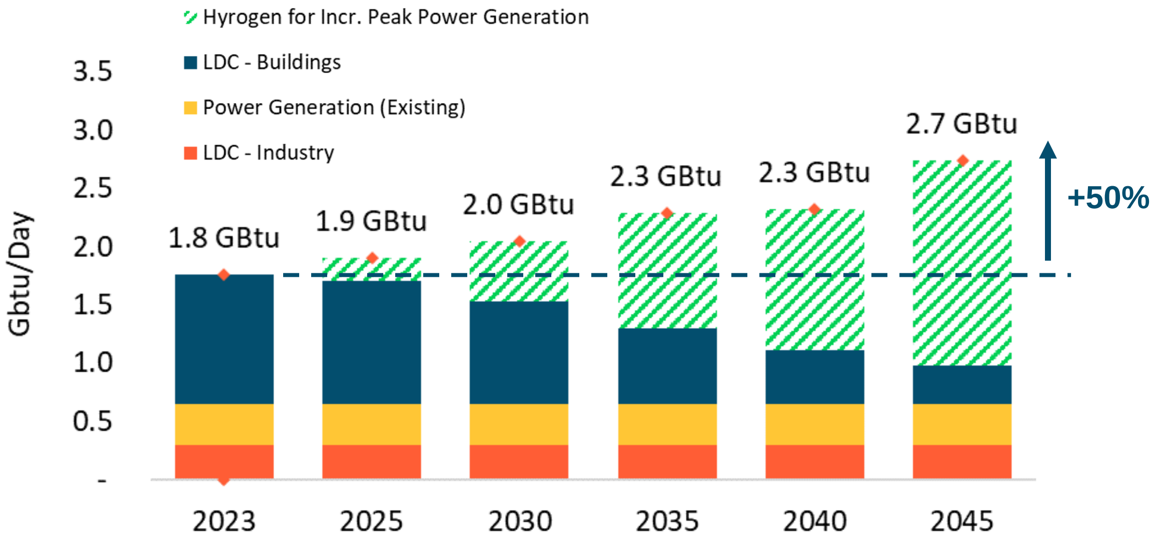
Alternative 1: Building local hydrogen-ready CTs in Western WA

- Serving the incremental peak with local hydrogen-ready CTs would require 8.2 GW additional capacity installed
- Combusting hydrogen to serve the incremental peak will reduce GHG emissions on design day
- However, if all incremental peak demand is served by hydrogen CTs, hydrogen demand (green shaded) on design day will be at the same scale as today's gas throughput, a big challenge for transporting and storing hydrogen

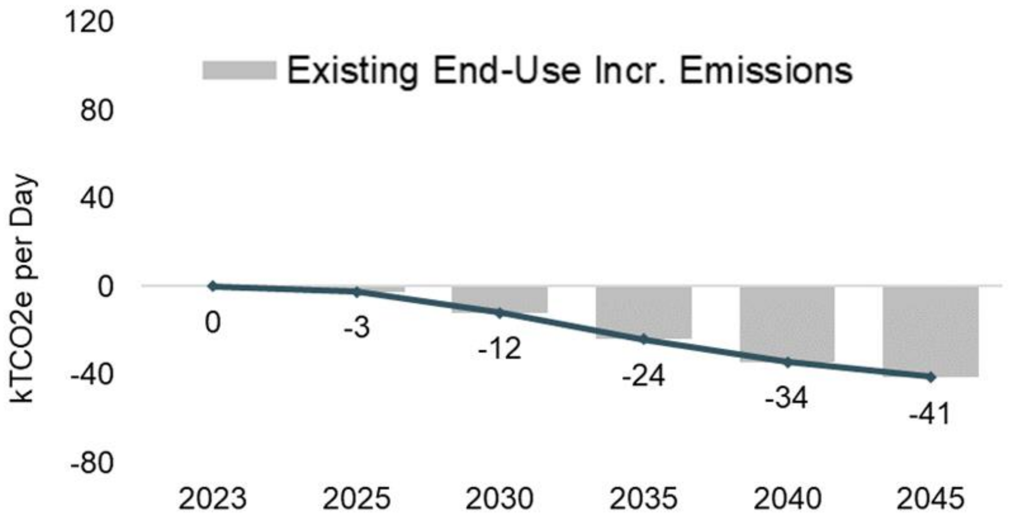
Local Hydrogen-ready CT Capacity to Serve Western WA



Design Day Gas and H2 Throughput in Western WA



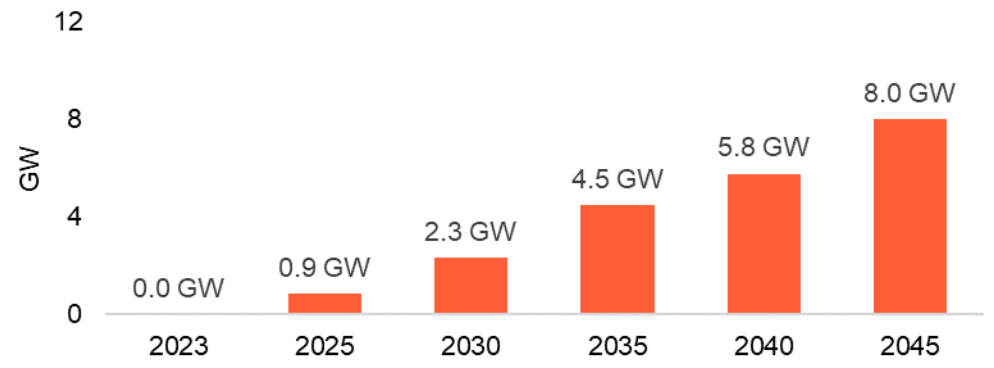
Design Day Net Emissions to Serve Western WA



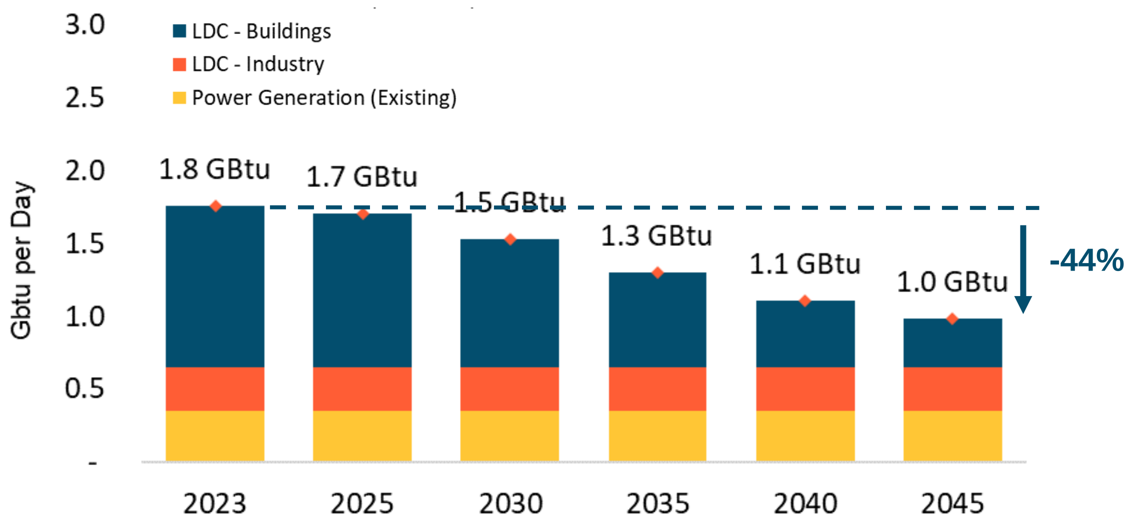
Alternative 2: Expanding transmission capacity to access hydrogen-ready CTs outside Western WA

