RESOLVE Preferred System Plan (PSP) Modeling Results

California Public Utilities Commission

Contents

RESOLVE Updates for 2021 PSP / 2022-23 Transmission Planning Process (TPP)

Summary of RESOLVE Updates since Dec 2020 2021-22 TPP Release – Inputs Related Changes

Update Category	Purpose	Key Changes
Mid-term Reliability (MTR)	Align reliability need in portfolios with MTR need per D.21-06-035	• Higher planning reserve margin (PRM) and load adders • Lower imports • Thermal generation retirements • Minimum build for long-lead time resources ordered
Baseline Resources	Update baseline generators to latest available data	• Include previously proposed ground truthing updates[1] • Update Gen List to align with LSE plan data and MTR baseline, update NQC %'s to match MTR model / 2021 CPUC NQC List
Resource Costs and Potential	Update to latest data vintage of standard IRP data sources	• Resource costs updated to match 2020 NREL ATB, Lazard Levelized Cost of Storage 6.0, NREL offshore wind study • Updated federal PTC and ITC extension to reflect statute and IRS guidance; including 10-year safe harbor option for offshore wind resources • By default, up to 4.7 GW offshore wind was allowed starting in 2030 and up to 3 GW WY+NM wind on new Tx starting in 2026 and up to 68 GW after 2030
LSE Planned Resources	Allow modeling of LSE planned additions	• Input data updated to allow forcing in of 46 and 38 MMT aggregated additions from 2020 LSE IRP plans, with changes as needed to fit within updated transmission constraints

[1] ftp://ftp.cpuc.ca.gov/energy/modeling/IRP%20Model%20Improvement%20and%20GHG%20Groundtruthing_updated.pdf

Summary of RESOLVE Updates since Dec 2020 2021-22 TPP Release – Model Development Related Changes

Update Category	Purpose	Key Changes
Code Base Update	Incorporate the latest RESOLVE code and functionality into the IRP model	• Update the model functionality to include custom constraints and additional input data flexibility. *Used extensively for transmission deliverability constraints and LSE planned resources.* • Enable ability to model multiple reliability constraints and multiple ELCC surfaces for the same reliability constraint. *Battery ELCC curve implementation updated.* • Enable ability to model multiple emission types and constraints and more flexible emissions accounting. *Feature update not used in PSP analysis.*
Transmission Deliverability Constraints	Incorporate latest CAISO transmission deliverability methodology, transmission limits, and upgrade costs	• Update deliverability methodology to align with CAISO • Update on-peak and off-peak transmission deliverability capacity • Include technology-specific resource output factors that relate resource capacity to transmission capacity • Include Li-ion battery and pumped storage capacity under transmission constraints • Revise solar locations granularity, add locational information for batteries to match the solar location • Limit transmission build to CAISO-determined upgrade amounts • Introduce constraints on out-of-state wind and offshore wind to only be selected as fully deliverable resources

[1] ftp://ftp.cpuc.ca.gov/energy/modeling/IRP%20Model%20Improvement%20and%20GHG%20Groundtruthing_updated.pdf

Mid-Term Reliability Decision (D.21-06-035) RESOLVE Implementation

- **PRM**: aligned with MTR Need Determination Model[1] "High Need" scenario from 2024
  - Existing requirement (**~15%**) + 2019 RSP Development calibration adder of (***4.3%***) + Operating Reserves adder of (***1.5%***) + Climate Impact adder of (***1.8%***)
  - **Total PRM = 22.5%**
- **Load Adders**: Per High Need scenario, load adders were added[2] for the managed peak impact[3] of:
  - 1) 2020 vs. 2019 IEPR
  - 2) IEPR Low vs. IEPR Mid BTM PV and 3) High Electrification vs. Mid-Demand IEPR (both held at constant values after 2026)
- **Additional Thermal Retirements:** 40-yr age based applied up to and including 2026 (~1 GW nameplate CHP + peakers)
- **Unspecified imports:** drop from 5 GW to 4 GW in 2024 per High Need scenario
- **Long lead-time resources (LLTs)**: To reflect D.21-06-035 requirements and allowances, 1 GW (NQC) geothermal and 1 GW (NQC) long-duration storage were "forced-in" by 2028 and 2025-2027 reliability need was reduced to minimize PRM overcompliance based on the allowed LLT delay (between 2026 and 2028)
- **Resource NQCs**: RESOLVE NQCs for each resource category were updated to reflect the 2021 CPUC NQC List used by MTR Need Determination Model
- **Persistence of Assumptions**: By default, the "High Need" scenario assumptions persist beyond 2026, though non-persistence of those assumptions was run as a sensitivity

[1] Available at https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/more-information-on-authorizing-procurement/irp-procurement-track
[2] Load adders were only added to RESOLVE's PRM constraint. The load forecast used in RESOLVE's dispatch module (i.e. hourly load/resource balance, GHG emissions, etc.) was not changed
[3] The managed peak impact is the IEPR peak load net of demand side resource peak impacts

Transmission Updates: Limits and Constraints

- CAISO updated on-peak and off-peak transmission capability and included technology-specific transmission information
  - CAISO released a white paper in July 2021 entitled "Transmission Capability Estimates for use in the CPUC's Resource Planning Process" which documents the updated capability estimates
    - Available at: http://www.caiso.com/Documents/WhitePaper-2021TransmissionCapabilityEstimates-CPUCResourcePlanningProcess.pdf
  - New transmission constraint limits generally increase the amount of available capacity on the transmission system relative to the 2019 CAISO white paper values, though this is not true for every constraint
    - The new limits also include geographic areas that were not covered in the 2019 white paper
      - 2019 CAISO white paper available at: https://www.caiso.com/Documents/WhitePaper-TransmissionCapabilityEstimates-InputtoCPUCIntegratedResourcePlanPortfolioDevelopment.pdf

Transmission Updates: Deliverability Methodology

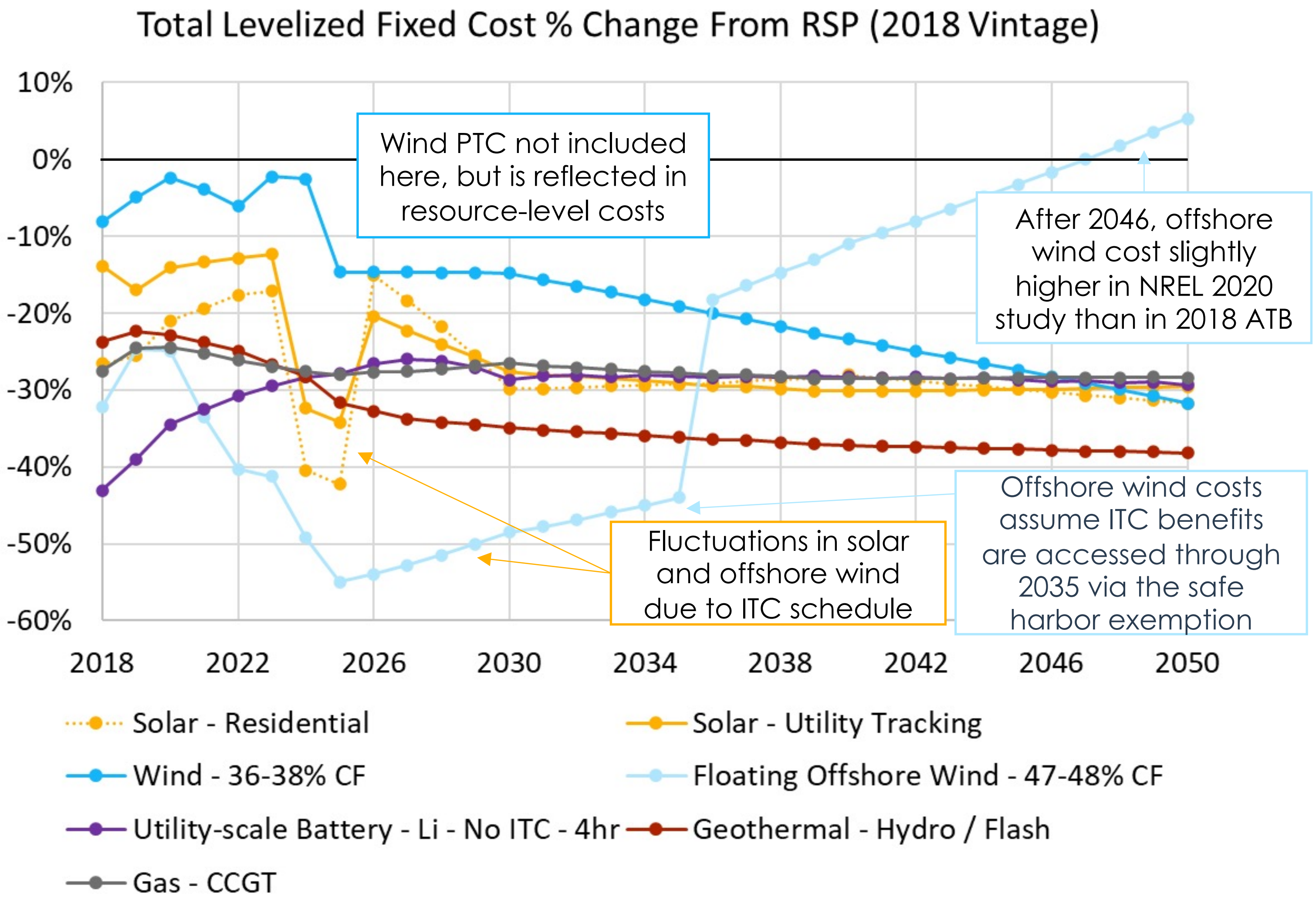
- RESOLVE has been updated to include three limits for each transmission constraint
  - On-Peak, Highest System Need (HSN) – represents net peak hours in early evening when solar output is low
  - On-Peak, Secondary System Need (SSN) – hours of very high demand, represents "shoulder" peak hours where solar output is usually more abundant
  - Off-Peak
- For a resource to receive full deliverability status, it must fit within the available transmission capacity
  - If economic, available transmission capacity can be expanded by CAISO-identified upgrades
  - RESOLVE incorporates resource-specific multipliers for each limit (HSN/SSN/off-peak)
- RESOLVE has also been updated to enforce the CAISO-identified upgrade build limits included in CAISO's 2021 new white paper

Transmission Updates: Storage + Solar

- Previous RESOLVE modeling did not consider interactions between storage and transmission constraints
  - Instead, interactions were addressed downstream in the bus-bar mapping process
- RESOLVE has been updated to:
  - Ensure that storage capacity has enough available transmission capacity to receive full deliverability
    - Lithium-ion battery and pumped storage resources were previous modeled as a single CAISO-wide resource; multiple resources are now modeled such that transmission limits in different areas of the CAISO grid can be considered
  - Model the interaction between storage charging and off-peak transmission limits by expanding off-peak transmission limits when storage is built
    - Storage consumes on-peak transmission capability
    - Storage creates off-peak transmission capability
  - Solar and battery locations aligned as a step towards modeling co-located and hybrid resources.
    - Full hybrid modeling out of scope
      - No interactions are modeled between solar and storage in hourly dispatch
      - Cost reductions from shared infrastructure are not modeled

