Energy+Environmental Economics

Pacific Northwest Zero-Emitting Resources Study

January 13, 2020

Dan Aas, Managing Consultant
Oluwafemi Sawyerr, Consultant
Clea Kolster, Consultant
Patrick O’Neill, Consultant
Arne Olson, Senior Partner

Outline

- Study Background and Context
- Methodology and Assumptions
- Results
- The Role of Firm Capacity
- Benefits of Firm Capacity
- Transmission, Land-Use and Qualitative Factors

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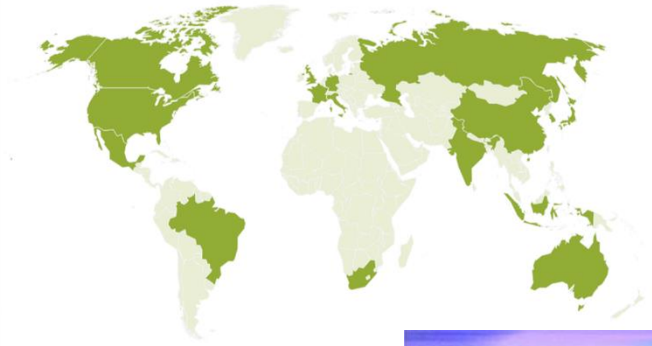
Study Background and Context

About E3

- **E3 is a San Francisco-based consultancy specializing in electricity economics with approximately 75 staff**
- **E3 consults extensively for utilities, developers, government agencies and environmental groups on clean energy issues**
  - United Nations Deep Decarbonization Pathways Project focused on US-wide decarbonization
  - Planning for Northwest and WECC-wide utilities' carbon reduction and clean energy goals to meet state-wide policy measures
  - Planning for long-term California climate goals including 40% reductions in greenhouse gas emissions by 2030 and 80% by 2050
  - Completed Deep Decarbonization in a High Renewables Future report for CA Energy Commission in 2018



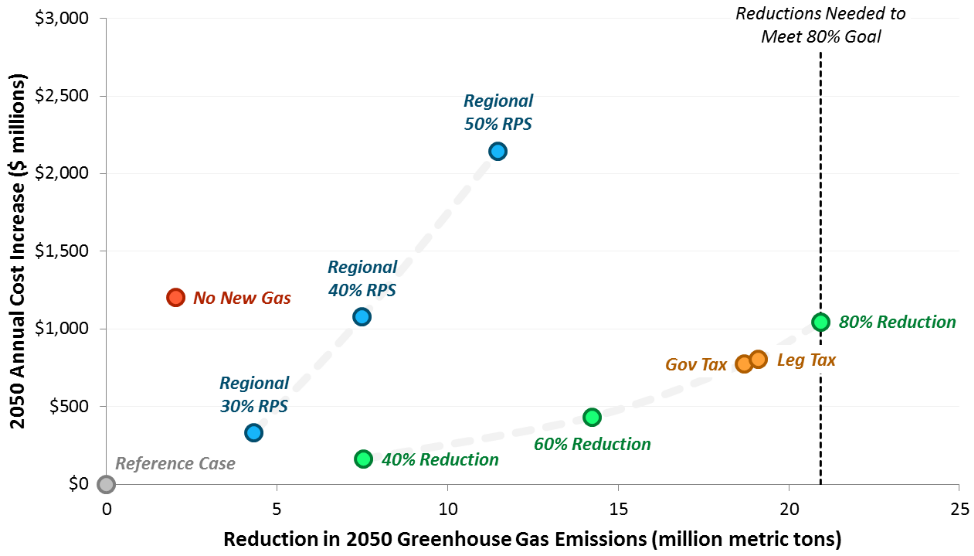
About This Study

- **Energy Northwest retained E3 to investigate the role of zero-emitting resources in meeting future energy needs under new state-based carbon policies**
- **The research focused on two key questions:**
  1. What are optimal electricity resource portfolios to achieve deep carbon emissions reductions in the Pacific Northwest?
  2. How does the availability of firm, zero-emitting generation affect the cost of achieving carbon goals while maintaining a reliable electric system?

Conclusions from recent Northwest electricity sector studies

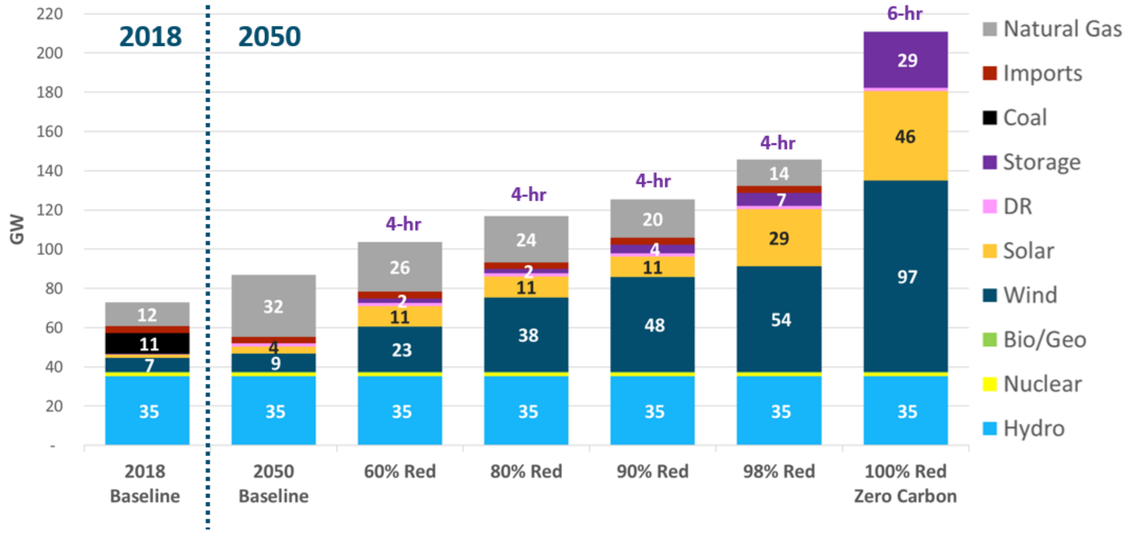
Pacific Northwest Low Carbon Scenario Analysis (2018)

- **A portfolio of hydro, renewables and natural gas is the least cost strategy to achieve an 80% reduction in electricity sector emissions in the Northwest**
- **Policies that directly target GHG reductions are lower cost than those that rely renewables mandates or gas generator bans**



Resource Adequacy in the Pacific Northwest (2019)

- **Firm generation is required to ensure a reliable system under deep decarbonization**
- **That generation is needed because the capacity contributions of wind, solar and storage are low at high penetrations**
- **Gas is the least cost option to provide firm capacity given existing technologies**



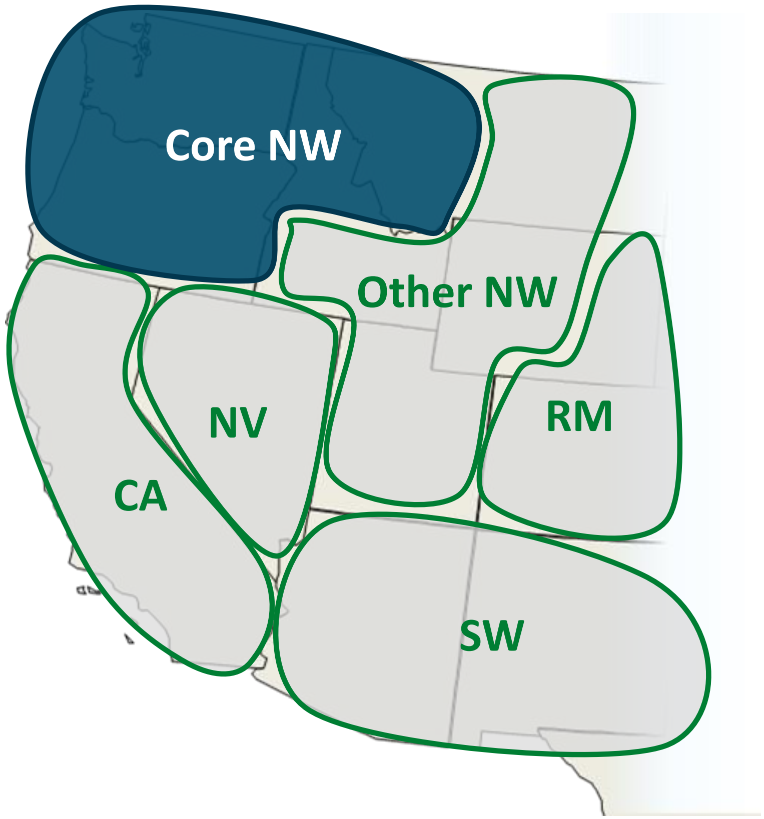
Recent Washington legislation targets significant increases in clean electricity supplies

- **In 2019, Washington adopted the Clean Energy Transformation Act (CETA)**
- **Key CETA provisions**
  - Eliminates coal portfolios after 2025
  - 80% of retail sales served by zero-emitting generation in 2030
  - Electric utilities must be carbon neutral by 2030, but can rely on Energy Transformation Projects for savings achieved beyond the 80% retail sales target
  - 100% of retail sales served by zero-emitting generation in 2045
  - Cost containment mechanisms including a cost-cap and alternative compliance payment

Clean Energy Transformation Act (CETA)

Methodology, Inputs & Scenarios

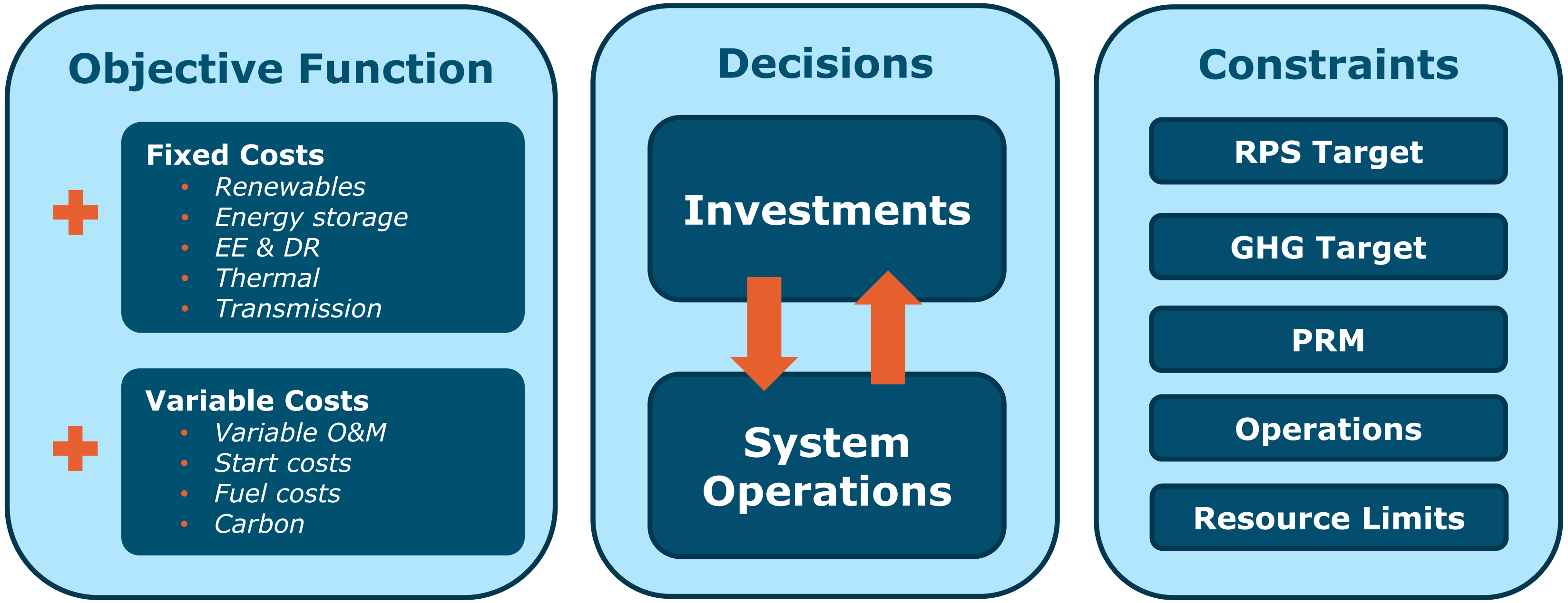
Study Approach



- CETA is a key motivation for this study, but Washington operates in a regional electricity system
- This study takes a regional view of electricity supplies, building on two key prior studies
  - *Pacific Northwest Low Carbon Scenario Analysis*
  - *Resource Adequacy in the Pacific Northwest*
- The study uses E3's RESOLVE model to optimize the portfolio of resources serving loads in the "Core NW" region

RESOLVE Develops Least-Cost Resource Portfolios to Meet Policy and Reliability Requirements

+ **This study uses E3's RESOLVE model to generate optimal resource portfolios under alternative policy regimes**
+ **RESOLVE co-optimizes investments and operations to minimize total NPV of electric system cost over the study time horizon**
  - Investments and operations optimized in a single stage to capture linkages between investment decisions and system operations
  - Selects resources based on total value to the entire system, not just levelized cost of energy



Zero-GHG resources considered in this study

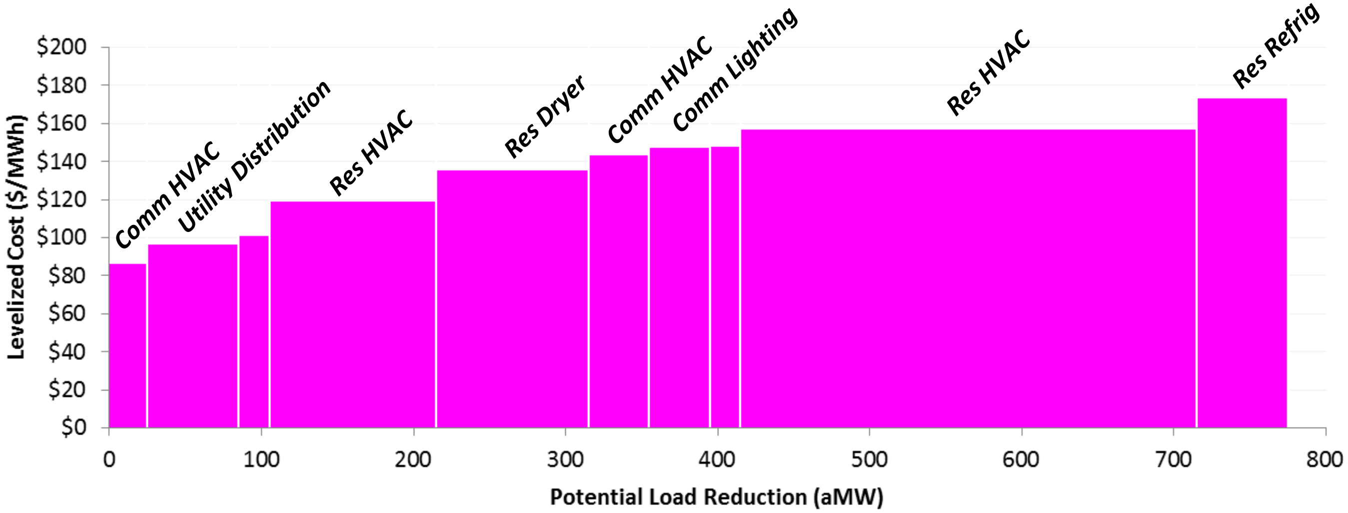
Energy Limited or Variable Zero-Emitting Resources	"Firm" Zero-Emitting Resources
Hydro Flexible resource that can help balance wind and solar	**Columbia Generating Station (CGS)** Existing zero-GHG firm capacity
Wind Inexpensive energy, high quality resource, but variable	**Small Modular Reactors (SMRs)** Firm, dispatchable zero-GHG generation
Solar Inexpensive energy, high quality resource in the West, but variable	**Biomethane** Zero-GHG fuel for existing infrastructure, not yet widely commercial, competing uses
Storage Rapidly decreasing costs, but energy and duration limited	**Carbon Capture and Sequestration** Low- to zero-GHG, not commercialized

New Resource Options:
Incremental Energy Efficiency and Demand Response

Energy Efficiency

+ **Supply curve of incremental EE developed from measures not selected in the NWPCC Seventh Power Plan**
  - Resources bundled by cost and end use for selection in RESOLVE

Energy Efficiency Supply Curve ($/MWh)



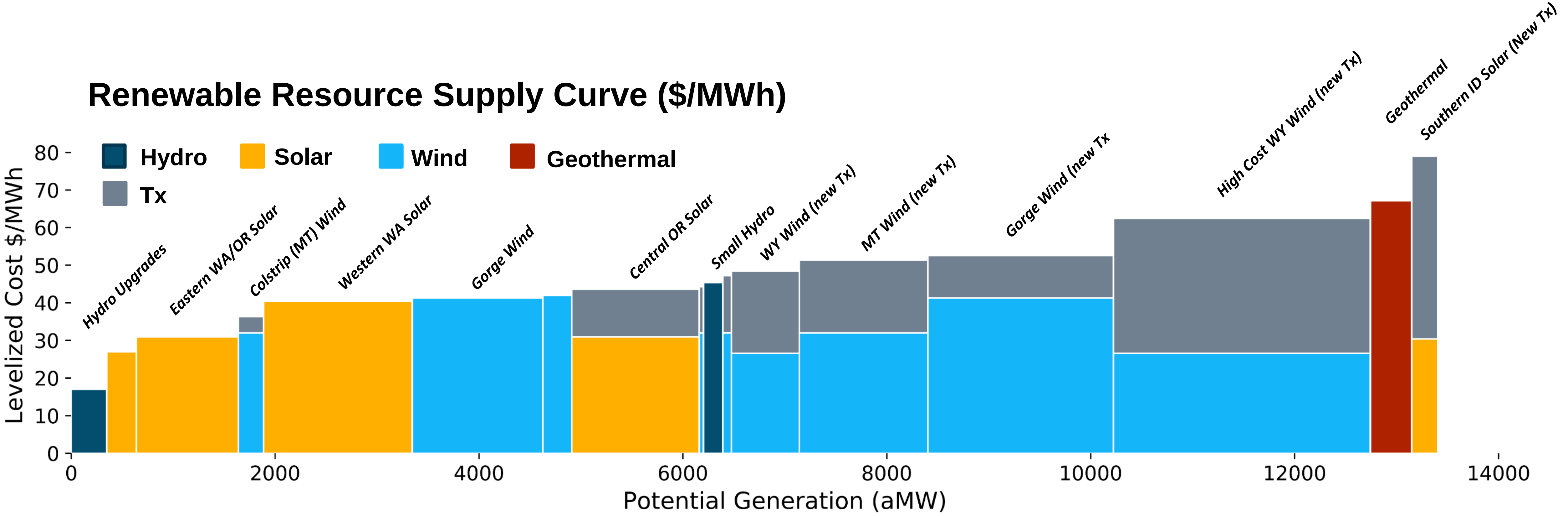
Note: chart shows only EE measures that are treated as options in RESOLVE; all EE identified by NWPCC as cost-effective is included in the load forecast

Demand Response

+ **Cost & potential incorporated from Navigant's *Assessing Demand Response Program Potential for the Seventh Power Plan***
  1. **Agricultural interruptible tariff: 657 MW** available by 2050 at a cost of **$19/kW-yr.**
  2. **Residential space & water heating direct load control (DLC): 902 MW** available by 2050 at a cost of **$59/kW-yr.**

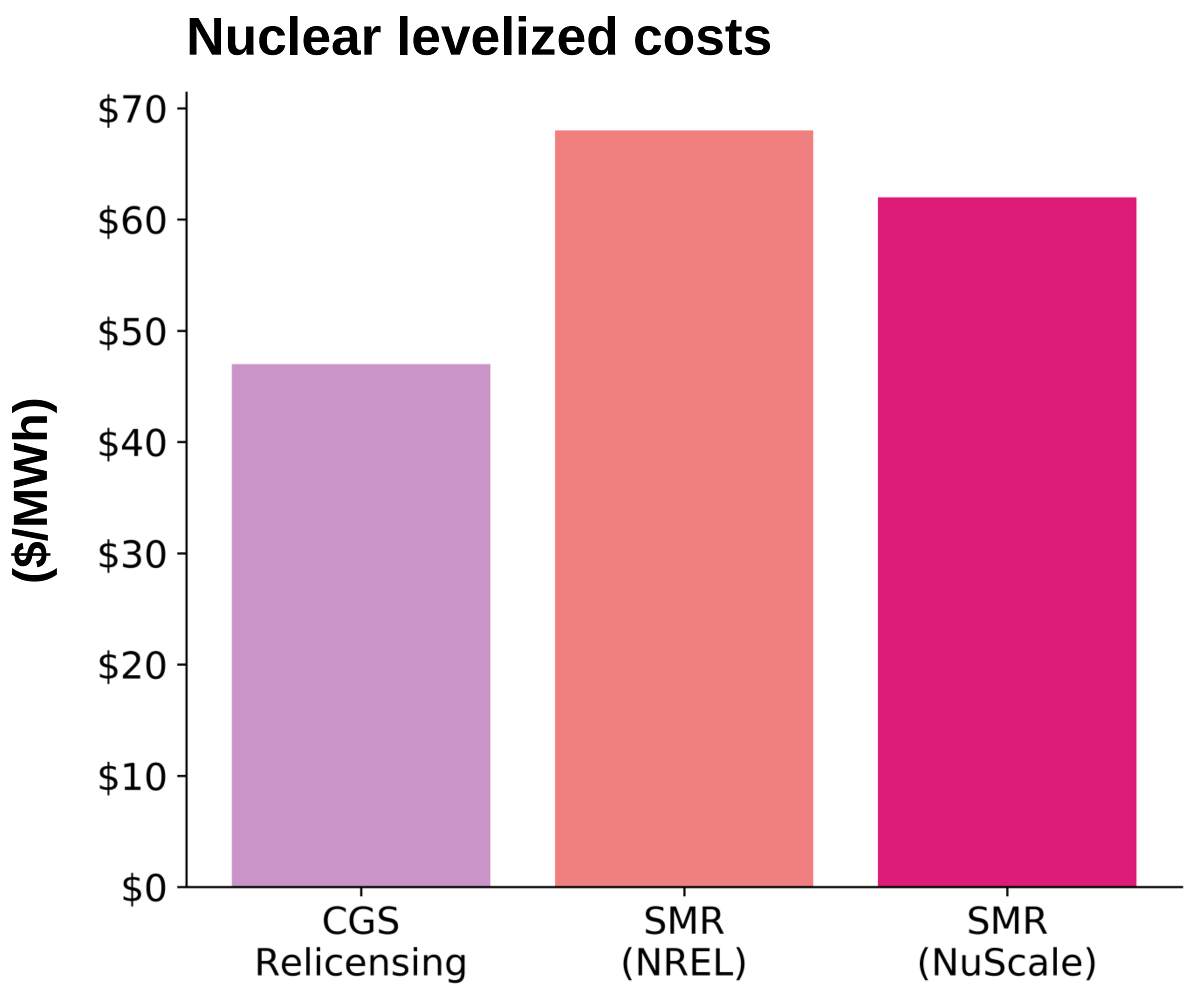
New Resource Options
Renewables

- Renewables available to the region are based on a supply curve that captures regional and technology diversity options for development
- Transmission adders reflect the need to ensure that new renewables built in the Northwest are deliverable to loads; scenarios with more renewables require more transmission investment.