+ Serving the incremental peak with non-local gas CTs would require expanding transmission capacity to Western WA by 8 GW
+ Transmission expansion could mitigate the stress on local hydrogen demand on design day
+ However, it will be challenging to expand or build new transmission capacity crossing the Cascades

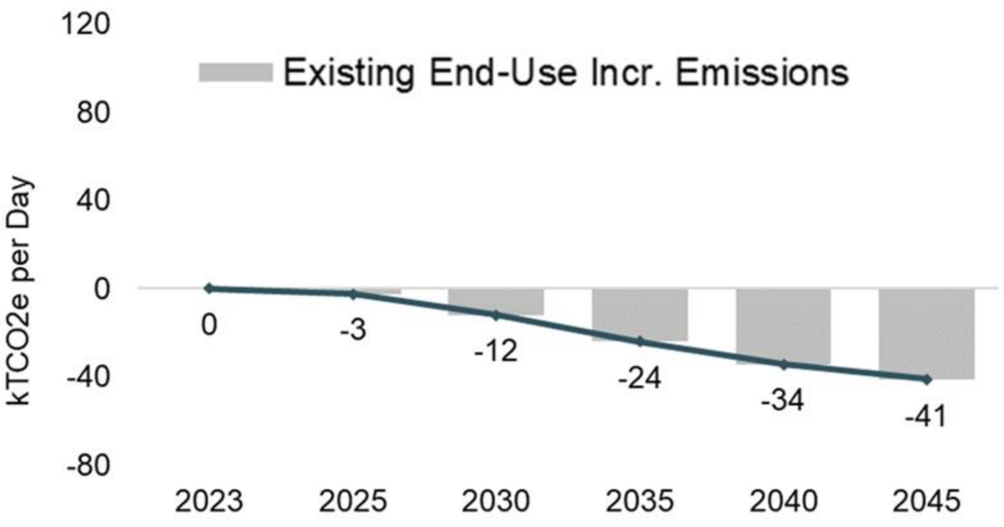
Additional Transmission Capacity to Serve Western WA



Design Day Gas Throughput in Western WA



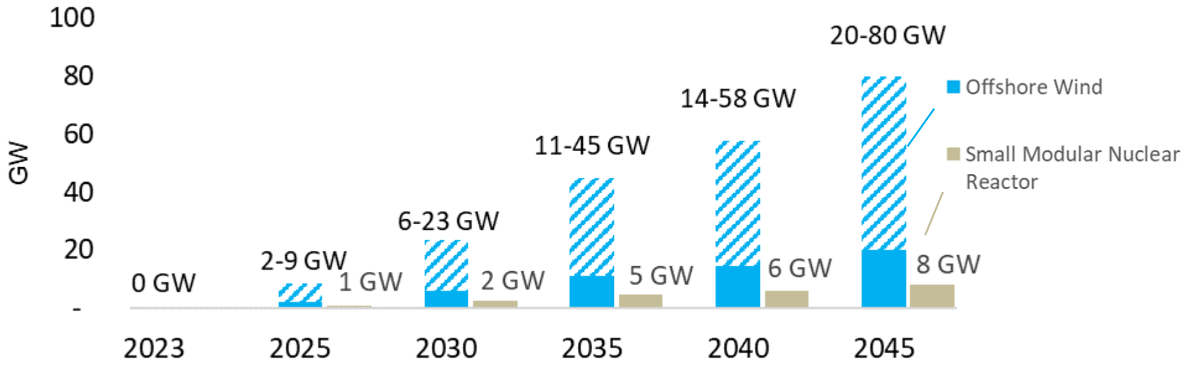
Design Day Net Emissions to Serve Western WA



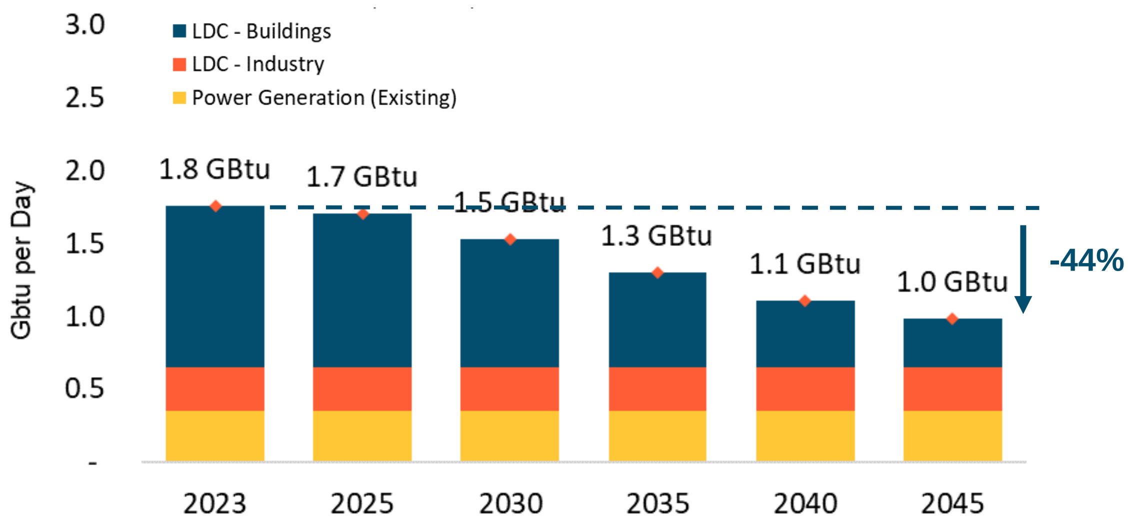
Alternative 3: Building clean resources

- Serving the incremental peak with clean resources can both mitigate the impact on the local gas system and reduce GHG emissions
- Small Modular Nuclear Reactor (SMR), as an emerging technology, will cost $65-75 billion in upfront cost to build at the scale of 8 GW.
- Using only offshore wind to meet the incremental peak will cost $60-370 billion, with effective load carrying capacity (ELCC) at 10-40% due to uncertainty; additional research is needed to narrow the range

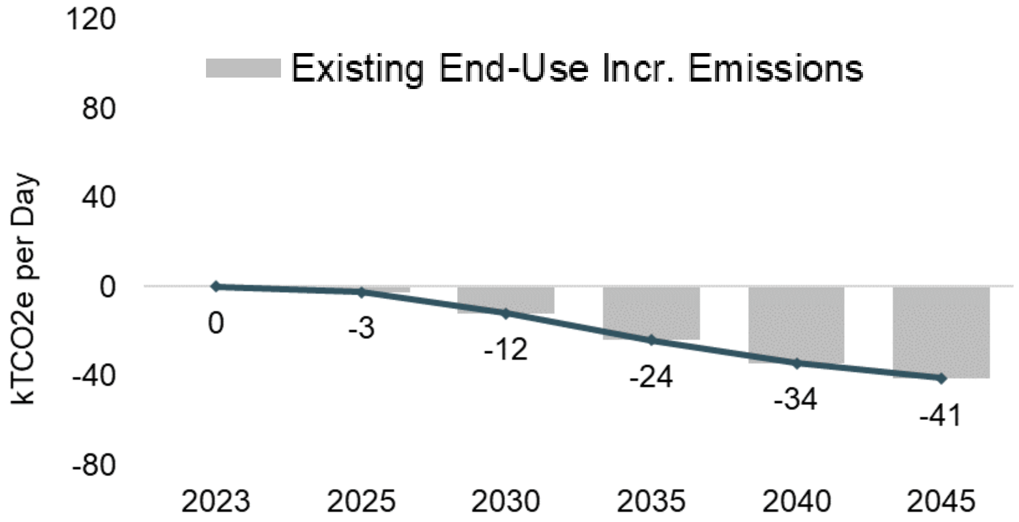
Clean Resource Capacity to Serve Western WA