Resource Costs

- Data source updated from 2018 (Reference System Plan, RSP) to 2020 vintage
  - Most generation technologies: NREL 2020 ATB
  - Offshore wind: NREL OCS Study BOEM 2020-048 [1] (RSP: NREL ATB and E3 WECC study)
  - Storage (utility-scale and BTM Li-ion batteries): Lazard LCOS v6.0
- Other updates had smaller impacts on levelized costs compared to data source updates
  - ITC/PTC schedule, solar PV inverter loading ratio, financing lifetime, etc.
  - See details in Appendix



[1] For more information on this study, refer to 8/27/2020 Modeling Advisory Group material available at: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2019-20-irp-events-and-materials

PSP Scenarios and Sensitivities

Overview of all scenarios and sensitivities

Summary of Core PSP Scenarios and Sensitivities

Scenario/Sensitivity Name	Purpose	Key Features
38 MMT Core (Proposed PSP)	Understand the CAISO system resources needs to meet the 38 MMT 2030 GHG target	• Accounts for D.21-06-035 • Utilizes a 38 MMT by 2030 GHG target • Accounts for the LSE plans for 38 MMT 2030 GHG target • Utilizes RESOLVE to select additional resources for 2031 and 2032 to complete 10-year planning timeframe • Utilizes the 2019 IEPR Mid load forecast and load profiles

Scenario/Sensitivity Name	Purpose	Key Changes from Proposed PSP (Similarities to Proposed PSP scenario shown in gold)
46 MMT Core	Understand the CAISO system resources needs to meet the 46 MMT 2030 GHG target	• Utilizes a 46 MMT by 2030 GHG target • Accounts for the LSE plans for 46 MMT 2030 GHG target
30 MMT Core	Understand the CAISO system resources needs to meet the 30 MMT 2030 GHG target	• Utilizes a 30 MMT by 2030 GHG target • Also accounts for the LSE plans for 38 MMT 2030 GHG target

Summary of PSP Sensitivities – High Electrification

Scenario/Sensitivity Name	Purpose	Key Changes from Proposed PSP (Similarities to Proposed PSP scenario shown in gold)

38 MMT with High Electrification (Managed Charging EV Profile)	Understand portfolio changes based on additional reliability and electric-sector GHG reduction needs if a high electrification future is assumed	• Updated loads to match 2020 CPUC High Electrification PATHWAYS scenario
		  • Higher transportation electrification, building electrification, and energy efficiency
		  • 2022-2032: Change from 2019 IEPR to High Electrification scenario
		  • 2033-2045: change from 2018 CEC High Biofuels to High Electrification Scenario
		• Also utilizes the 2019 IEPR Mid load profile for light-duty EVs

38 MMT with High Electrification (Unmanaged Charging EV Profile)	Understand portfolio changes based on additional reliability and electric-sector GHG reduction needs if a high electrification future is assumed	• Utilizes a load profile created by E3 for light-duty EVs which reflects an unmanaged charging behavior • All other inputs and assumptions are identical to the 38 MMT High Electrification (Managed Charging EV Profile)
30 MMT with High Electrification (Managed Charging EV Profile)	Understand portfolio changes based on additional reliability and electric-sector GHG reduction needs if a high electrification future is assumed with a 30 MMT GHG target	• Utilizes a 30 MMT by 2030 GHG target • All other inputs and assumptions are identical to the 38 MMT High Electrification (Managed Charging EV Profile)

Summary of PSP Sensitivities – Cost Sensitivities

Scenario/Sensitivity Name	Purpose	Key Changes from Proposed PSP (Similarities to Proposed PSP scenario shown in gold)

38 MMT with High Solar PV and Storage Costs	Understand portfolio changes based on higher cost trajectories for solar PV and battery storage resources	• Utilizes a higher cost trajectory for the solar PV and battery storage costs
		  • Uses the "conservative" scenario from the 2020 NREL ATB for the solar PV
		  • Uses the "High" cost trajectory from the NREL Cost Projections for Utility-Scale Battery Storage: 2020 Update[1]
		• All other inputs and assumptions are identical to the 38 MMT Core

38 MMT with No Offshore Wind ITC Extension	Understand portfolios changes if offshore wind developers are unable to make enough investments by 2025 to access the 10-year safe harbor provision that secures the ITC benefit for projects with online dates through 2035	• ITC extends only through 2025 for offshore wind • Beyond 2025 ITC drops from 30% to 0% • All other inputs and assumptions are identical to the 38 MMT Core

[1] For more information on this study, it is available at: https://www.nrel.gov/docs/fy20osti/75385.pdf

Summary of PSP Sensitivities – Policy Sensitivities

Scenario/Sensitivity Name	Purpose	Key Changes from Proposed PSP (Similarities to Proposed PSP scenario shown in gold)
38 MMT with No LSE Plans	Test portfolio changes if the resource build requirements to account for the LSE plans are not incorporated	• Does not account for the LSE plans for the 38 MMT by 2030 GHG target • All other inputs and assumptions are identical to the 38 MMT Core scenario

38 MMT with No MTR Persistence	Test portfolio changes if the MTR "high need" scenario reliability drivers are reduced closer to the previously established IRP assumptions
	
	This case represents system needs if there was a lower PRM (than 22.5%) with slightly lower load and higher imports
		• Beyond 2026 following changes are incorporated
		  • Removes ~1.8% "climate impacts" PRM adder, reducing the PRM from 22.5% to 20.7%
		  • Removes the "2019 IEPR Low BTM PV" load adder
		  • Removes the "High Electrification" load adder
		  • Increases unspecified imports capacity limit back up from 4 GW to 5 GW
		• All other inputs and assumptions are identical to the 38 MMT Core scenario

Summary of PSP Sensitivities – IEPR Load Forecast Sensitivities

Scenario/Sensitivity Name	Purpose	Key Changes from Proposed PSP (Similarities to Proposed PSP scenario shown in gold)

38 MMT with 2020 IEPR	Test portfolio changes if the 2020 IEPR load forecast is utilized	• Utilizes the 2020 IEPR Mid forecast
		  • Updates load forecasts for all load components
		  • Updates BTM solar and other BTM generation forecasts
		  • Updates BTM Storage forecast and ELCC values
		• Utilizes the 2020 IEPR Mid load profiles
		• All other inputs and assumptions are identical to the 38 MMT Core scenario

38 MMT with 2020 IEPR with 2020 IEPR High EV (Managed Charging EV Profile)	Understand portfolio changes based on additional reliability and electric-sector GHG reduction needs if a high electrification future manifests due to higher light-duty EV loads	• Utilizes the 2020 IEPR High forecast for light-duty EV load component • All other inputs and assumptions are identical to the 38 MMT with 2020 IEPR sensitivity
38 MMT with 2020 IEPR with 2020 IEPR High EV (Unmanaged Charging EV Profile)	Understand portfolio changes based on additional reliability and electric-sector GHG reduction needs if a high electrification future manifests due to higher light-duty EV loads	• Utilizes a load profile created by E3 for light-duty EVs which reflects an unmanaged charging behavior • All other inputs and assumptions are identical to the 38 MMT with 2020 IEPR with 2020 IEPR High EV (Managed Charging EV Profile) sensitivity

Proposed PSP (38 MMT Core Portfolio)

With LSE Plans

38 MMT Core portfolio overview

- **Purpose**: understand the CAISO system resources needs to meet the 38 MMT 2030 GHG target, accounting for the LSE plans for the 38 MMT goal and D.21-06-035
- **Key metrics to be discussed**:
  - Selected resources* throughout modeling period
  - Planning reserve margin highlights
  - GHG emissions
  - Selected resources beyond the 38 MMT LSE plans
  - Transmission selection details and insights

* Selected resources include A) baseline resources not in the CAISO transmission baseline, B) review + planned resources from LSE Plans, C) MTR resources, D) any other resources RESOLVE selects for reliability, GHGs, or economics

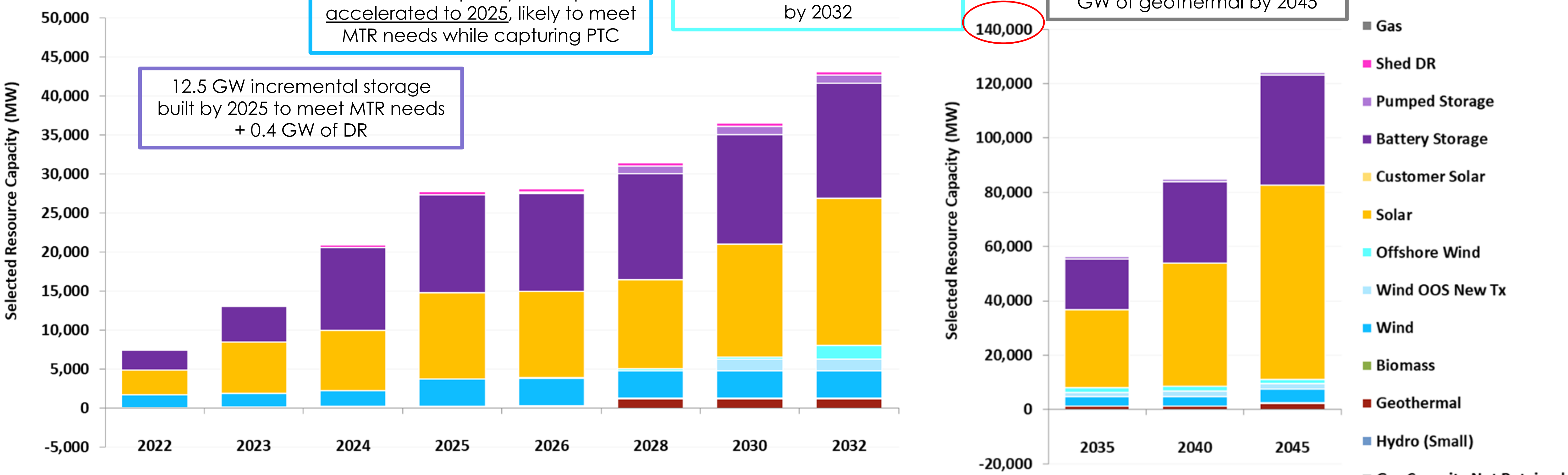
Selected resources – 38 MMT Core

12.5 GW incremental storage built by 2025 to meet MTR needs + 0.4 GW of DR

2030 wind capacity in LSE plans accelerated to 2025, likely to meet MTR needs while capturing PTC

Over 3 GW of out-of-state and offshore wind selected by 2032

Over 3 GW of out-of-state and offshore wind selected + 2.2 GW of geothermal by 2045



Solar through 2024 driven by LSE plans, 11 GW solar deployed by 2025 (hitting annual deployment limit)

