2019 IRP DRAFT
SOCIAL COST OF CARBON PORTFOLIO RESULTS

PSE PUGET SOUND ENERGY

12/11/2019

WEBINAR

Conclusions

1. Renewable resources required to comply with CETA is the key constraint driving the new portfolio resource additions.

2. With the CETA renewable requirement, the application and the value of **social cost of carbon** has little to no effect on portfolio resource additions.

3. With the CETA renewable requirement, significantly more conservation is added than the 2017 IRP.

Overview

- Baseline portfolio inputs and assumptions
- CETA renewable resource requirements
- Social costs of carbon modeling application
- Portfolio results:
  - Resource additions
  - Total and annual portfolio costs

IRP Scenarios

Scenario	Demand	Gas Price	CO_2 price/Regulation	RPS/Clean Energy Regulation
1. Base	Mid	Mid	**CO_2 price:** CA AB32, and BC **CO_2 Regulation:** Social Cost of Carbon and upstream natural gas GHG in WA	WA CETA plus all other state regulations in the WECC
2. Low	Low	Low	**CO_2 price:** CA AB32, and BC **CO_2 Regulation:** Social Cost of Carbon and upstream natural gas GHG in WA	WA CETA plus all other state regulations in the WECC
3. High	High	High	**CO_2 price:** CA AB32, and BC **CO_2 Regulation:** Social Cost of Carbon and upstream natural gas GHG in WA	WA CETA plus all other state regulations in the WECC
4. Base + CO_2 tax	Mid	Mid	CO_2 Price: SCC applied to all thermal plants in WECC	WA CETA plus all other state regulations in the WECC

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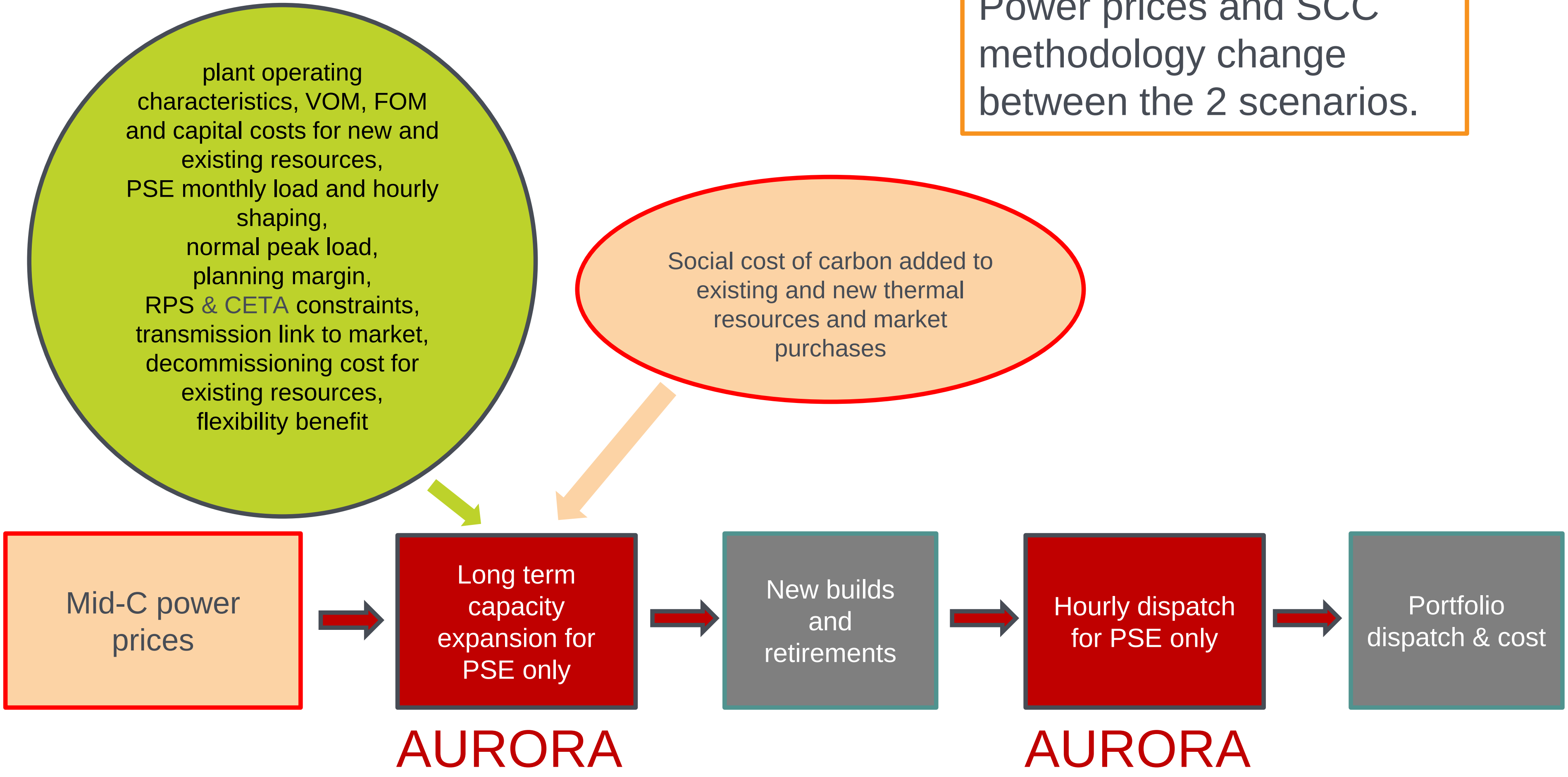
IRP Portfolio Model

- Aurora long term capacity expansion model evaluates **the total portfolio costs** and risks of a wide variety of resource alternatives and portfolio strategies.
- The optimization model is a mixed integer linear programing model.
- The portfolio model is used to identify the least cost portfolio resource additions in a given market scenario.
- The annual portfolio costs are the costs that flow to customers.

IRP Portfolio Modeling Process

Power prices and SCC methodology change between the 2 scenarios.



plant operating characteristics, VOM, FOM and capital costs for new and existing resources,
PSE monthly load and hourly shaping,
normal peak load,
planning margin,
RPS & CETA constraints,
transmission link to market,
decommissioning cost for existing resources,
flexibility benefit

Social cost of carbon added to existing and new thermal resources and market purchases

Mid-C power prices → Long term capacity expansion for PSE only → New builds and retirements → Hourly dispatch for PSE only → Portfolio dispatch & cost

AURORA

AURORA

Draft portfolio modeling assumptions are the same for both scenarios

Inputs	Assumptions
Time horizon	The original time horizon for the 2019 IRP was 2020 – 2039, but the time frame was updated to 2020 – 2045 to better understand the implications of CETA for the electric analysis. Because work had started on the electric analysis for data through 2039, the data was extended by trending the remaining six years to 2045. This trend is applied to PSE's electric demand forecast, gas prices, power prices, and electric DSR savings.
Demand	The 2019 IRP Base (Mid) Demand Forecast is applied for PSE in the portfolio model.
Natural gas price	Mid gas prices are applied, a combination of forward market prices and Wood Mackenzie's Fall 2018 fundamental long-term base forecast. Levelized 20-yr Sumas gas price is \$3.56/MMBtu.
CETA Constraint	At least 80% of delivered load must be met with renewable or non-emitting resources by 2030 and 100% by 2045. Colstrip units 3 and 4 retire by 12/31/2025.
Upstream emissions	For natural gas generation fuel, upstream CO_2 emissions are added to the emission rate of natural gas plants in PSE's portfolio model. The upstream segment of 10,803 g/MMBtu from GREET model is converted to 23 lb/mmBtu and then applied to the emission rate of gas plants.
Economic Retirement	The portfolio model allows for economic retirement of existing resources. Colstrip units 1 and 2 retire 12/31/2019.

Draft portfolio modeling assumptions are the same for both scenarios

THERMAL RESOURCES									
IRP Modeling Assumptions (2018 $)	Nameplate (MW)	First year available	Fixed O&M ($/kw-yr) [6]	Variable O&M ($/MWh)	Baseload Heat Rate[2] (Btu/kWh)	Capital Costs ($/kw)			
						EPC[3]	Owner's Costs[4]	Interconnection[5]	Total
F-Class CCCT 1x1 with Duct Fire (DF)	355	2022	$13.44	$2.45	6,624	$853	$221	$94	$1,167
Frame Peaker Duel-fueled 1x0 with Oil Backup	225	2021	$11.40	$0.69	9.904	$554	$131	$139	$825
Recip Peaker NG only 12x0	219	2021	$3.74	$5.30	8,445	$842	$201	$148	$1,192

NOTES

1. Expected capacity factor for wind, solar and biomass; for thermal resources, the capacity factor is dependent on dispatch cost for the scenario.