Design Day Gas Throughput in Western WA



Design Day Net Emissions to Serve Western WA

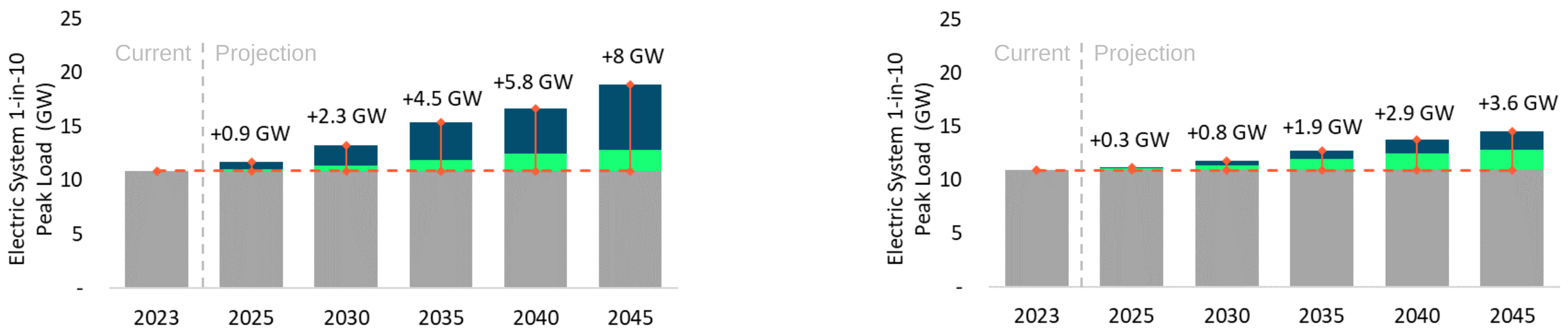


Switching gas heating to dual-fuel heat pumps can significantly reduce peak impact on the electric system

+ **Hybrid Scenario** has peak electric demand increase at a much slower pace due to the reliance on the gas system to provide peak heating need during cold spells
+ Incremental peak electric demand is **more than halved** in the **Hybrid Scenario** compared to **the State Energy Strategy Scenario**

Electric System 1-in-10 Peak Demand – Western WA

State Energy Strategy Scenario	Hybrid Scenario

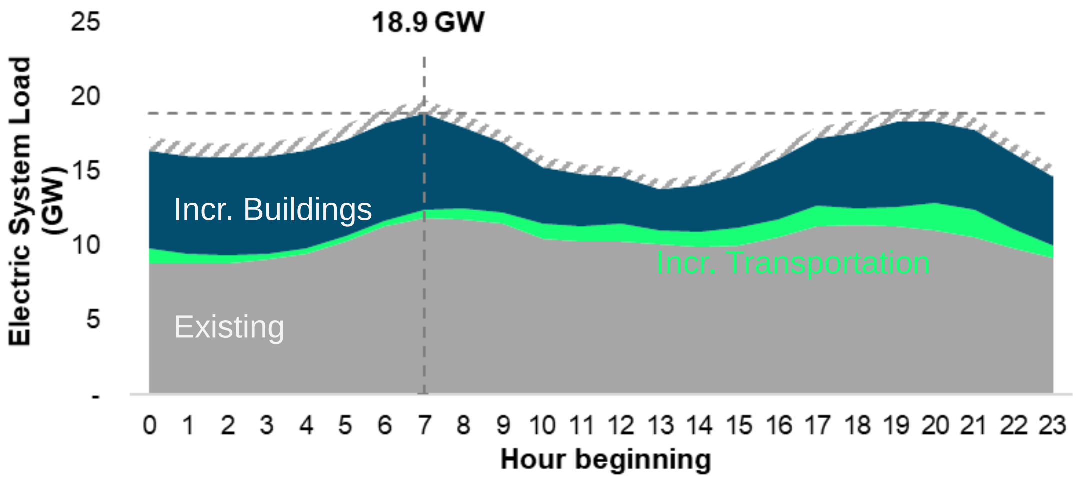


Hybrid Scenario has a much smaller peak impact due to the use of gas backup during the extreme cold event

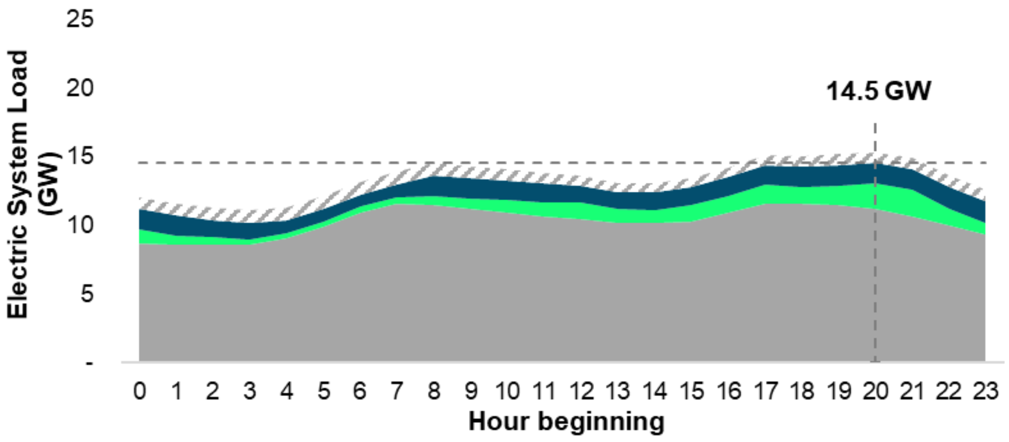
+ Switching the electrified gas heating in the SES to dual-fuel heat pumps reduces peak impact by ~4.4 GW during the extreme event in 2045

Hourly Load on the 1-in-10 Peak Day

State Energy Strategy Scenario (2045)



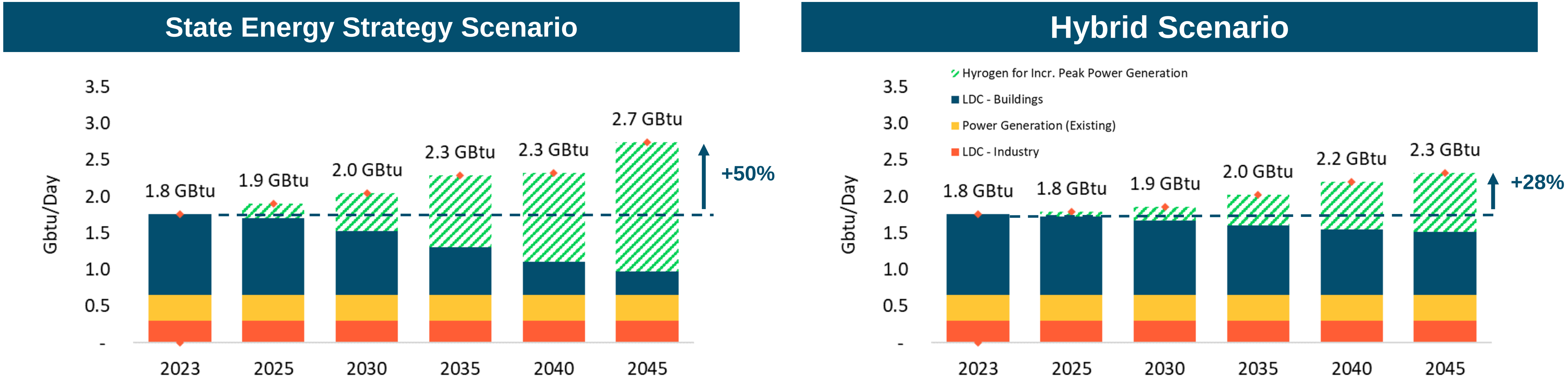
Hybrid Scenario (2045)