1.1 GW geothermal and 1 GW pumped storage selected per MTR order

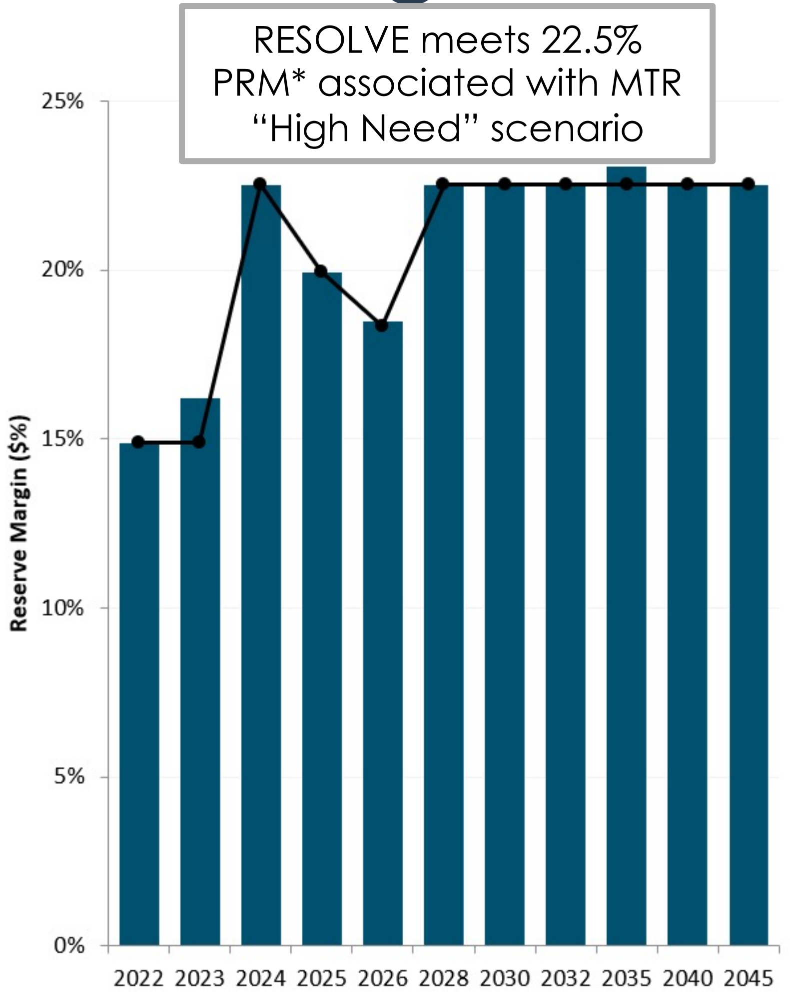
All gas retained through 2045 to meet higher PRM and ~40 MW of additional gas capacity by 2045

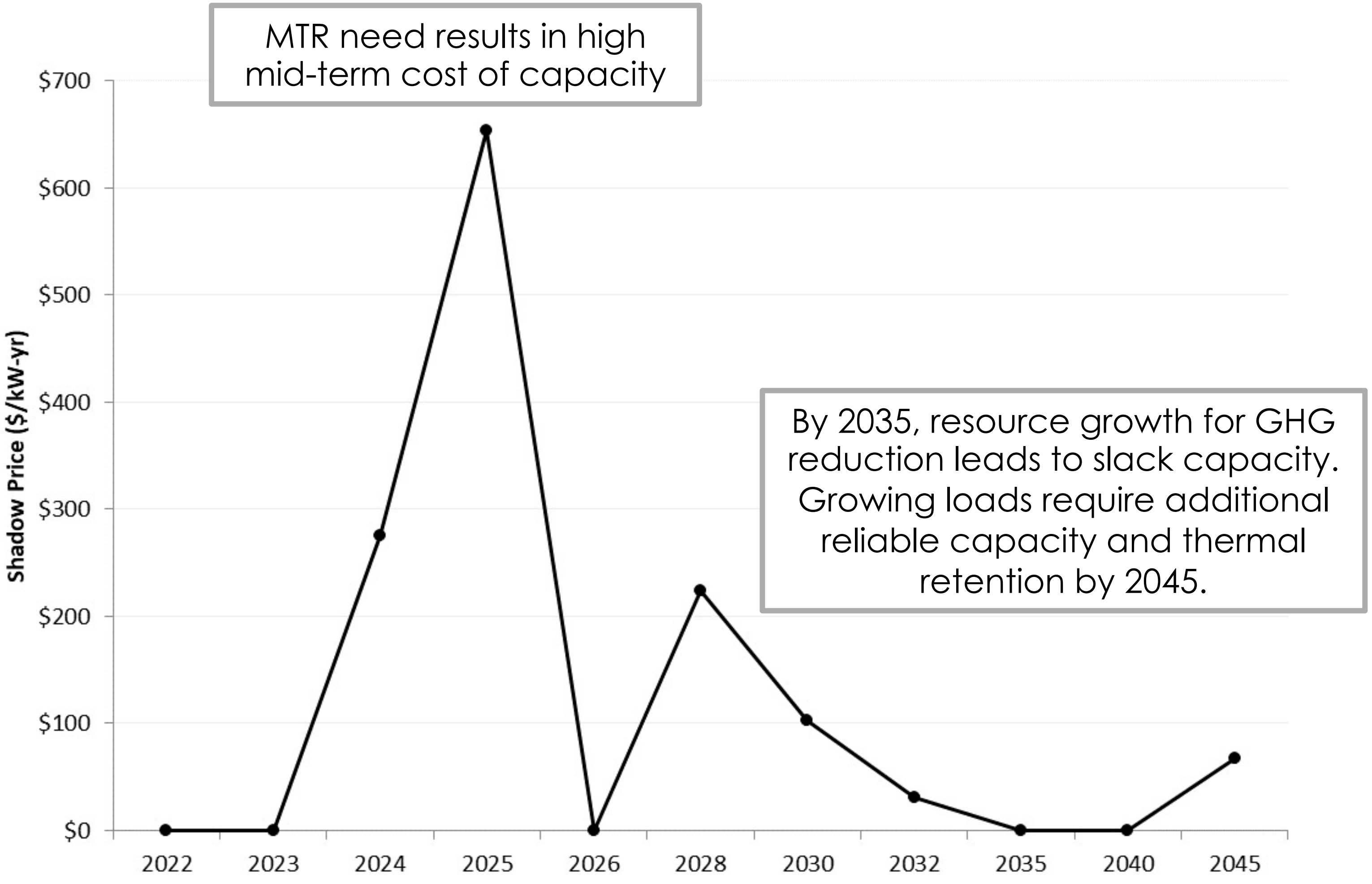
Selected resources – 38 MMT Core

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	1	1	1	1	1	37
Biomass	*MW*	34	65	83	107	107	134	134	134	134	134	134
Geothermal	*MW*	14	114	114	114	184	1,160	1,160	1,160	1,160	1,160	2,252
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	*MW*	-	-	-	-	0	0	1,500	1,500	1,500	1,970	1,970
Offshore Wind	*MW*	-	-	-	-	120	195	195	1,708	1,728	1,728	1,728
Solar	*MW*	3,094	6,549	7,750	11,000	11,000	11,397	14,457	18,883	28,675	45,319	71,419
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,565	4,604	10,617	12,553	12,553	13,609	14,086	14,751	18,718	30,076	40,738
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	*MW*	151	151	353	441	441	441	441	441	441	441	441
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	(0)	(0)	(0)	(0)
Storage + DR	*MW*	**2,716**	**4,755**	**10,970**	**12,993**	**13,189**	**15,049**	**15,527**	**16,192**	**20,159**	**31,517**	**42,179**
Total Resources (Renewables + Storage + DR)	*MW*	**7,577**	**13,224**	**20,988**	**27,768**	**28,154**	**31,489**	**36,527**	**43,131**	**56,910**	**85,382**	**124,772**

- Resources selected by RESOLVE between 2030 and 2032, i.e., beyond the planning horizon of the current LSE plans:
  - ~4.5 GW solar PV, ~0.7 GW battery storage, ~1.5 GW offshore wind

Planning reserve margin – 38 MMT Core

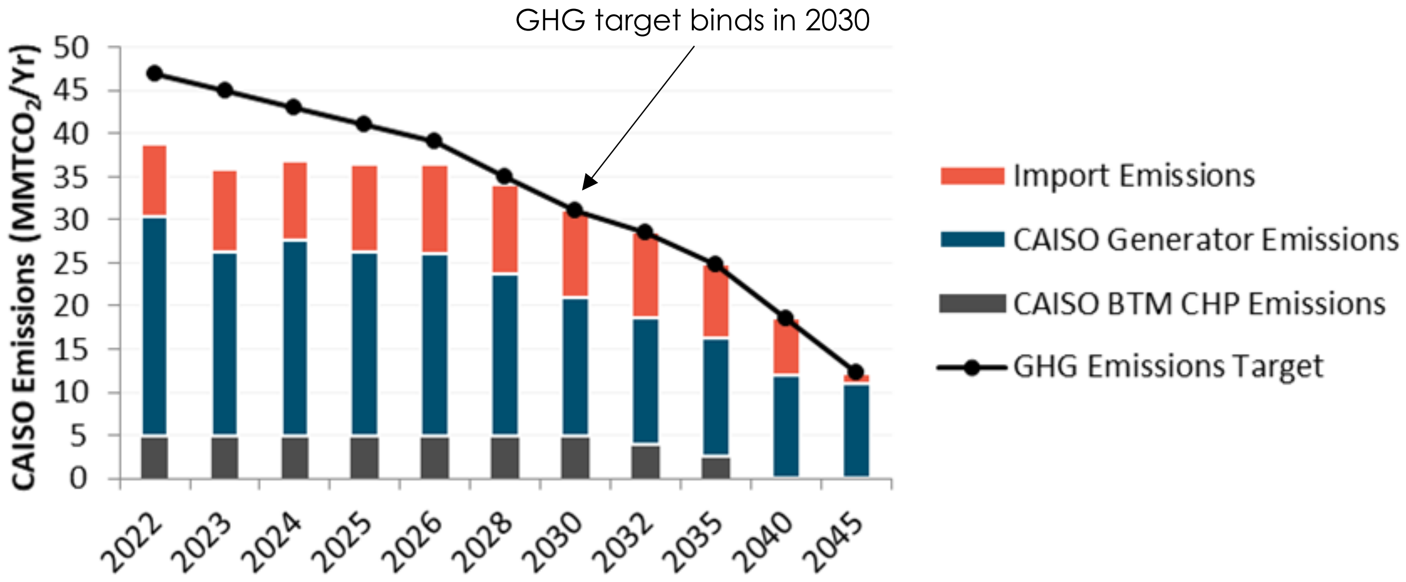


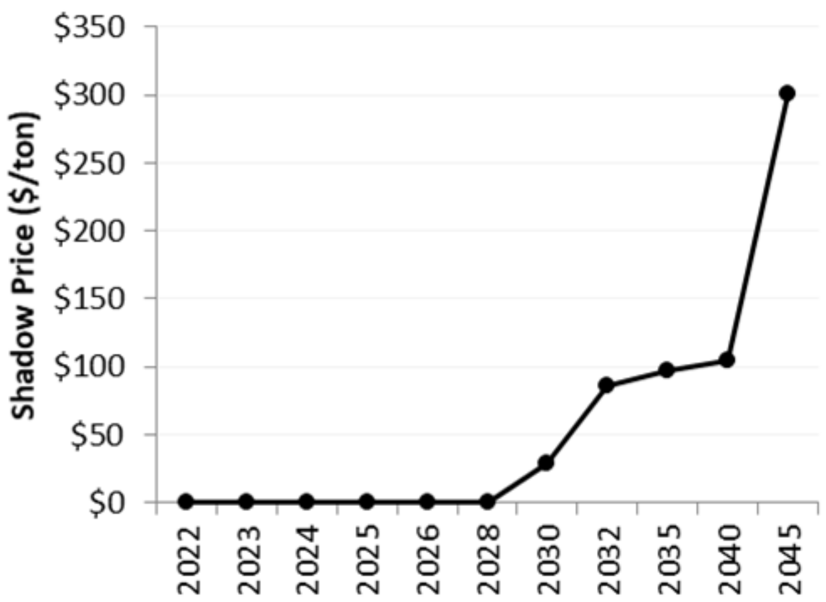


* PRM need is reduced in 2025-2027 to account for the allowed 2-yr delay in the 2 GW of LLT resource additions from 2026 to 2028, per D. 21-06-035. An ~18.5% PRM is achieved in 2026.