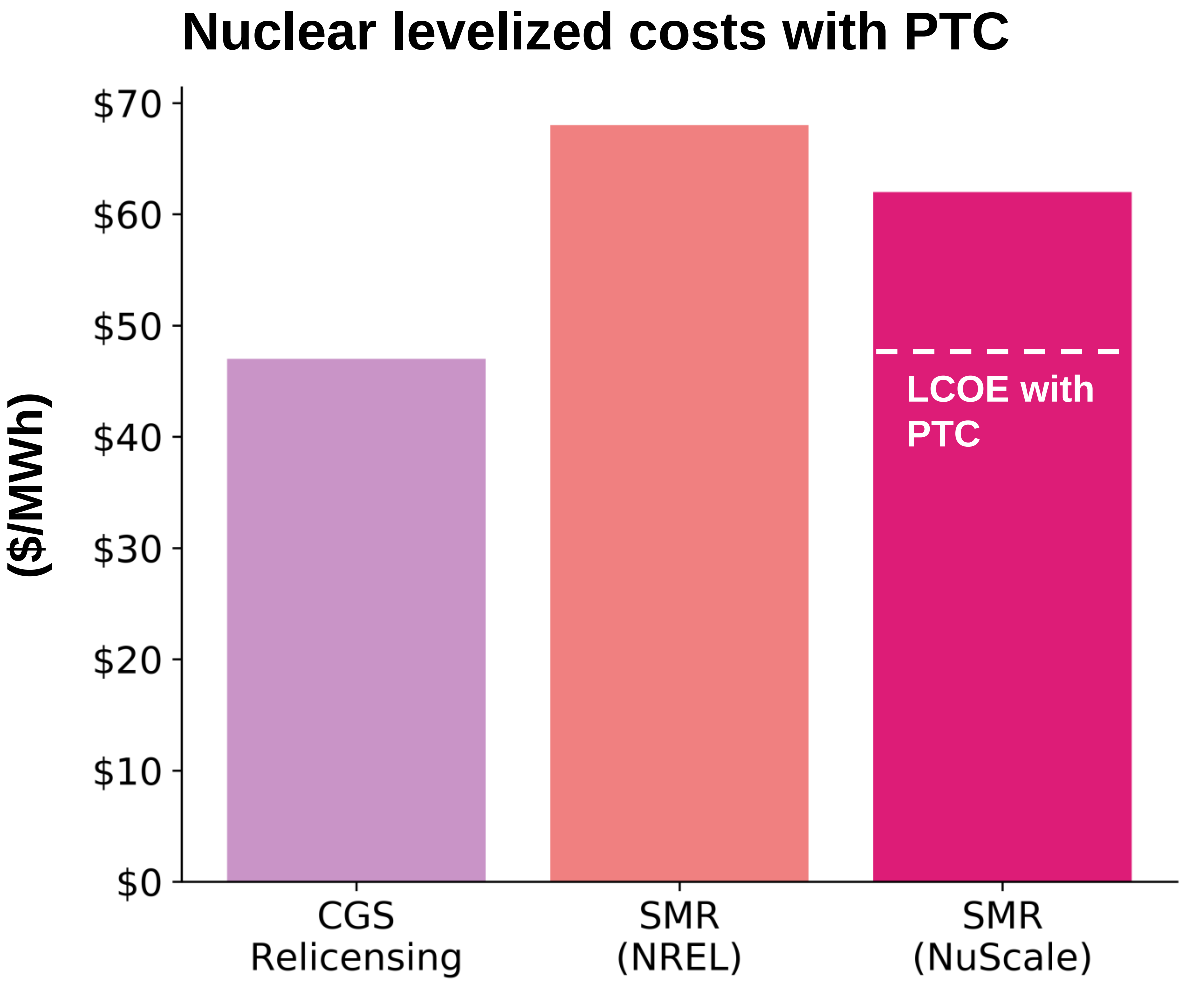
New Resource Options
Nuclear

+ **CGS is up for relicensing in 2043. The estimated cost of extending the life of CGS was provided by Energy Northwest**
+ **Nuclear SMRs are an emerging technology. E3 used two cost sources for SMRs:**
    - NREL Annual Technology Baseline (NREL ATB): a publicly available source of consistent cost forecasts for multiple technologies
    - NuScale "nth of a kind" Estimate: NuScale is an SMR vendor that provided E3 with cost and performance estimates for the technology it is developing
+ **SMRs are not yet commercial, but NuScale estimates initial projects could be online by the mid-2020s**



New Resource Options
Nuclear

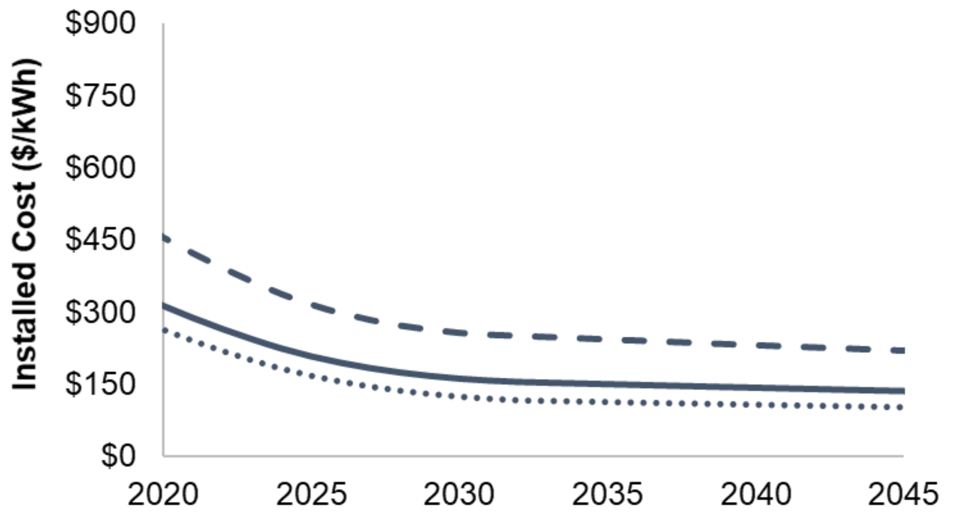
- In 2018, the U.S. Congress passed a nuclear production tax credit (PTC)
- The PTC allows for up to 6,000 MW of new advanced nuclear generators to receive a tax credit of $18/MWh for their first eight years of operation.
- This analysis includes a sensitivity that assumes the Northwest can claim up to 3,000 MW of Nuclear PTC subsidy



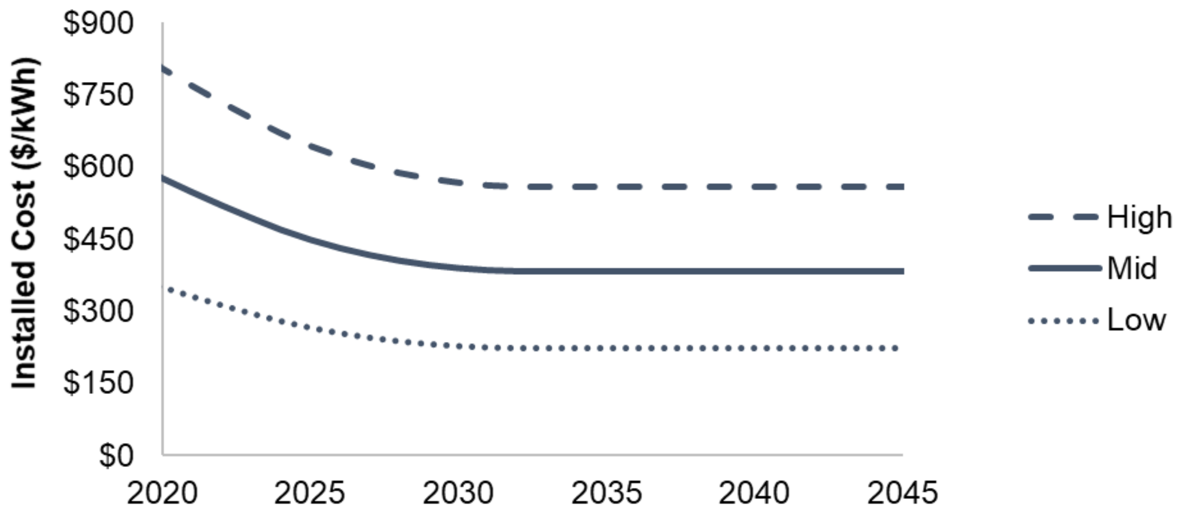
New Resource Options
Energy Storage

- **Pumped hydro storage: up to 5,000 MW assumed to be available at a cost of $2,450/kW based on a survey of existing literature**
  - Pumped hydro is assumed to have an effective capacity of 50%
- **Battery storage: unlimited quantities of lithium-ion and flow batteries assumed to be available**
  - Cost assumptions (current & future) derived from Lazard Levelized Cost of Storage v4.0, including high, mid and low-cost projections

Li-Ion Battery All-In Costs ($/kWh)



Flow Battery All-In Costs ($/kWh)

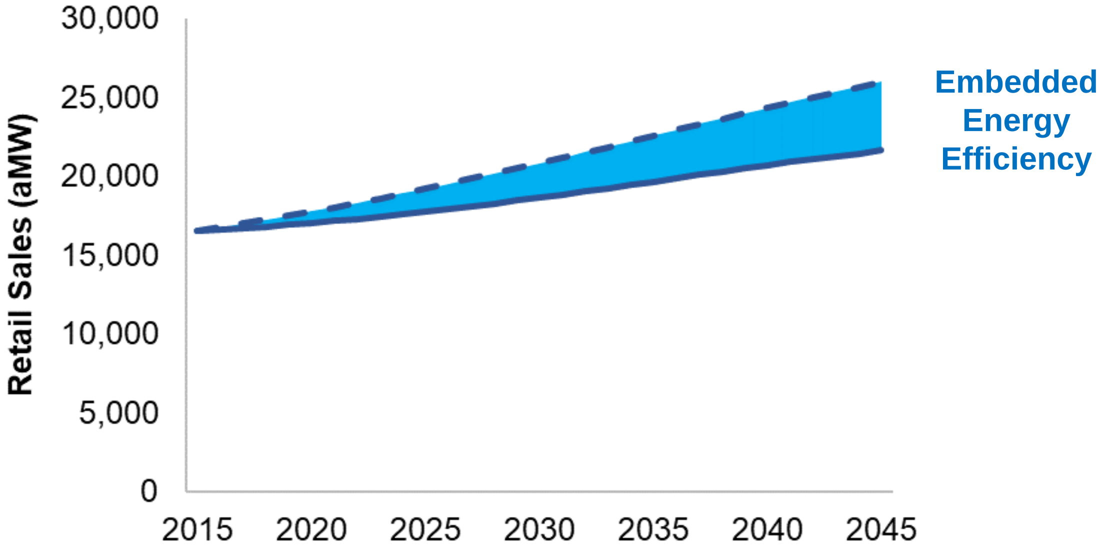


Capital costs shown for 4-hr storage devices; RESOLVE can select optimal duration for energy storage resources

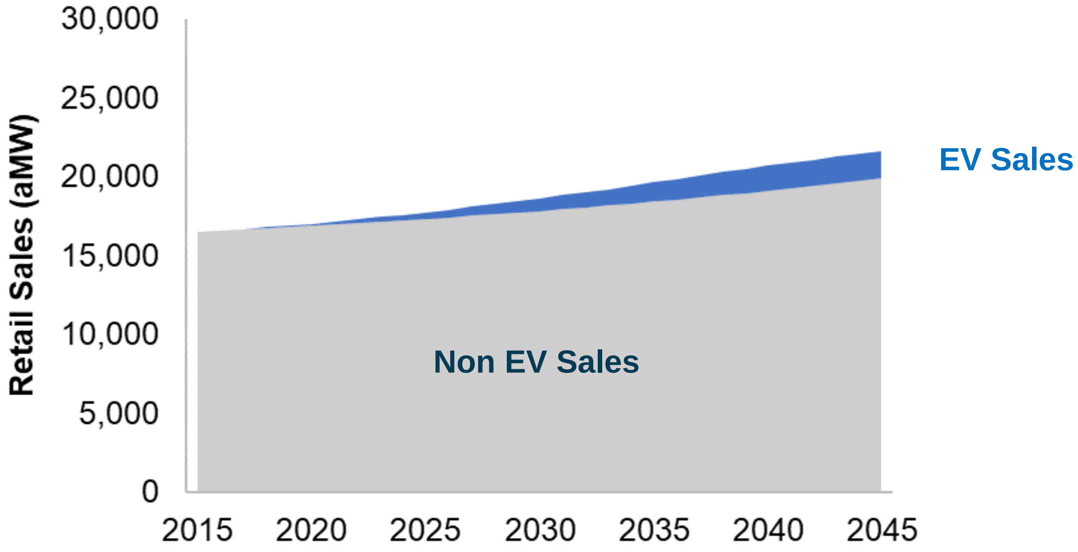
Load Forecast and Transport Electrification

+ **All scenarios capture recent policies and trends:**
  - **Achievement of cost-effective energy efficiency** as identified in NWPCC 7th Power Plan
  - **Large-scale electrification of light-duty transportation:** Passenger vehicles and truck electrification levels based on adoption scenarios in *Pacific Northwest Pathways to 2050*
+ **The pre-electrification CAGR is 0.7%, the post electrification CAGR is 0.95%**

Retail Sales Forecast (aMW)



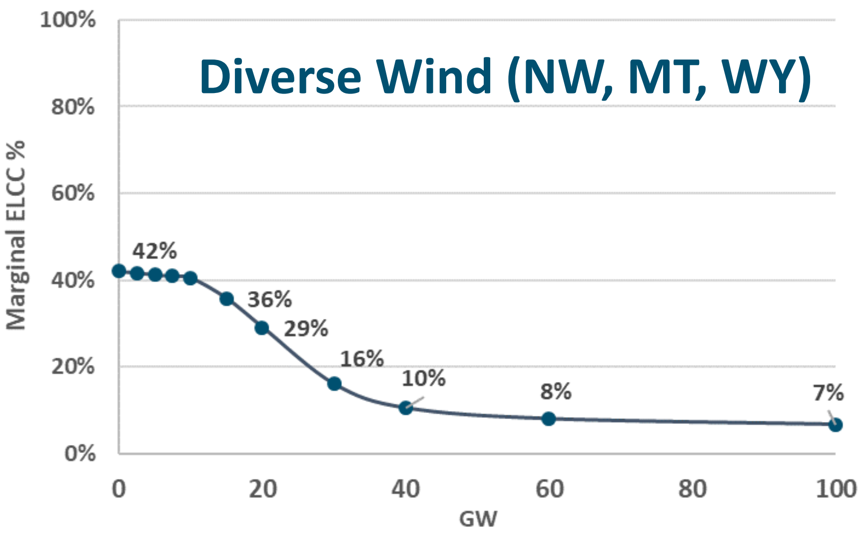
High EV Case Retail Sales Forecast (aMW)

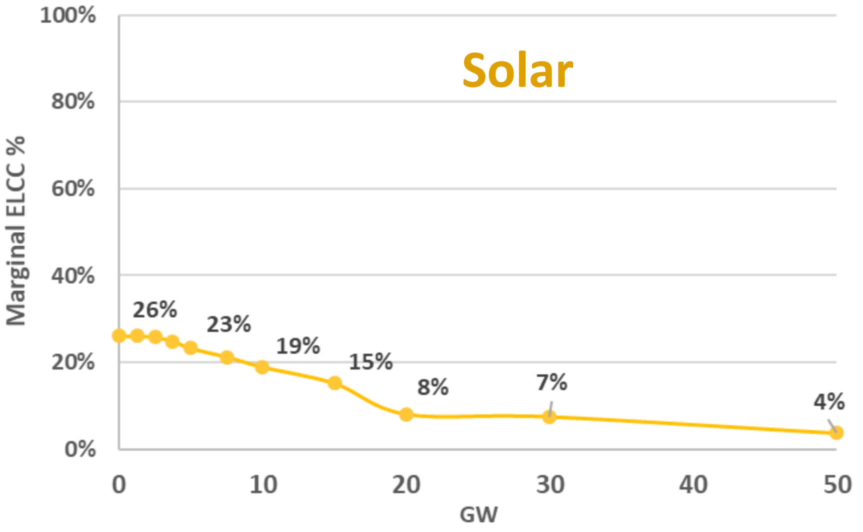


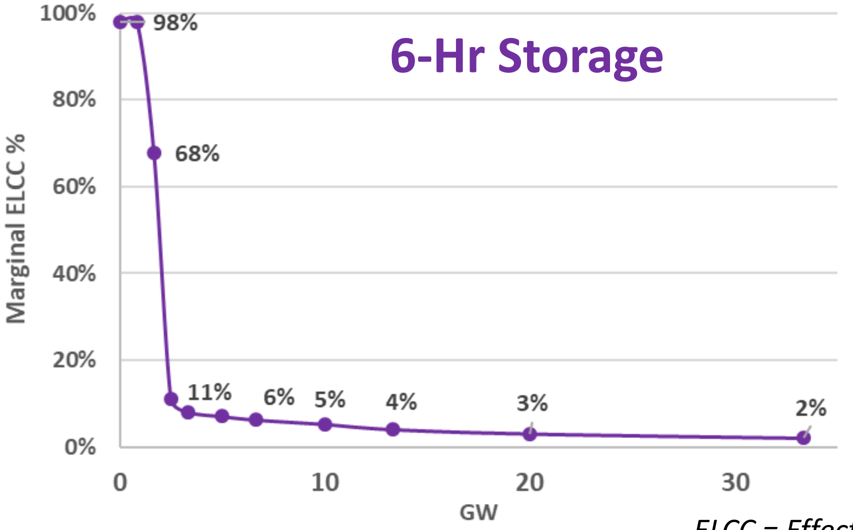
Resource Options
Cost and Operations

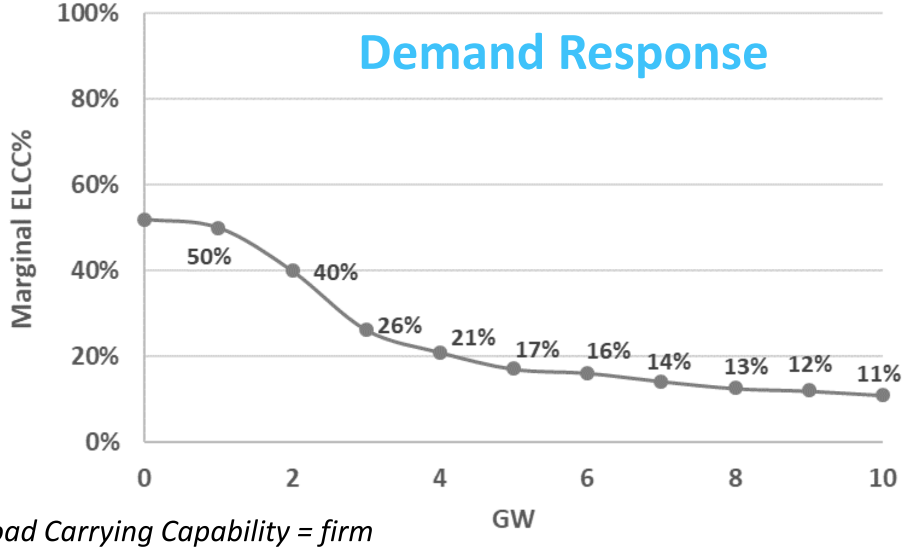
Resource Type	2045 Capital Cost (2018 $/kW)	2045 Fixed O&M Cost (2018 $/kW-yr)	Operations
Utility-Scale Solar PV (Single-axis tracking)	$ 980	$ 12	No fuel cost
Onshore Wind (TRG6 - ~36% CF)	$ 1,080	$ 35	No fuel cost
CGS Relicensing	$ 406	$ 162	"Must run" with scheduled maintenance outages
NREL ATB Nuclear Small Modular Reactors (SMR)	$ 5,650	$ 99	Uranium fuel; Heat rate of 10,000 Btu/kWh
NuScale "Nth of a Kind" SMR	$ 4,900	Similar to NREL	Uranium fuel; Heat rate of 9,000 Btu/kWh
Gas Combustion Turbine (Frame)	$ 850	$ 12	NG fuel; Heat rate 12,000 Btu/kWh
CCGT with Carbon Capture and Storage (Post-Combustion 90-100% Capture)	$ 1,700	$ 33	NG fuel; Heat rate 8,000 Btu/kWh
4-hour Li-Ion Battery	$ 590	$2	Round trip efficiency of 92%
Biogas (a drop-in fuel to gas units)	N/A	Equivalent to Gas CT	Very high fuel cost ~32$/MMBTU

This study incorporates new information on the capacity contribution of renewables, storage and DR









ELCC = Effective Load Carrying Capability = firm contribution to system peak load

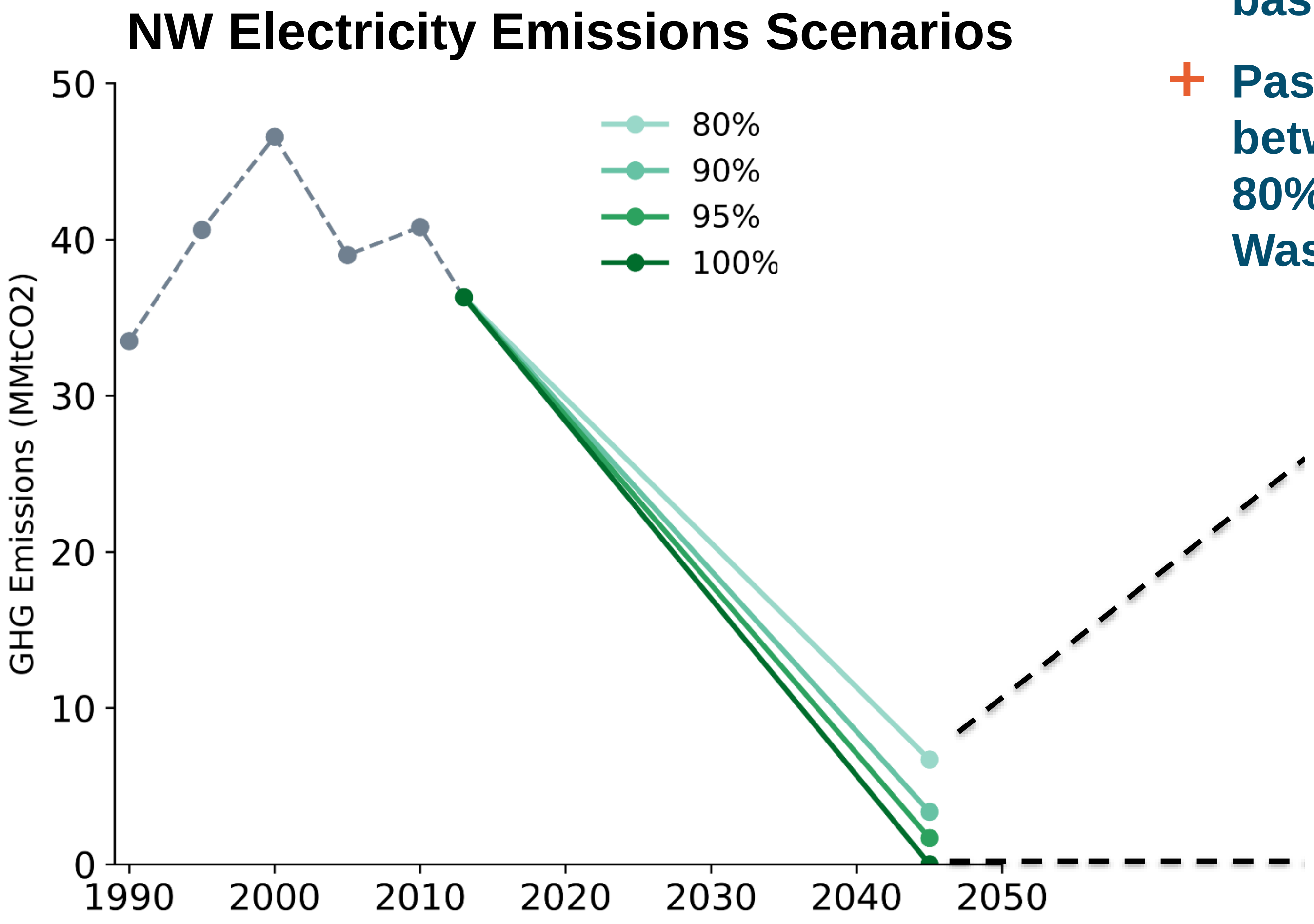
- A reliable electric system requires enough capacity to meet peak loads and contingencies
- This study incorporates information from E3's 2019 report *Resource Adequacy in the Northwest* about the effective capacity contribution of renewables, storage and DR at various penetration levels

Scenario Definitions

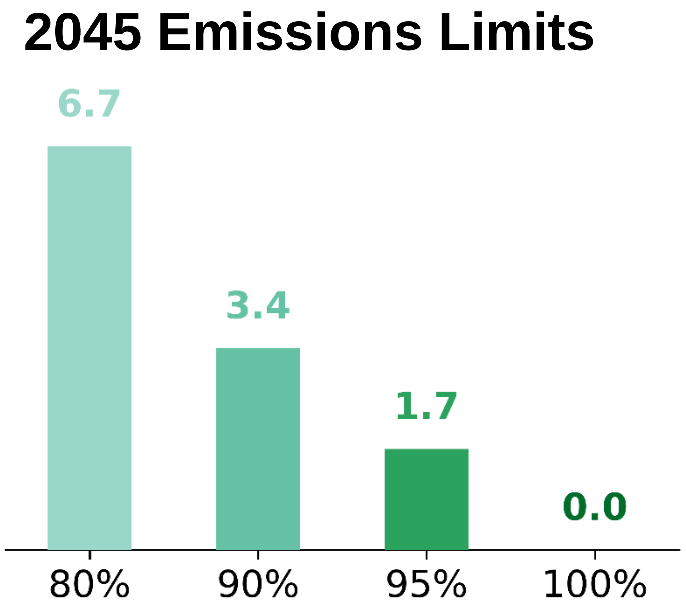
This study is scenario based

- This scenario-based study is designed to examine how the region's bulk electricity system changes through 2045 as a result of varying inputs such as:
  i. Resource cost
  ii. Resource availability
  iii. Regional policy implementation
- Each scenario is compared to the "Reference Scenario"
- E3 determines the "Reference Scenario" such that it
  - Reflects key regional laws like Oregon's 2016 Coal to Clean legislation and elements of Washington's 2019 Clean Energy Transformation Act, assuming all coal serving WA is retired after 2025 and all coal serving OR is retired after 2035.

E3 tested each scenario under four carbon emissions reductions targets



- Different levels of policy stringency are assessed based on an electricity sector GHG cap
- Past work by E3 suggests that a GHG cap of between 3 and 5 MMtCO2 is needed to achieve 80% economy-wide emissions reductions in Washington and Oregon



Scenarios

+ **The study calculates the cost of complying with increasingly stringent carbon targets under several alternative scenarios:**
  1. Renewables and New Gas Available
  2. Renewables, New Gas and CGS Relicensing Available
  3. Renewables, New Gas, CGS and Zero-Emitting Firm
  4. No New Gas
  5. Nuclear Production Tax Credit
+ **Each portfolio is evaluated for compliance with CETA**

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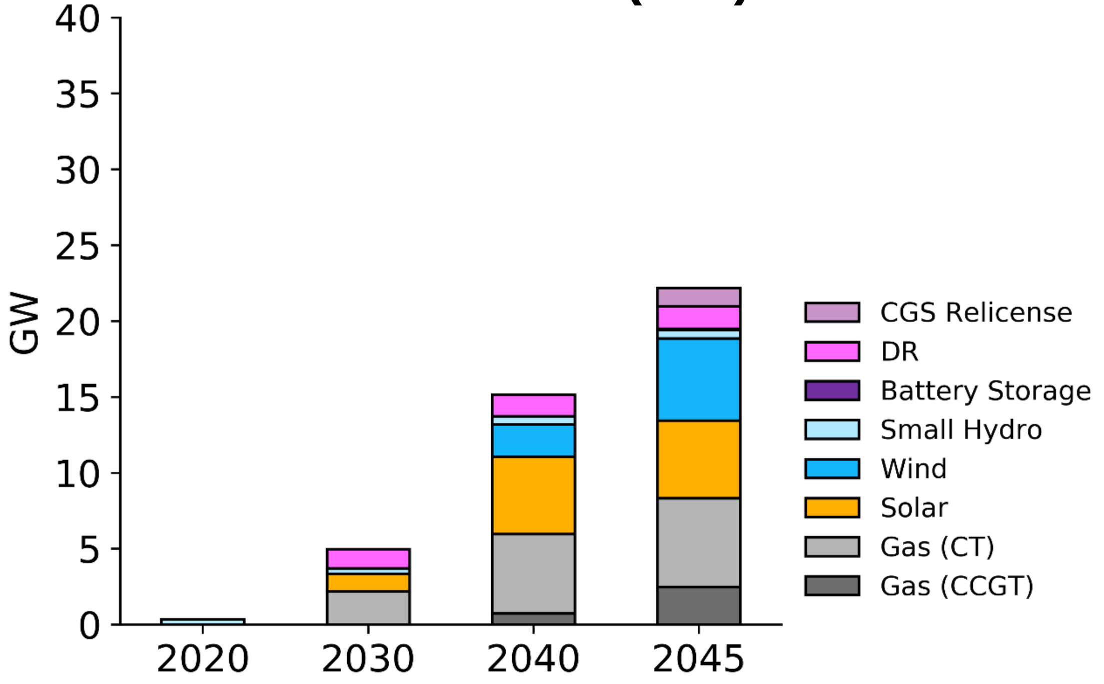
Results