2. Heat rate for CCCT is for the primary unit, the heat rate for the secondary duct firing is expected to be 8,867 Btu/kWh.

3. EPC stands for engineer, procure, construct and is what is usually referred to as "overnight costs"

4. Owner's costs include all the financing and AFUDC

5. Interconnection costs includes the transmission, substation and gas pipeline infrastructure. Interconnection cost of offshore wind only includes onshore interconnection and does not include the cost of the marine cable to shore.

6. The fixed O&M costs for the Lithium-Ion battery include costs associated with maintaining capacity for the 20-yr life with no degradation. The fixed O&M costs for the Frame Peaker include 48 hours of oil.

Draft portfolio modeling assumptions are the same for both scenarios

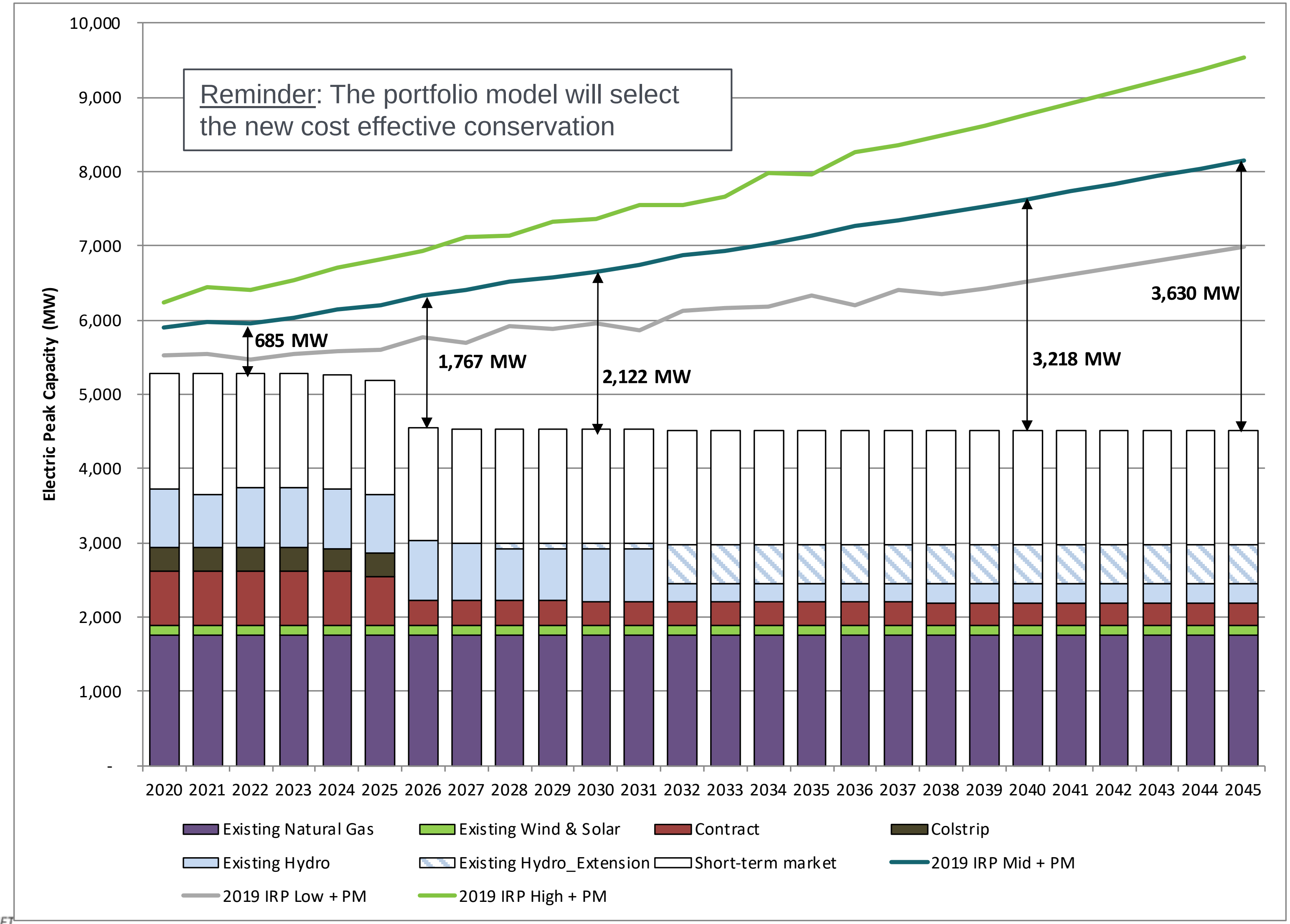
RENEWABLE AND ENERGY STORAGE RESOURCES									
IRP Modeling Assumptions (2018 $)	Nameplate (MW)	First year available	Capacity Factor[1] (%)	Fixed O&M ($/kw-yr)[6]	Variable O&M ($/MWh)	Capital Costs ($/kw)			
						EPC[3]	Owner's Costs[4]	Interconn-ection[5]	Total
WA Wind Plant	100	2022	46%	$37.00	$0.00	$1,410	$226	$86	$1,722
MT Wind Plant	300	2022	46%	$37.00	$0.00	$1,354	$217	$46	$1,617
Offshore Wind	300	2025	35%	$120.00	$0.00	$5,000	$1,480	$67	$6,547
Central Station Solar Tracking PV	100	2022	24%	$27.19	$0.00	$1,338	$174	$103	$1,614
Biomass	15	2021	85%	$345.20	$6.60	$7,036	$2,031	$628	$9,695
2-hour Lithium-Ion Battery	25	2021	N/A	$20.54	$0.00	$1,331	$219	$380	$1,930
4-hour Lithium-ion Battery	25	2021	N/A	$32.16	$0.00	$2,346	$334	$380	$3,059
4-hour Flow Battery	25	2021	N/A	$30.80	$0.00	$1,493	$239	$380	$2,111
6-hour Flow Battery	25	2021	N/A	$40.27	$0.00	$2,050	$328	$380	$2,758
Pumped Storage Hydro	500	2025	N/A	$14.55	$0.90	$1,800	$812	$49	$2,661
Central Station Solar Tracking PV + 2-hr Lithium-Ion Battery	100 Solar + 25 Battery	2022	24%	$42.44	$0.00	$2,669	$393	$103	$3,164

Modeling Constraint: Peak Capacity Need

The portfolio model must meet the peak capacity need and has two components:

1. Customer Demand
   - Peak capacity need is a one-hour system peak in December.
2. Planning Margin (PM)
   - A 5% LOLP, including operating reserves, results in a 17.8% planning margin. The planning margin increases to 18.3% in 2026 after Colstrip Units 3 and 4 are removed from the energy supply portfolio.

Resource adequacy analysis resulted in a 685 MW capacity deficit in 2022 (before conservation)



Reminder: The portfolio model will select the new cost effective conservation

Modeling Constraint: Energy Need

- PSE must meet load requirements in every hour.
  - This constraint takes the monthly and annual demand forecast and shapes it to PSE’s hourly load.

- The Aurora dispatch model will make sure that loads are met in every hour by either dispatching resources or purchasing from market, whatever is lowest cost.
  - Market is limited to the available transmission.
  - If there is not enough renewable resources or transmission for market purchases, then the model will dispatch resources un-economically for reliability.

- The long term capacity expansion model can also add new resources based on PSE’s needs and the lowest cost way to make sure the portfolio stays balanced.

Modeling Constraint: Renewable Need

The Clean Energy Transformation Act requires utilities to:

2030: carbon neutral energy supply

- At least 80% of delivered load must be met by non-emitting and renewable resources
- Up to 20% alternative compliance options