GHG emissions – 38 MMT Core

- Combination of MTR + LSE Plans + low cost solar + batteries results in emissions target being met at no incremental cost before 2030
- LSE plans **<u>do not meet the 2030 GHG target</u>** on their own (even with forcing LLTs + MTR on top)





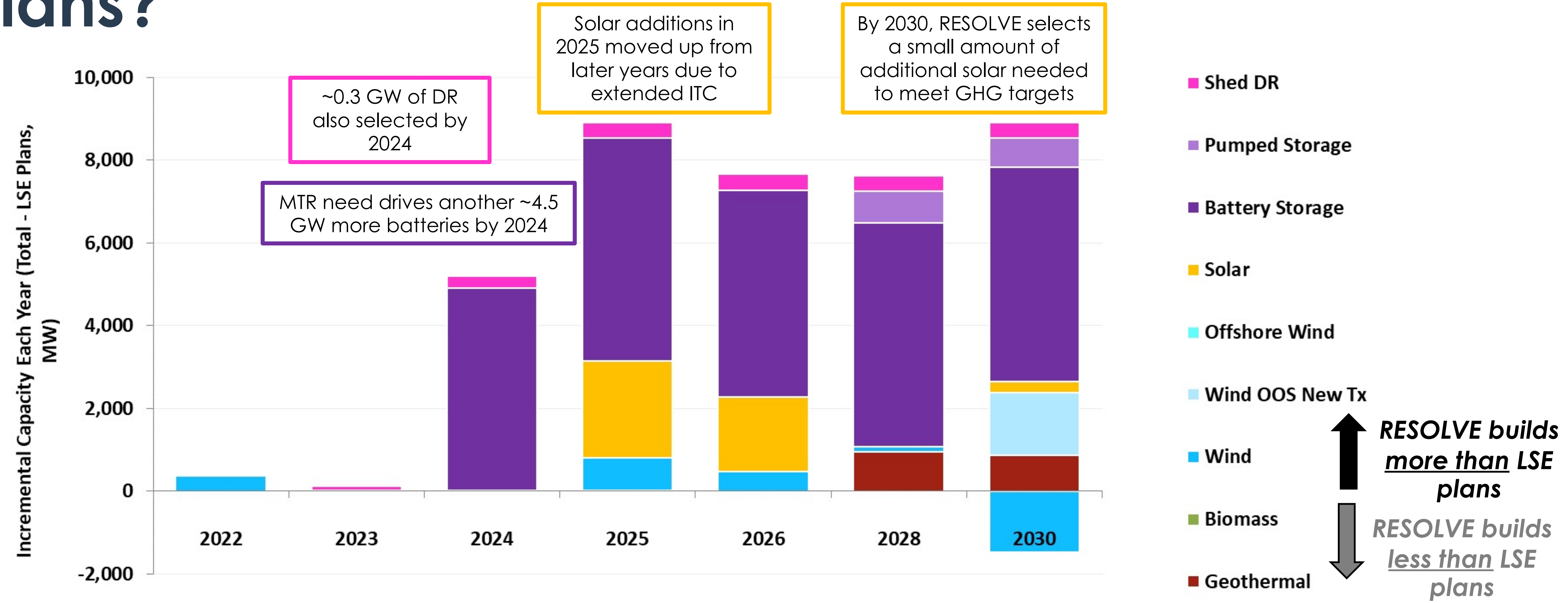
What Does RESOLVE pick on top of 38 MMT LSE Plans?

Incremental Capacity Addition On Top of LSE Planned Resources

Technology Class	Unit	2022	2023	2024	2025	2026	2028	2030
Battery Storage	MW	-	-	4,882	5,377	5,009	5,406	5,183
Pumped Storage	MW	-	-	-	-	-	764	692
Biomass	MW	-	-	-	12	-	-	-
Shed DR	MW	-	89	288	375	375	376	376
Geothermal	MW	-	-	-	-	-	940	868
Solar	MW	-	-	-	2,344	1,793	-	286
Wind	MW	365	22	22	796	475	134	(1,478)
Offshore Wind	MW	-	-	-	-	-	-	-
Wind OOS New Tx	MW	-	-	-	-	-	-	1,500

- The incremental build is calculated in each year by subtracting the "minimum build requirements" due to the LSE plans from the selected resources in that year
  - Positive values indicate RESOLVE selecting more resources than was indicated in the LSE plans
    - The only instance of a negative delta, for the onshore wind, is because OOS wind is allowed to meet the LSE planned wind resources
    - The amounts differ from year to year because the amounts RESOLVE chooses to select beyond the LSE plans is not fixed

What Does RESOLVE pick on top of 38 MMT LSE Plans?



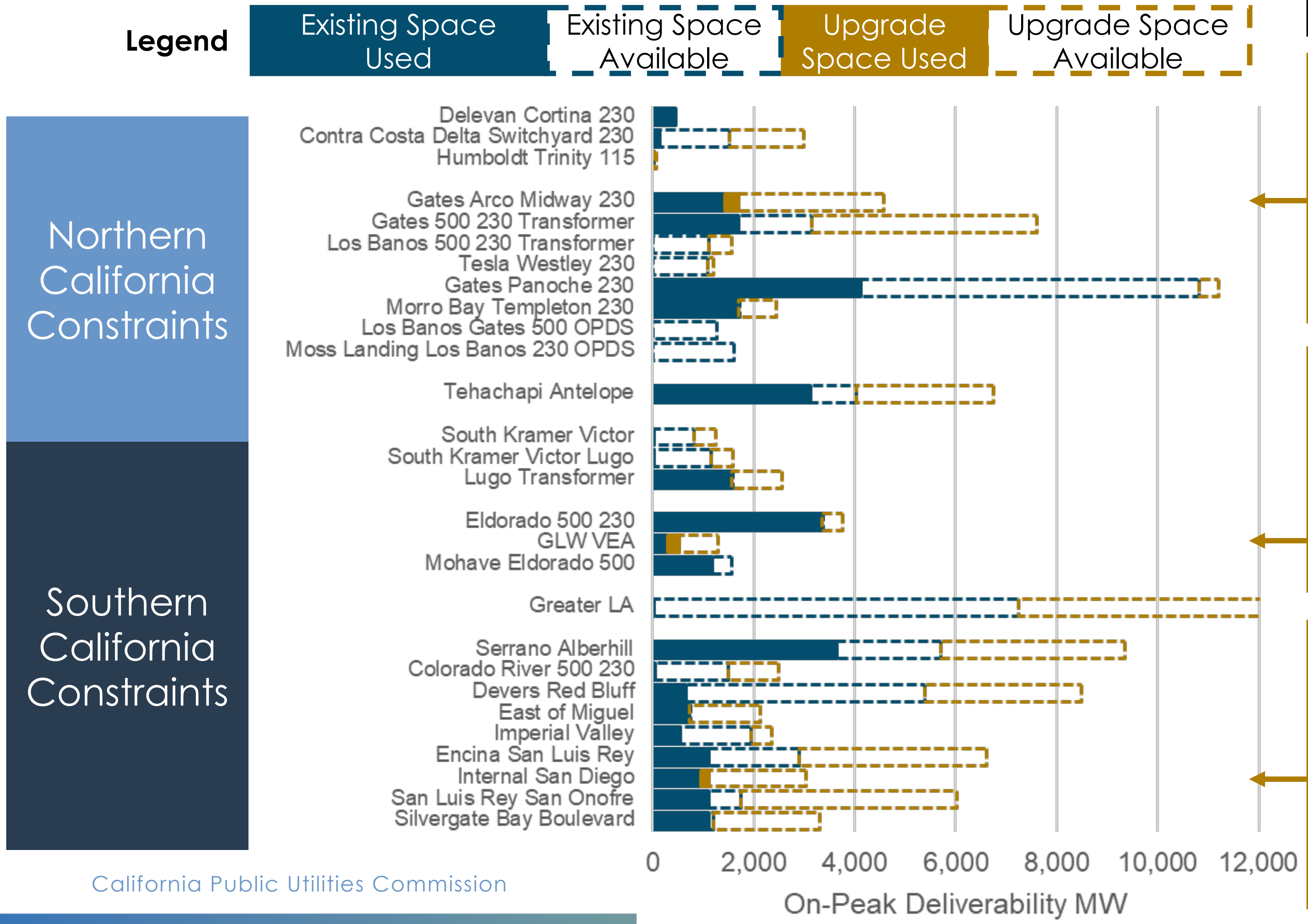
Graph shows the cumulative capacity RESOLVE builds on top of or earlier than LSE plans in each year

Wind is moved up to 2025 to meet MTR and for the extended PTC, but no incremental wind selected by 2030

Geothermal and long duration storage for MTR built on top of ~0.3 GW of each of these resources in LSE plans

1.5 GW of out-of-state wind on new transmission is selected in place of 1.7 GW of in-CAISO wind and out-of-state wind on existing transmission. Replacement driven by transmission constraints, wind resource limits, and the allowance of OOS Wind to meet the LSE plan need