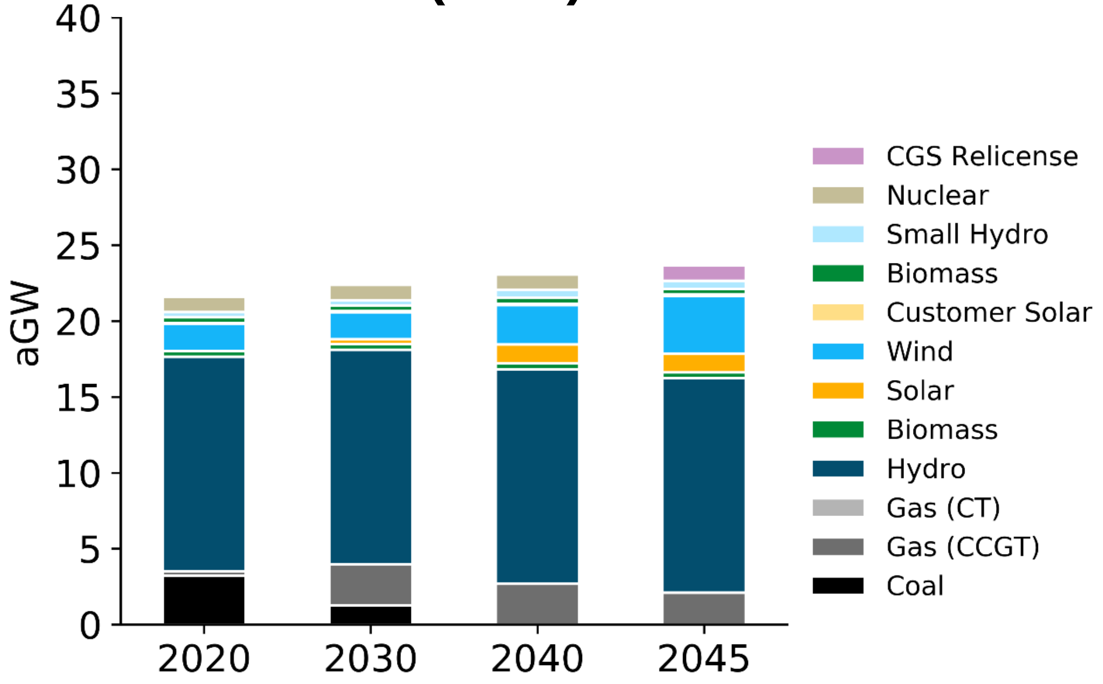
Reference Scenario

- Coal retires post 2025 (CETA, WA) and 2035 (Coal to Clean, OR). Natural gas is built to replace that firm capacity
- Most capacity selected is zero-emitting, including the relicensing of Columbia Generating Station
- In 2045, zero-emitting electricity generation is 105% of retail sales in the Northwest

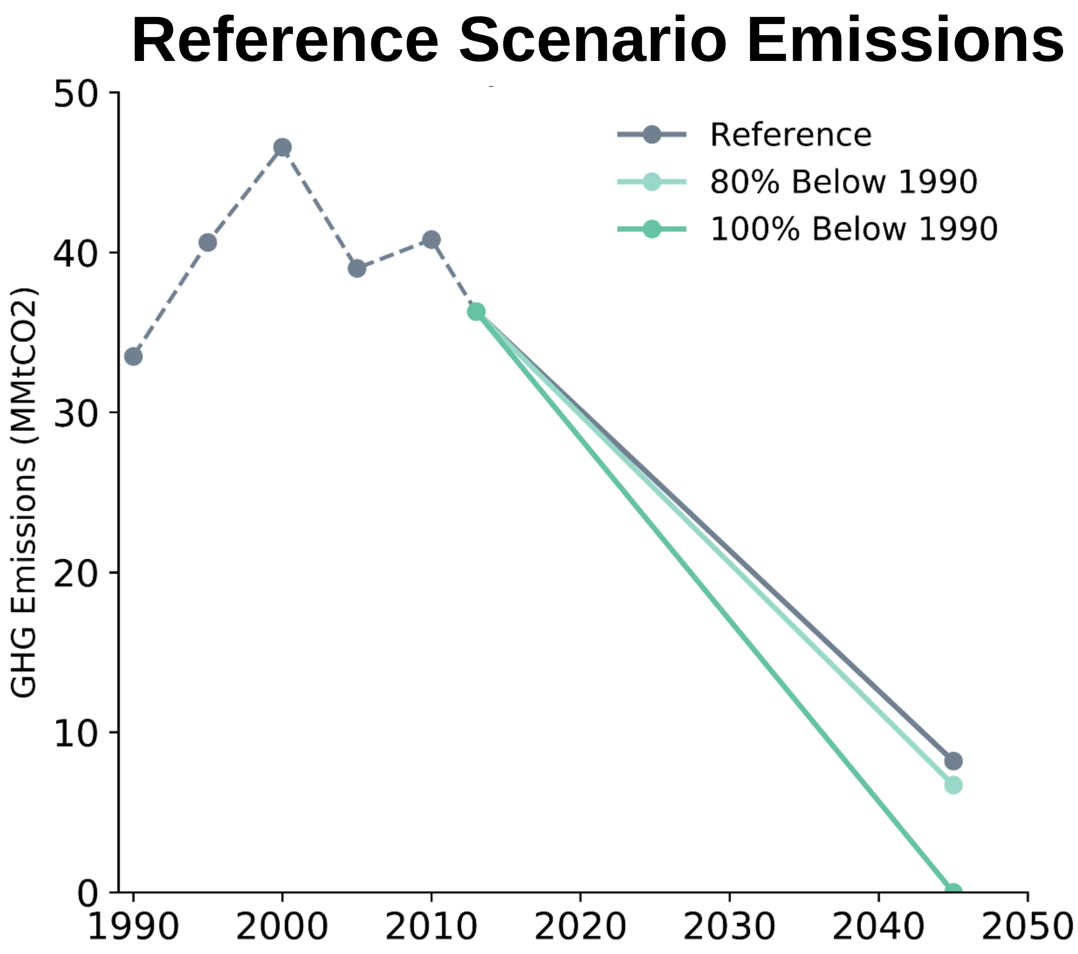
Resources Added (GW)



Generation (aGW)



The Reference Scenario also achieves deep emissions reductions



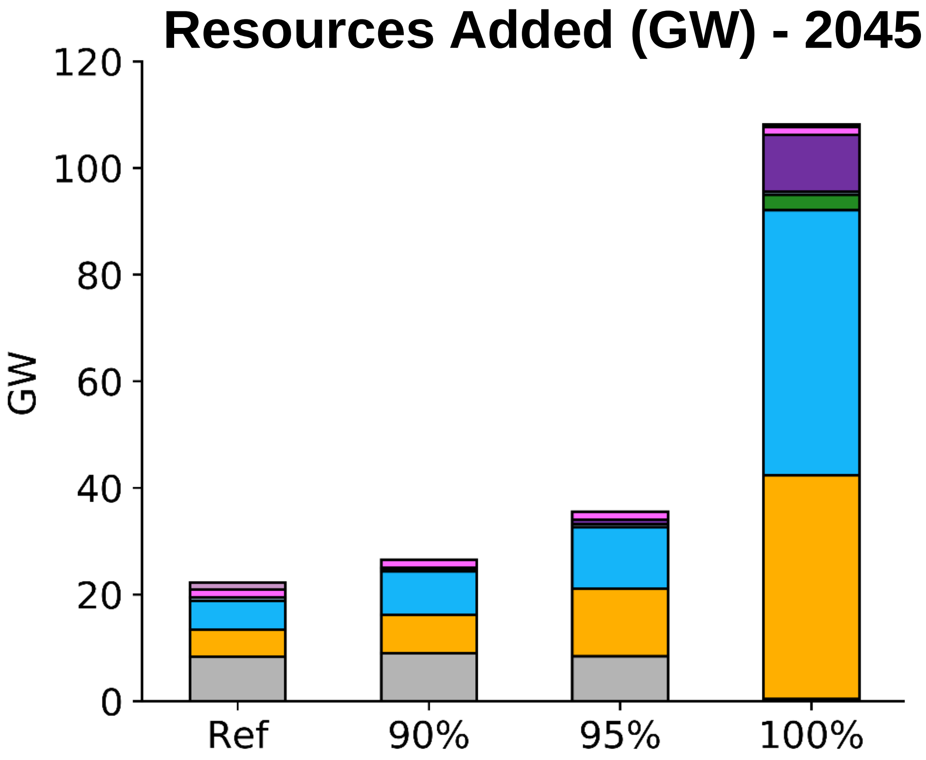
- The largest source of emissions reductions in the Reference scenario are coal retirements that are stipulated in WA and OR law
- In 2045, emissions are 76% below 1990 levels in the Core NW region or 8.0 MtCO2/year.
- The only remaining source of GHG emissions in the Reference scenario after 2035 are from natural gas generators

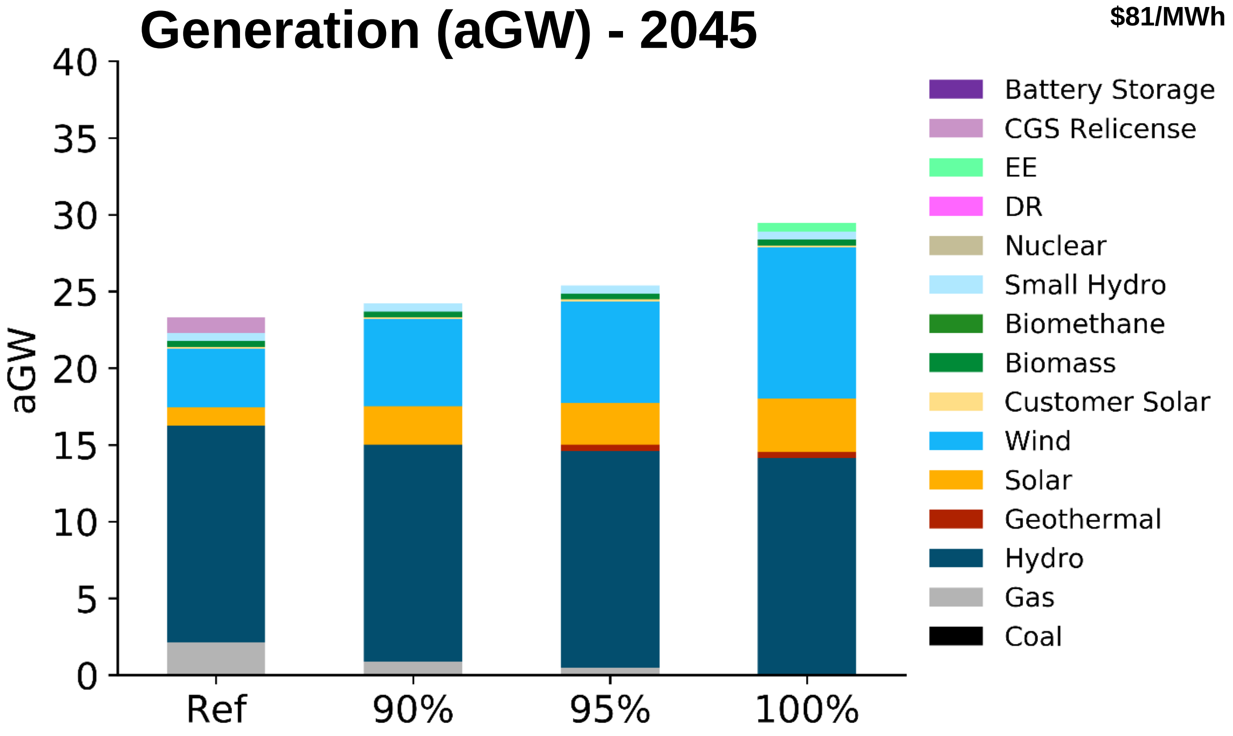
1. Renewables + Gas

- The pairing of renewables and gas can achieve deep emissions reductions at manageable costs
- Costs increase markedly when fossil gas is not available to provide firm capacity

	90%	95%	100%
Incr. Cost	+$200M	+500M	+$8,600M
Retail Rate ($/MWh)	$94	$94	$138
Zero-GHG %	107%	116%	123%

Note: retail rate in 2020 is $81/MWh



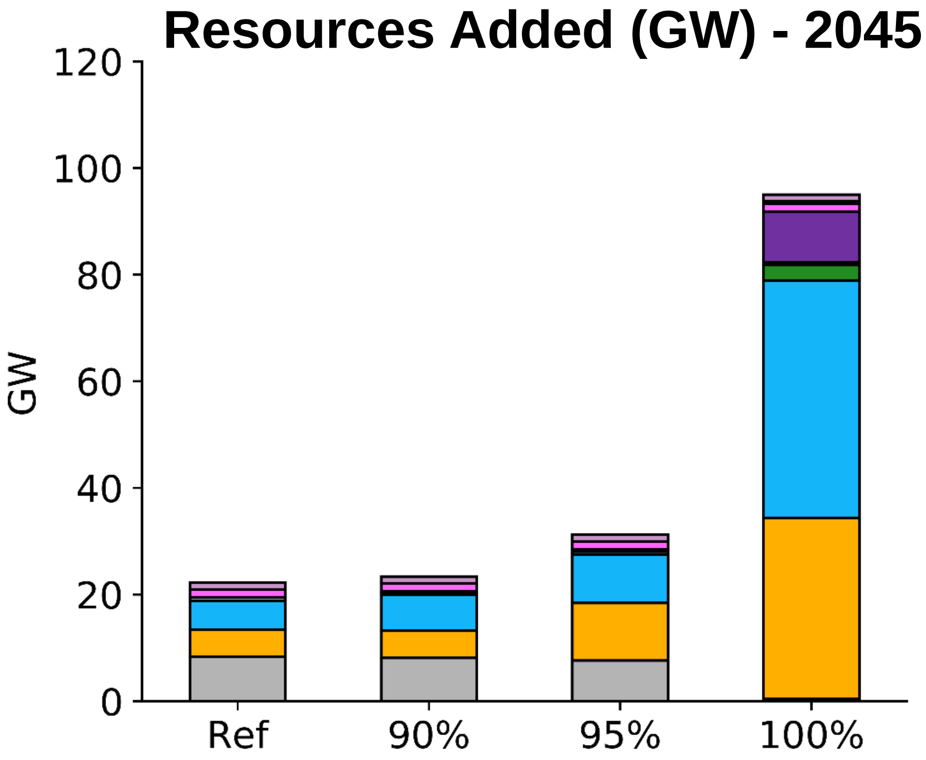


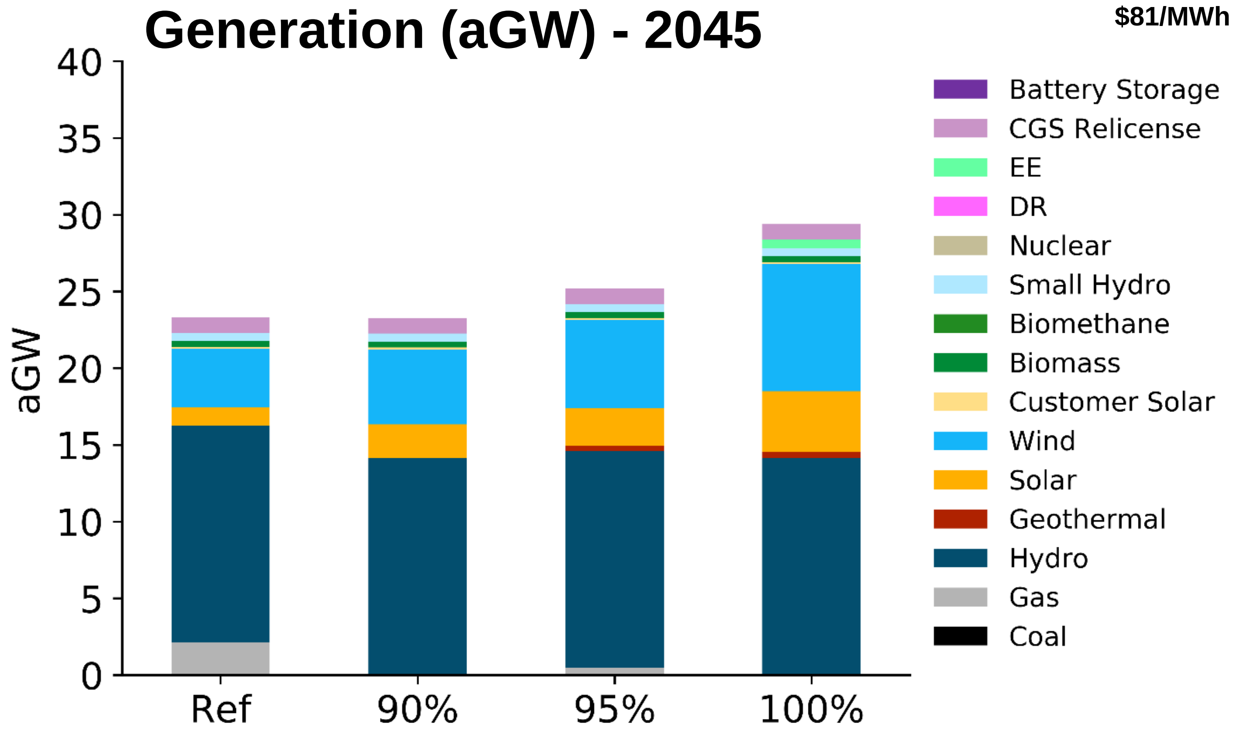
2. Renewables + CGS

- Relicensing CGS decreases the cost of electric sector decarbonization in the NW by between $120M and $1,350M per year in 2045
- A case with no additional firm capacity remains prohibitively expensive

	90%	95%	100%
Incr. Cost	+80M	+300M	+7,250M
Retail Rate ($/MWh)	$94	$94	$131
Zero-GHG %	105%	115%	122%

Note: retail rate in 2020 is $81/MWh





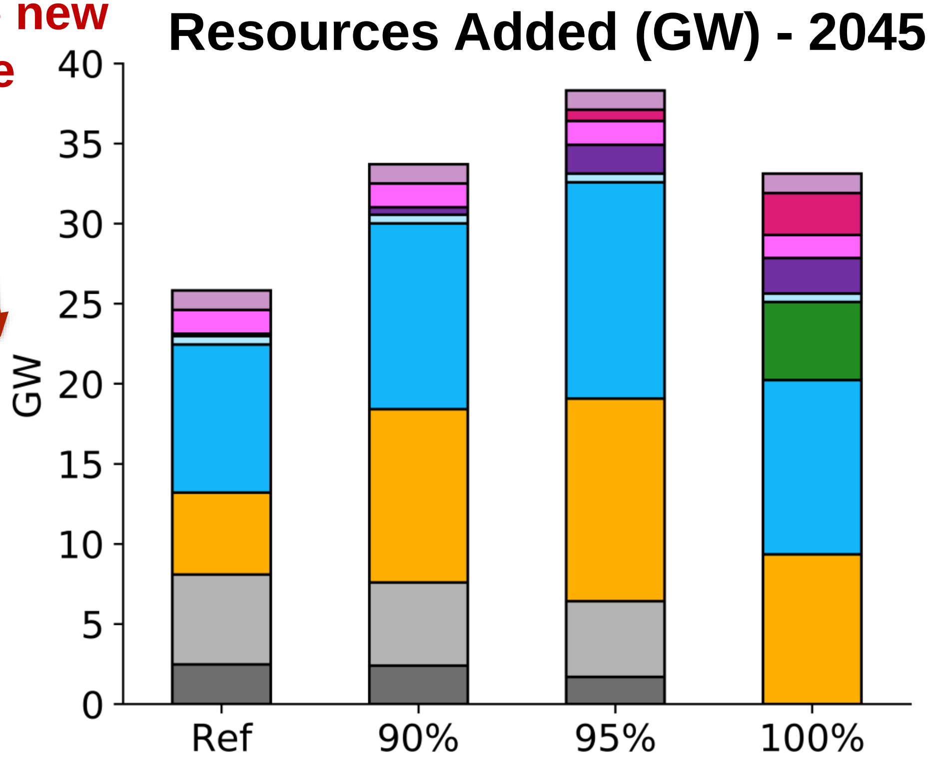
3a. Zero-Emitting Firm, NREL SMR Costs

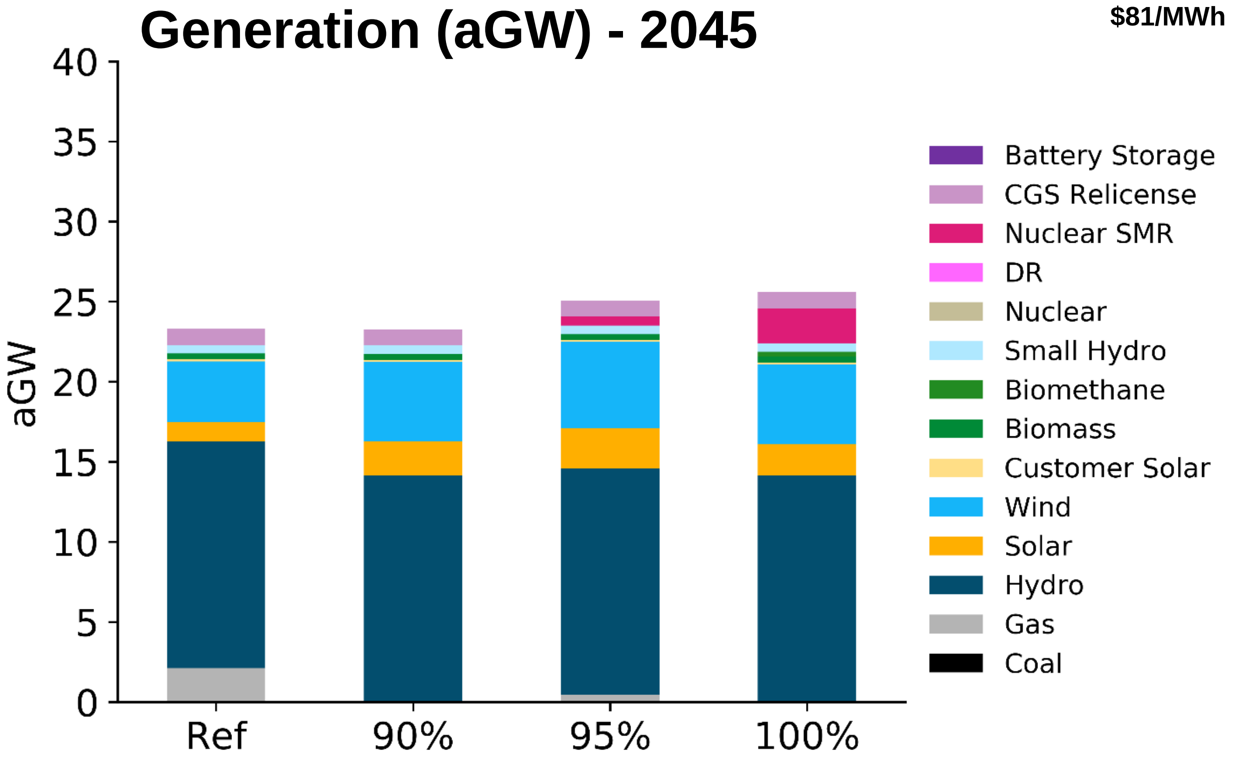
- Adding zero-emitting firm capacity reduces the cost of achieving 100% GHG reductions by $6,700M per year
- At NREL costs, zero-emitting resources include both biomethane and SMRs

	90%	95%	100%
Incr. Cost	80M	+275M	+520M
Retail Rate ($/MWh)	$94	$94	$98
Zero-GHG %	115%	122%	127%

Note: retail rate in 2020 is $81/MWh

Note new scale



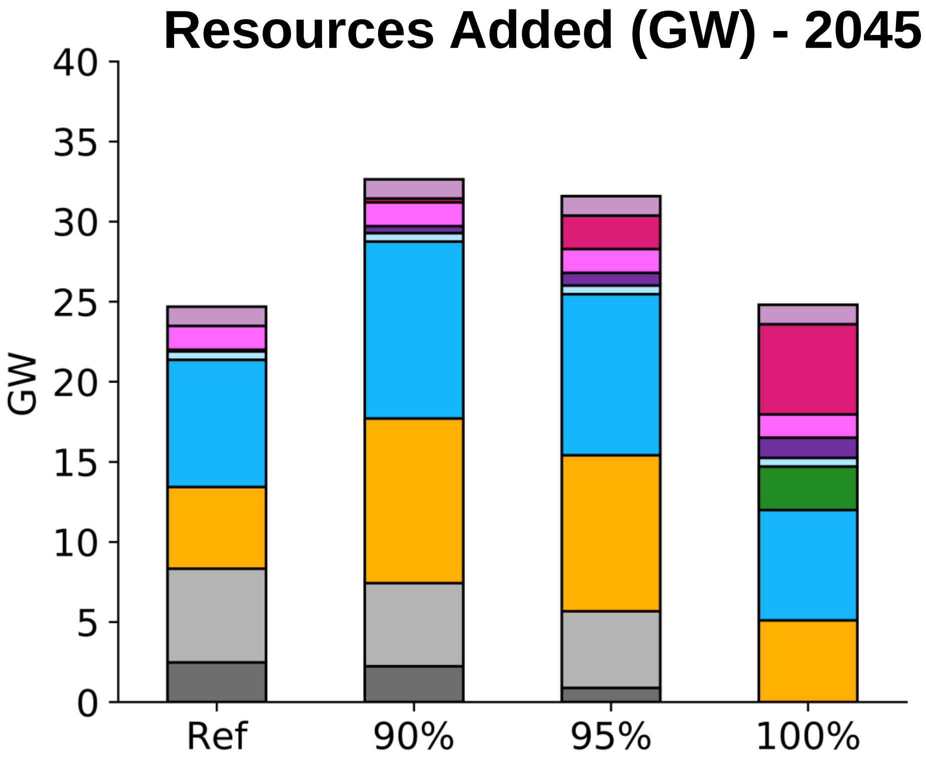


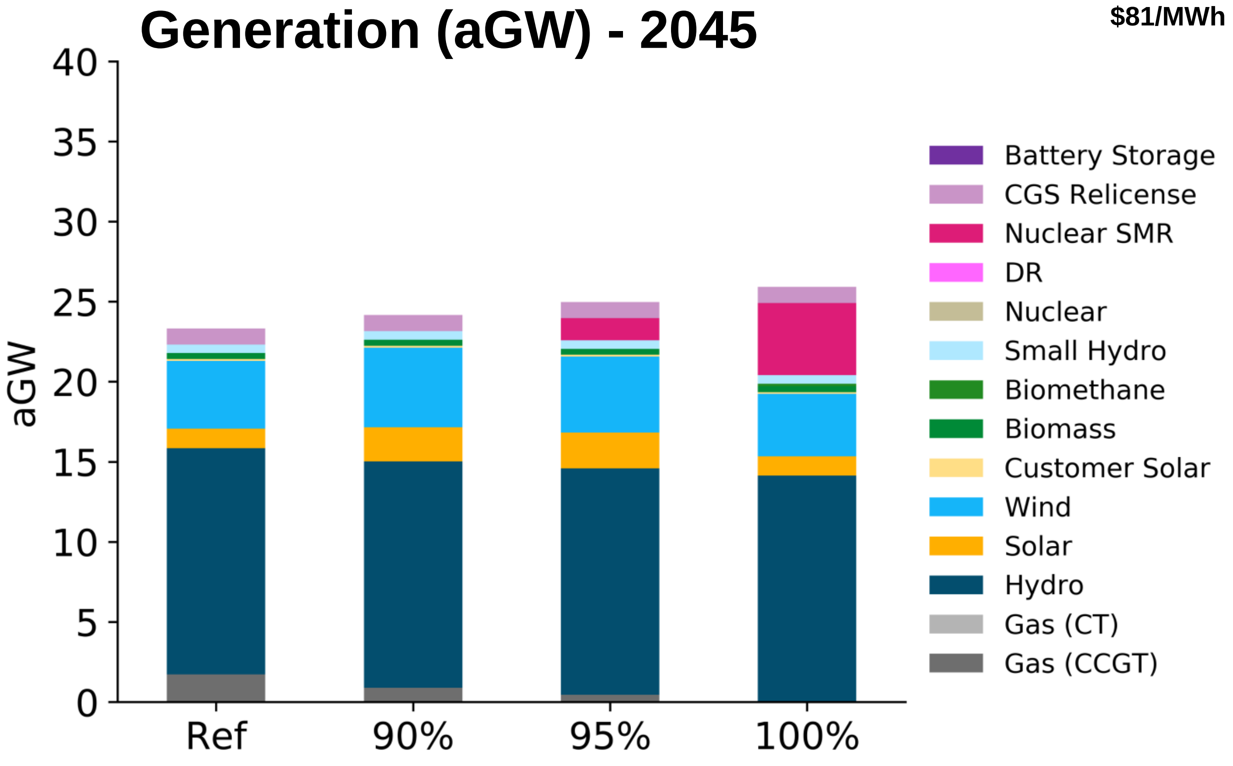
3b. Zero-Emitting Firm, NuScale SMR Costs