Switching gas heating to dual-fuel heat pumps can alleviate the impact on design day gas throughput

- In the Hybrid gas, design day total gas throughput for existing end-uses largely remains at today's scale since dual-fuel heating systems will rely on back-up gas heating during cold spell
- Hybrid Scenario will need less than half of the hydrogen in the SES scenario to serve incremental electric demand in Western WA using local hydrogen-ready gas CTs

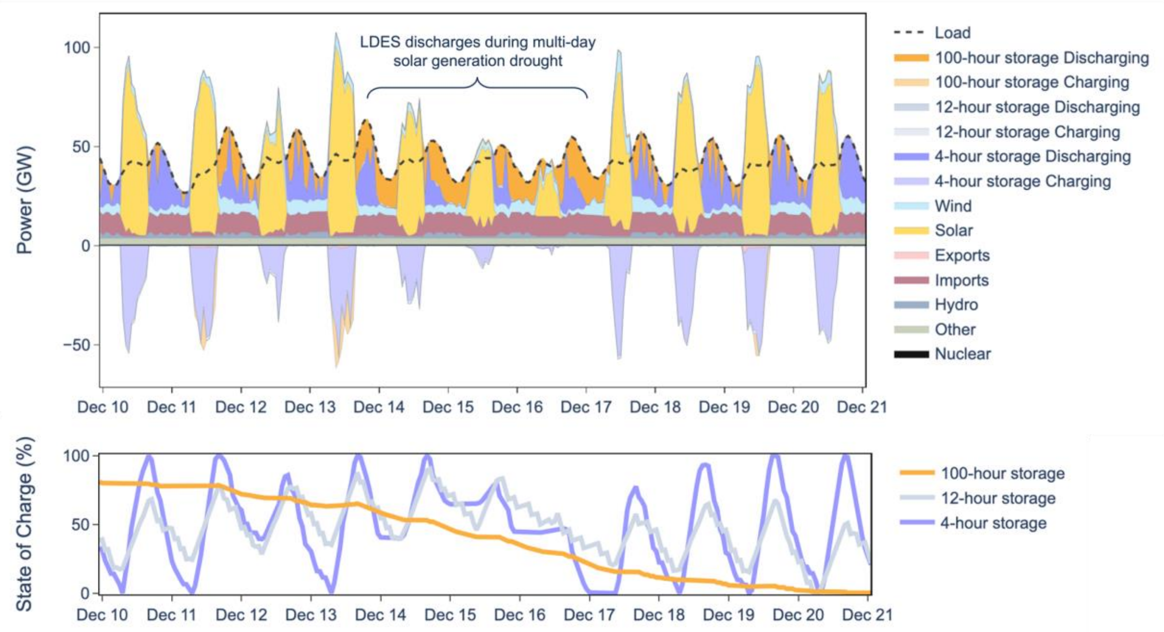
Design Day Gas and Hydrogen Throughput in Western WA



Energy storage will likely have a limited role for serving peak heat need during multi-day cold snaps

- **Single cold snap may last multiple days, which limits the role for Li-ion battery storage to fully serve the peak heat need**
  - Li-ion battery typically has duration of 1-12 hours
- **Long-duration energy storage with up to 100-hr duration will likely be needed to cover multi-day cold snaps, but it is still an expensive option with limited commercial application today**
  - Technologies such as thermal storage or Iron-air storage are available but are still at very early demonstration phases and not fully commercialized
  - Typically, these technologies have round-trip efficiency (RTE) at less than 50% (CPUC and CEC report), much less efficient compared to the 80-90% RTE of Li-ion battery
  - Long-duration storage technologies such as iron-air storage today costs $1,500-3,000 per kW

Example modeled for a multi-day winter renewable lull in CAISO shows the need for 100-hour storage when no in-state combustion is allowed

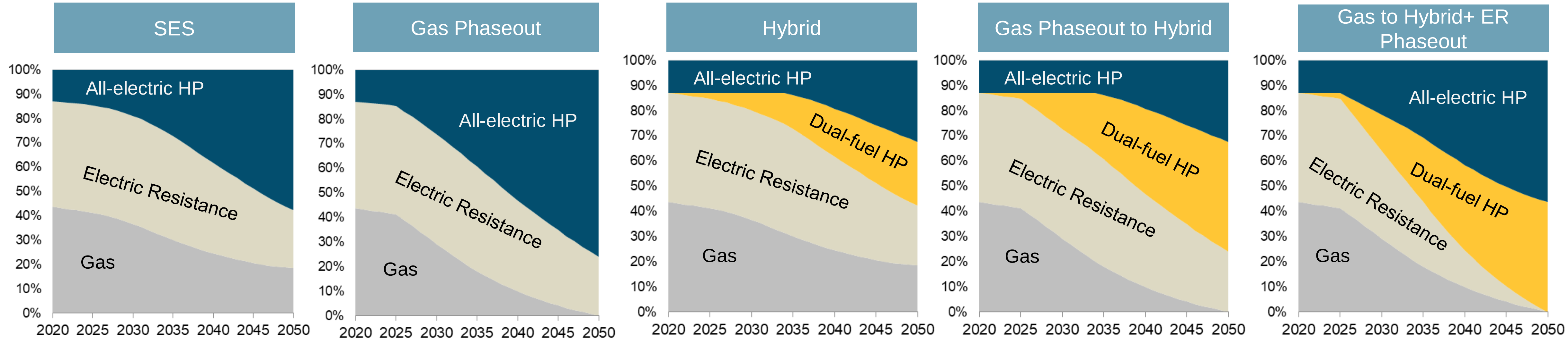


Source: Final Public Workshop for CEC EPC-19-056 Assessing the Value of Long Duration Energy Storage by E3, Form Energy and UCSD Center for Energy Research

Load sensitivities explore further impact from phasing out gas heating to hybrid heat pumps and electric resistance

Original Scenario	Sensitivity Scenario	Sensitivity Design
State Energy Strategy (SES)	**Gas Phaseout**	Replacing all remaining gas heating with all-electric heat pumps by 2050
Hybrid	**Gas Phaseout to Hybrid**	Replacing all remaining gas heating with dual-fuel heat pumps by 2050
Hybrid	**Gas Phaseout to Hybrid + ER Phaseout**	+ Replacing all remaining electric resistance heating with all-electric heat pumps by 2050

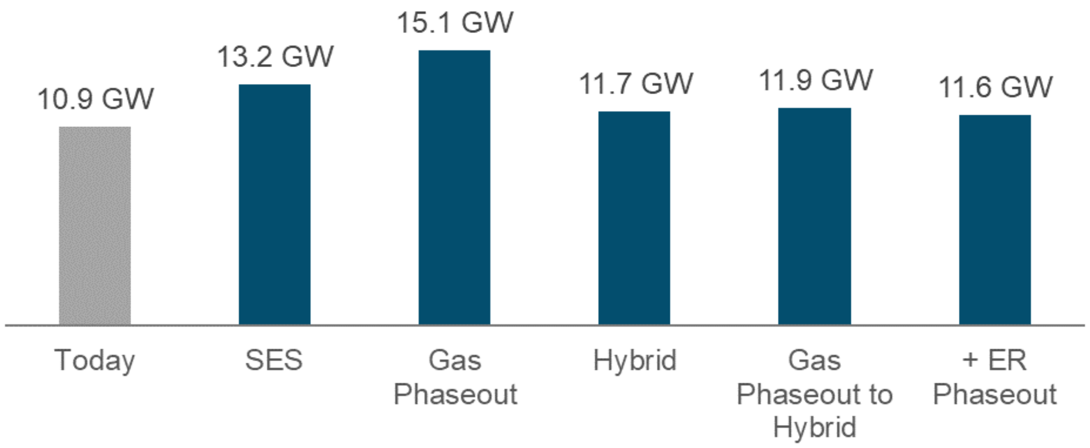
Residential HVAC Stocks by Technology by Scenario