On-Peak Transmission utilization and upgrades: 2032 – 38 MMT Core



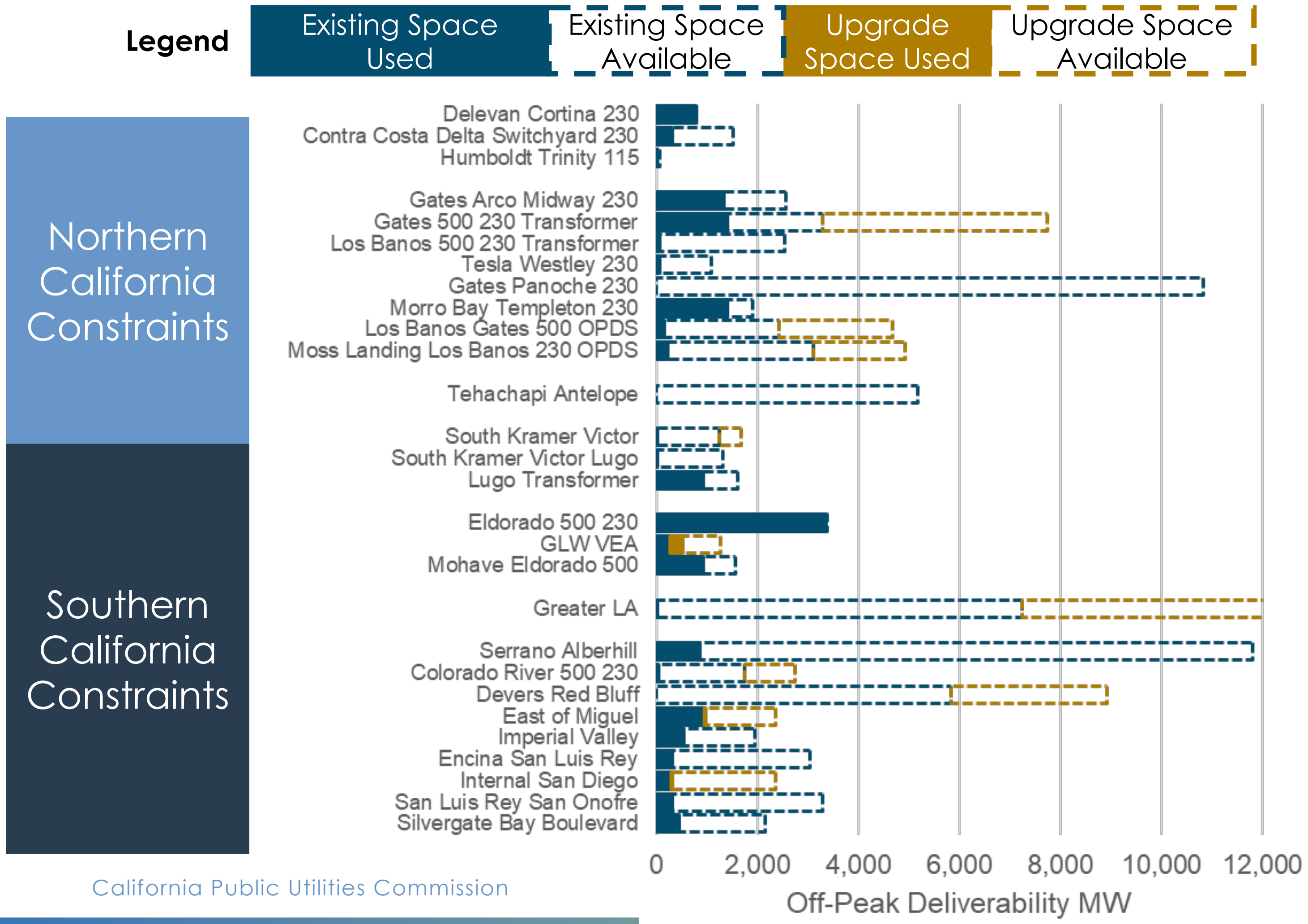
Using the new CAISO transmission limits, RESOLVE results indicate that in many areas of the grid, available space will remain on existing transmission even with the buildout included in the 38 MMT Core portfolio

Midway – Gates 230kV Line
- Partial upgrade selected in 2032
  - 277 MW selected out of 3,137 MW on-peak (ADNU) max
- Limiting constraint for wind development, especially offshore wind – selection of Morro bay offshore wind in 2032 drives upgrade timing. Morro Bay-Templeton constraint also limits offshore development but has expensive upgrade.

GLW VEA Area Constraint
- Partial upgrade selected in 2028
  - 221 MW selected of 1000 MW on-peak max
- Driven by diverse resources in GLW-VEA
  - Geothermal to meet long-lead-time MTR requirement in 2028, wind to meet LSE plan demand for wind

San Diego Internal Constraint
- Partial upgrade selected in 2028
  - 148 MW selected out of 2,067 MW on-peak max
- Limiting constraint for Imperial Geothermal development
  - Off peak limit on existing system only 290 MW; on peak limit is less limiting at 968 MW
  - ~500 MW batteries built by mid 2020s to expand off-peak limits

Off-Peak Transmission utilization and upgrades: 2032 – 38 MMT Core



- Off peak generally less limiting than on-peak in 2032 timeframe
  - Battery deployment expands off-peak transmission capability (via charging)

Transmission upgrades – full or partial?

- RESOLVE is a linear optimization and cannot perform all-or-nothing upgrade decisions
  - It is therefore possible that RESOLVE can select a partial upgrade, which may not be feasible and would require subsequent analysis to confirm whether the full upgrade is cost-effective
    - Converting to a mixed-integer program to enable all-or-nothing upgrade decisions would potentially result in unacceptable model runtimes
- 38 MMT Core result: the three upgrades in the 2032 timeframe are all partial upgrades
  - Given that RESOLVE did not find it economical to select the full upgrade capacity, further analysis is necessary to determine whether each upgrade should move forward

Transmission upgrades (MW) – 38 MMT Core

Transmission Constraint	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Silvergate Bay Boulevard	-	-	-	-	-	-	-	-	-	-	1,833
San Luis Rey San Onofre	-	-	-	-	-	-	-	-	-	-	1,287
Internal San Diego	-	-	-	-	-	148	148	148	148	148	2,067
Encina San Luis Rey	-	-	-	-	-	-	-	-	-	-	134
Imperial Valley	-							-	-	-	-
East of Miguel	-							-	-	-	438
Devers Red Bluff	-							-	-	-	-
Colorado River 500 230	-							-	-	-	-
Serrano Alberhill	-							-	-	-	3,648
Greater LA	-							-	-	-	-
Mohave Eldorado 500	-	-	-	-	-	-	-	-	-	-	-
GLW VEA	-	-	-	-	-	221	221	221	221	221	221
Eldorado 500 230	-	-	-	-	-	-	-	-	-	-	400
Lugo Transformer	-								-	980	980
South Kramer Victor Lugo	-								-	-	-
South Kramer Victor	-								-	-	-
Tehachapi Antelope	-								-	-	2,700
Moss Landing Los Banos 230 OPDS	-								-	-	-
Los Banos Gates 500 OPDS	-								-	-	-
Morro Bay Templeton 230	-								-	-	-
Gates Panoche 230	-								-	-	378
Tesla Westley 230	-								-	-	-
Los Banos 500 230 Transformer	-	-	-	-	-	-	-	-	-	-	-
Gates 500 230 Transformer	-	-	-	-	-	-	-	-	-	-	-
Gates Arco Midway 230	-	-	-	-	-	-	-	277	277	277	277
Humboldt Trinity 115	-	-	-	-	-	-	-	-	-	-	-
Contra Costa Delta Switchyard 230	-	-	-	-	-	-	-	-	-	-	-
Delevan Cortina 230	-	-	-	-	-	-	-	-	41	41	1,340

Most upgrades cannot be built in early and mid 2020s due to construction time

Few upgrades through 2032; selected upgrades relatively inexpensive (see appendix for transmission upgrade costs)

SCE Eastern + SDG&E area constraints are unable to fully utilize the individual upgrades until significant need in 2045, because of multiple overlapping constraints

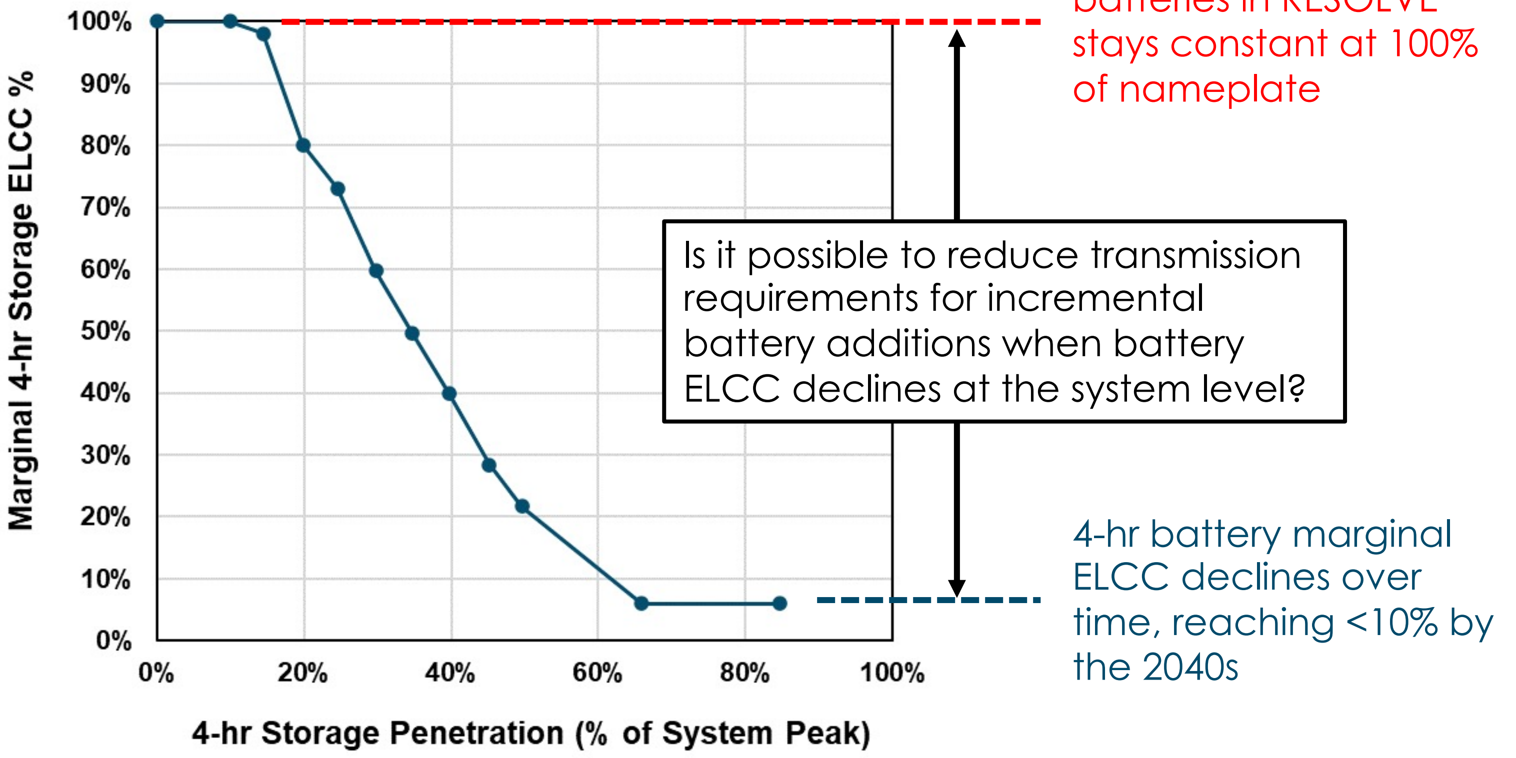
In general, there are fewer transmission upgrades selected vs. past RESOLVE analyses due to updated transmission limits and methodology