- If Nuclear SMRs are available at costs provided by NuScale, additional new nuclear is built in the 95% and 100% GHG reduction cases
- The impact of lower cost SMRs is most stark in the 100% GHG reduction case

	90%	95%	100%
Incr. Cost	+80M	+210M	+410M
Retail Rate ($/MWh)	$94	$94	$96
Zero-GHG %	115%	122%	129%

Note: retail rate in 2020 is $81/MWh



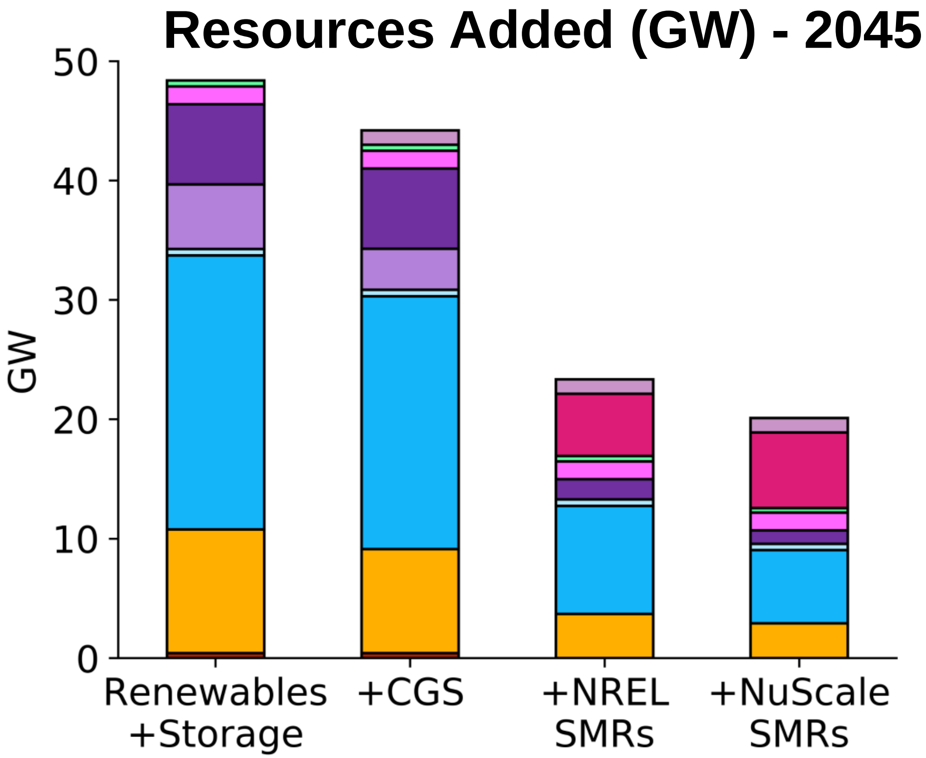


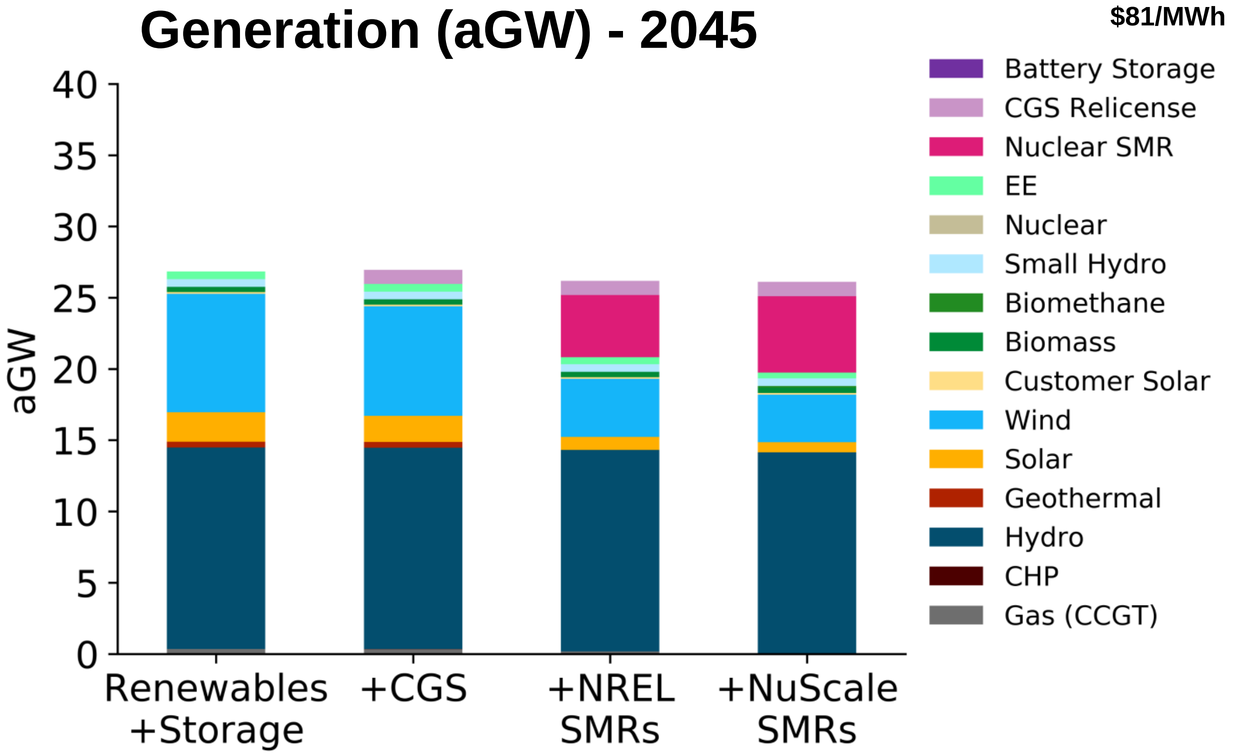
4. No New Gas Sensitivity (90% GHG reduction)

- No new gas leads to substantially higher costs and markedly different portfolios in all but the NuScale cost case
- These results are broadly similar across the 80%, 90% and 95% GHG reduction scenarios

	RE + Storage	+CGS	+NREL	+NuScale
Incr. Cost	+$4700M	+$3600M	+$1050M	+$690M
Retail Rate ($/MWh)	$118	$112	$97	$95
Zero-GHG %	128%	128%	127%	127%

Note: retail rate in 2020 is $81/MWh

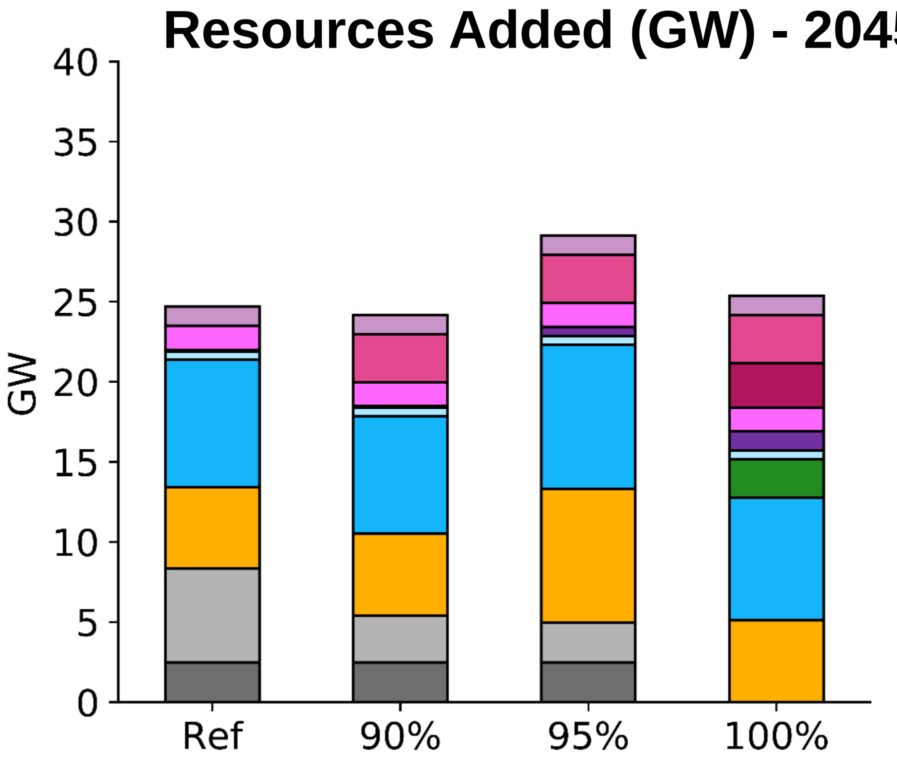


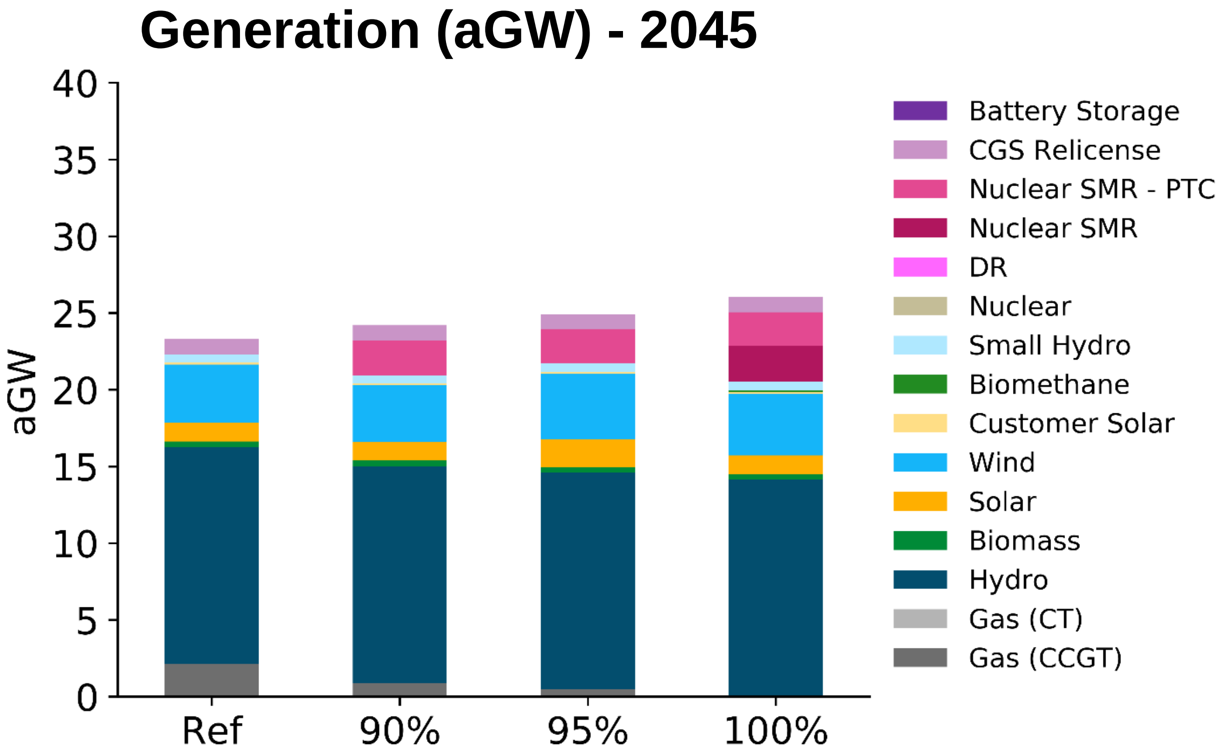


5. Nuclear Production Tax Credit, NuScale Costs

- A nuclear production tax credit leads to Nuclear SMR generation being built in less emissions constrained scenarios
- In the 90% reduction case, scenario costs are slightly negative relative to Reference

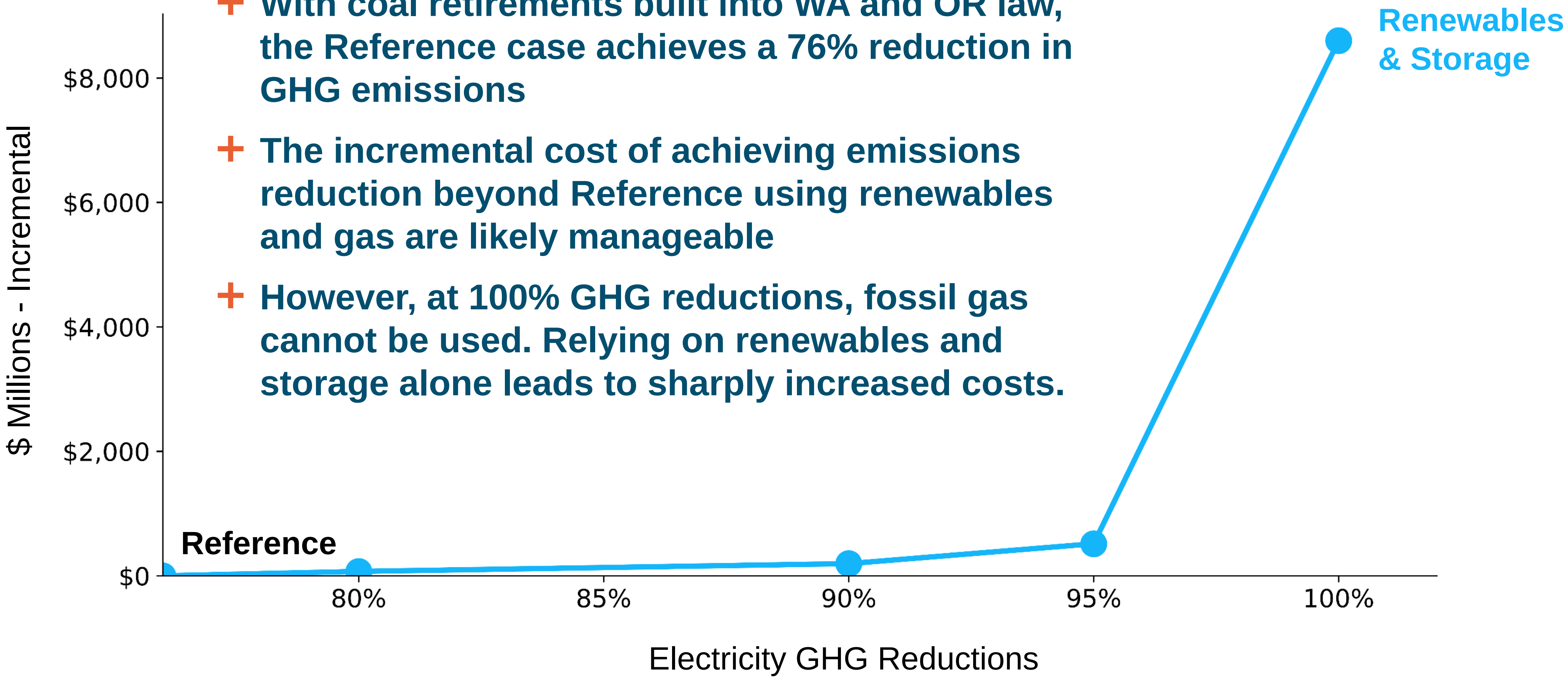
	90%	95%	100%
Incr. Cost	-47M	+11M	+247M
Retail Rate ($/MWh)	$93	$93	$95
Zero-GHG %	116%	121%	129%





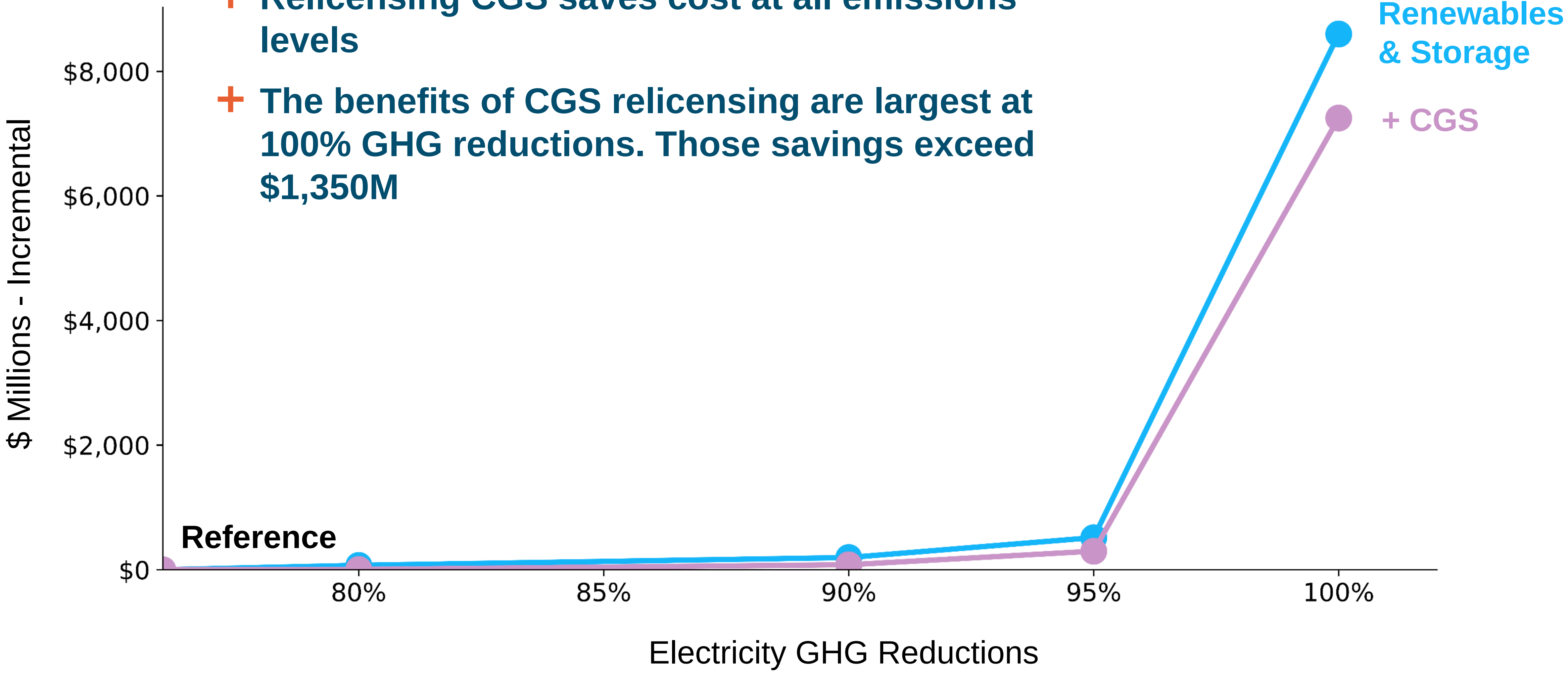
Abatement Costs – Renewables + Storage

- With coal retirements built into WA and OR law, the Reference case achieves a 76% reduction in GHG emissions
- The incremental cost of achieving emissions reduction beyond Reference using renewables and gas are likely manageable
- However, at 100% GHG reductions, fossil gas cannot be used. Relying on renewables and storage alone leads to sharply increased costs.



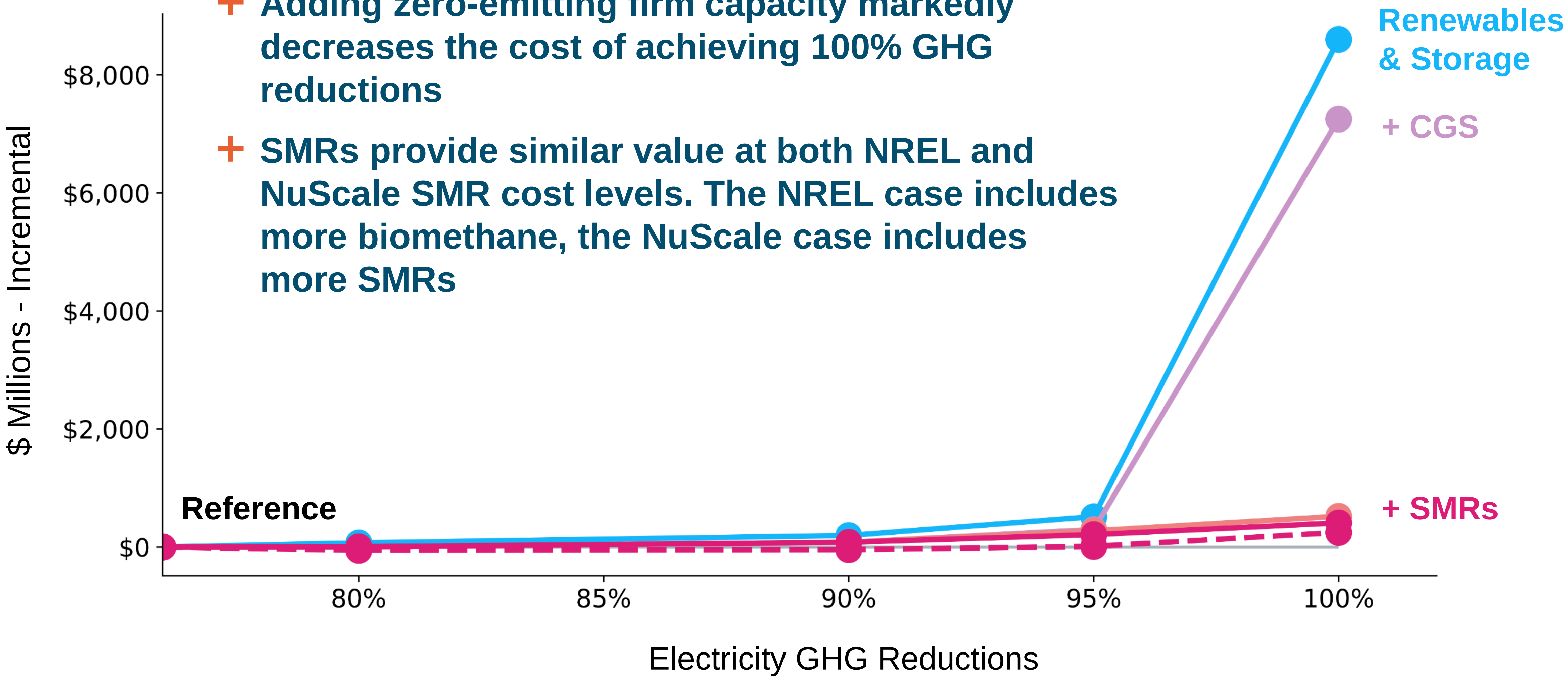
Abatement Costs – CGS Relicensing

- Relicensing CGS saves cost at all emissions levels
- The benefits of CGS relicensing are largest at 100% GHG reductions. Those savings exceed $1,350M



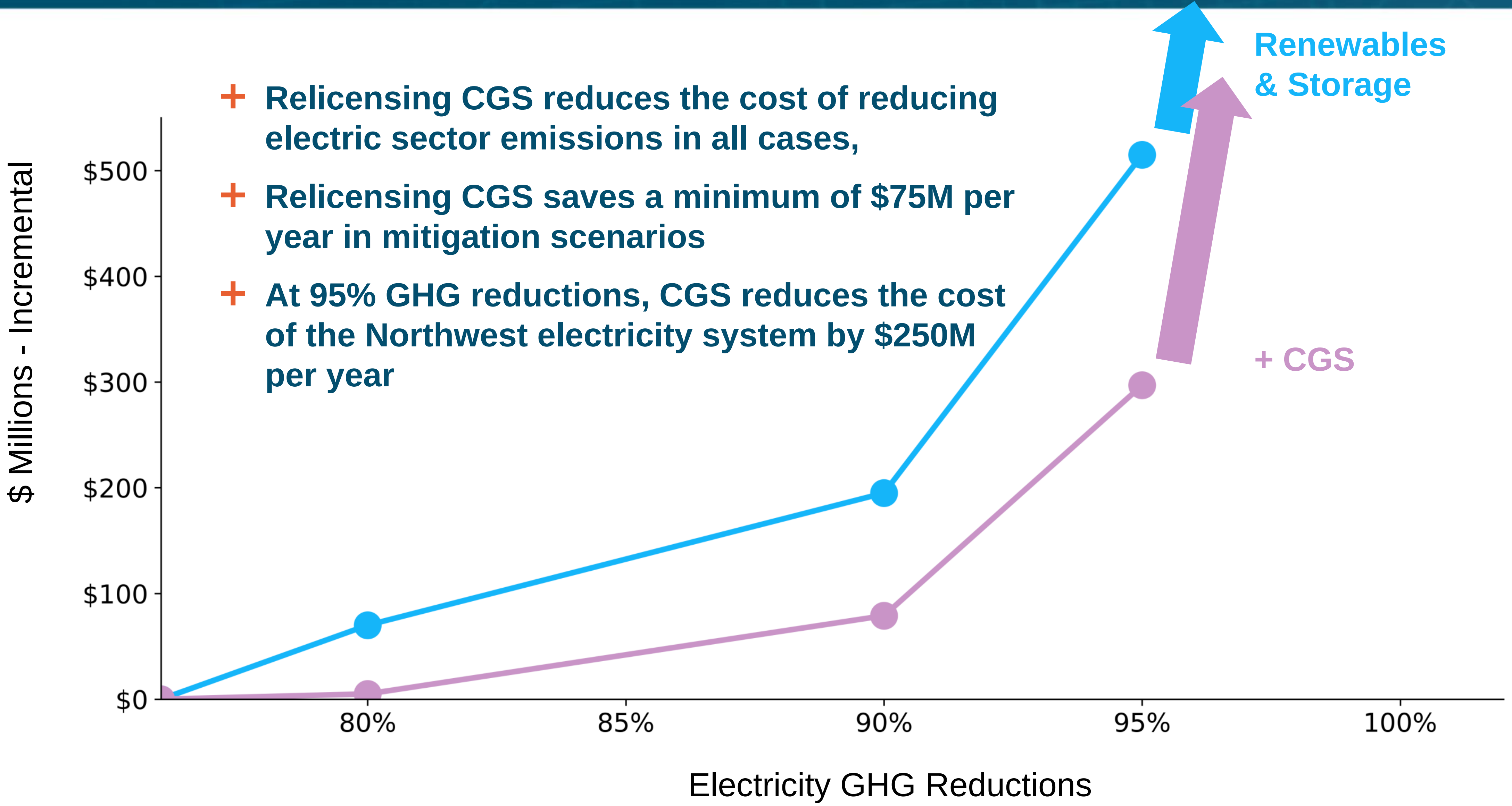
Abatement Costs – Zero-GHG Firm (NuScale)