2045: carbon free energy supply

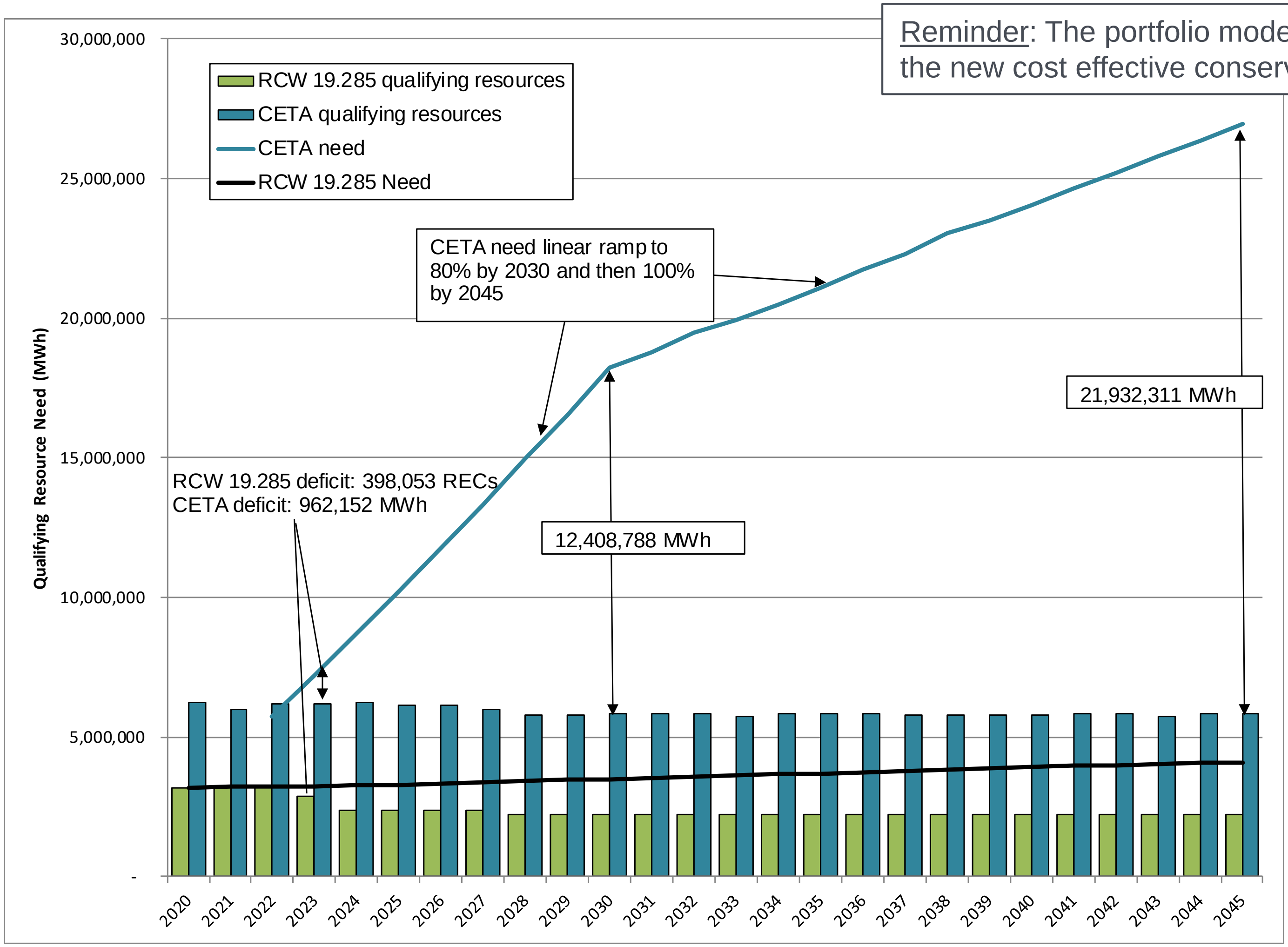
- 100% of delivered load must be met by non-emitting and renewable resources

- CETA requirement is modeled as a linear ramp to 80% by 2030 and then 100% by 2045.
- The CETA renewable need is expressed as a minimum annual energy constraint. The portfolio model is required to build enough renewable resources on an annual basis to meet the annual energy constraint.
- CETA compliance is modeled as:

Annual renewable energy (MWh) >= Annual delivered load (MWh)

Renewable need modeled

Renewable resource need/REC need for RCW 19.285 and CETA



CETA need linear ramp to 80% by 2030 and then 100% by 2045

RCW 19.285 deficit: 398,053 RECs
CETA deficit: 962,152 MWh

12,408,788 MWh

21,932,311 MWh

Reminder: The portfolio model will select the new cost effective conservation

Draft SCC Modeling Assumptions

1. SCC as fixed cost adder
    1) Thermal plants
        - Step 1: run dispatch of plant
        - Step 2: calculate emission cost for each year:

          CO_2 emissions (tons) * SCC ($/ton) = emission cost ($)
        - Step 3: add emission cost ($) from step 2 to FOM
        - Step 4: run portfolio model for optimal portfolio results
    2) Unspecified market purchases

       SCC ($/ton) * emission rate (ton/MWh) = adder ($/MWh)

2. SCC as a tax is applied as a traditional CO_2 tax in WECC wide run for power prices and in PSE's portfolio model.

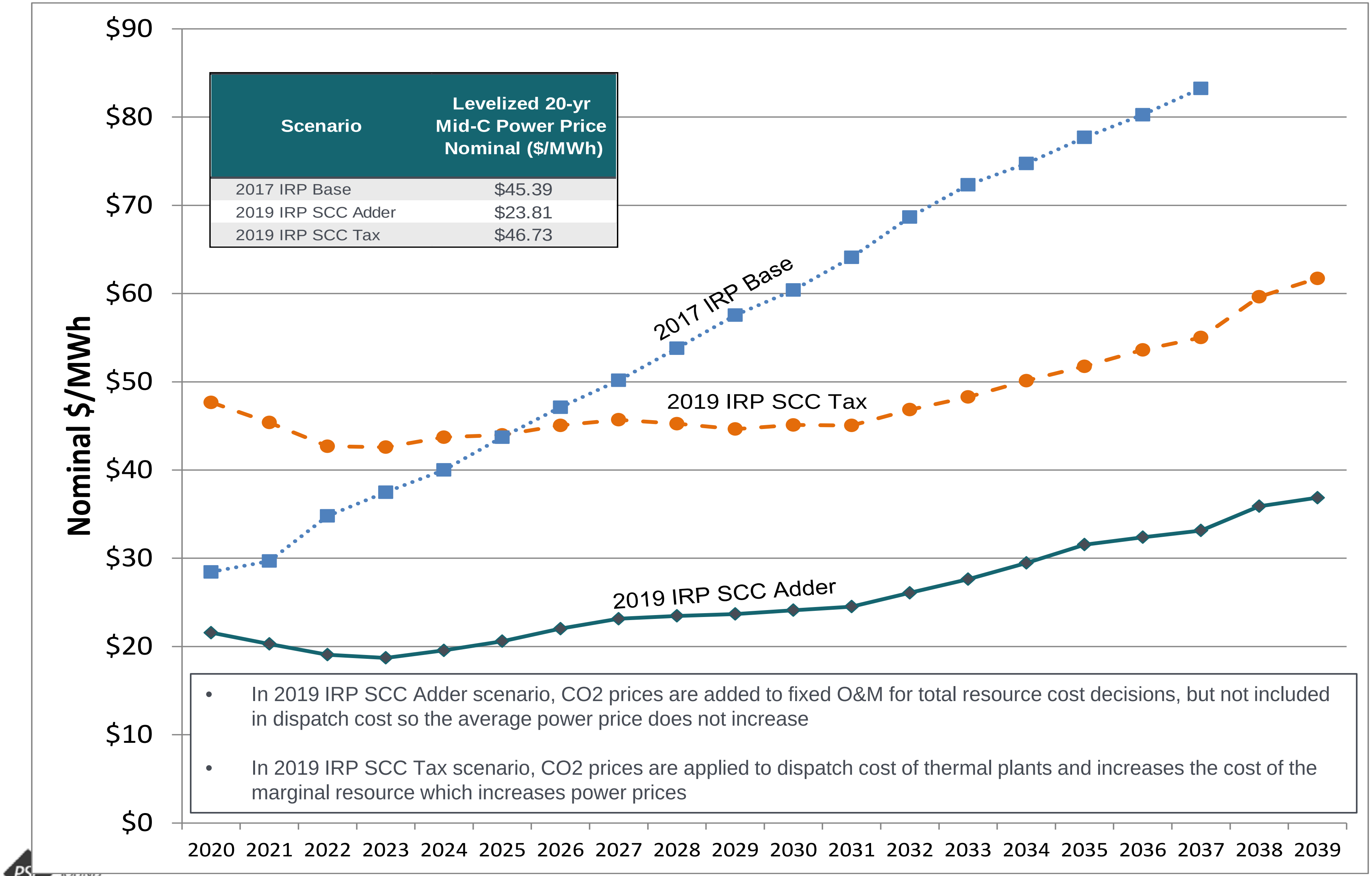
Draft portfolio modeling assumptions that change between scenarios

Inputs	SCC as Adder	SCC as Tax
Power prices	Uses Mid-C Power Price forecast where the SCC is applied as an adder for new thermal resources in the PNW. Levelized 20-yr Mid-C Power Price is $23.81.	Uses Mid-C Power Price forecast where the SCC is applied as a tax for new and existing thermal resources across the WECC. Levelized 20-yr MidC Power Price is $46.73.
Modeling application	Applied as an adder to the fixed O&M for existing and new thermal plants during the Long Term Capacity Expansion run when the model determines resource retirements and new build decisions.	Applied as a traditional CO_2 tax to existing and new thermal plants during the Long Term Capacity Expansion run when the model determines resource retirements and new build decisions.
Inclusion in Hourly Dispatch for calculation of Portfolio Costs	The adder is not included in the hourly dispatch.	The SCC as a tax is included in the dispatch of existing and new thermal plants.