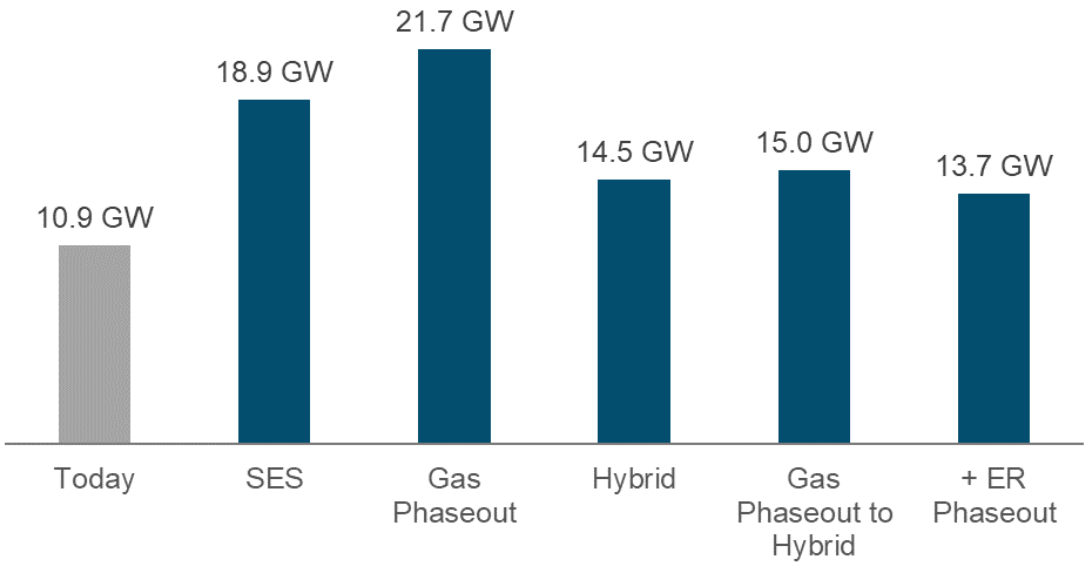
Bar chart of peak demand impacts by load sensitivity. One for 2030 and one for 2045

- **By 2030, Hybrid scenarios already have peak impact of ~1.5 GW lower than SES**
  - Phasing out gas to all-electric heat pumps will result in an additional 2 GW of peak impact
- **By 2045, peak demand in Hybrid scenarios is 4+ GW lower than SES**
  - Phasing out gas to all-electric heat pumps results in ~3 GW of additional peak impact

2030 Electric System 1-in-10 Peak Demand – Western WA



2045 Electric System 1-in-10 Peak Demand – Western WA



Resource Capacity "Bookend" Alternatives in 2045 by World View

Values represent the amount of capacity required if incremental peak were served entirely with one resource type. In practice, a portfolio of options could be deployed.

Scenario	Alternative1: Local Hydrogen-ready CTs	Alternative 2: Transmission Expansion	Alternative 3 Clean Resources	
			3a. SMR	3b. Offshore Wind
State Energy Strategy	8.2 GW	8 GW	8.2 GW	20-80 GW
Hybrid	3.7 GW	3.6 GW	3.7 GW	9-36 GW
Gas Phaseout	11 GW	10.8 GW	11 GW	27-108 GW
Gas Phaseout to Hybrid	4.2 GW	4.1 GW	4.2 GW	10-41 GW
Gas Phaseout to Hybrid and ER Phaseout	2.9 GW	2.8 GW	2.9 GW	7-28 GW

Resource Capacity Costs "Bookend" Alternatives in 2045 by World View

Costs are estimated based on the amount of capacity required if incremental peak were served entirely with one resource type. In practice, a portfolio of options could be deployed.

Scenario	Alternative 1: Local Hydrogen-ready CTs**	Alternative 3 Clean Resources	
		3a. SMR	3b. Offshore Wind
State Energy Strategy	$11-18 Billion	$69-74 Billion	$58-264 Billion
Hybrid	$7-13 Billion	$31-33 Billion	$26-119 Billion
Gas Phaseout	$14-22 Billion	$92-99 Billion	$78-356 Billion
Gas Phaseout to Hybrid	$7-13 Billion	$35-38 Billion	$29-135 Billion
Gas Phaseout to Hybrid and ER Phaseout	$6-12 Billion	$24-26 Billion	$20-92 Billion

* Unit net cost of new entry (net CONE) ranges are applied to each resource as $950-1,250/kW for hydrogen-ready CTs, $8,400-9,000 for SMR, and $2,900-3,300 for offshore wind. Upfront capital costs are based on technology cost ranges from NREL ATB 2022. Revenue from serving energy to the system is estimated based on E3's capacity expansion model results for the Pacific Northwest
** Alternative 1 also includes cost to build hydrogen pipelines to bring hydrogen produced from outside of Western WA, assuming $10 million per mile of pipeline cost and 350-800 miles of pipeline needs to be built to bring hydrogen from Eastern WA or Wyoming/Utah.

Design Day Gas Demand in 2045 by World View

Scenario	Alternative1: Local Hydrogen-ready CTs	Alternative 2: Transmission Expansion	Alternative 3 Clean Resources (SMR, offshore wint, etc.)
State Energy Strategy	2.7 GBtu/day	1.0 GBtu/day	1.0 GBtu/day
Hybrid	2.3 GBtu/day	1.5 GBtu/day	1.5 GBtu/day
Gas Phaseout	3.1 GBtu/day	0.7 GBtu/day	0.7 GBtu/day
Gas Phaseout to Hybrid	2.4 GBtu/day	1.5 GBtu/day	1.5 GBtu/day
Gas Phaseout to Hybrid and ER Phaseout	2.1 GBtu/day	1.5 GBtu/day	1.5 GBtu/day