- Adding zero-emitting firm capacity markedly decreases the cost of achieving 100% GHG reductions
- SMRs provide similar value at both NREL and NuScale SMR cost levels. The NREL case includes more biomethane, the NuScale case includes more SMRs



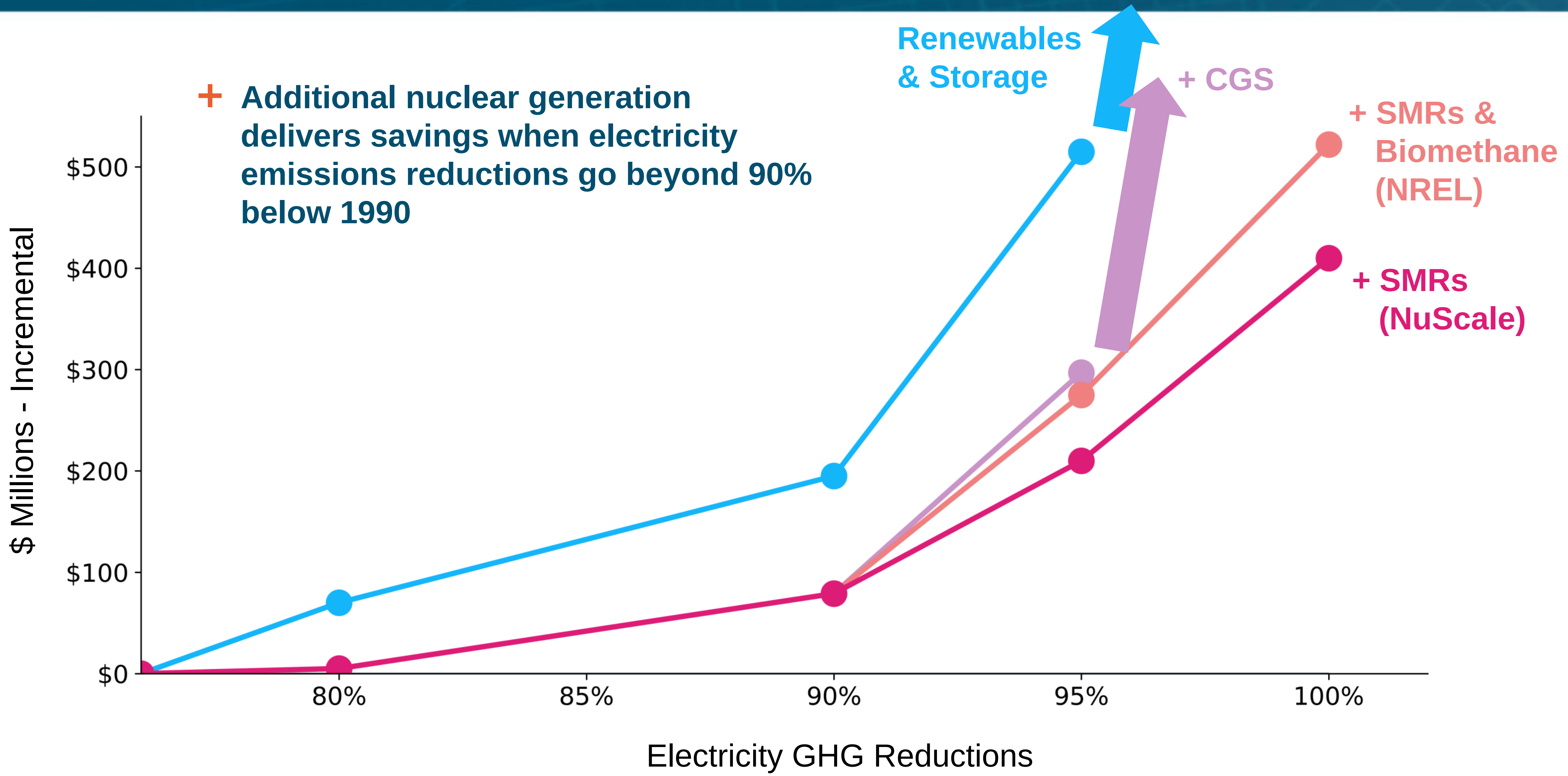
Abatement Costs – CGS Relicensing

- Relicensing CGS reduces the cost of reducing electric sector emissions in all cases,
- Relicensing CGS saves a minimum of $75M per year in mitigation scenarios
- At 95% GHG reductions, CGS reduces the cost of the Northwest electricity system by $250M per year



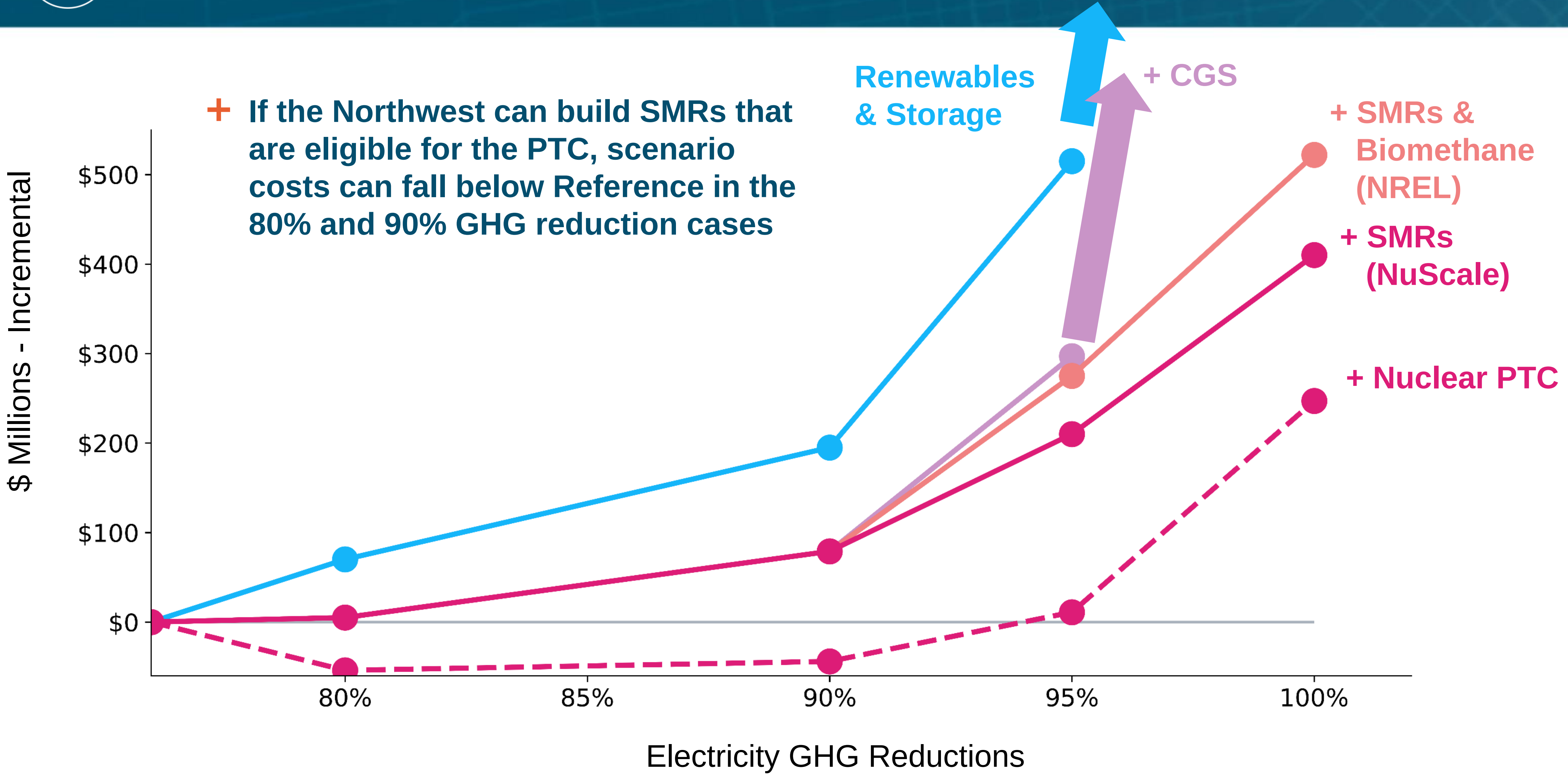
Abatement Costs – with Nuclear SMR

+ Additional nuclear generation delivers savings when electricity emissions reductions go beyond 90% below 1990



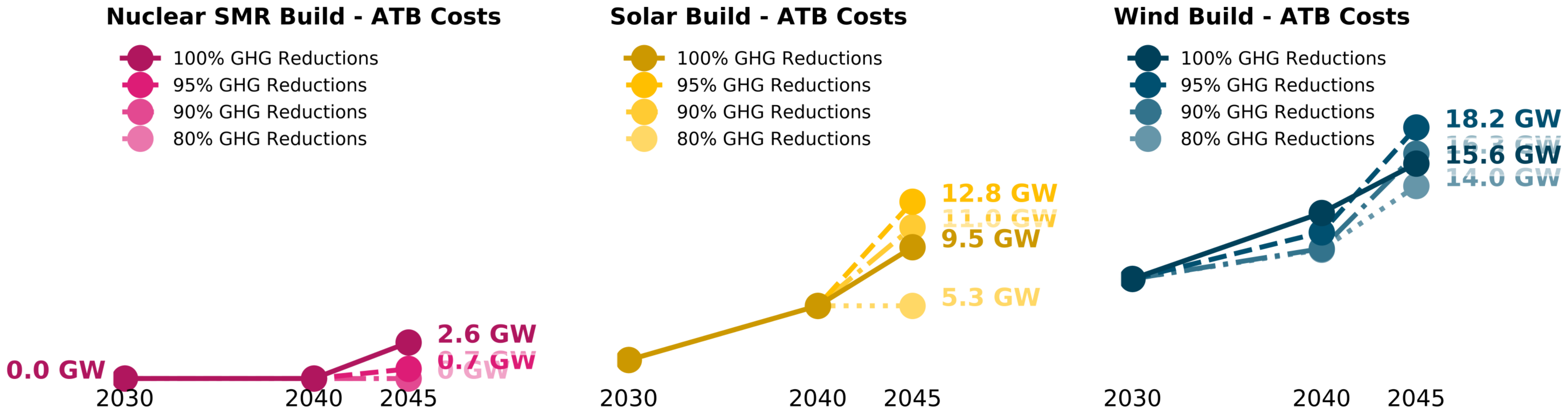
Abatement Costs – Nuclear PTC

+ If the Northwest can build SMRs that are eligible for the PTC, scenario costs can fall below Reference in the 80% and 90% GHG reduction cases



The Role of Firm Zero-Emitting Capacity

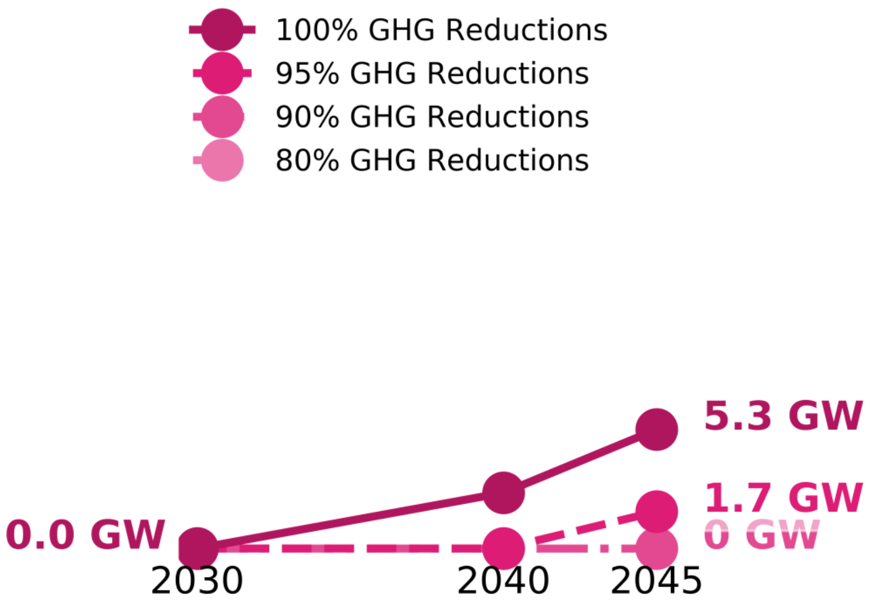
Zero-Emitting Resource Builds: NREL SMR Costs



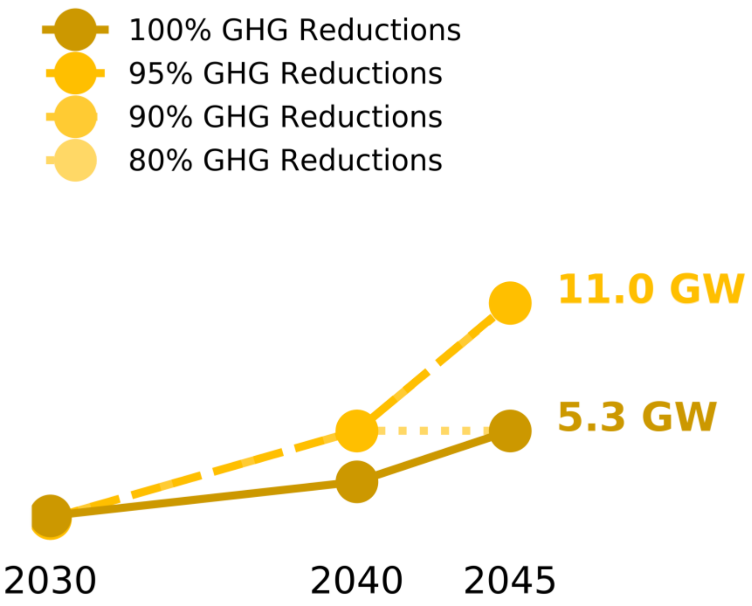
- At NREL ATB Costs, SMRs are not built until 2045, and only in the most stringent emissions reductions scenarios to provide firm capacity
- Low-cost SMRs reduce the need to overbuild renewables for capacity purposes
- Renewables remain an important source of zero-GHG electricity in all scenarios

Zero-Emitting Resource Builds: NuScale Costs

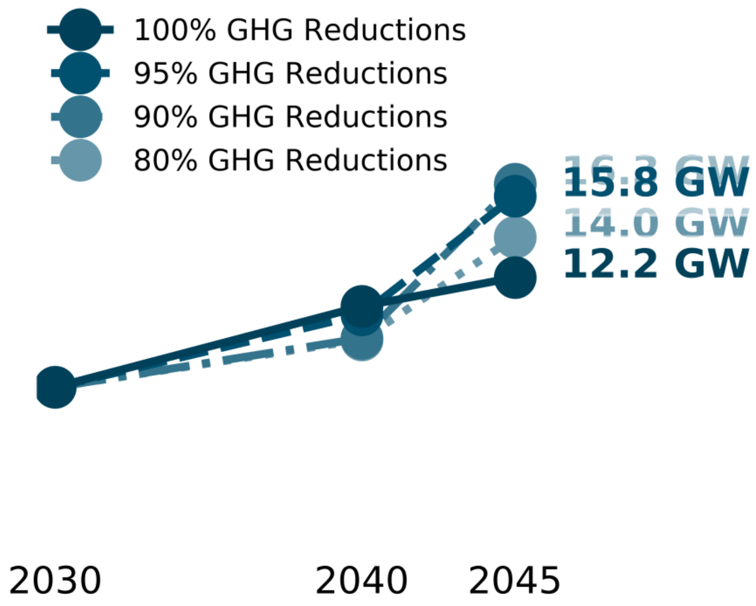
Nuclear SMR Build - NuScale Costs



Solar Build - NuScale Costs

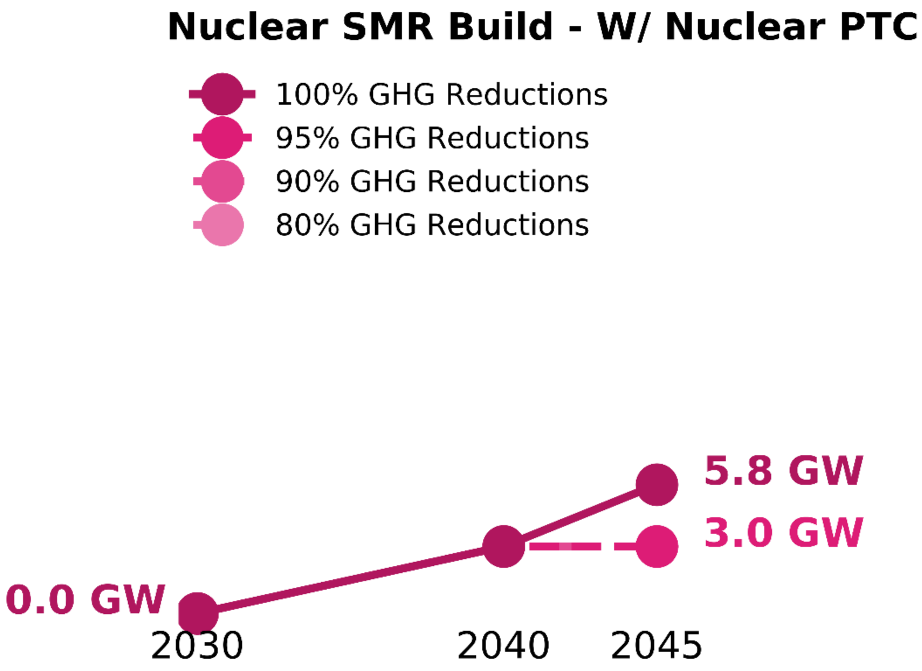


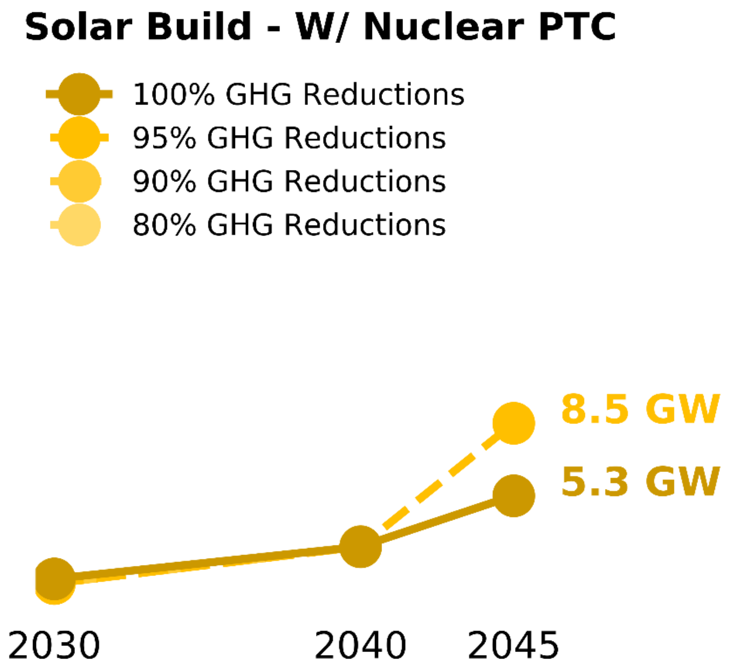
Wind Build - NuScale Costs

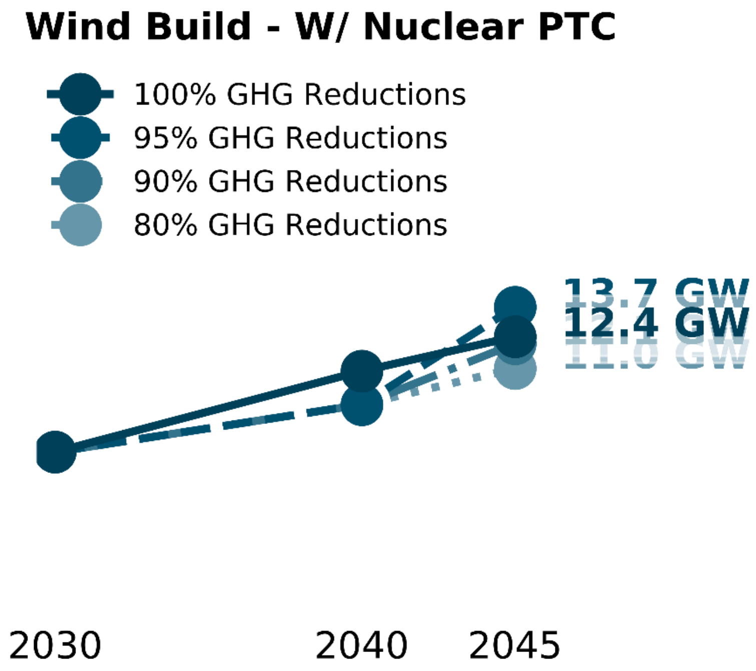


- **At NuScale costs, SMRs are built earlier in time and in larger quantities compared to NREL costs.**
- **Renewables continue to be valuable resources that coexist in a system with lower-cost SMRs.**

Zero-Emitting Resource Builds: Nuclear Production Tax Credit, NuScale Costs

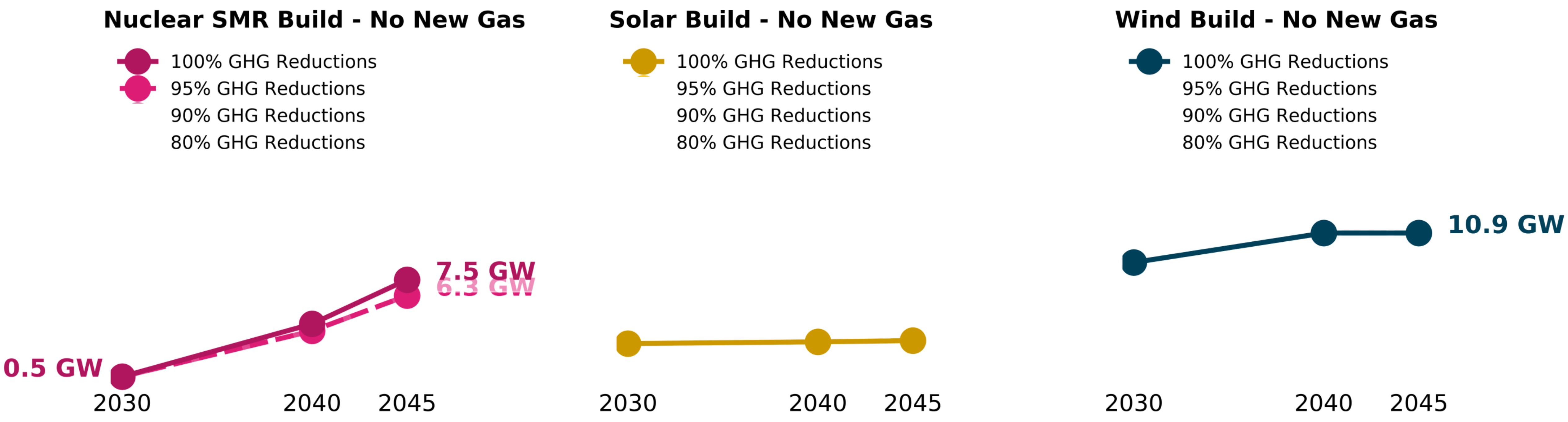






- 3 GW of Nuclear SMRs are eligible for subsidy in the Nuclear SMR PTC case.
- By 2040, the full amount of available PTC capacity is selected in all emissions reduction scenarios

Zero-Emitting Resource Builds: No New Gas, NuScale Costs

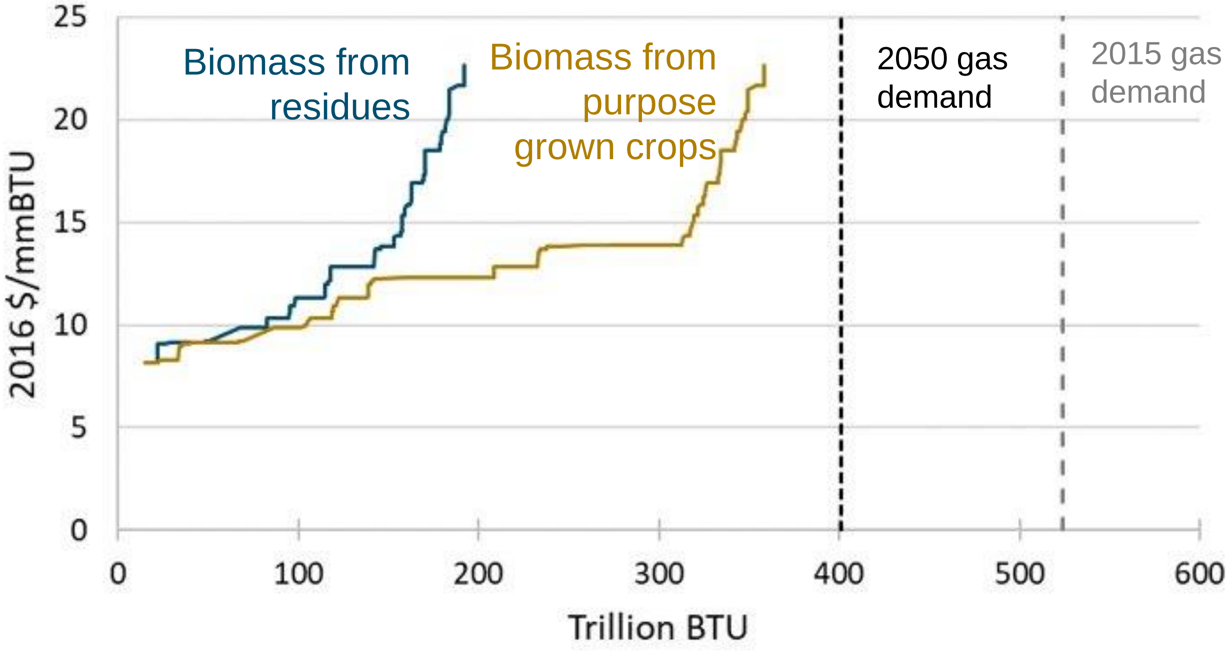


- **When no new gas can be built to serve the Northwest, Nuclear SMRs are built as early as 2030 to meet the region's firm capacity needs.**
- **Nuclear SMR generators have high capacity factors and low operating costs, so once built they reduce the amount of zero-GHG energy needed from other resources**

Other sources of firm zero-emitting capacity

+ **Biomethane is a potential alternative zero-GHG firm resource to nuclear SMR.**
+ **It can be produced using either waste residues or purpose grown crops.**