Draft portfolio modeling assumptions that change between scenarios

Inputs	SCC as Adder	SCC as Tax
Emission rate on system purchases	PSE is using the 0.437 metric tons CO2/MWh for unspecified market purchases from Section 7 of E2SSB 5116, paragraph 2. The emission rate is held constant through 2045.	The power price forecast assumed in this scenario includes the social cost of carbon as a tax. Emissions rate on system purchases does not apply.
Social cost of carbon for system purchases	The social cost of carbon is added to the market price as a $/MWh when importing system purchases into PSE's portfolio. The model assumes that all system purchases are unspecified.	The power price forecast assumed in this scenario includes the social cost of carbon as a tax.
Social cost of carbon for contracts	Emissions costs for contracts are calculated by taking the emission rate for unspecified market purchases multiplied by the social costs of carbon.	Emissions costs for contracts are calculated by taking the emission rate for unspecified market purchases multiplied by the social costs of carbon.

Annual Average Mid-C Power Price Forecast



Scenario	Levelized 20-yr Mid-C Power Price Nominal ($/MWh)
2017 IRP Base	$45.39
2019 IRP SCC Adder	$23.81
2019 IRP SCC Tax	$46.73

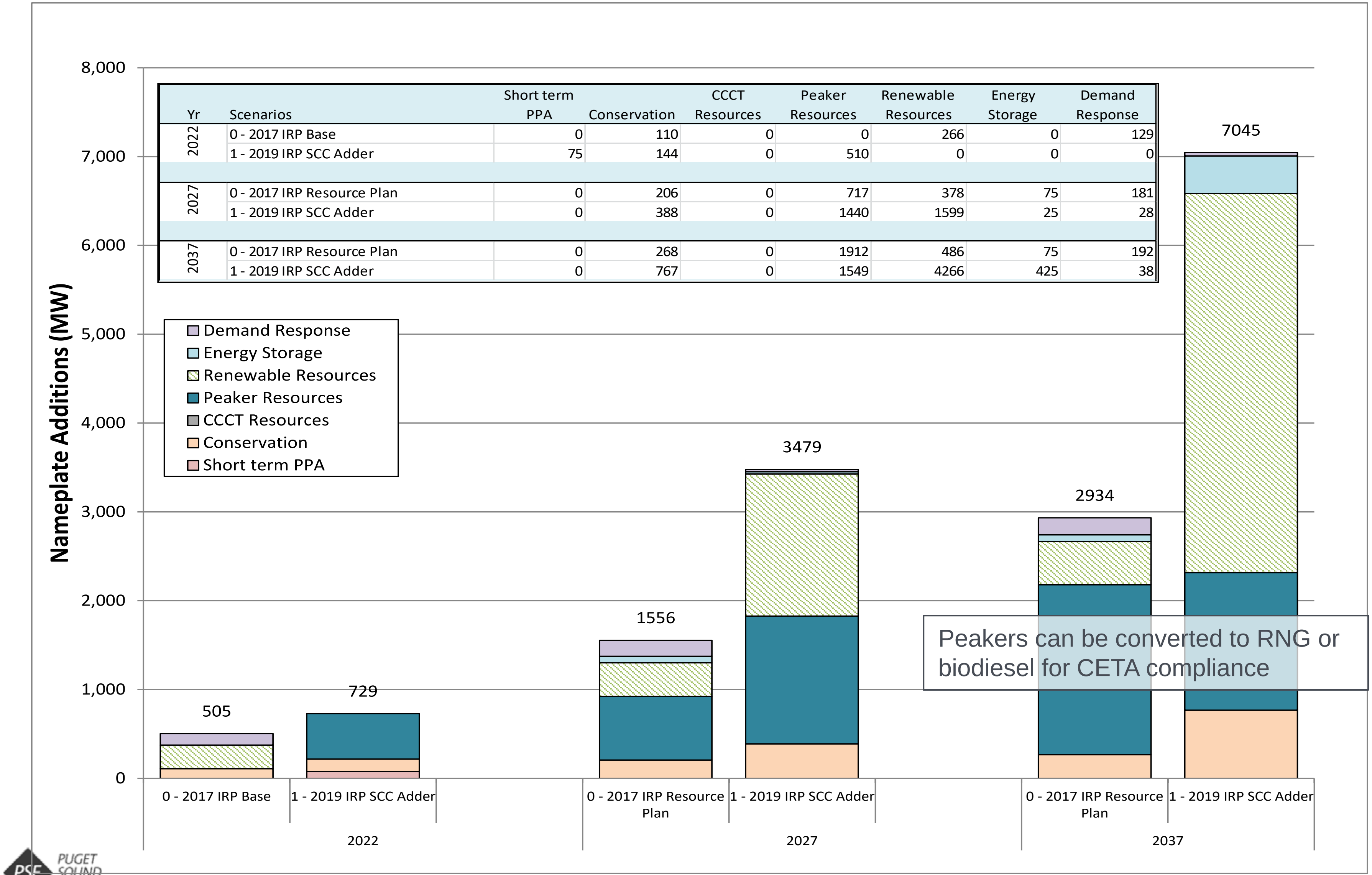
- In 2019 IRP SCC Adder scenario, CO2 prices are added to fixed O&M for total resource cost decisions, but not included in dispatch cost so the average power price does not increase
- In 2019 IRP SCC Tax scenario, CO2 prices are applied to dispatch cost of thermal plants and increases the cost of the marginal resource which increases power prices

CETA compliant scenarios

- All scenarios meet CETA renewable and non-emitting requirements.

- Scenario labels are applied to distinguish between key differences:
  1. SCC Adder
  2. SCC Tax
  3. No SCC

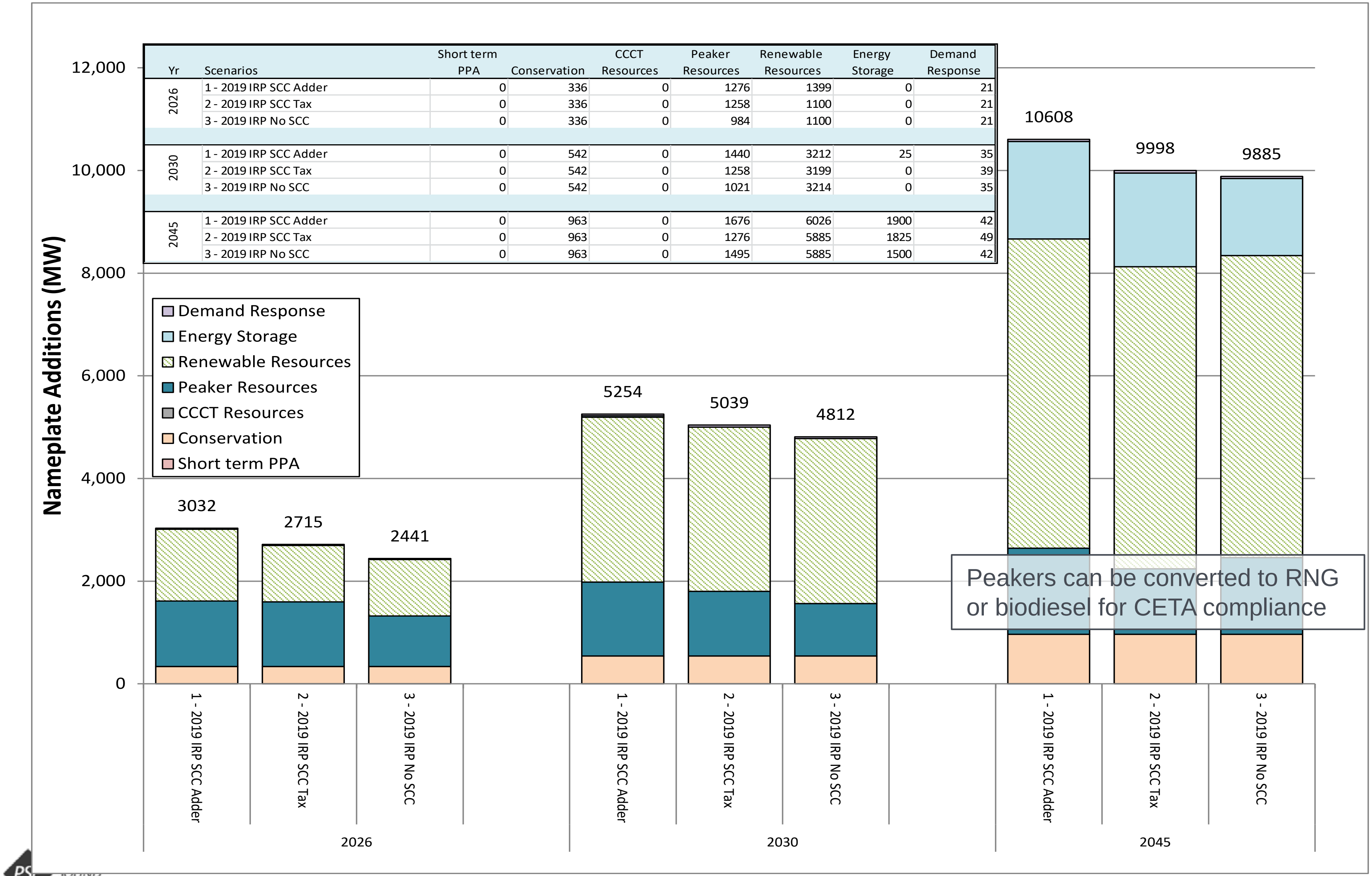
2017 IRP vs 2019 IRP SCC Adder new resource additions