Design Day Net Emissions Impact in 2045 by World View

2045 Net Emissions Impact from Serving Western WA on Design Day

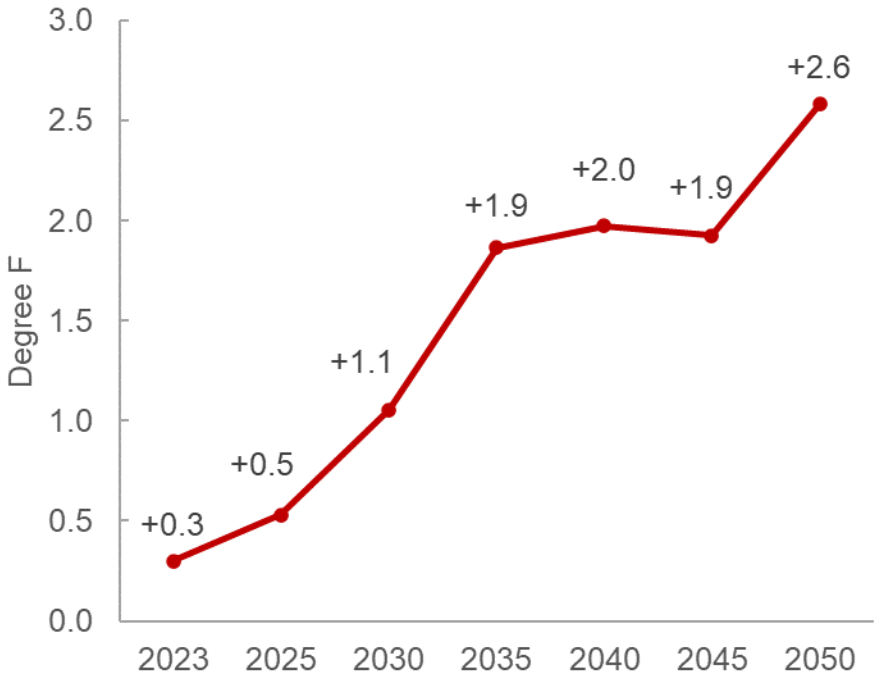
Scenario	Local Gas CTs (Counterfactual Scenario)	Clean Resources (Hydrogen-ready CTs, SMR, offshore wind, etc.)
State Energy Strategy	+52 ktCO2e	-41 ktCO2e
Hybrid	+30 ktCO2e	-13 ktCO2e
Gas Phaseout	+70 ktCO2e	-55 ktCO2e
Gas Phaseout to Hybrid	+33 ktCO2e	-13 ktCO2e
Gas Phaseout to Hybrid and ER Phaseout	+20 ktCO2e	-13 ktCO2e

Appendix

Approach to Model Climate Impact

- **E3 leveraged historical temperature data and projected future temperatures from climate models provided by PSE for its service territory**
- **We first calculate the change in average winter daily minimum temperature throughout all winter months (i.e. December, January and February) in four steps:**
  1. Find minimum daily temperature in all winter months of future years from the climate model results
  2. Find average winter daily minimum temperature for every historical year
  3. Take an 11-year rolling average to smooth out data over time, with each model year as the center of the rolling average window
  4. Calculate change in average winter daily minimum temperature of all future years from 2018
- **We find the new 1-in-10 peak based on the increase in average winter daily minimum temperature relative to the temperature associated with the historical 1-in-10 peak modeled in RESHAPE**

Change in Average Winter Daily Minimum Temperature Relative to Today

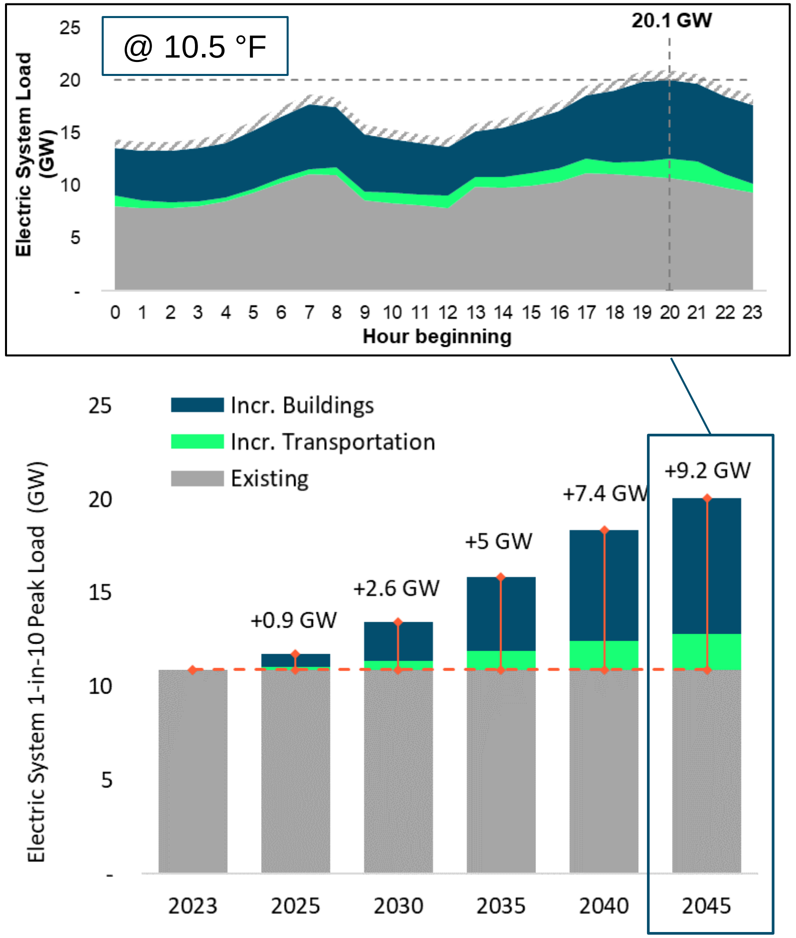


With Climate Impact, 1-in-10 peak load impact in the SES scenario is reduced by 1.2 GW in 2045

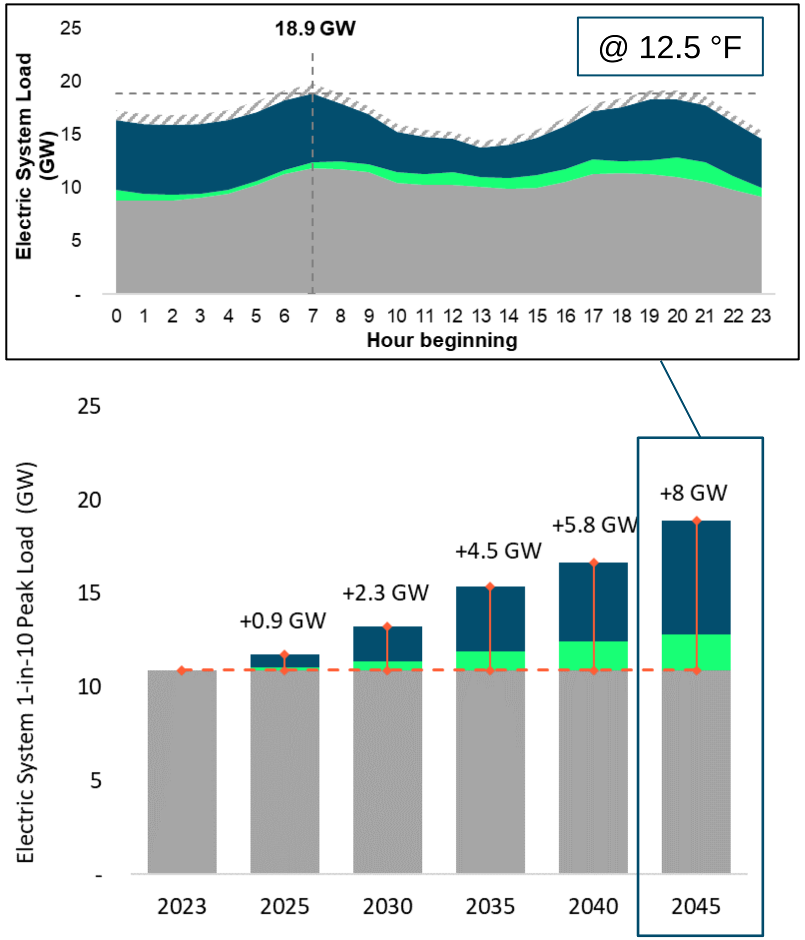
- Climate impact on the peak load increases over time as higher levels of heating electrification takes place

- There is almost no 1-in-10 peak impact on the Hybrid scenario as backup gas furnaces provide heating during the extreme cold events