Northwest Biomethane Supply Curve

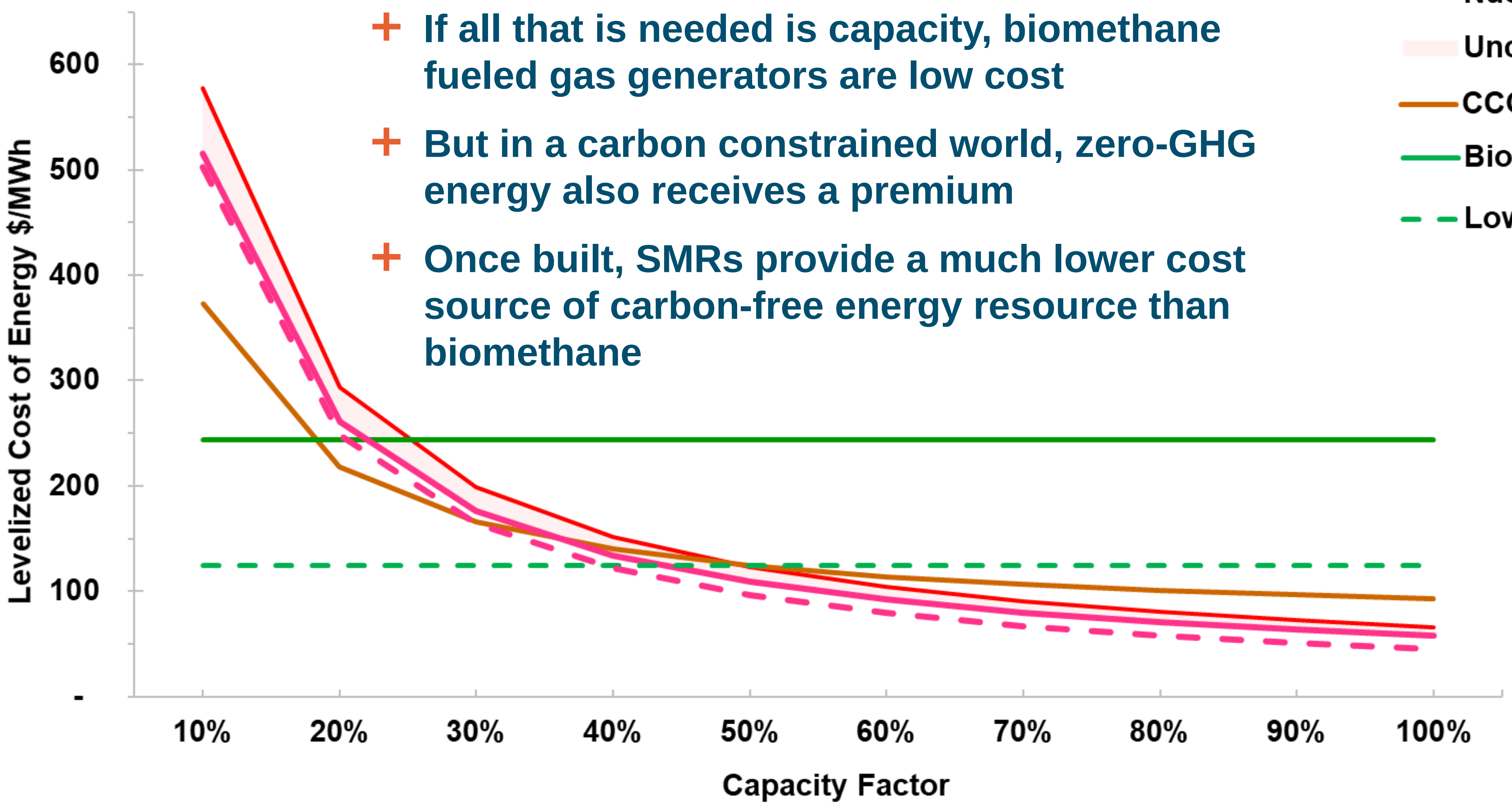


Source: *Pacific Northwest Pathways to 2050*

+ **Biomethane Pros**
  - “Drop in” zero-GHG fuel that can be used in existing gas infrastructure
+ **Biomethane Cons**
  - Potential for higher value in other uses (e.g. bio-jet fuel)
  - Sustainability concerns with purpose-grown crops
  - Advanced biofuels production not yet commercial at scale

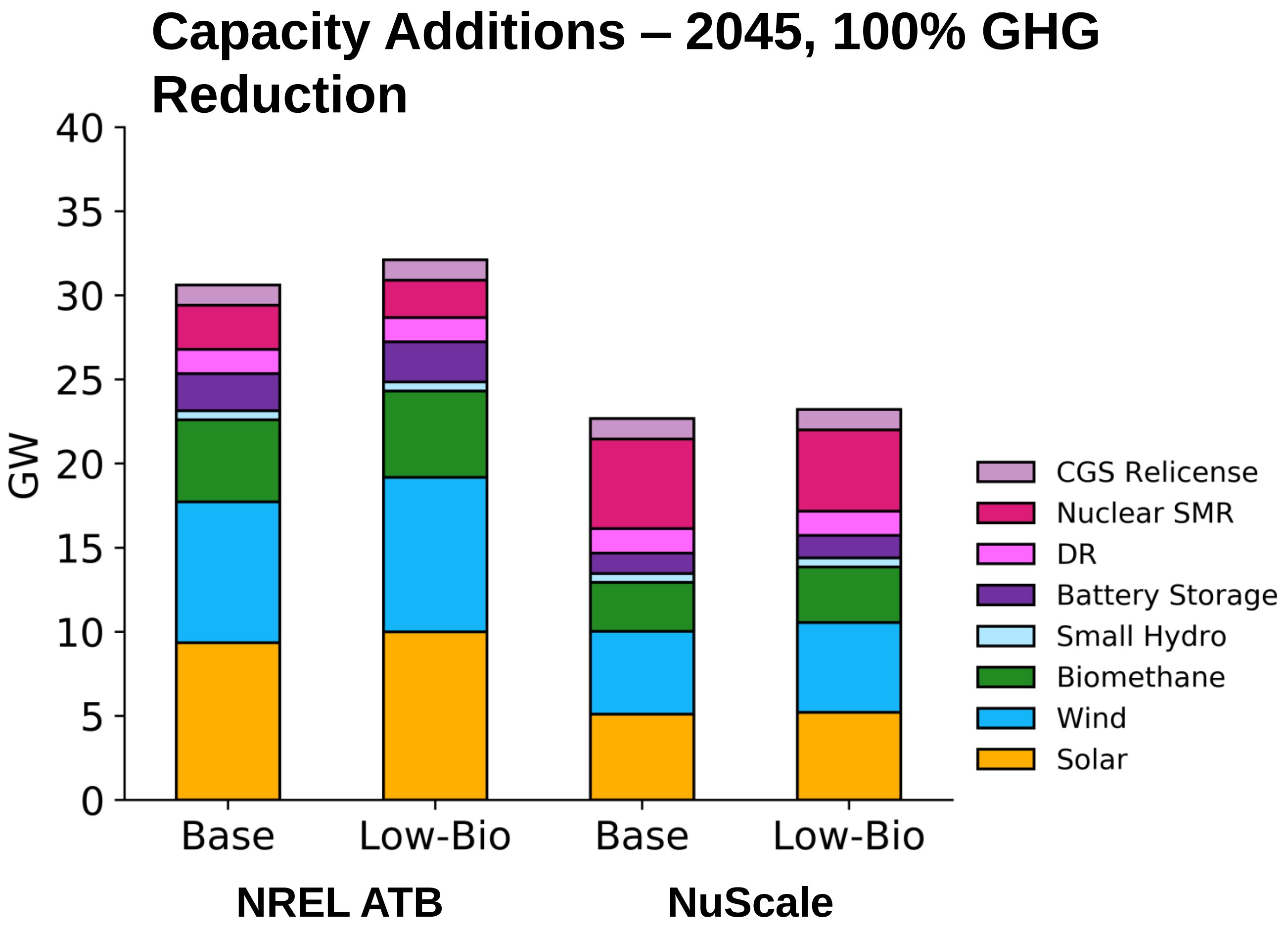
Biomethane can be valuable as a capacity resource, but is a relatively expensive source of energy

- Biomethane relies on existing or new gas generators with low-capital costs
- If all that is needed is capacity, biomethane fueled gas generators are low cost
- But in a carbon constrained world, zero-GHG energy also receives a premium
- Once built, SMRs provide a much lower cost source of carbon-free energy resource than biomethane



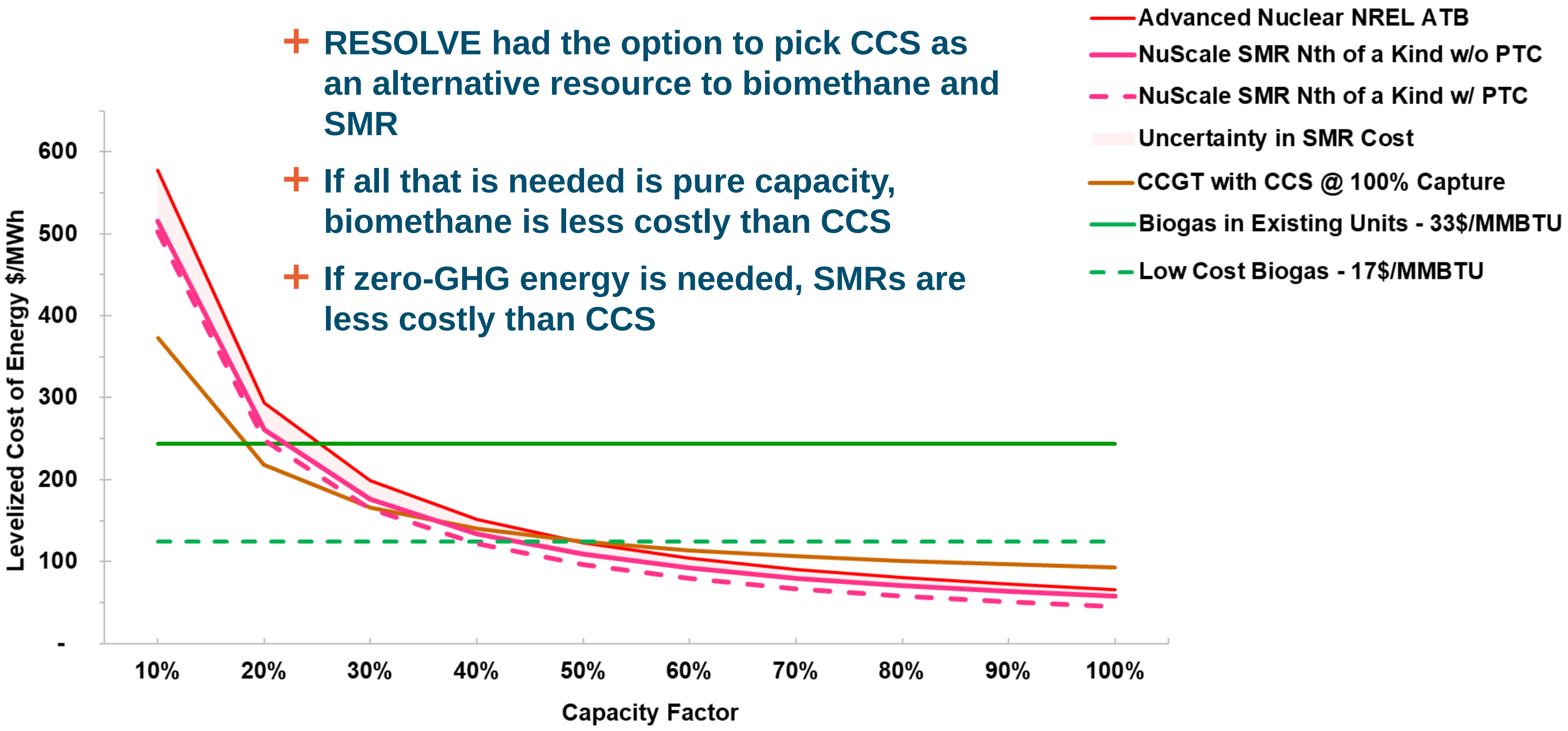
Lower cost biomethane sensitivity

- E3's base case assumes relatively expensive biomethane ($33 / MMBtu), reflecting a world-view with competing demands for biomass feedstocks
- E3 assessed a lower-cost biomethane sensitivity ($17 / MMBtu), but that lower resource cost does not materially change portfolios
- This study did not examine the cost of using hydrogen as an alternative fuel in gas combustion turbines. However, the cost of climate neutral hydrogen is unlikely to fall below the lower-bound biomethane costs in this study



Carbon capture and sequestration (CCS) was not selected in this study

- RESOLVE had the option to pick CCS as an alternative resource to biomethane and SMR
- If all that is needed is pure capacity, biomethane is less costly than CCS
- If zero-GHG energy is needed, SMRs are less costly than CCS



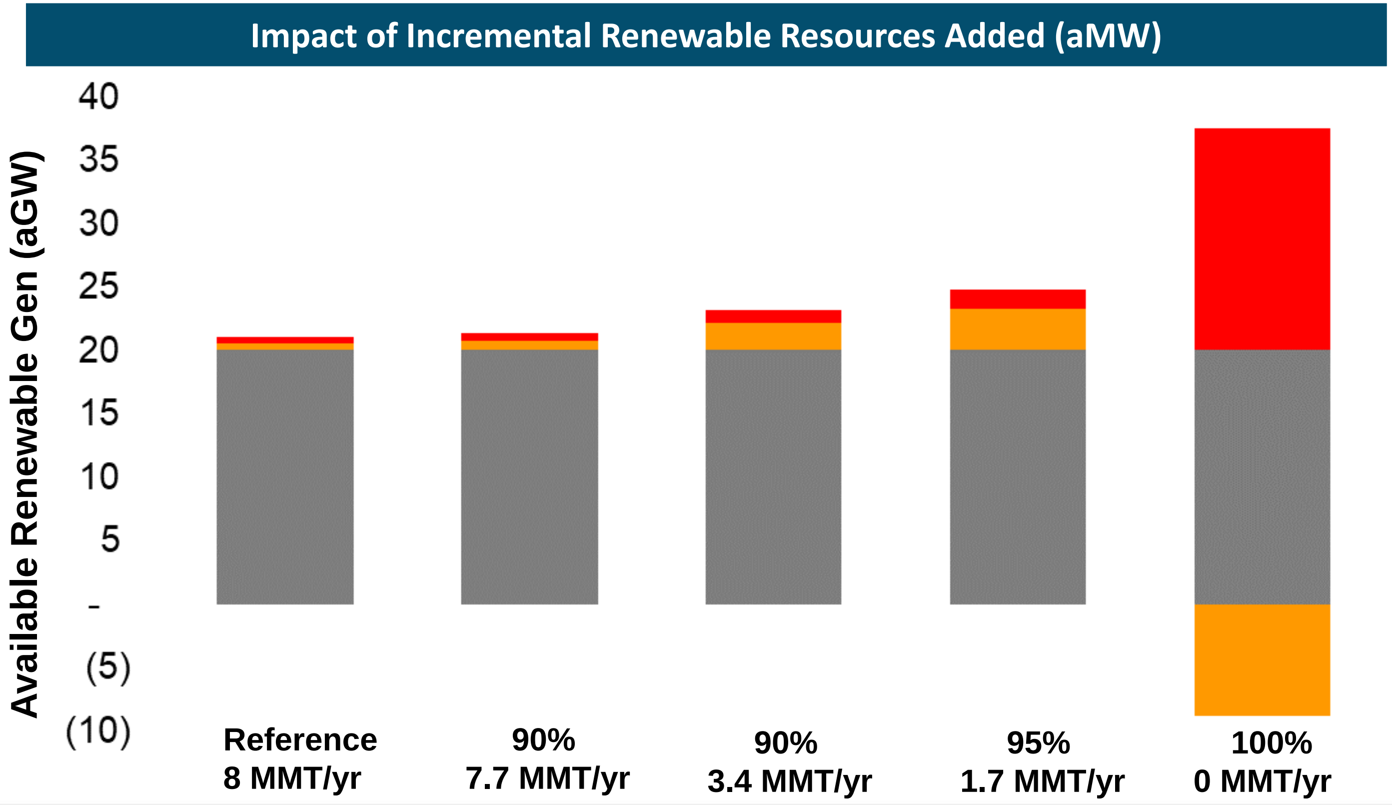
Benefits of Firm Zero-Emitting Capacity

A deeply decarbonized electricity system will require firm capacity to ensure reliable electric service

+ **Capacity is the ability to generate electric energy at any given point in time**
  - The consequence of inadequate capacity is loss of load that is inconvenient, expensive and threatening to human health
  - Utilities plan their systems to ensure that loss of load occurs very rarely
+ **Not all resources provide the same amount of capacity**
  - “Firm” resources’ capacities are equal (or near to equal) their nameplate
  - Resources that are variable or energy limited provide a fraction of their nameplate as firm capacity
  - The implication is that these resources must be overbuilt to reliably serve peak loads

Renewable curtailment increases dramatically at zero-GHG emissions due to a large overbuild

- If renewables coupled with storage are the only sources of non-GHG-emitting energy available, these become less and less effective at reducing carbon in the Northwest compared to the Reference Scenario and as the amount of GHG emissions allowed in the electricity sector decrease
- Frequency and magnitude of renewable curtailment events grows considerably, driving up cost of reducing GHG emissions



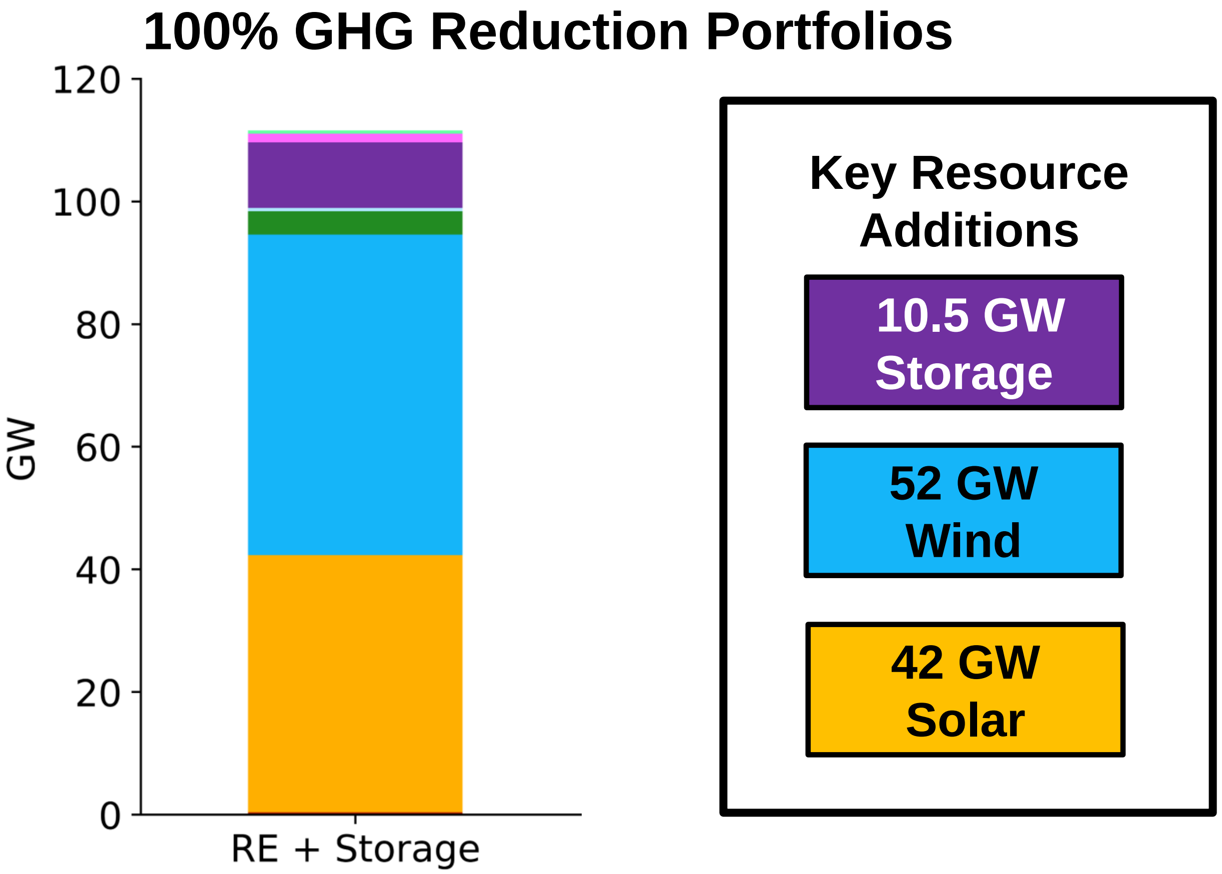
In the 100% GHG reduction case, ~ 7aGW more renewable generation takes place compared to the Reference scenario, reducing emissions by 8 MMT/year while…

…40% is curtailed

…30% displaces fossil generation in the Northwest

…30% is exported to other parts of WECC

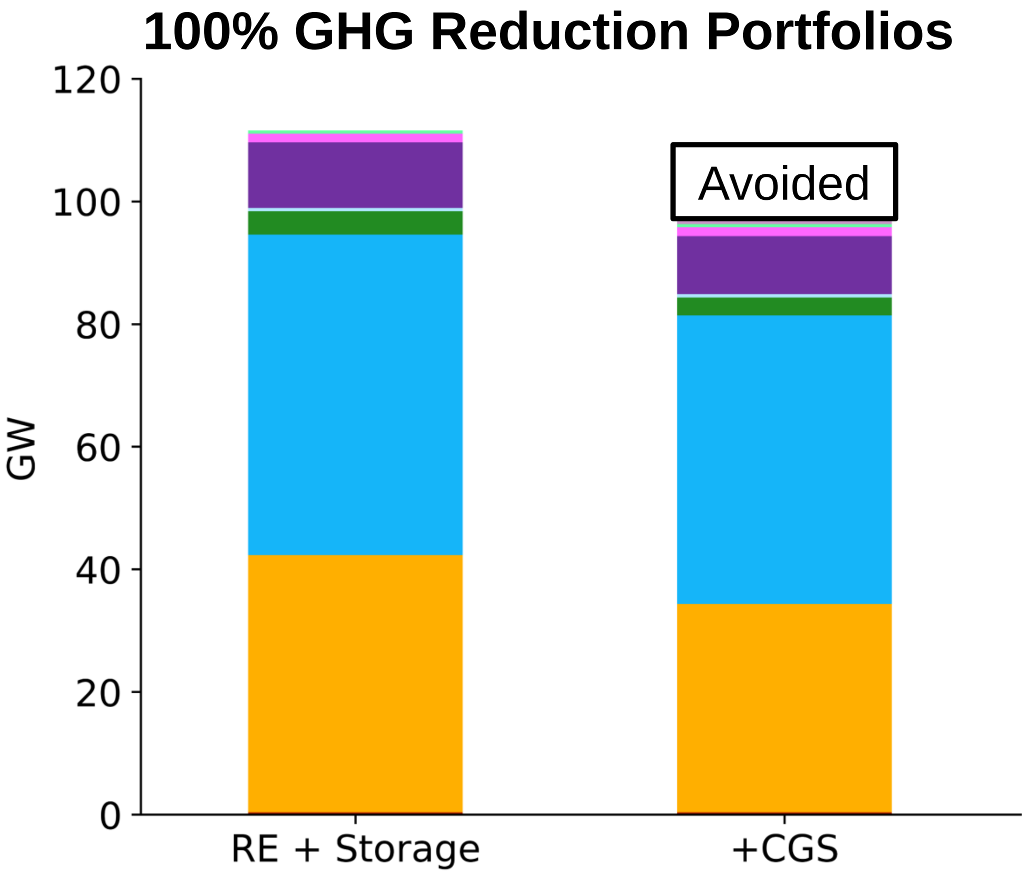
Benefits of zero-emitting firm capacity at 100% GHG reductions – (1 of 4)



A system that largely relies on wind, water, solar and battery storage (RE + Storage) requires over 100 GW of new capacity additions in 2045 to maintain reliability

This system costs more than $8B per year over the Reference Scenario

Benefits of zero-emitting firm capacity at 100% GHG reductions – (2 of 4)

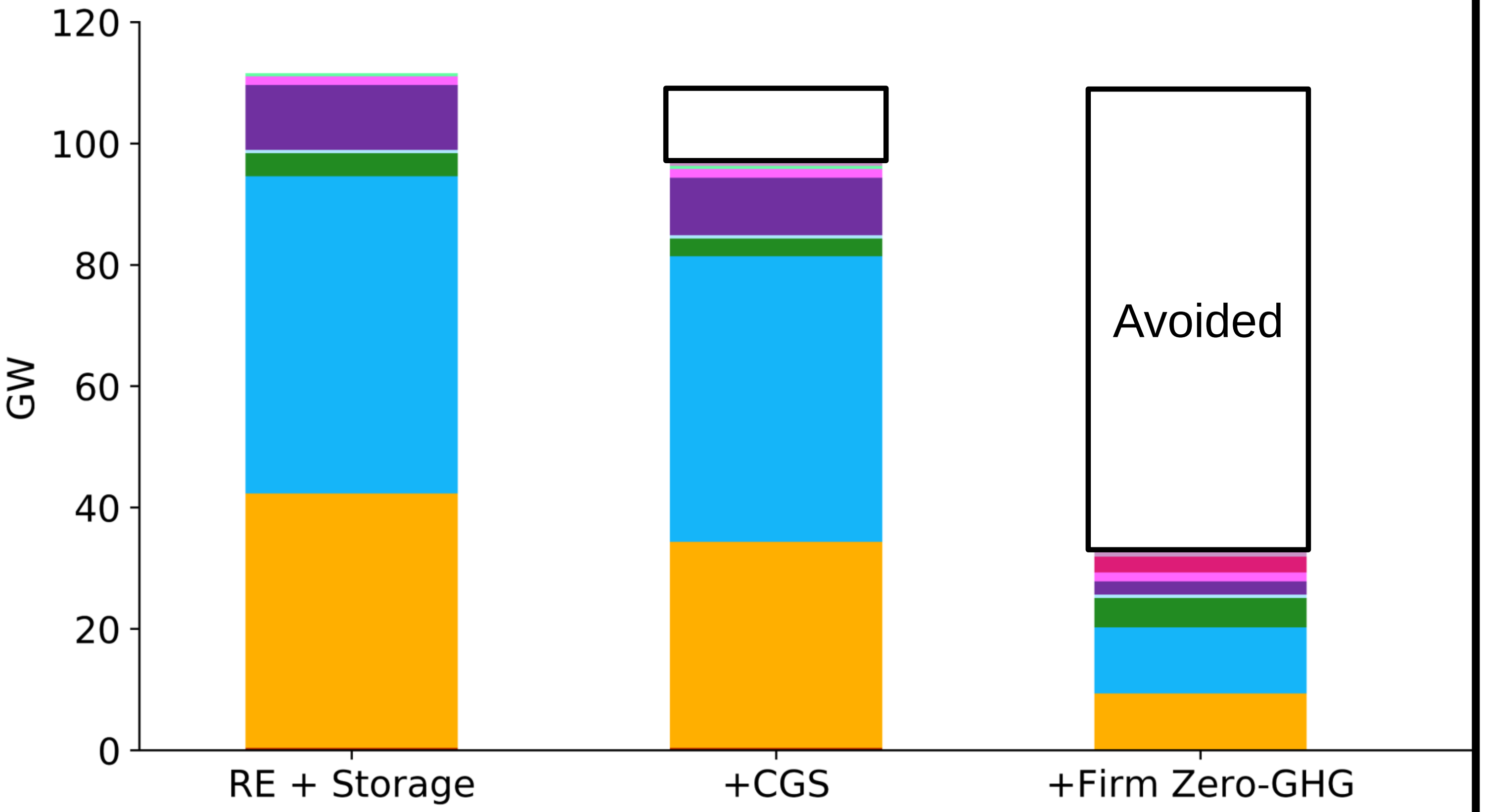


Adding	Avoids
+1.2 GW CGS	-1.2 GW Storage
	-5.2 GW Wind
	-8 GW Solar
+1.2 GW Firm	-14.4 GW Non-firm