Yr	Scenarios	Short term PPA	Conservation	CCCT Resources	Peaker Resources	Renewable Resources	Energy Storage	Demand Response
2022	0 - 2017 IRP Base	0	110	0	0	266	0	129
	1 - 2019 IRP SCC Adder	75	144	0	510	0	0	0
2027	0 - 2017 IRP Resource Plan	0	206	0	717	378	75	181
	1 - 2019 IRP SCC Adder	0	388	0	1440	1599	25	28
2037	0 - 2017 IRP Resource Plan	0	268	0	1912	486	75	192
	1 - 2019 IRP SCC Adder	0	767	0	1549	4266	425	38

Peakers can be converted to RNG or biodiesel for CETA compliance

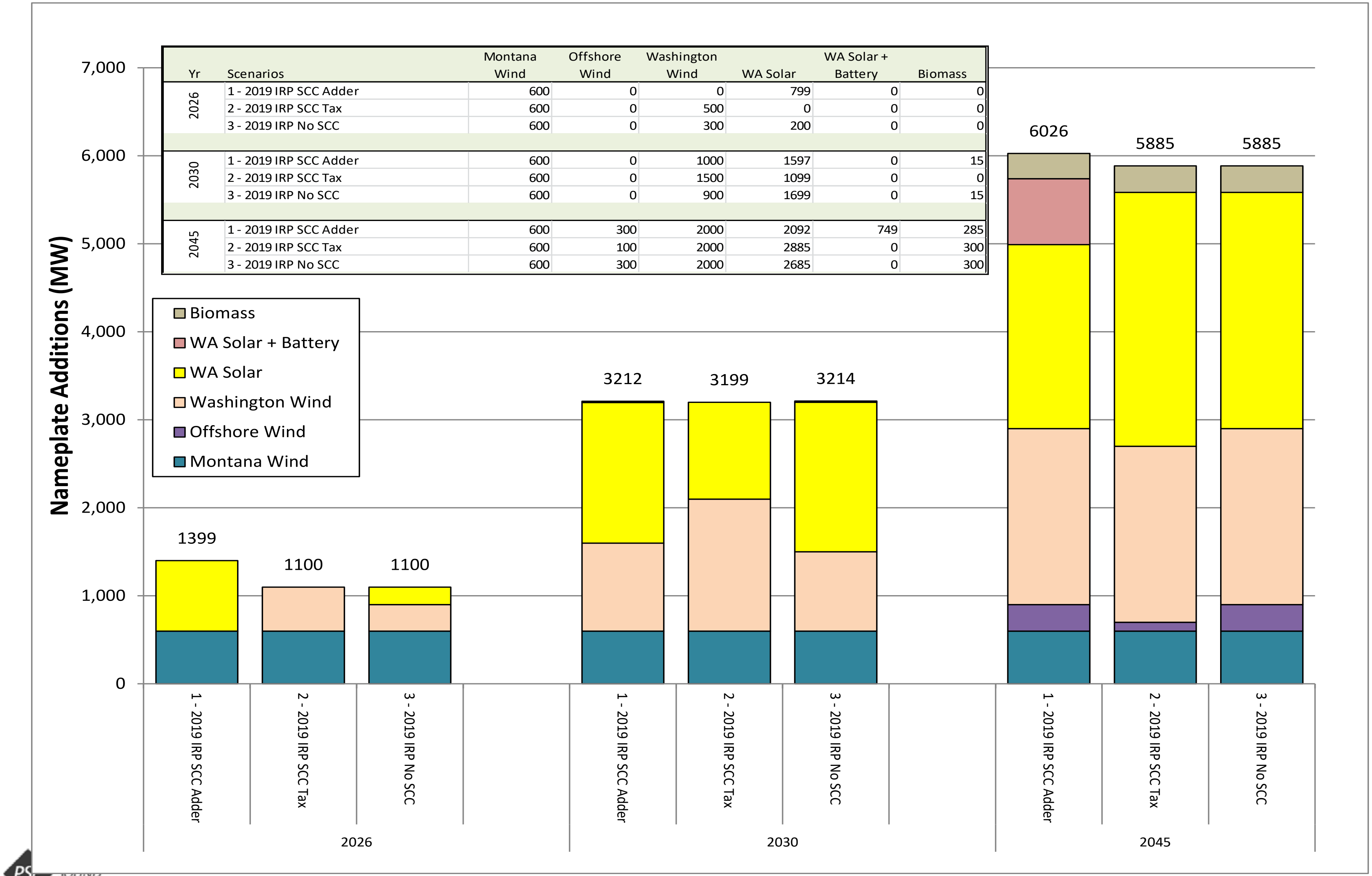
New resource additions for CETA compliant portfolios



Yr	Scenarios	Short term PPA	Conservation	CCCT Resources	Peaker Resources	Renewable Resources	Energy Storage	Demand Response
2026	1 - 2019 IRP SCC Adder	0	336	0	1276	1399	0	21
	2 - 2019 IRP SCC Tax	0	336	0	1258	1100	0	21
	3 - 2019 IRP No SCC	0	336	0	984	1100	0	21
2030	1 - 2019 IRP SCC Adder	0	542	0	1440	3212	25	35
	2 - 2019 IRP SCC Tax	0	542	0	1258	3199	0	39
	3 - 2019 IRP No SCC	0	542	0	1021	3214	0	35
2045	1 - 2019 IRP SCC Adder	0	963	0	1676	6026	1900	42
	2 - 2019 IRP SCC Tax	0	963	0	1276	5885	1825	49
	3 - 2019 IRP No SCC	0	963	0	1495	5885	1500	42

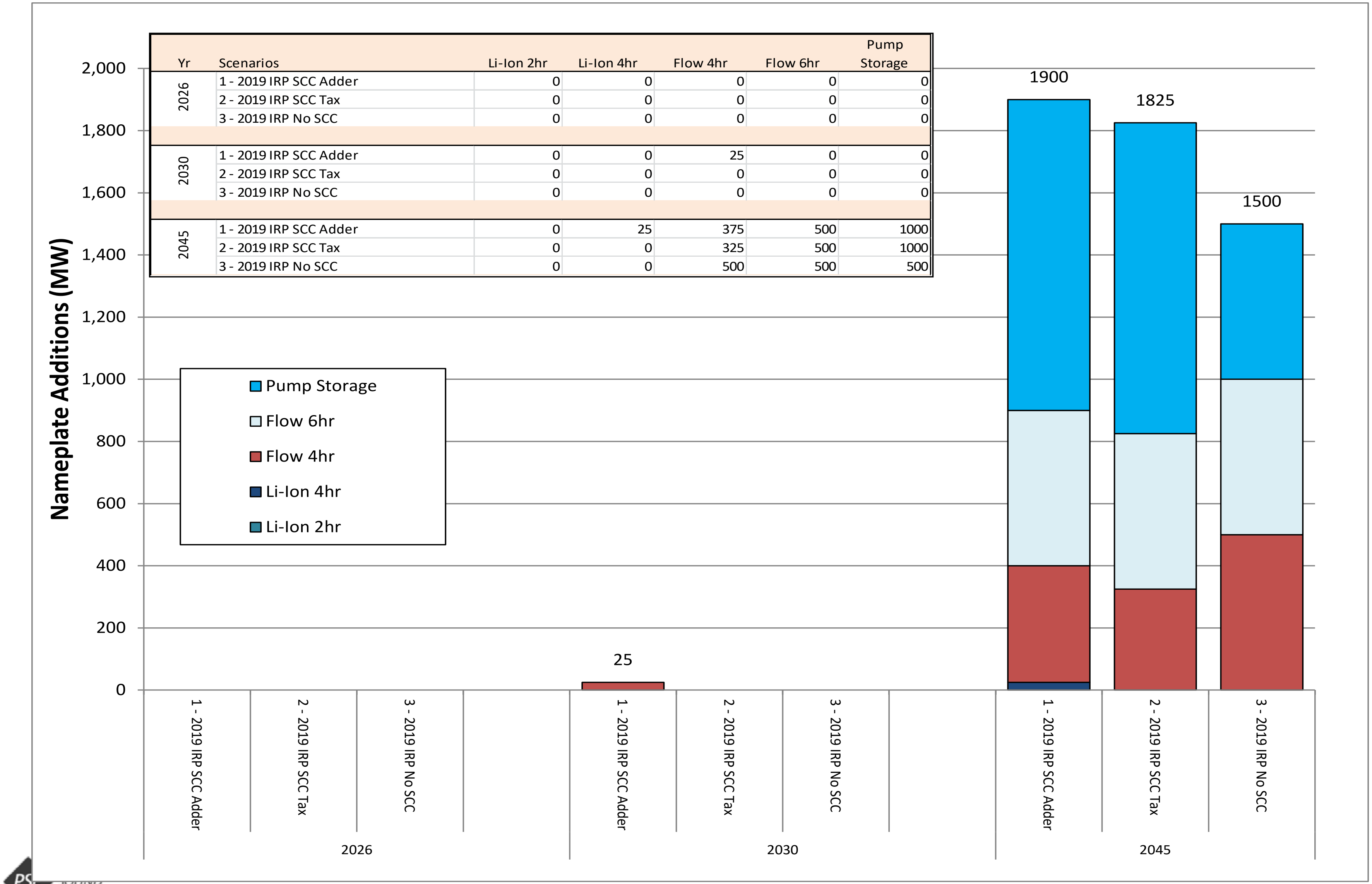
Peakers can be converted to RNG or biodiesel for CETA compliance