Most upgrades selected by 2045, albeit with large uncertainty on long-run transmission needs for incremental solar and batteries

Storage ELCC – Transmission connection

- Additional analysis is required to explore transmission needs for battery/short duration storage at high penetration levels
- Battery Effective Load Carrying Capability (ELCC) declines in part because sustained discharge for more than 4 hours is required to receive full resource adequacy credit
  - It may be possible to size on-peak transmission to longer discharge periods, potentially reducing transmission needs

Battery Storage ELCC Curve – 2019-2020 RSP Input and Assumptions[1]



[1] Curve is updated with more data points, enabled by RESOLVE updates described earlier. Data source remains as per Inputs and Assumptions, available at: ftp://ftp.cpuc.ca.gov/energy/modeling/Inputs%20%20Assumptions%202019-2020%20CPUC%20IRP%202020-02-27.pdf

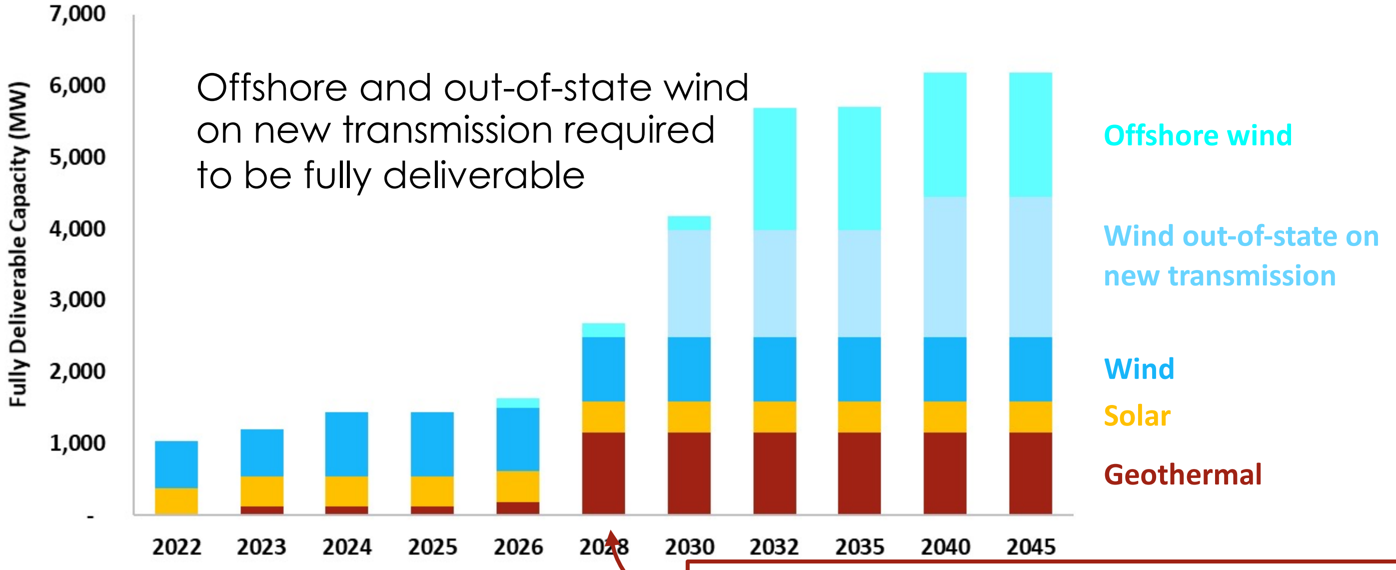
NOTE: These planning track assumptions are not the same as the marginal ELCCs for MTR procurement purposes that will be published by staff by 8/31/2021, as required by D.21-06-035

Fully Deliverable Capacity

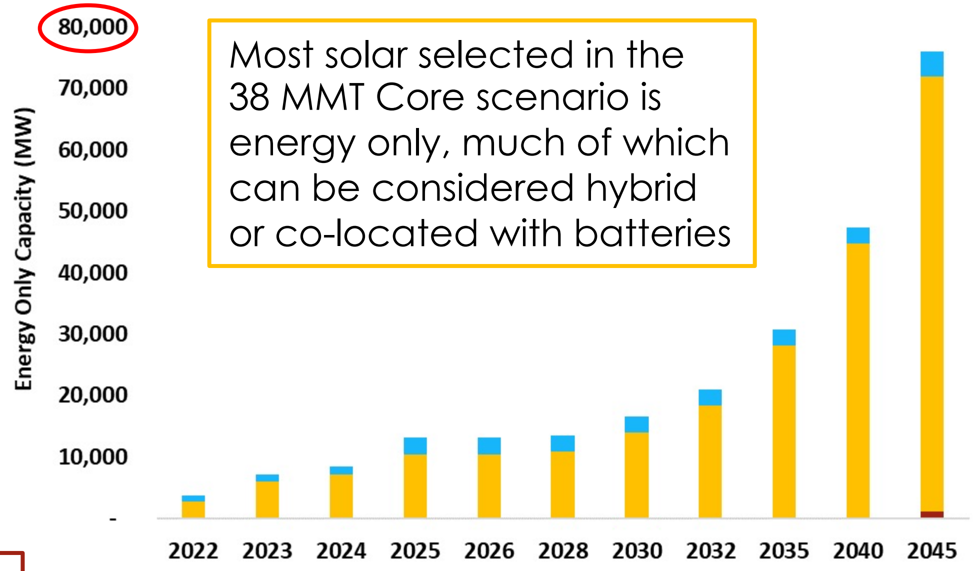
- Contributes to the planning reserve margin
- Uses both on-peak and off-peak transmission space
- RESOLVE will choose full deliverability if the benefits of a resource's planning reserve margin contribution outweigh costs of reserving on-peak transmission capacity
- All storage is fully deliverable (not shown below

Energy Only Capacity

- Does *not* contribute to the planning reserve margin
- Uses only off-peak transmission space
- RESOLVE will choose energy only if the benefits of a resource's planning reserve margin contribution do not outweigh costs of reserving on-peak transmission capacity



Geothermal required to be fully deliverable to satisfy mid-term (~2028) reliability order criteria



Key transmission observations

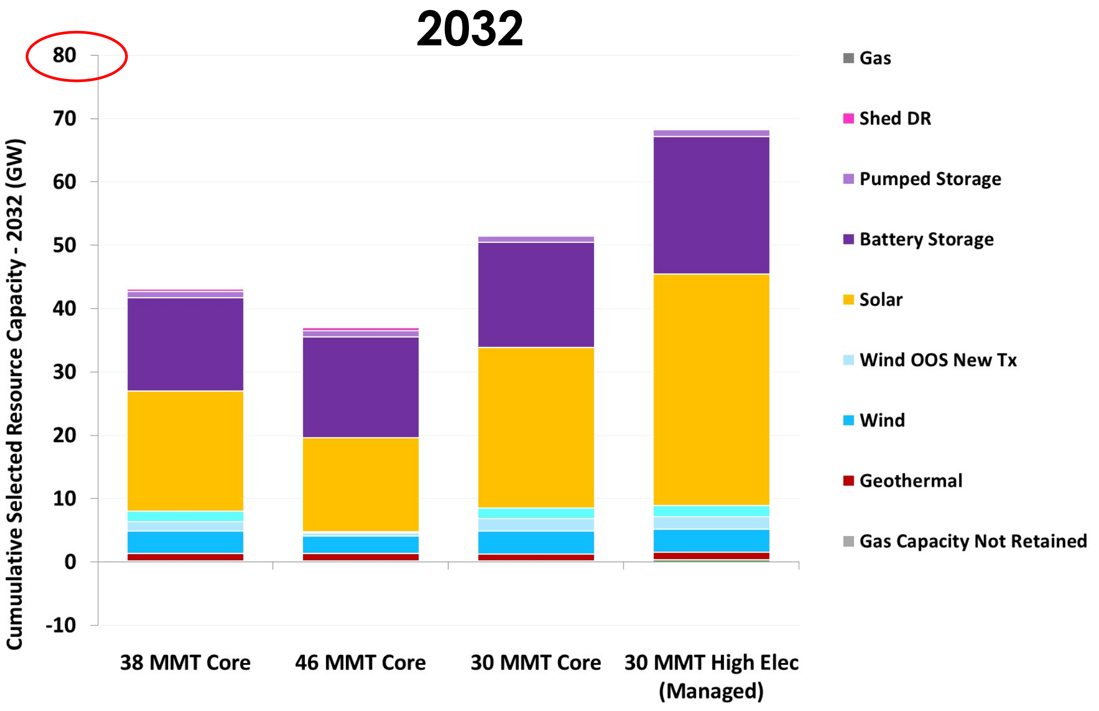
- In the 2032 timeframe transmission upgrades are driven by non-solar, non-battery resources
  - Solar and battery locations are flexible; wind and geothermal locations are not
  - Upgrades driven by solar and batteries observed in the 2040-5 timeframe, but transmission requirements for a high solar + battery future are uncertain
- Transmission upgrade sizing is typically larger than RESOLVE finds to be optimal
  - Resource potential limits or nearby/nested transmission limits tend to limit effectiveness of GW-size upgrades for wind or geothermal
- Out of state wind on new transmission is limited by key transmission constraints
  - Wyoming wind limited by the Mohave/Eldorado 500 kV constraint for which the CAISO study does not include any identified upgrade for RESOLVE to model
  - New Mexico wind is limited by the East of Miguel constraint, that RESOLVE generally sees as cost prohibitive to upgrade
  - Additional transmission capacity on the existing system may be available and would be valuable for resource diversity, especially after 2030
- SDG&E + Eastern SCE area has multiple overlapping constraints that limit resource development and also impede full utilization of individual transmission upgrades

Sensitivity Scenario Results

Scenario Definitions

- 38 MMT w/ No LSE Plans: 38 MMT GHG target in 2030 without LSE plans included; essentially a re-run of a reference system portfolio with updated assumptions, and is intended for comparison purposes only
- 38 MMT Core: 38 MMT GHG target in 2030 with LSE plans incorporated, along with the MTR resources of 11,500 MW, and resource augmentation for 2031 and 2032
- 38 MMT w/ 2020 IEPR: 38 MMT Core with the 2020 IEPR mid-demand load forecast
- 38 MMT w/ 2020 IEPR + 2020 High EV: 38 MMT Core with the 2020 IEPR mid-demand load forecast mixed with the 2020 IEPR high electric vehicle (EV) load forecast
- 38 MMT High Electrification: 38 MMT Core with a high electrification demand forecast for both managed and unmanaged EV profiles, based on a high electrification demand scenario developed by Commission staff using the PATHWAYS model in 2020 for modeling purposes
- 38 MMT No Offshore Wind ITC Extension: 38 MMT Core with an assumption that developers do not invest to a level significant enough by end of 2025 to access safe harbor provisions of the offshore wind ITC, making projects ineligible for the full ITC benefits
- 38 MMT High Solar and batteries Cost: 38 MMT Core with high solar and battery storage cost assumptions
- 38 MMT No MTR Persistence: 38 MMT Core with MTR non-persistence assumption to test portfolio changes if the MTR "high need" scenario reliability drivers are reduced similar to the previously-established IRP planning assumptions
- 46 MMT Core: 46 MMT GHG target in 2030, based on LSE plans and augmented with the 11,500 MW of MTR NQC and 2031 and 2032 resources
- 30 MMT Core: 30 MMT GHG target in 2030, based on the LSE plans designed to achieve the 38 MMT target, augmented with the 11,500 MW of MTR NQC, 2031 and 2032 resources, and additional resources necessary to achieve the lower 30 MMT GHG target
- 30 MMT High Elec: 30 MMT Core with a high electrification demand forecast, based on a high electrification demand scenario developed by Commission staff using the PATHWAYS model in 2020 for modeling purposes.