1-in-10 Peak Load, SES Scenario
No Climate Impact



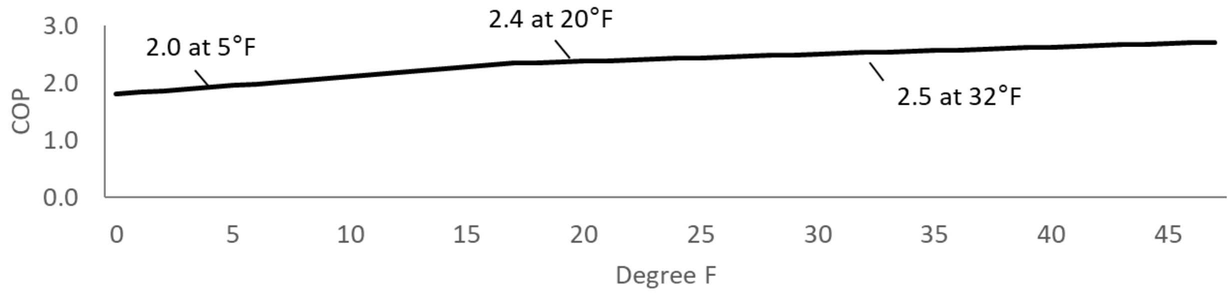
1-in-10 Peak Load, SES Scenario
With Climate Impact



Heat Pump Configurations

- E3 models a cold-climate all-electric heat pump in this analysis, sized to serve full heating load at 20°F with an average annual coefficient of performance (COP) at 2.6
- A dual-fuel heat pump is also modeled assuming gas backup will provide full heating load below 30°F, serving about 15% of the annual heating demand
- Heat pump efficiencies and configurations are aligned with those modeled by Cadmus in the updated gas decarbonization study

Heat Pump COPs Modeled at Different Outdoor Temperatures



Heat Pump Sizing Criteria and Achieved Performance in Western WA

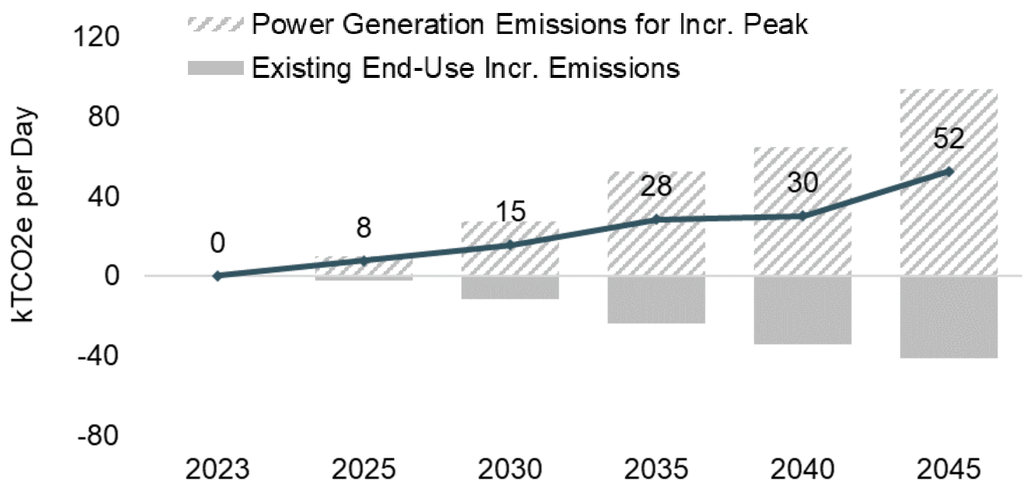
Heat Pump	Sizing Criteria	Percent of Heating Demand Met by Gas Backup	Achieved Annual Average COP
All-electric ASHP (electric resistance backup)	**~20F** (99% of heating hours)	**0%**	**2.6** (*Performance Curve Aligned with Cadmus*)
Dual-fuel HP (gas backup)	**30F** (~90% of heating hours)	**15%**	**2.7** (*Performance Curve Aligned with Cadmus*)

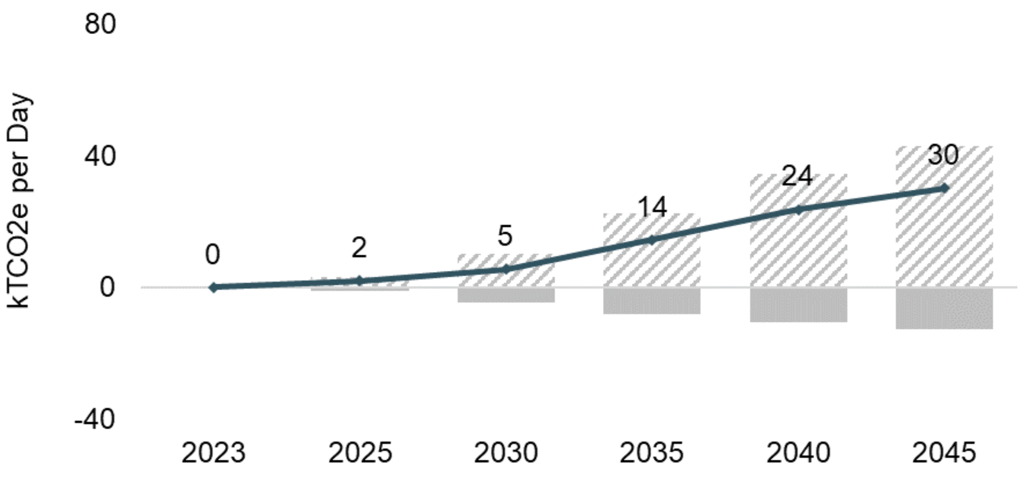
Dual-fuel heat pumps can significantly reduce the emissions increase from serving the incremental all-electric heating demand with gas CTs

- **If all incremental electric demand in Western WA is served by gas CTs, Hybrid Scenario** can reduce the net increase in design day GHG emissions in 2045 by 40% compared to the **State Energy Strategy Scenario**
- ***CAVEAT: Power generation emissions only represent the gas design day. Emissions on an annual basis will need to comply with CETA and achieve 100% clean by 2045***