A closer look at renewable resource additions for CETA compliant portfolios



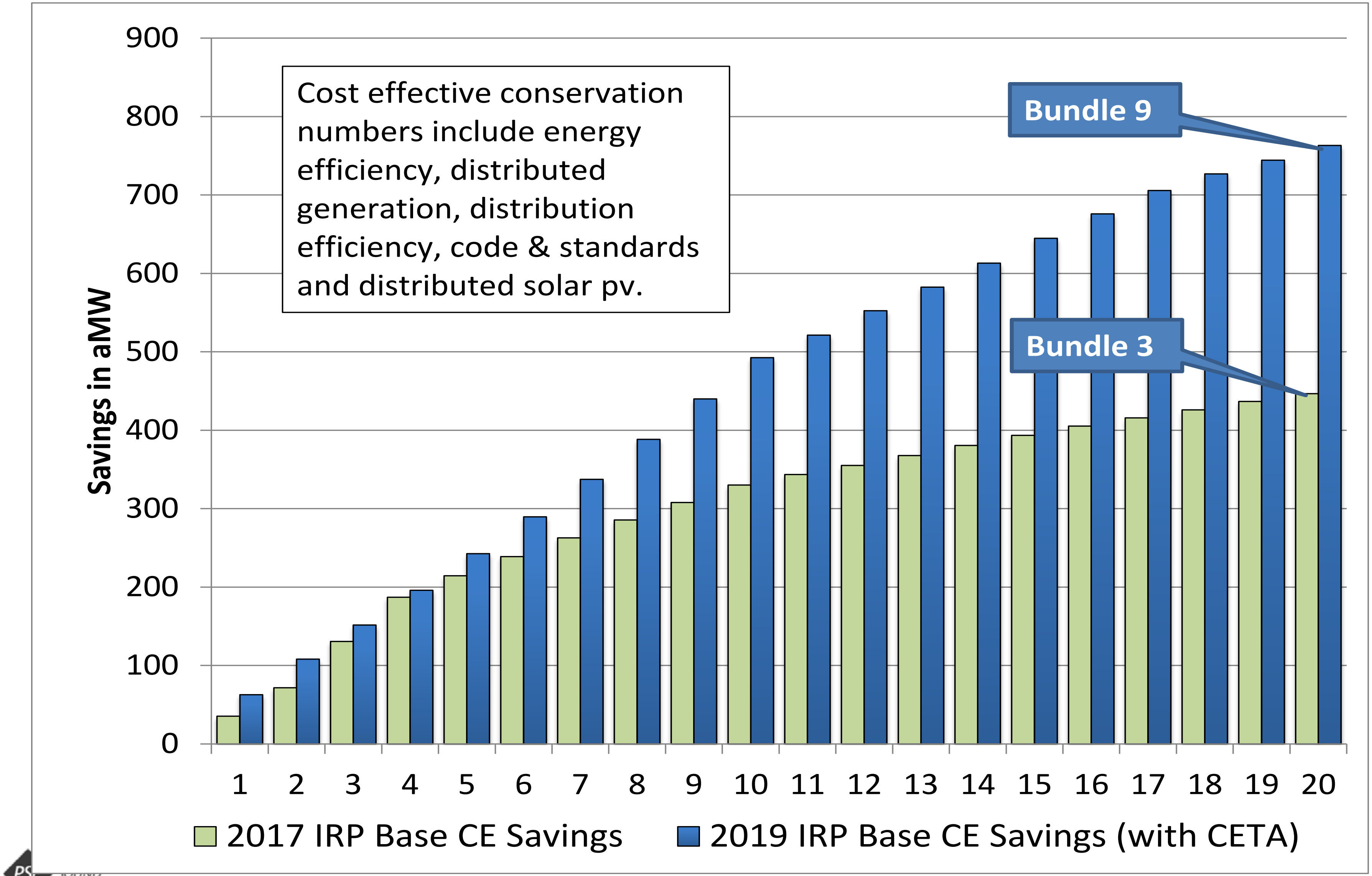
Yr	Scenarios	Montana Wind	Offshore Wind	Washington Wind	WA Solar	WA Solar + Battery	Biomass
2026	1 - 2019 IRP SCC Adder	600	0	0	799	0	0
	2 - 2019 IRP SCC Tax	600	0	500	0	0	0
	3 - 2019 IRP No SCC	600	0	300	200	0	0
2030	1 - 2019 IRP SCC Adder	600	0	1000	1597	0	15
	2 - 2019 IRP SCC Tax	600	0	1500	1099	0	0
	3 - 2019 IRP No SCC	600	0	900	1699	0	15
2045	1 - 2019 IRP SCC Adder	600	300	2000	2092	749	285
	2 - 2019 IRP SCC Tax	600	100	2000	2885	0	300
	3 - 2019 IRP No SCC	600	300	2000	2685	0	300

A closer look at energy storage resource additions for CETA compliant portfolios



Yr	Scenarios	Li-Ion 2hr	Li-Ion 4hr	Flow 4hr	Flow 6hr	Pump Storage
2026	1 - 2019 IRP SCC Adder	0	0	0	0	0
	2 - 2019 IRP SCC Tax	0	0	0	0	0
	3 - 2019 IRP No SCC	0	0	0	0	0
2030	1 - 2019 IRP SCC Adder	0	0	25	0	0
	2 - 2019 IRP SCC Tax	0	0	0	0	0
	3 - 2019 IRP No SCC	0	0	0	0	0
2045	1 - 2019 IRP SCC Adder	0	25	375	500	1000
	2 - 2019 IRP SCC Tax	0	0	325	500	1000
	3 - 2019 IRP No SCC	0	0	500	500	500