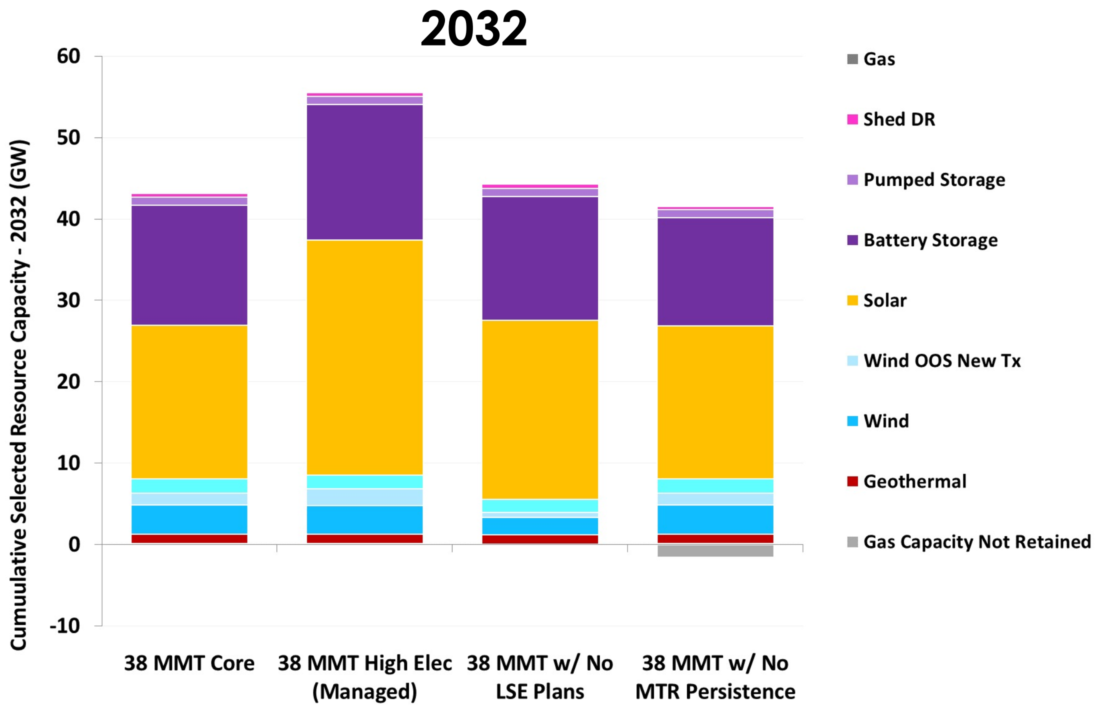
Summary of alternate GHG target sensitivities



Metrics	Unit	38 MMT Core	46 MMT Core	30 MMT Core	30 MMT w/ High Electrification
PV Total Resource Cost Delta Relative to LSE Plan Scenario	$MM	$905,213	-$521	+$1,589	+$69,334
Levelized Average Rate Delta Relative to LSE Plan Scenario	cts/ kWh	19.3	-0.0	+0.0	-0.7
New Transmission for Selected Resources (within CAISO), 2032	MW	646	266	646	646
Total GHG Abatement cost (GHG shadow price + CARB floor), 2032	$/tCO2	117	33	163	176
Res. Monthly Bill at 500 kWh/mo and 600 kWh/mo, 2032	$/mo	$126.1 $151.3	+$0.67[1] +$0.80	+$1.06 +$1.26	N/A[2]

[1] Residential monthly bill is slightly higher in the 46 MMT sensitivity because the resources procured for meeting D.21-06-035 already push the GHG emissions lower than 46 MMT, so the difference between achieving the resource build out is lower than the operating cost savings achieved from reduced usage of the thermal fleet
[2] Residential monthly bill for High Electrification will depend on how much the monthly usage increases due to adoption of electrification

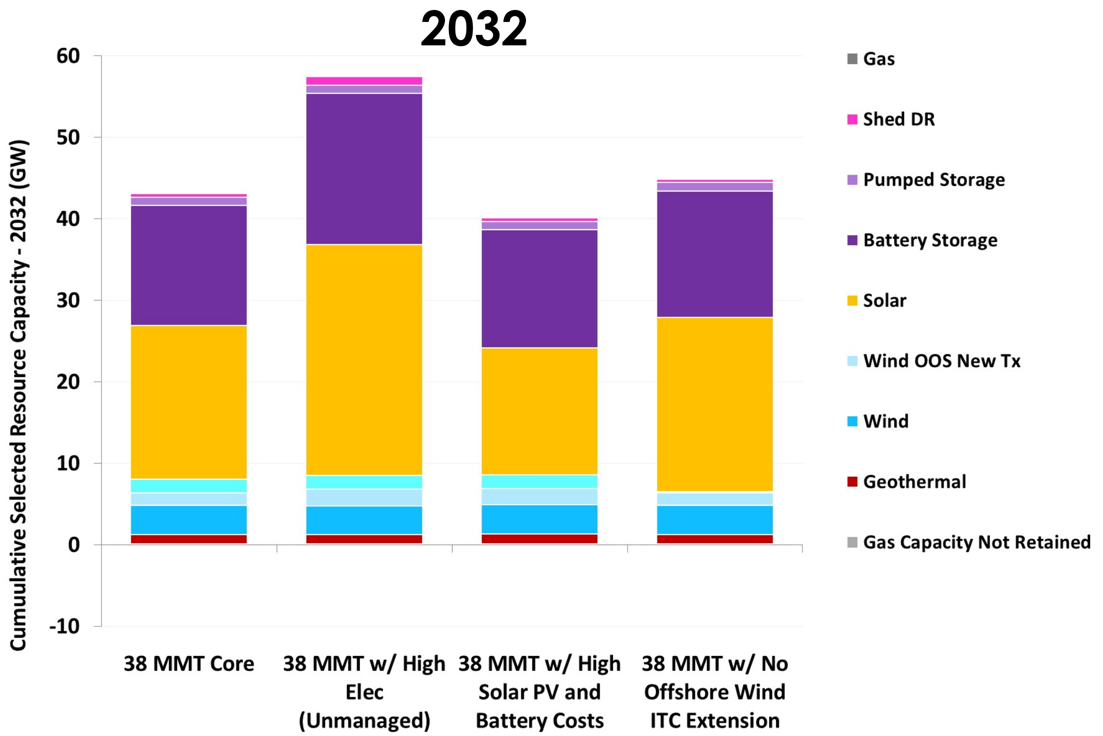
Summary of 38 MMT scenarios and sensitivities



Metrics	Unit	38 MMT Core	38 MMT w/ High Electrification (Core)	38 MMT w/o LSE Plans	38 MMT w/ MTR Non-Persistence
PV Total Resource Cost Delta Relative to LSE Plan Scenario	$MM	$905,213	+$67,849	-$3,211	-$843
Levelized Average Rate Delta Relative to LSE Plan Scenario	cts/ kWh	19.3	-0.7	-0.1	-0.0
New Transmission for Selected Resources (within CAISO), 2032	MW	646	527	256	646
Res. Monthly Bill at 500 kWh/mo and 600 kWh/mo, 2032	$/mo	$126.1 $151.3	N/A[1]	-$0.48 -$0.58	-$0.17 -$0.21

[1] Residential monthly bill for High Electrification will depend on how much the monthly usage increases due to adoption of electrification

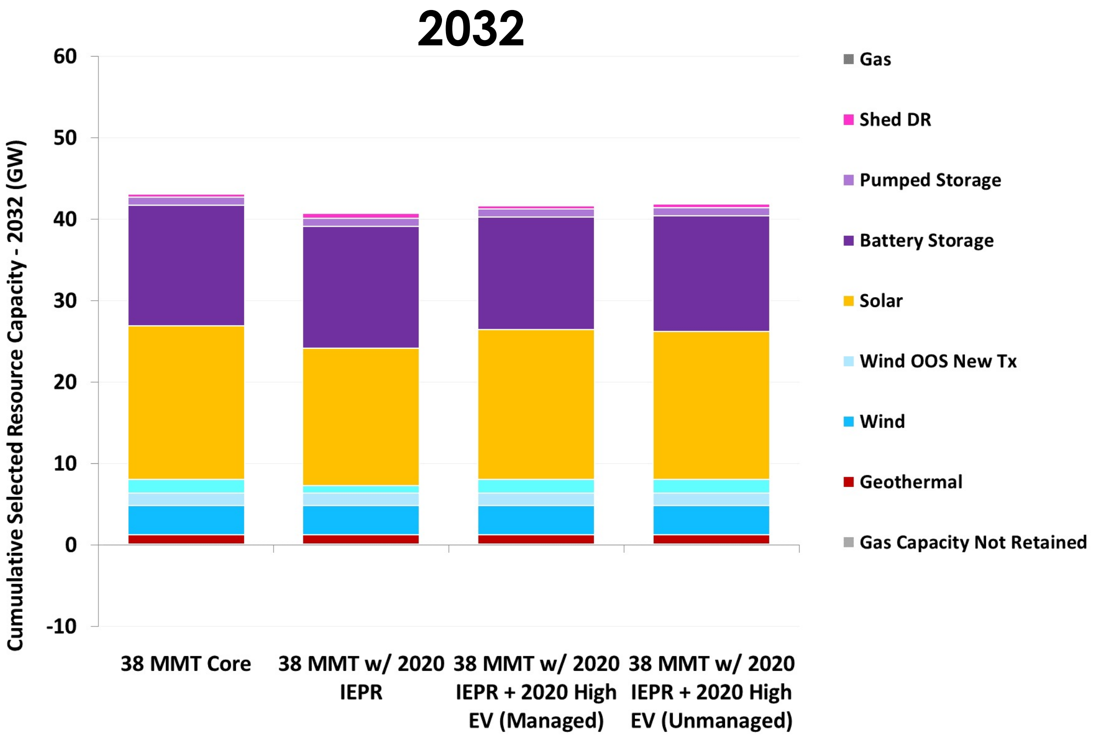
Summary of additional scenarios and sensitivities