Relicensing CGS reduces the total cost of a zero-emissions NW electricity system by $1.4 billion per year in 2045

Benefits of zero-emitting firm capacity at 100% GHG reductions – (3 of 4)

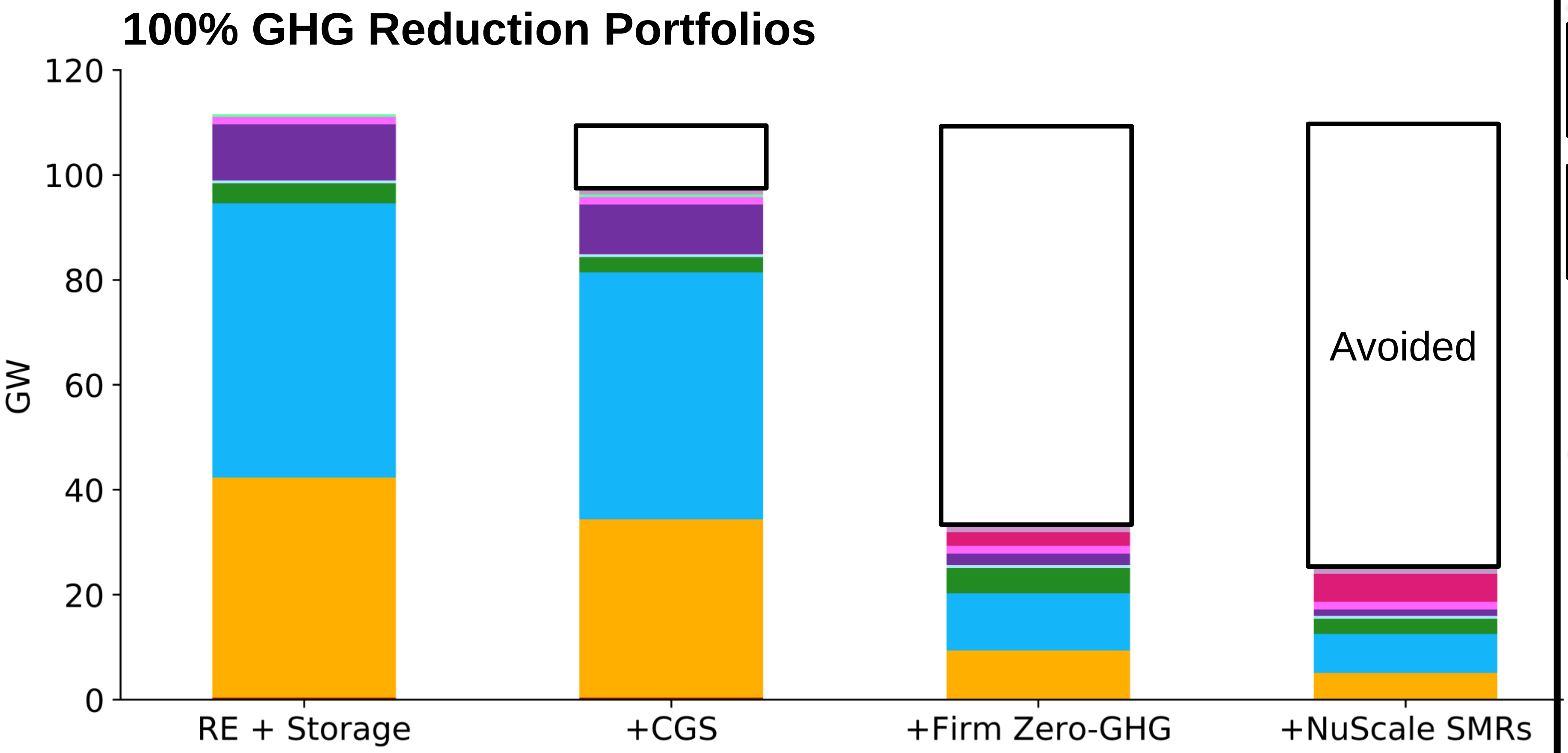
100% GHG Reduction Portfolios



Adding	Avoids
+1.2 GW CGS	**-8.5 GW Storage**
+2 GW Biomethane	**-41 GW Wind**
+2.6 GW SMRs	**-32 GW Solar**
+5.8 GW Firm	**-81.5 GW Non-firm**

CGS + additional firm, zero-GHG generation reduces electric system costs by almost $8 billion per year relative to RE + Storage

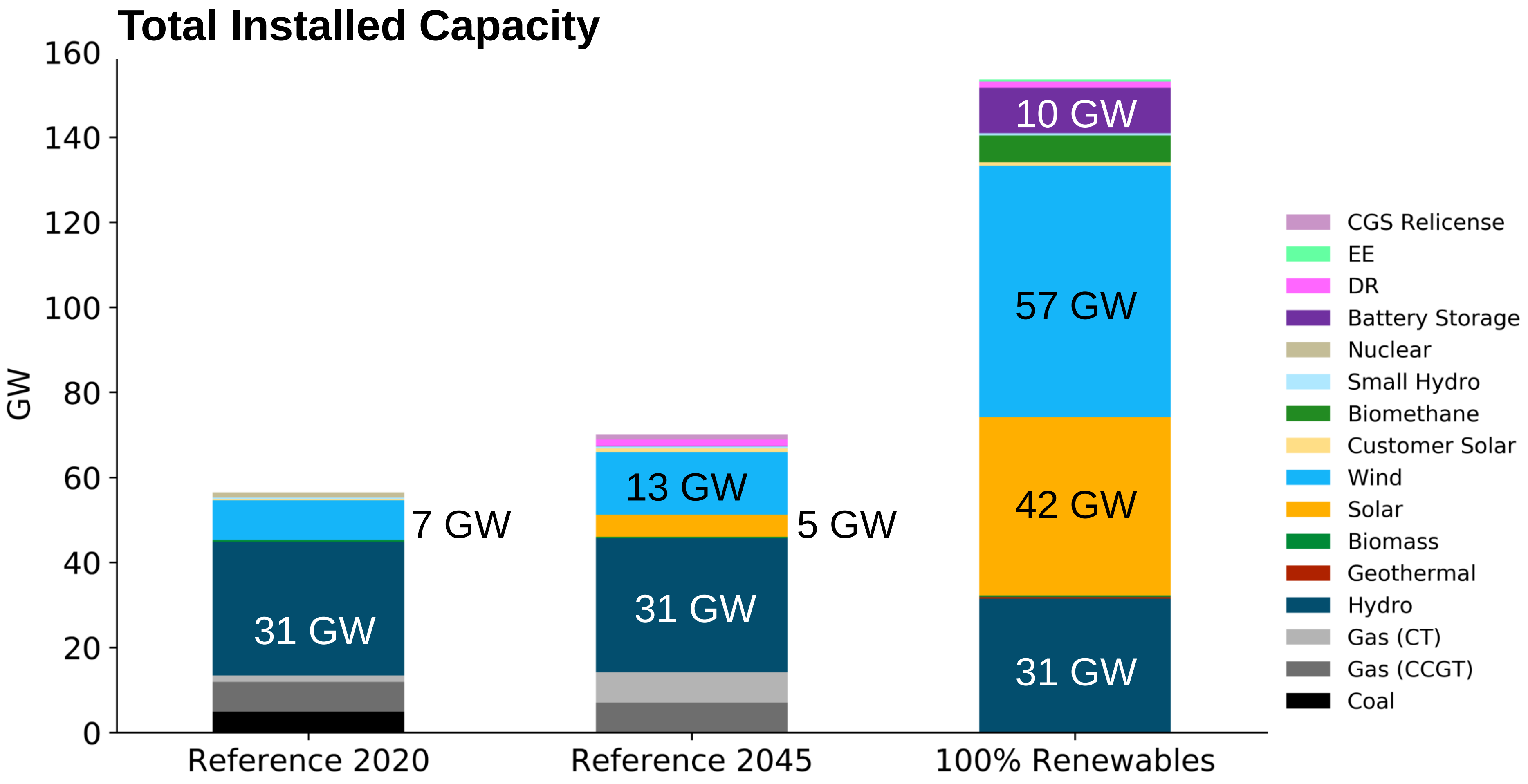
Benefits of zero-emitting firm capacity at 100% GHG reductions – (4 of 4)



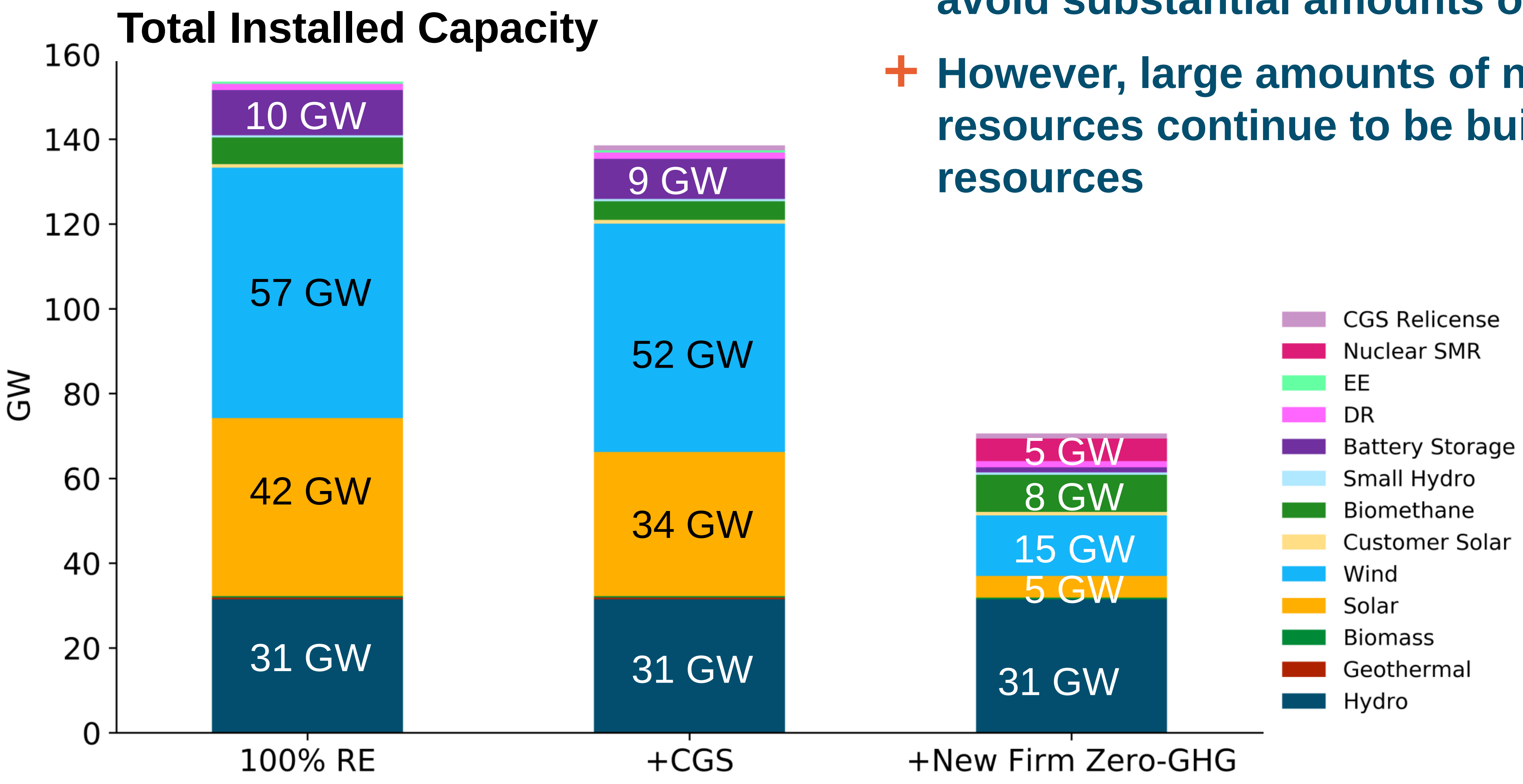
Adding	Avoids
+1.2 GW CGS	-9.5 GW Storage
+5.3 GW SMRs	-44.8 GW Wind
	-37 GW Solar
+6.5 GW Firm	-91 GW Non-firm

CGS + NuScale SMRs reduce system costs by almost $8B per year relative to RE + Storage

Total Installed Capacity: Reference vs 100% Renewables



Total installed capacity, 100% GHG Reduction Scenarios

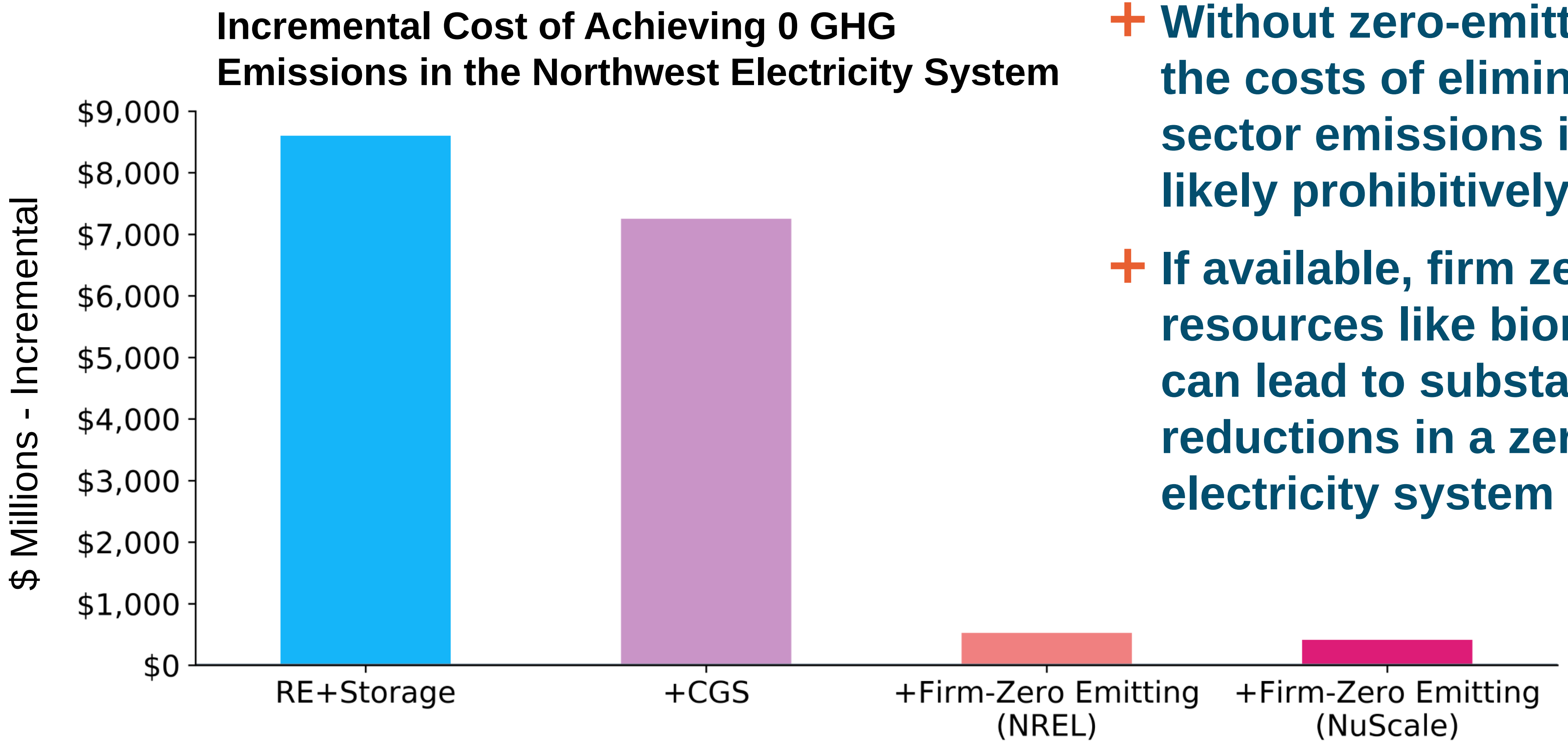


- Firm resources like nuclear SMR and biomethane avoid substantial amounts of renewable overbuild
- However, large amounts of new wind and solar resources continue to be built alongside firm resources

NW wind and solar capacities in 100% case with SMRs

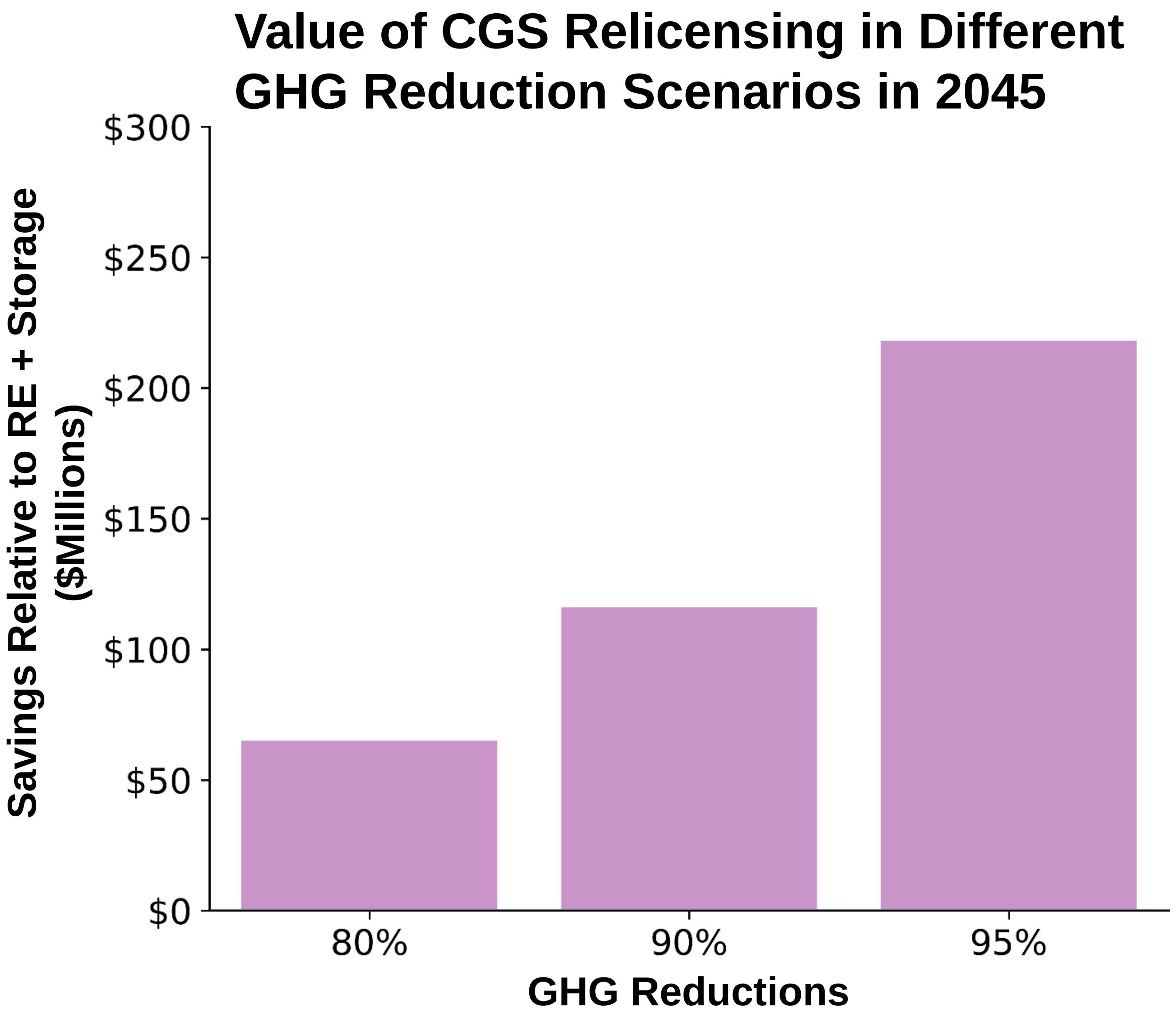
Year	Wind	Solar
2020	9 GW	0.03 GW
2045	15 GW	5 GW

Costs relative to Reference of achieving zero-GHG emissions in the Northwest electricity system



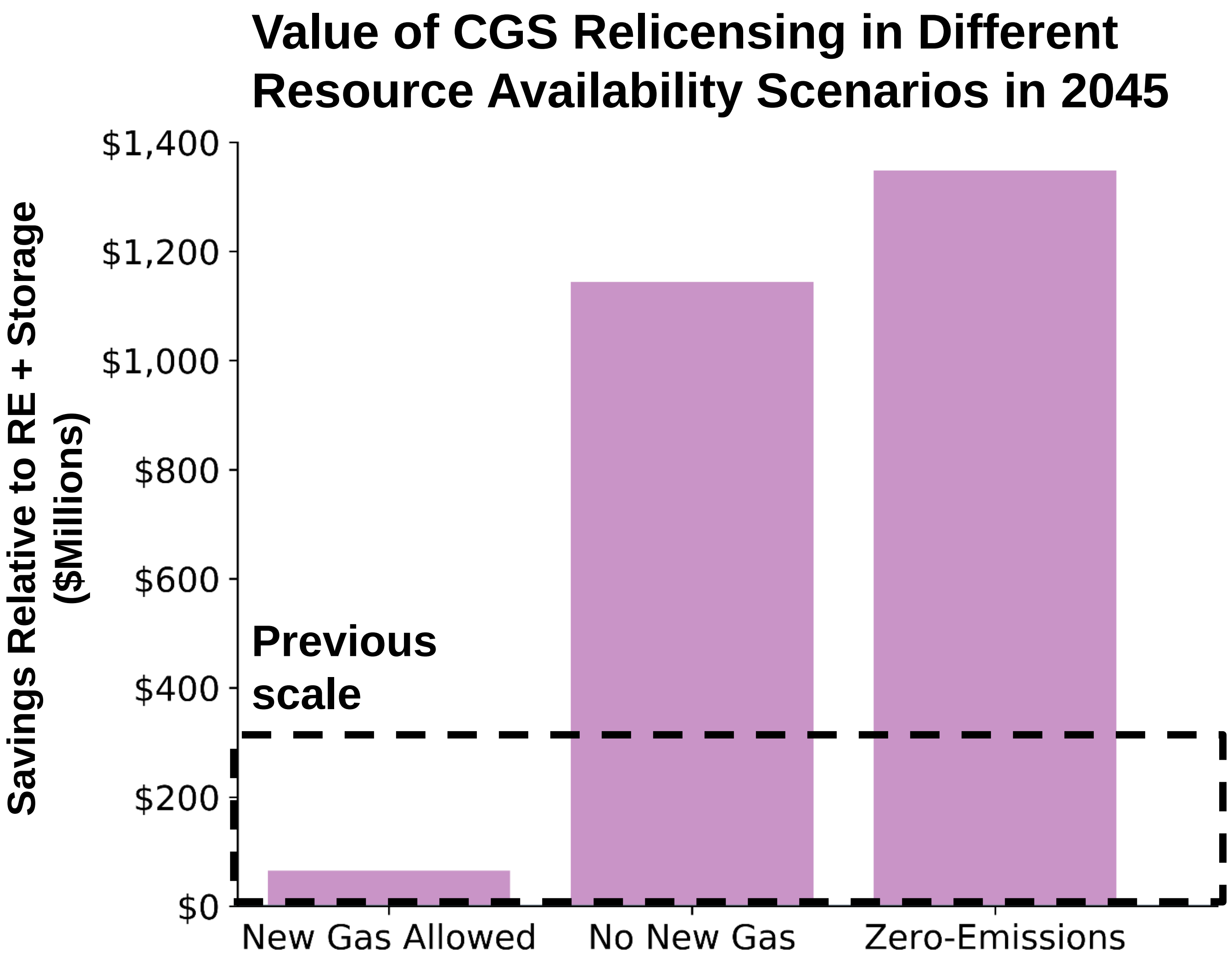
- Without zero-emitting firm capacity, the costs of eliminating electricity sector emissions in the region are likely prohibitively expensive
- If available, firm zero-emitting resources like biomethane or SMRs can lead to substantial cost reductions in a zero-emissions electricity system

Value of Existing Nuclear – GHG Policy

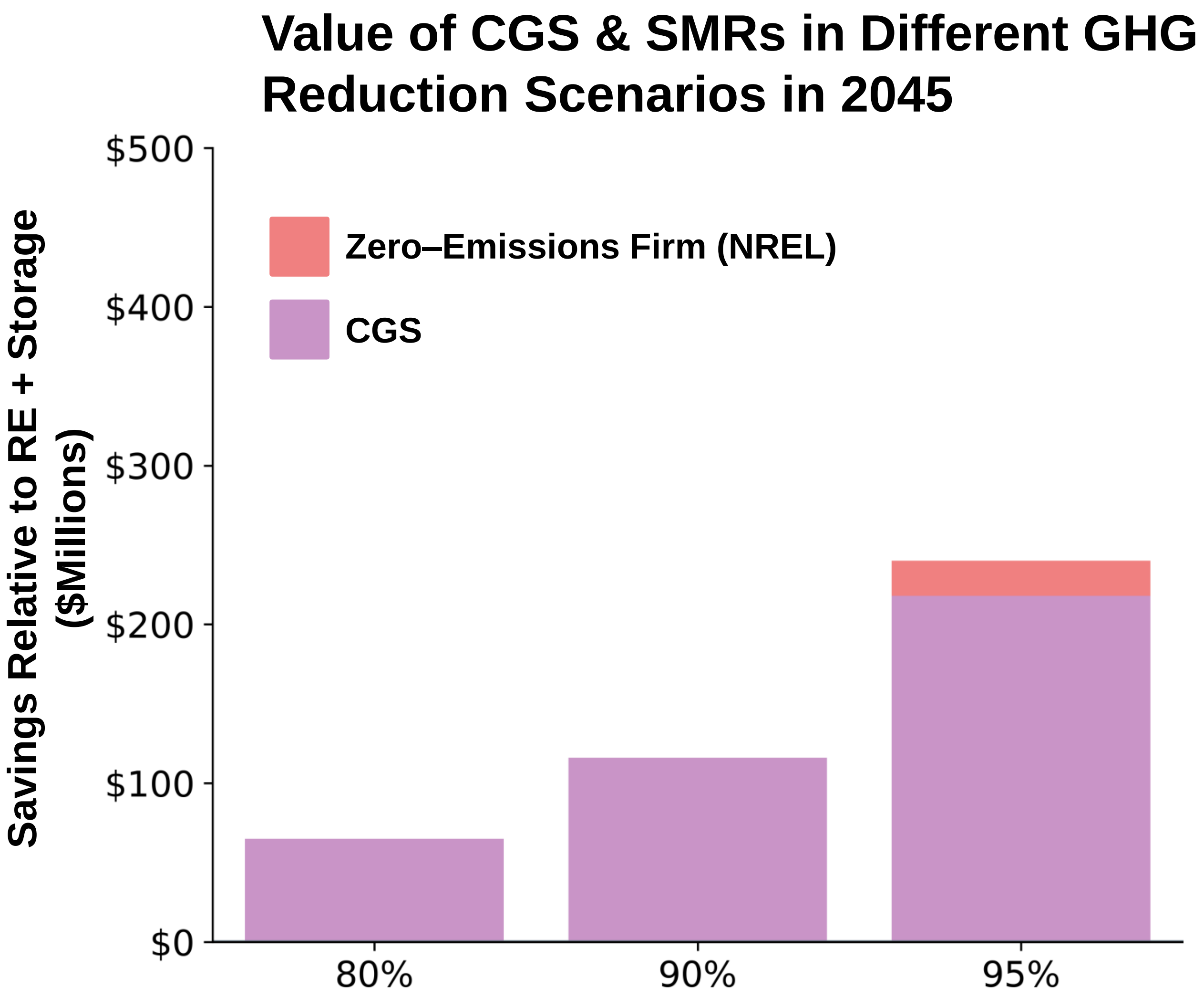


- CGS relicensing is selected in all scenarios, including the Reference case
- This figure shows the savings from CGS relative to a scenario that relies exclusively on renewables, storage and gas
- The value of CGS increases as the stringency of GHG emissions policy in the region tightens