A closer look at conservation for CETA compliant portfolios

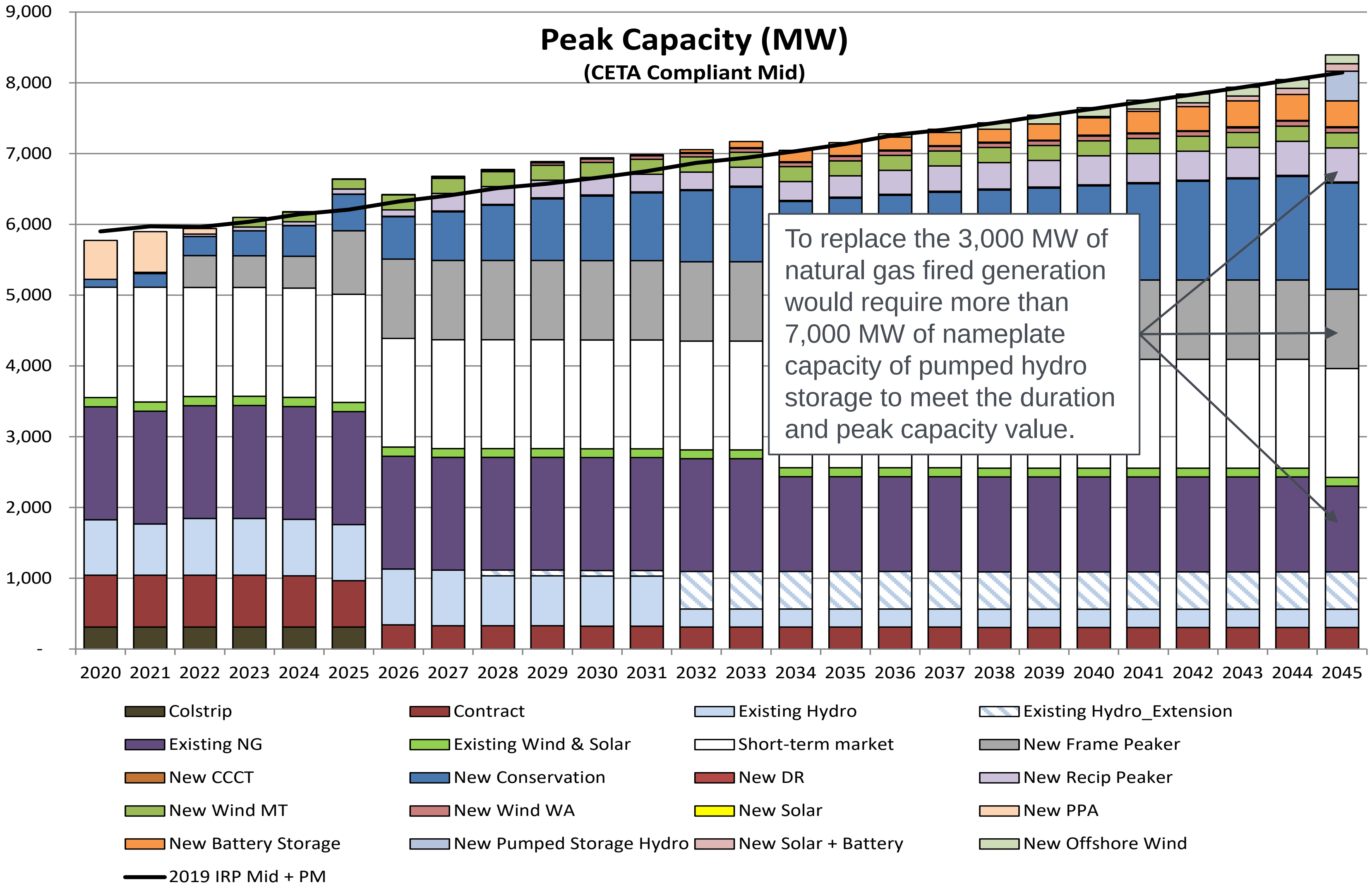


Cost effective conservation numbers include energy efficiency, distributed generation, distribution efficiency, code & standards and distributed solar pv.

Bundle 9

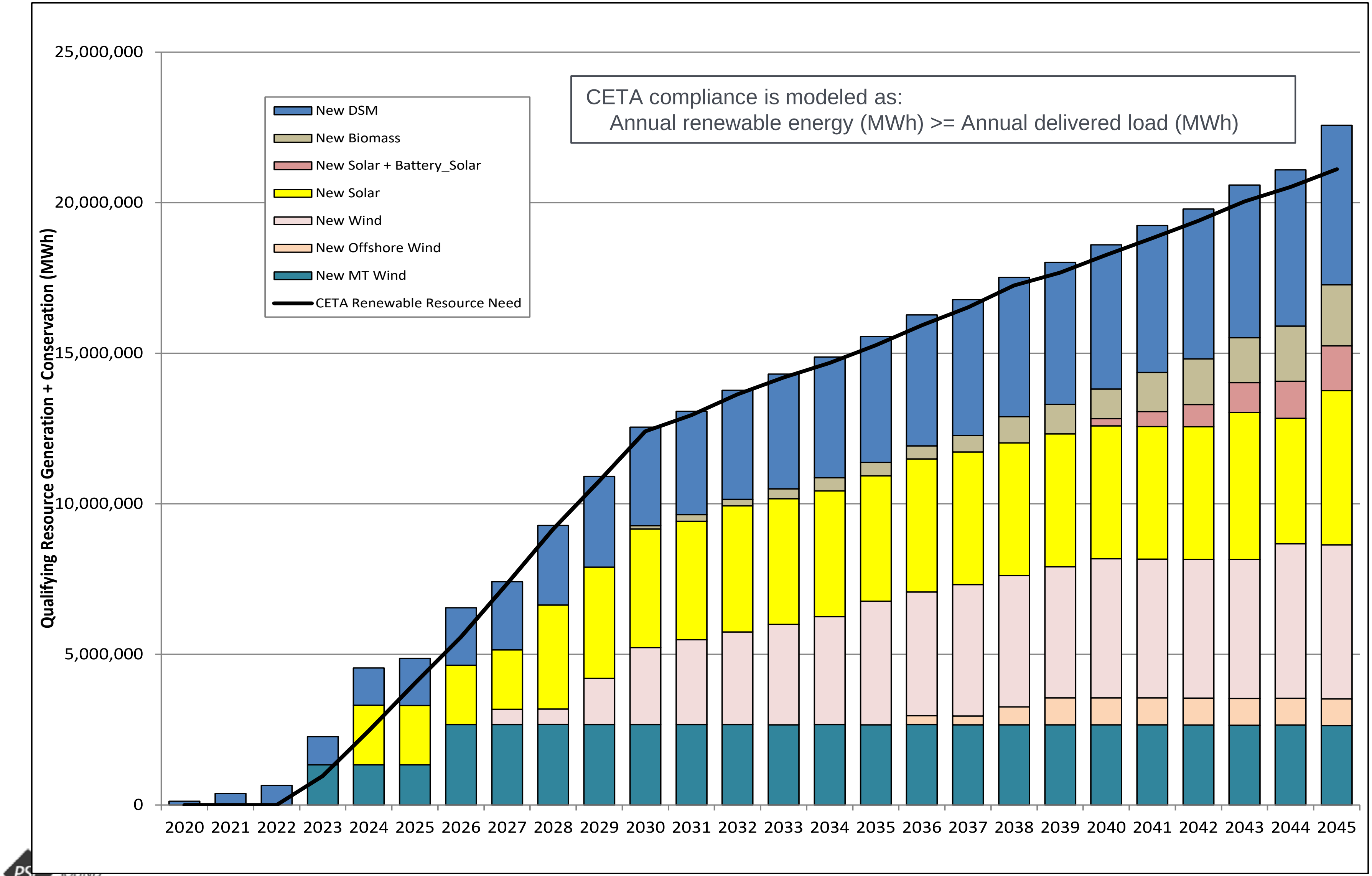
Bundle 3

Peak capacity for SCC Adder portfolio



To replace the 3,000 MW of natural gas fired generation would require more than 7,000 MW of nameplate capacity of pumped hydro storage to meet the duration and peak capacity value.

Meeting the CETA renewable need in the SCC Adder scenario



CETA compliance is modeled as:
Annual renewable energy (MWh) >= Annual delivered load (MWh)

Takeaways from analysis

- Less demand response than 2017 IRP resource plan, but more energy storage. Demand response costs are higher than the 2017 IRP and have a lower peak capacity credit. Energy storage can be used to shape renewable energy.

- With the CETA renewable requirement, significantly more conservation is added than the 2017 IRP.

- In the SCC adder scenario, older, less efficient CCCT plants are retired and replaced with newer, more efficient peaker plants that can be converted to a renewable fuel.
  - Further study of retirement costs is needed.

- In the SCC tax scenario, existing plants are not retired.

- The capacity factors of existing CCCT plants drop to less than 10% by 2045.

- To replace the 3,000 MW of natural gas fired generation would require more than 7,000 MW of nameplate capacity of pumped hydro storage to meet the duration and peak capacity value.