Net Emissions Impact to Serve Western WA

State Energy Strategy Scenario	Hybrid Scenario



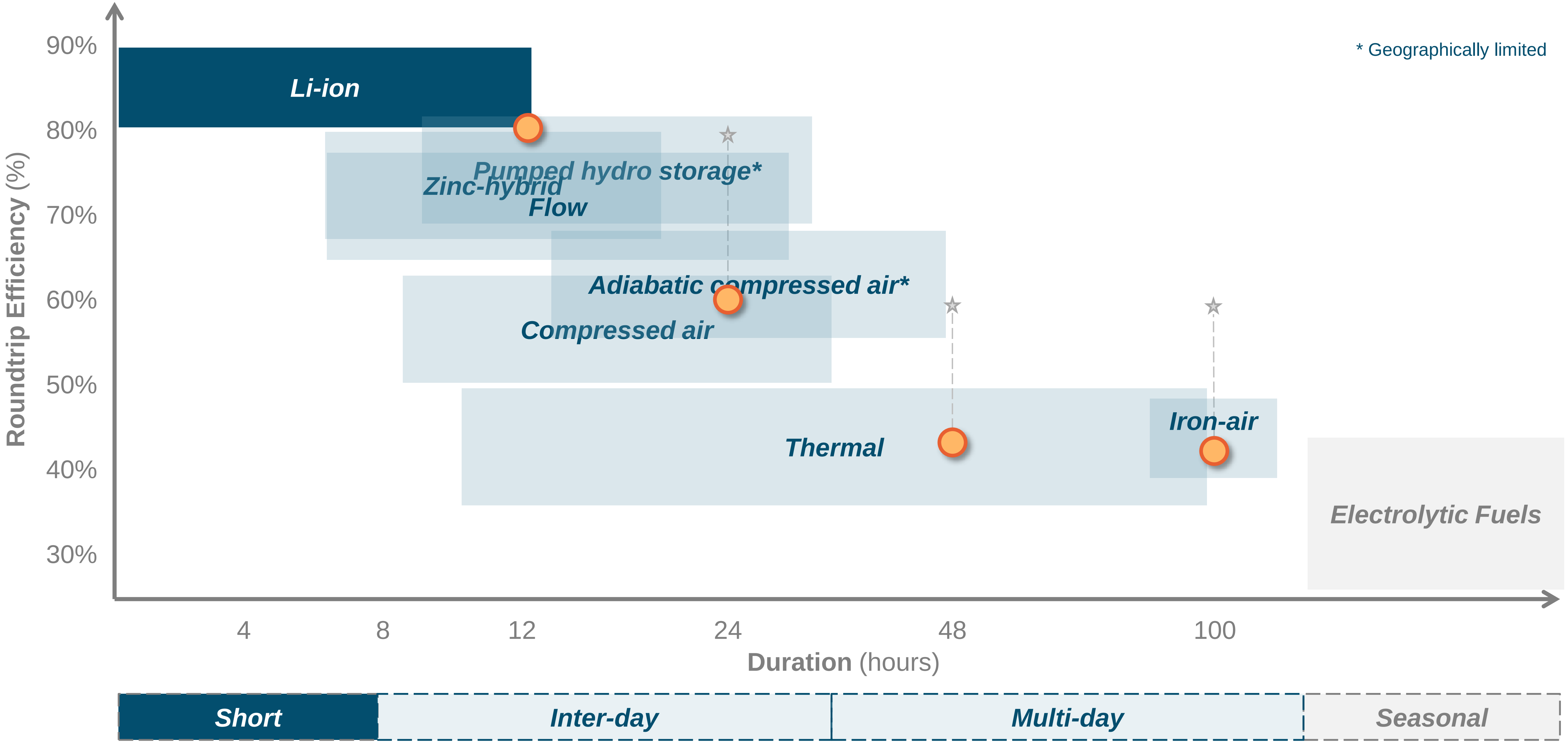


Design Day Net Emissions Impact in 2045 by World View

2045 Net Emissions Impact from Serving Western WA on Design Day

Scenario	Local Gas CTs (Counterfactual Scenario)	Clean Resources (SMR, offshore wind, etc.)
State Energy Strategy	+52 ktCO2e	-41 ktCO2e
Hybrid	+30 ktCO2e	-13 ktCO2e
Gas Phaseout	+70 ktCO2e	-55 ktCO2e
Gas Phaseout to Hybrid	+33 ktCO2e	-13 ktCO2e
Gas Phaseout to Hybrid and ER Phaseout	+20 ktCO2e	-13 ktCO2e

Long-duration energy storage technologies typically have low round-trip efficiencies

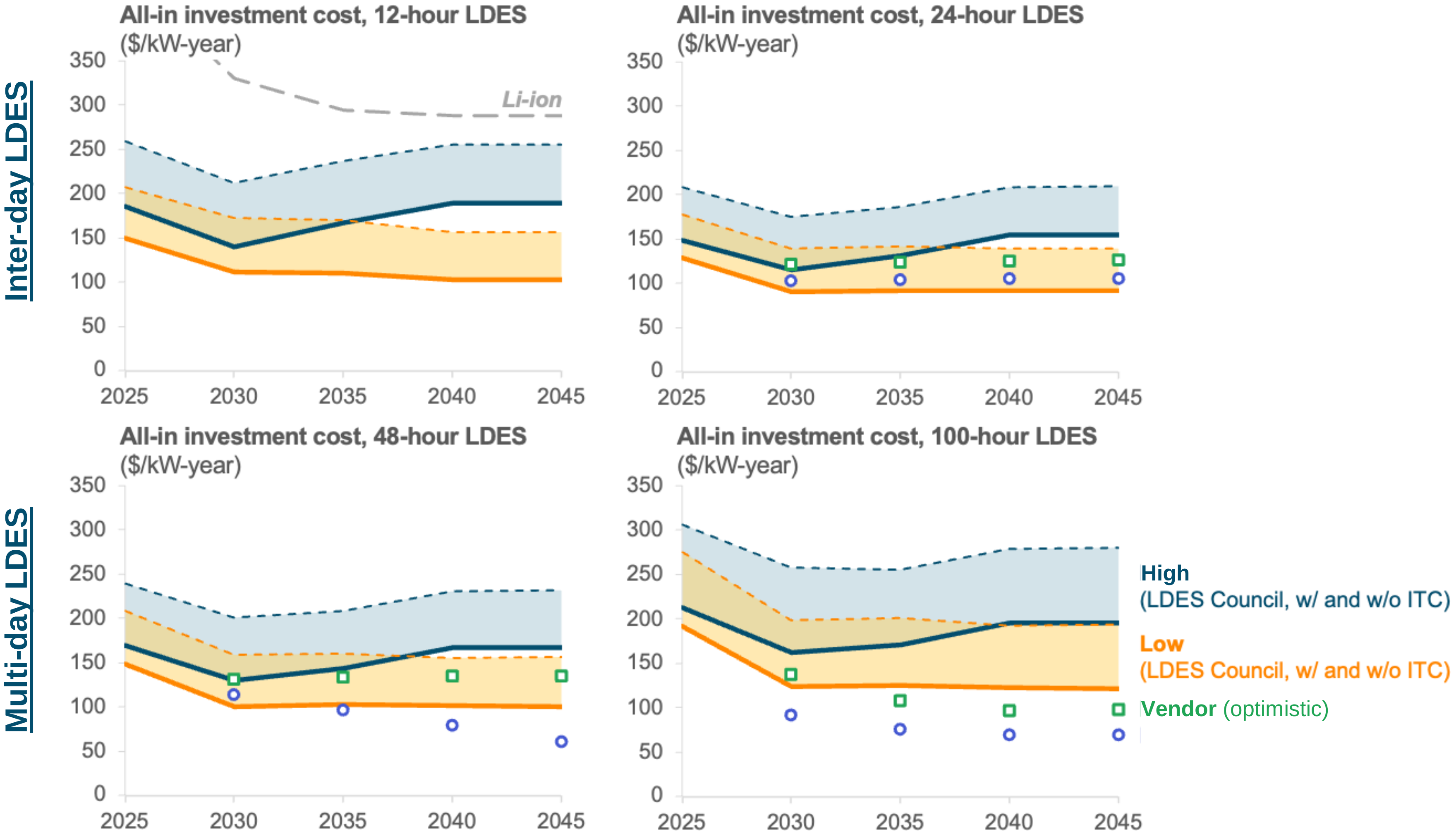


Source: Final Public Workshop for CEC EPC-19-056 Assessing the Value of Long Duration Energy Storage by E3, Form Energy and UCSD Center for Energy Research

Long-duration storage technologies such as iron-air storage have high costs today

+ **Team leveraged survey data from LDES Council**
  - For inter-day storage techs, median energy storage cost* projected to be **$54-67/kWh**
  - For multi-day storage techs, median energy storage cost* projected to be **$8-10/kWh**

+ **Team used standard financing assumptions to convert overnight into $/kW-year at archetypal durations shown to right**



** Energy storage cost component only, not including power and balance-of-system costs*

Source: Final Public Workshop for CEC EPC-19-056 Assessing the Value of Long Duration Energy Storage by E3, Form Energy and UCSD Center for Energy Research