Value of Existing Nuclear – Resource Availability

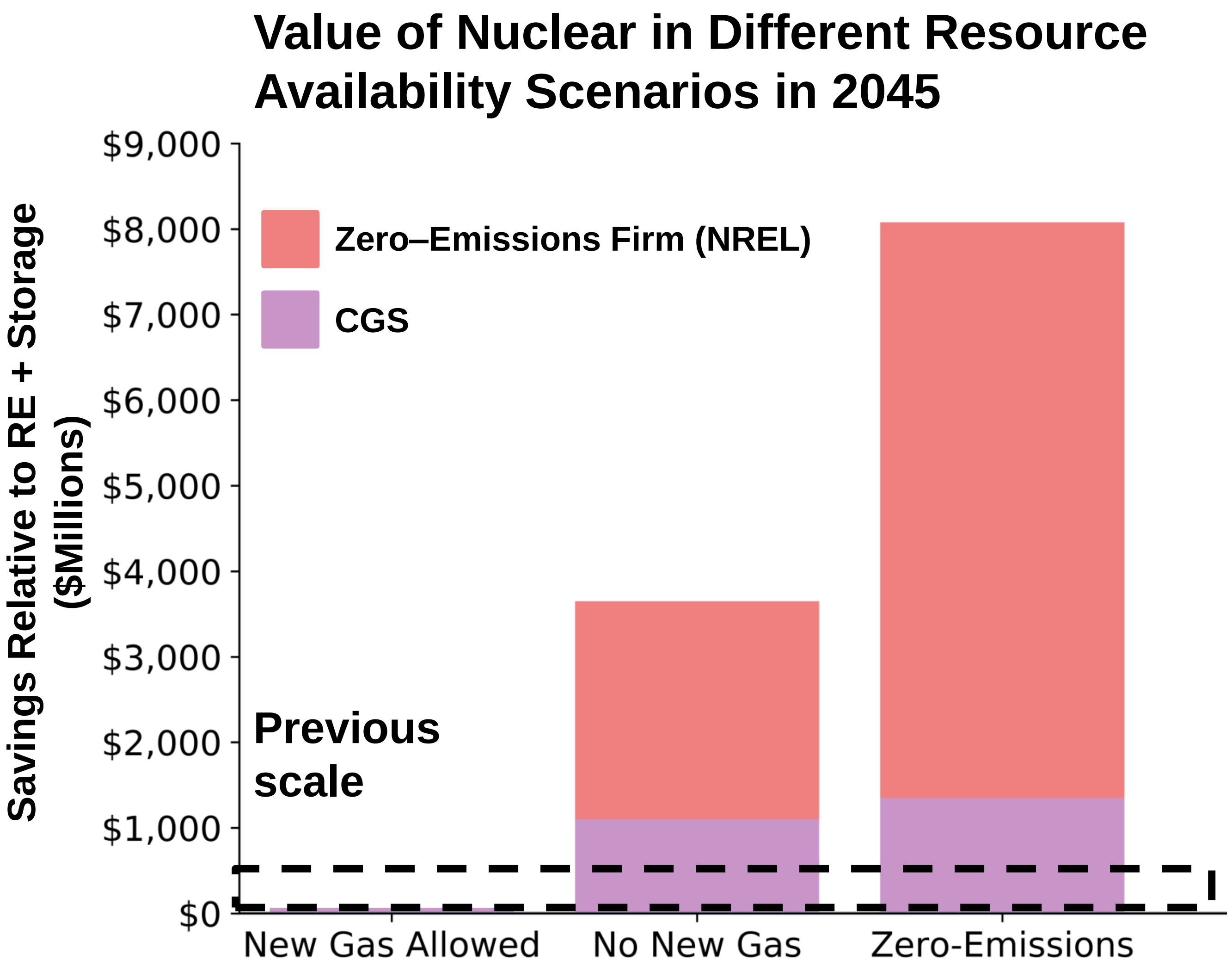


- The benefits of CGS relicensing increase markedly when gas generation is not available to backstop renewables
- Scenarios that rely primarily on renewables and storage typically include rarely used gas capacity to contain costs.
- In 2045, CGS relicensing produces up to $1.35 billion in annual savings.



- At NREL costs, SMRs are not built in the 80% and 90% GHG reduction cases.
- In those cases, it is less costly to build renewables and storage, backed by rarely used gas capacity
- SMRs begin to provide value in the 95% GHG reduction scenario. In that scenario, SMRs reduce the over-build of renewables and storage required to maintain a reliable system

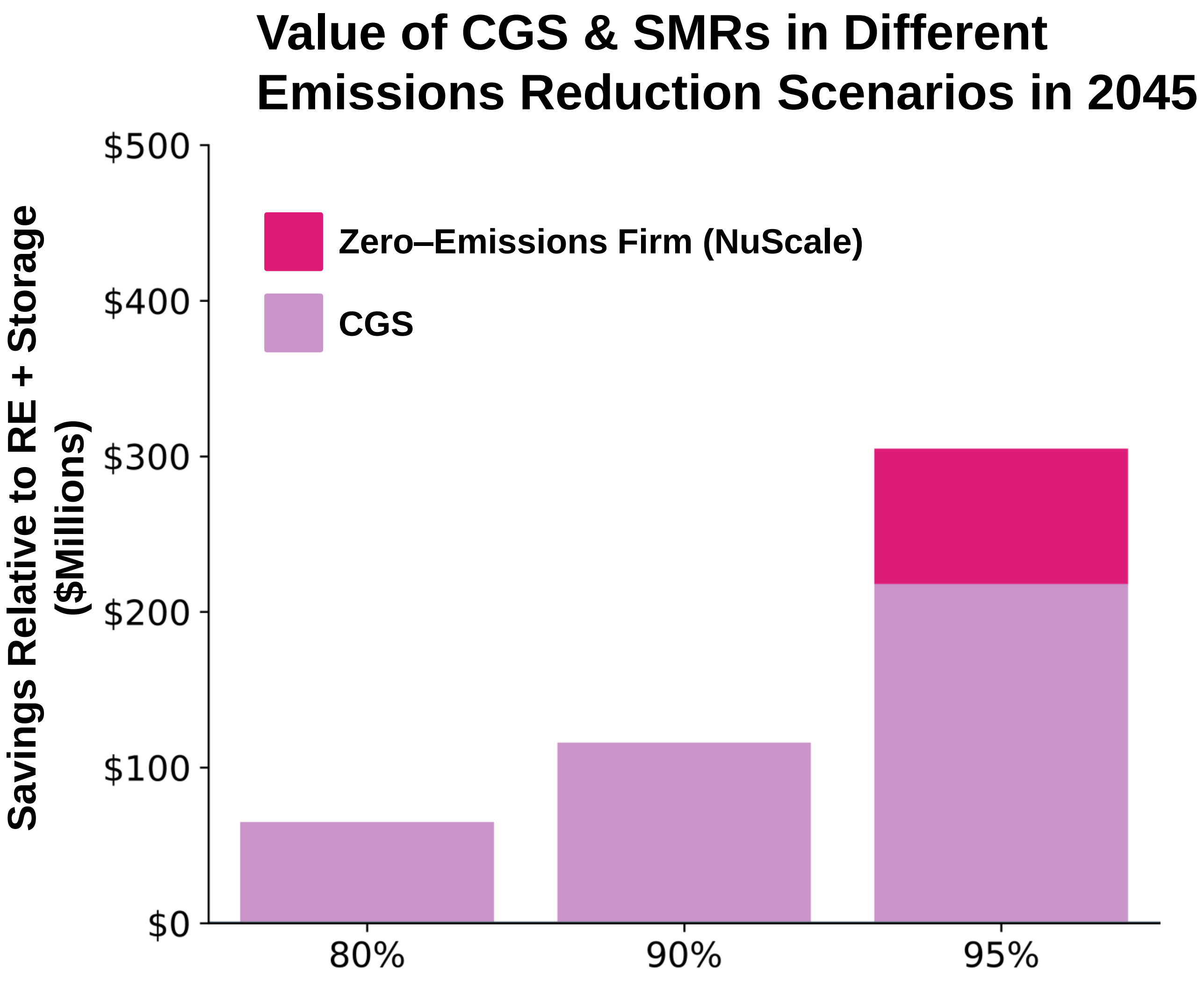
Value Zero-Emissions Firm – Resource Availability NREL SMR Costs



Note: values for “New Gas Allowed” and “No New Gas” are from the 80% GHG emissions reduction cases

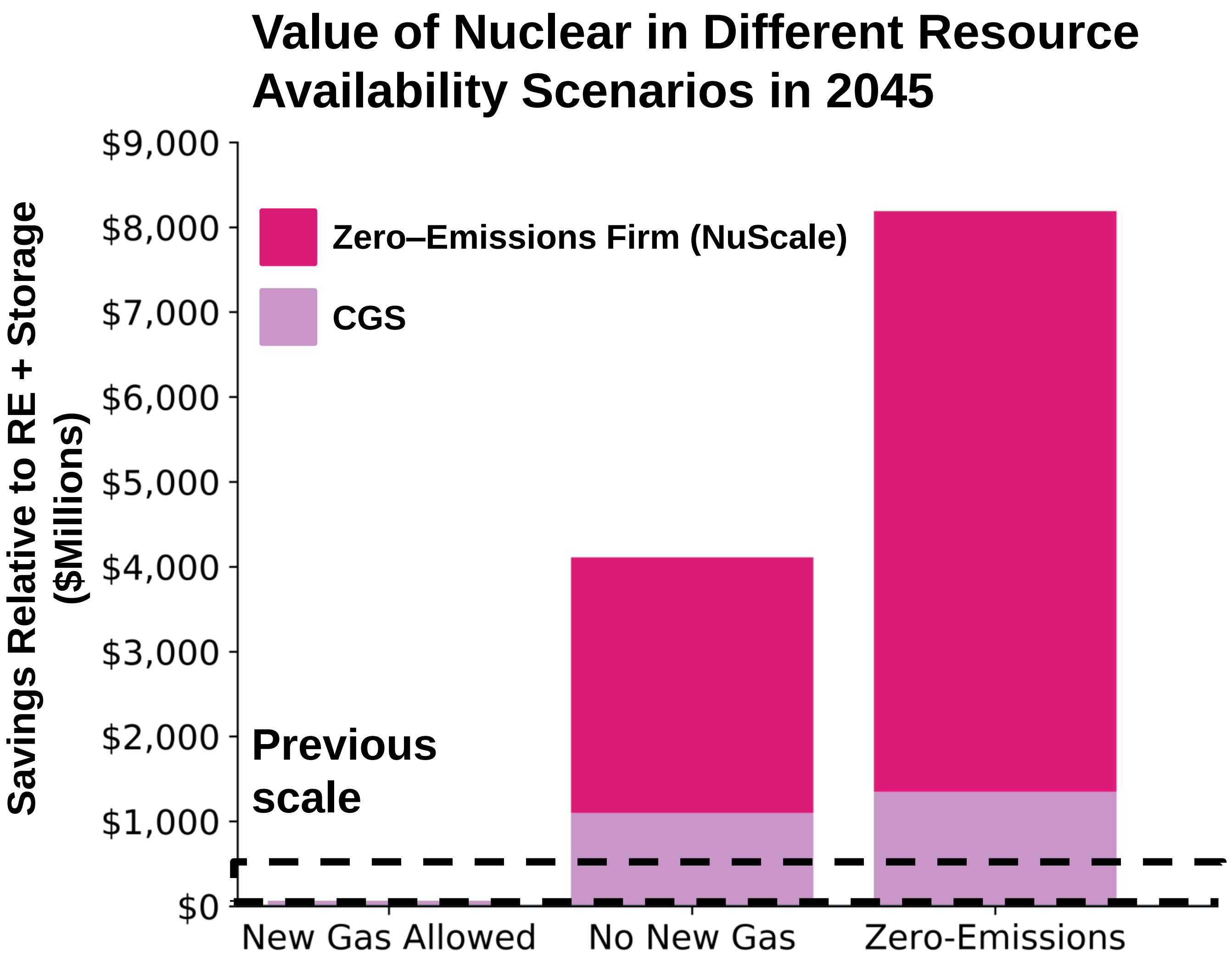
- The value of zero-emitting firm resources increase substantially if new gas generation cannot be built in the Northwest
- In the Zero-Emissions case, both biomethane and new nuclear resources are built to provide firm zero-emitting capacity

Value Zero-Emissions Firm – GHG Policy NuScale SMR Costs



- At NuScale costs, SMRs provide additional value in each emissions reduction scenario.
- The value of SMRs increases as emissions limits tighten due to their ability to provide both zero-emitting energy and capacity
- Those attributes become particularly valuable as emissions limits tighten because they allow for reduced overbuild of renewables and storage

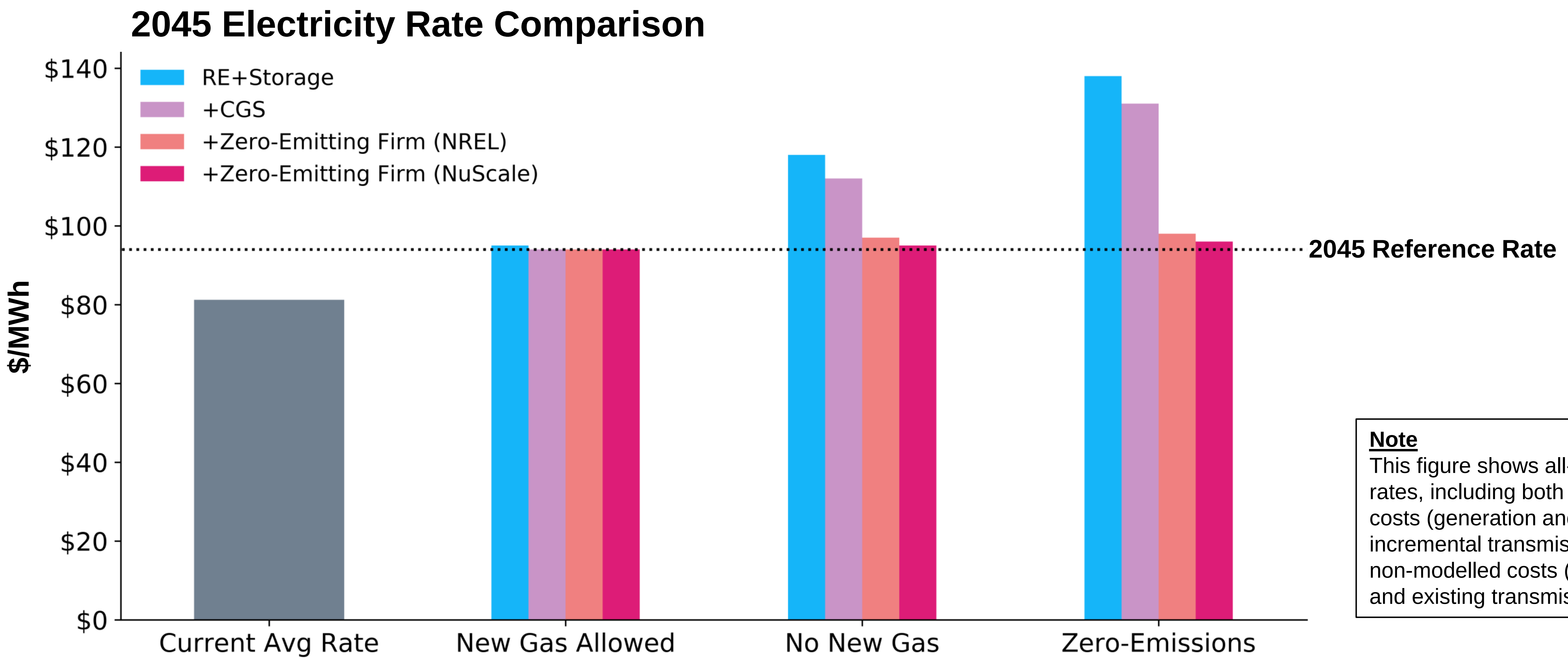
Value Zero-Emissions Firm – Resource Availability NuScale SMR Costs



Note: values for "New Gas Allowed" and "No New Gas" are from the 80% GHG emissions reduction cases

- If SMRs are available at NuScale costs, new nuclear provides value in all scenarios, including the New Gas Allowed case
- The value of SMRs increases markedly in the No New Gas and Zero-Emissions cases
- In those cases, new nuclear is the only zero-emitting firm resource added

Zero-emitting firm resources reduce electricity rates, particularly in scenarios with gas resource limitations



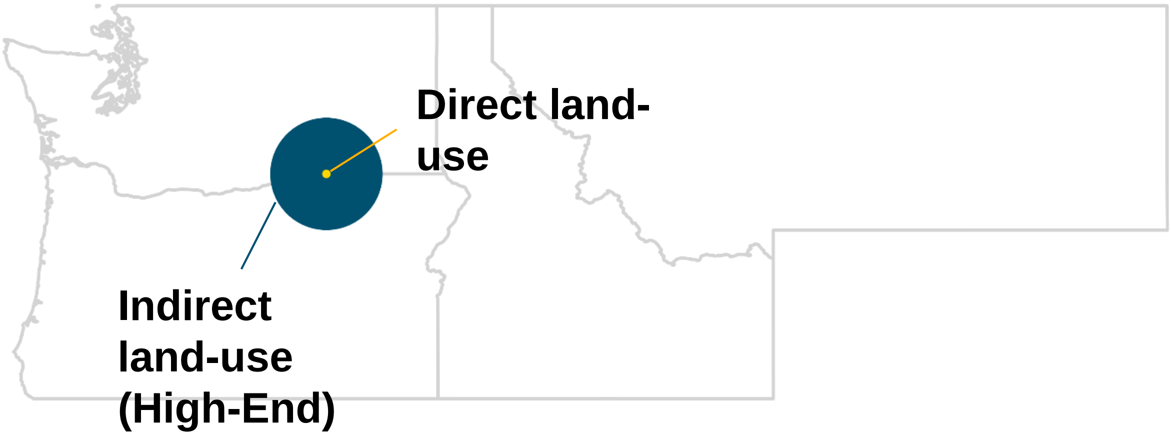
Note
This figure shows all-in retail rates, including both modelled costs (generation and incremental transmission) and non-modelled costs (distribution and existing transmission)

Additional Considerations: Transmission, Land-Use, and Qualitative Factors

Achieving zero-GHG emissions with renewables alone requires a large amount of land

Estimate of land use from renewables

Note: figure is to scale, but does not denote specific locations where renewables are built



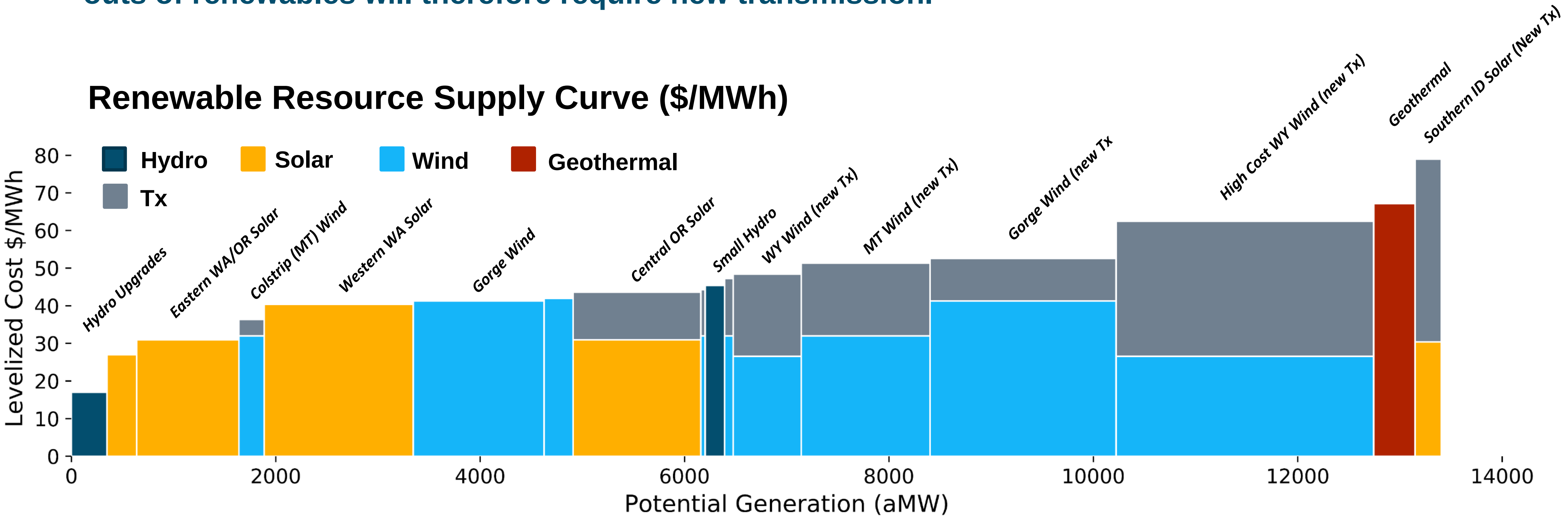
Direct land-use of wind and solar built to serve the Northwest are up to 2.5 times the area of Portland and Seattle

Indirect land-use of wind and solar are as high as 10 to 50 times the area of Portland and Seattle

+ **Land-use impacts are split into two categories:**
  - Direct: land that cannot be used for other purposes
    - 8000 acres/GW solar, 2000 acres/GW wind
  - Indirect: land that can be used for activities like ranching or agriculture
    - Up to 140,000 acres/GW wind

Transmission implications

+ New renewable generation tends to be located in regions of the Northwest and West that are distant from loads
+ While, some renewable resources can potentially repurpose transmission paths used by retiring thermal generators, the capacities of those existing paths are finite. Scenarios with large build outs of renewables will therefore require new transmission.



Transmission Requirements by Scenario

- The transmission requirements of each scenario depend on the amount renewables built
- In the highest case, the RE + Storage scenario, 79 GW of capacity requires new transmission to be deliverable to loads in a zero-GHG case
- Transmission requirements are substantially reduced in that case when firm zero-GHG resources are available

New Transmission Requirements

Scenario	Case	Capacity Requiring New Transmission
New Gas Allowed	NREL ATB	1.2 GW
	NuScale	1.2 GW
No New Gas	NREL ATB	0.7 GW
	NuScale	0.6 GW
Zero-GHG	RE + Storage	79 GW
	NREL ATB	0.7 GW
	NuScale	0.6 GW

- This study does not include a complete accounting of incremental transmission requirements of connecting zero-emitting firm resources. The transmission needs of these resources will depend on the degree to which they can be built at existing sites or near to existing paths.

Qualitative Non-Modelled Impacts of Resource Groups

	Variable Renewables and Batteries	Nuclear Technology Resources	Fossil-Based, Low-Carbon Resources
Land Use Requirement	High Low energy density of solar and wind require large surface coverage.	Low SMRs can be sited at existing nuclear generation sites or on limited land area as a result of high energy density of SMR units.	Mid Fossil fuel extraction, carbon sequestration and biomethane growth (assumed from waste crops and residues).
Waste Impact	Mid Variety of materials required for PV, wind turbine build, and Li-ion batteries; potential waste challenges for failed PV and end-of-life Li-ion batteries and wind turbines.	Mid Used nuclear fuel storage technology well-developed and highly regulated and can be safely stored on site in cast iron tanks for 100+ years; heavy materials required for new units.	High GHGs and non-GHG pollutants resulting from combustion.
Resiliency	Good Renewables diffuse the impact of a single outage due to modular units.	Good Low volatility of uranium price, fuel on-site, SMRs further limit the impact of a single unit outage; nuclear plants designed to withstand severe weather events.	Average Subject to volatility of natural gas prices, including policy exposure, and availability of resource via Northern pipeline.
Equipment lifetime	Wind turbines - 25-30 yrs; Solar PV panels - 25-30 yrs w/ inverter replacement every 15 years; Li-ion batteries - 10-15 yrs, function of number of total cycles.	SMRs are licensed for 40 years and likely renewable to 60 years and perhaps beyond.	Gas generating plants are typically designed to last 35-40 yrs but can be recommissioned to last 60 + years.
State & Federal Incentives	ITC (end 2021) & PTC (end 2022)	Federal PTC and incentives for nuclear technology development	45Q tax credit for carbon sequestration

Energy+Environmental Economics

Conclusions

Differences from 2017 PGP Study

Scenarios and Assumptions

- Assumes coal retirements in the Reference case to reflect CETA and Coal to Clean
- Examines beyond 80% GHG emissions reductions
- Updated resource costs for renewables and storage
- Addition of zero-GHG generation resources, including:
  - Biomethane
  - Carbon capture and sequestration
  - Nuclear small modular reactors
- Incorporation of effective load carrying capability for findings for renewables, storage and demand response from *Resource Adequacy in the Pacific Northwest*

Key Results

- The Reference case achieves greater than 100% of loads served with zero-GHG resources & 76% GHG reduction from 1990 levels
- A relatively small amount of SMRs are selected at deep (> 95% below 1990 levels) emissions reduction levels when using NREL costs. The role of SMRs expands if NuScale costs are realized, a PTC is available or if new gas generators cannot be built in the NW
- 100% GHG reductions in the electricity sector can be achieved at manageable cost, but only if firm zero-emissions technologies become commercially available.

3 Key Takeaways

1. **Relicensing Columbia Generating Station reduces costs in all scenarios under best-available relicensing cost estimates**
   - The value of relicensing CGS falls between $75 Million to $1.35 Billion annually in 2045
2. **The role of SMRs in the Northwest's future electricity system depend on cost assumptions**
   - At NREL ATB costs, SMRs are only built in the most stringent emissions reduction or constrained land-use cases, the role of SMRs expands at NuScale costs and if the Northwest can capture the Nuclear Production Tax Credit
3. **The value of zero-emitting firm capacity resources are highest in scenarios where natural gas generation cannot be built**
   - Firm zero-emitting resources (CGS, biomethane powered gas generators, and SMRs) reduce costs by up to $8 billion annually when natural gas cannot be used to provide peak capacity

Thank You

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