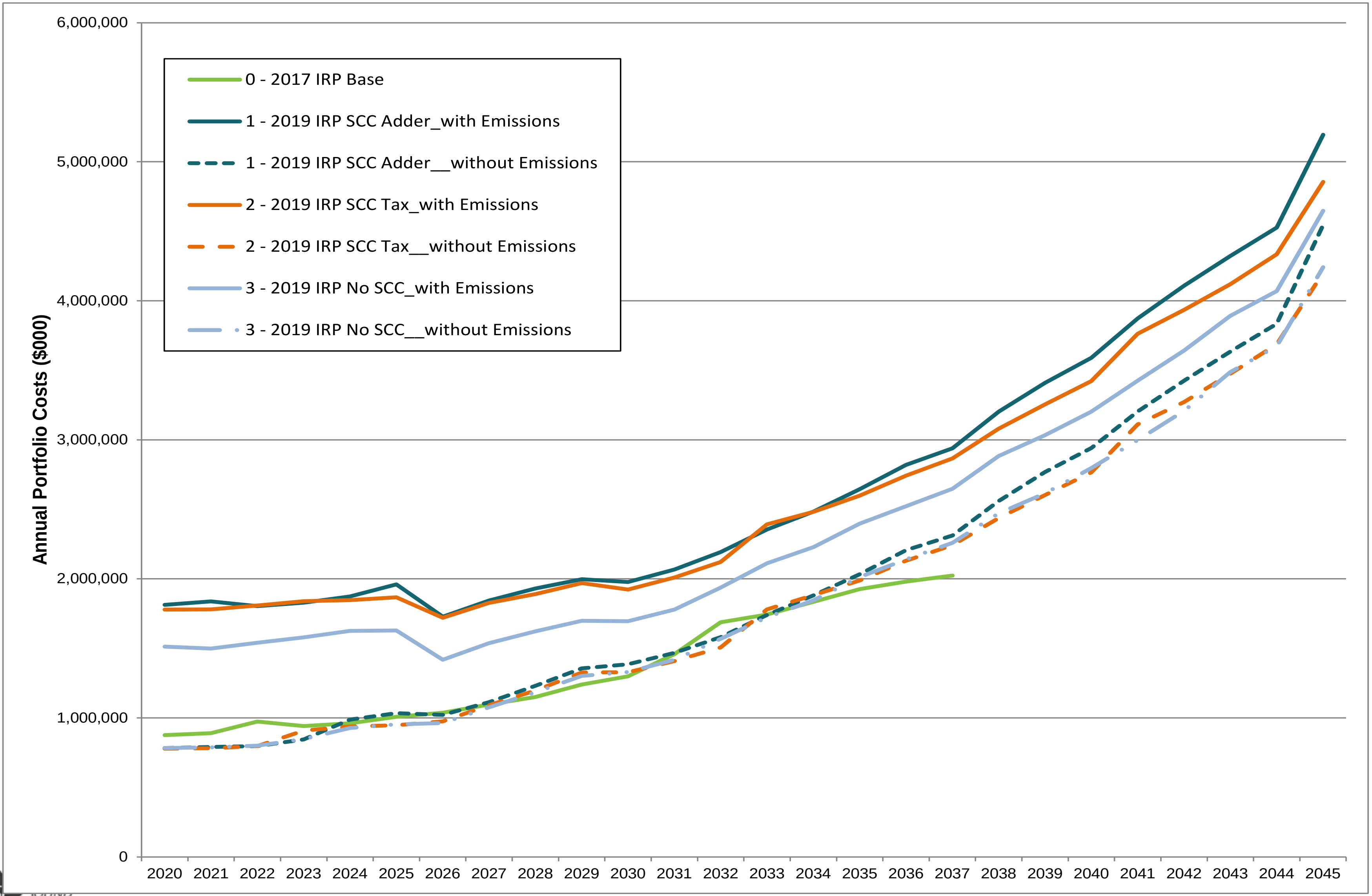
- Even if the peaker plants have a 20-year life and retire before 2045, they are still the lowest cost option to meet capacity needs after retiring Colstrip and Centralia.

Total portfolio costs

- Resource decisions are based on the impact to portfolio costs.
- The portfolio is calculated on an annual basis for the entire life of each plant and is expressed in ($000).
- Annual portfolio costs include
  - Capital cost to build
    - Return on Ratebase
    - Depreciation Expense
    - Taxes and insurance

    New Resources
  - Transmission Costs
  - Fixed Operations & Maintenance
  - Fuel Cost
    - Gas plants include pipeline transport costs along with fuel use and taxes
  - Variable Operations & Maintenance
  - Start-up costs
  - Emission cost

CETA Compliant Portfolio Costs



Net present value (NPV)

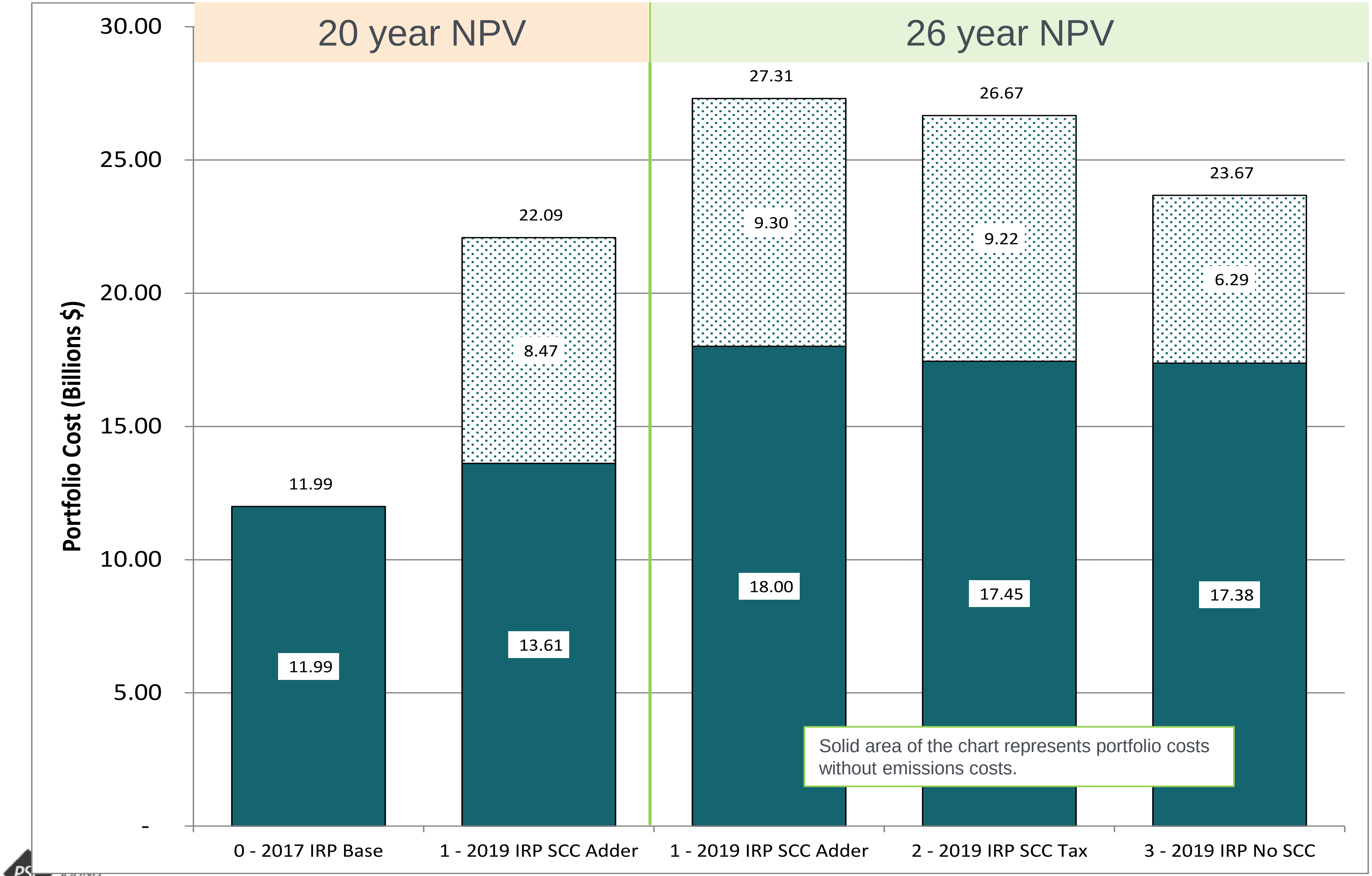
- In finance, the net present value or net present worth applies to a series of cash flows occurring at different times. The present value of a cash flow depends on the interval of time between now and the cash flow. It also depends on the discount rate. NPV accounts for the time value of money.

- Net present value (NPV) is a method used to determine the current value of all future cash flows generated by a project, including the initial capital investment. It is widely used in capital budgeting to establish which projects are likely to turn the greatest profit.

Total Portfolio Cost = NPV of the annual portfolio costs

$$= \sum_{t=0}^{n} \left(\frac{Annual\ portfolio\ costt}{(1 + discount\ rate)^{t}} \right)$$

CETA Compliant Portfolio Costs – NPV



Solid area of the chart represents portfolio costs without emissions costs.

Conclusions

1. Renewable resources required to comply with CETA is the key constraint driving the new portfolio resource additions.

2. With the CETA renewable requirement, the application and the value of **social cost of carbon** has little to no effect on portfolio resource additions.

3. With the CETA renewable requirement, significantly more conservation is added than the 2017 IRP.