Metrics	Unit	38 MMT Core	38 MMT w/ High Electrification (Unmanaged)	38 MMT w/ High PV and Battery Costs	38 MMT w/o OSW ITC Extension
PV Total Resource Cost Delta Relative to LSE Plan Scenario	$MM	$905,213	+$72,469	+$23,072	+$773
Levelized Average Rate Delta Relative to LSE Plan Scenario	cts/ kWh	19.3	-0.6	+0.1	+0.0
New Transmission for Selected Resources (within CAISO), 2032	MW	646	527	3,349	369
Res. Monthly Bill at 500 kWh/mo and 600 kWh/mo, 2032	$/mo	$126.1 $151.3	N/A[1]	+$0.52 +$0.62	+$0.07 +$0.08

[1] Residential monthly bill for High Electrification will depend on how much the monthly usage increases due to adoption of electrification

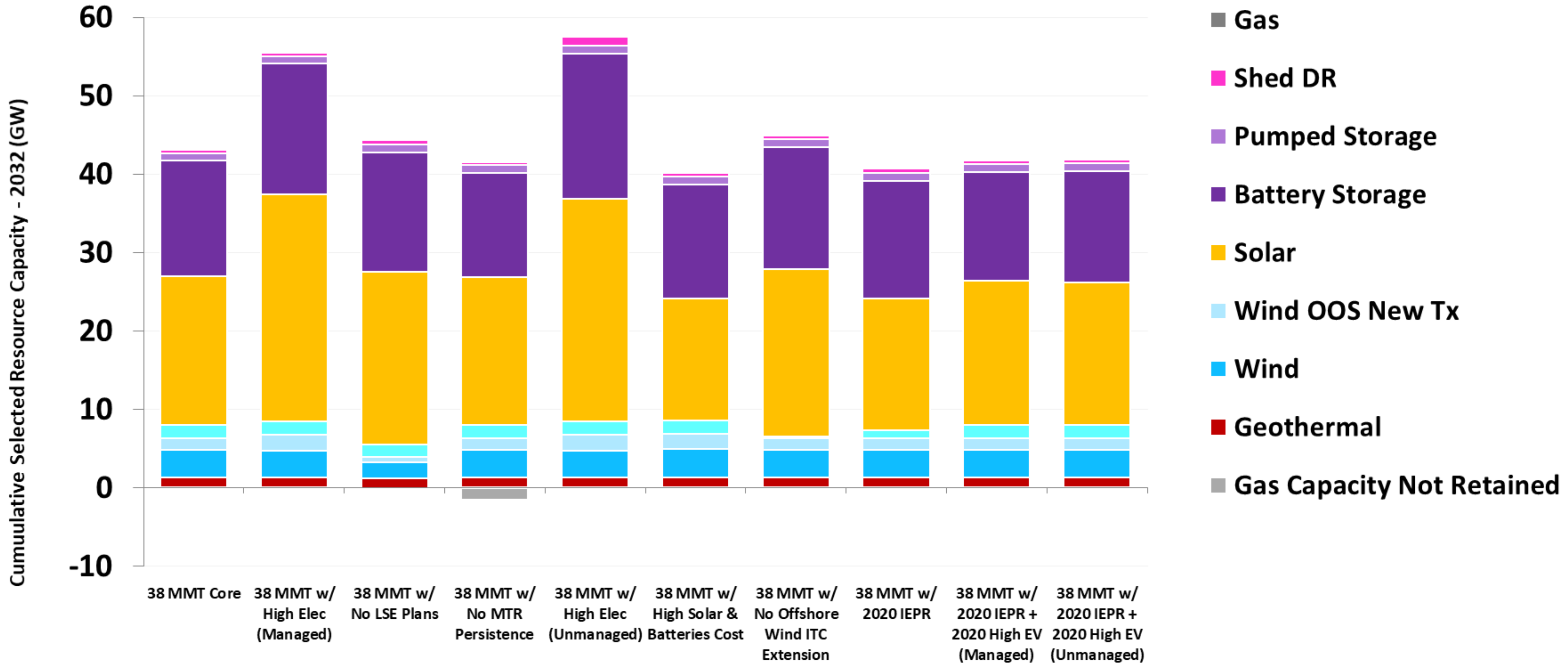
Summary of additional scenarios and sensitivities



[1] Residential monthly bill for High Electrification will depend on how much the monthly usage increases due to adoption of electrification

Metrics	Unit	38 MMT Core	38 MMT w/ 2020 IEPR	38 MMT w/ 2020 IEPR + 2020 High EV (Managed)	38 MMT w/ 2020 IEPR + 2020 High EV (Unmanaged)
PV Total Resource Cost Delta Relative to LSE Plan Scenario	$MM	$905,213	-$2,800	-$1,218	+$773
Levelized Average Rate Delta Relative to LSE Plan Scenario	cts/ kWh	19.3	+0.22	-0.01	+0.01
New Transmission for Selected Resources (within CAISO), 2032	MW	646	414	646	678
Res. Monthly Bill at 500 kWh/mo and 600 kWh/mo, 2032	$/mo	$126.1 $151.3	+$2.94 +$3.52	N/A[1]	N/A[1]

Summary of All Scenarios and Sensitivities



38 MMT with High Electrification (Managed Charging EV Profile)

With LSE Plans

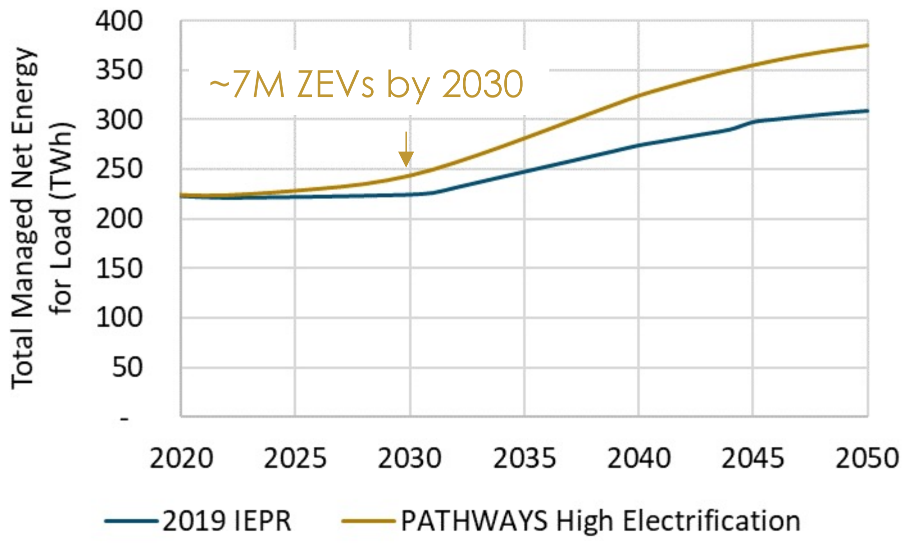
Updated 2020 High Electrification Scenario

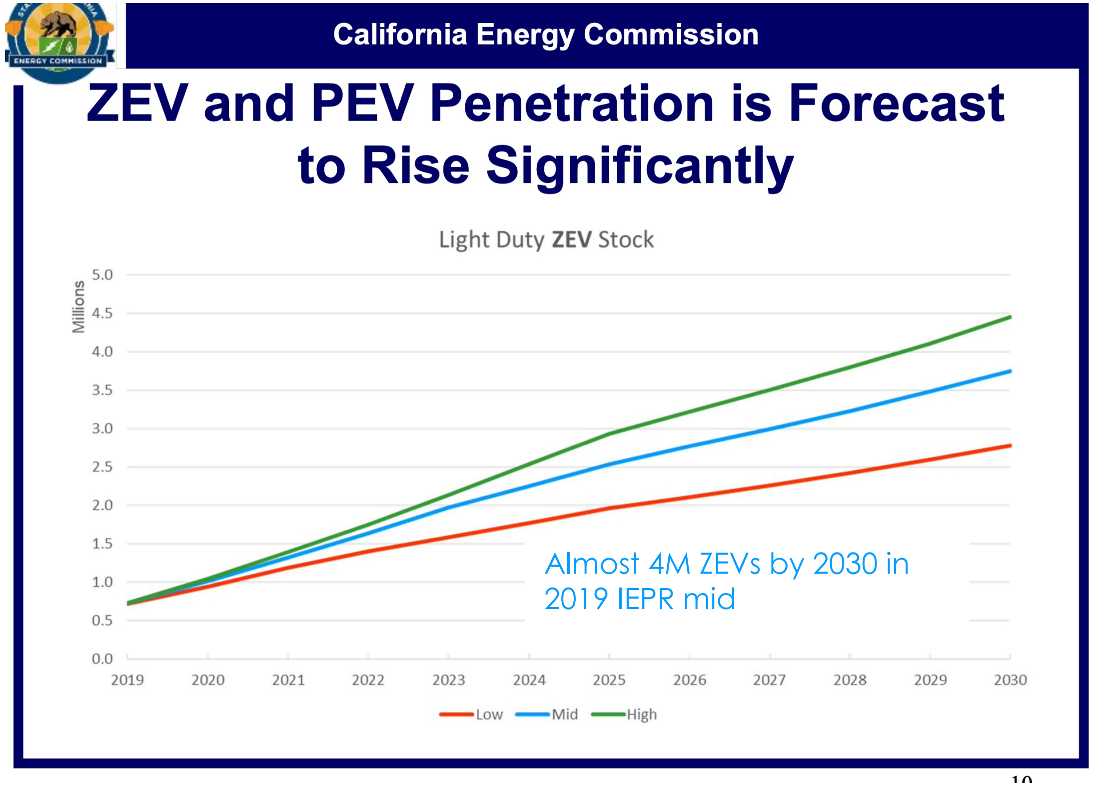
- Updated PATHWAYS High Electrification scenario is consistent with the 2020 E3 report for CARB on Achieving Carbon Neutrality in California (High CDR Case)

Measure	2030 Assumptions
Building EE	**High**: Harmonized with 2017 Scoping Plan EE
Industry EE	**High**: Harmonized with 2017 Scoping Plan EE
Smart Growth	**6% reduction** in per capita LDV VMT relative to 2017
Building Electrification	**50% of new sales** for water heaters and HVAC are heat pumps (~2 TWh)
Vehicle efficiency	**High**: retain federal waiver for CA mpg (new LDA are 45 mpg and LDTs 34 mpg in 2030)
Light-duty vehicle electrification	**7 million on-road ZEVs** (67% sales, 23 TWh)
Trucks & off-Road electrification	**15% MDV and 9% HDV BEVs** (60% and 22% sales, 15 TWh)
Clean Electricity	76% RPS (**30 MMT CO_2 statewide**)
Biofuels	**398 TBTU** (all available waste & residue feedstocks, including importing to CA population share of US feedstocks)
Pipeline Hydrogen	**5% blend by energy** (off-grid renewable electrolysis)
Non-Combustion	**40% reduction** in CH_4 and F-gases

High Electrification Sensitivity

Comparison of 2020 CPUC PATHWAYS High Electrification and 2019 IEPR Mid





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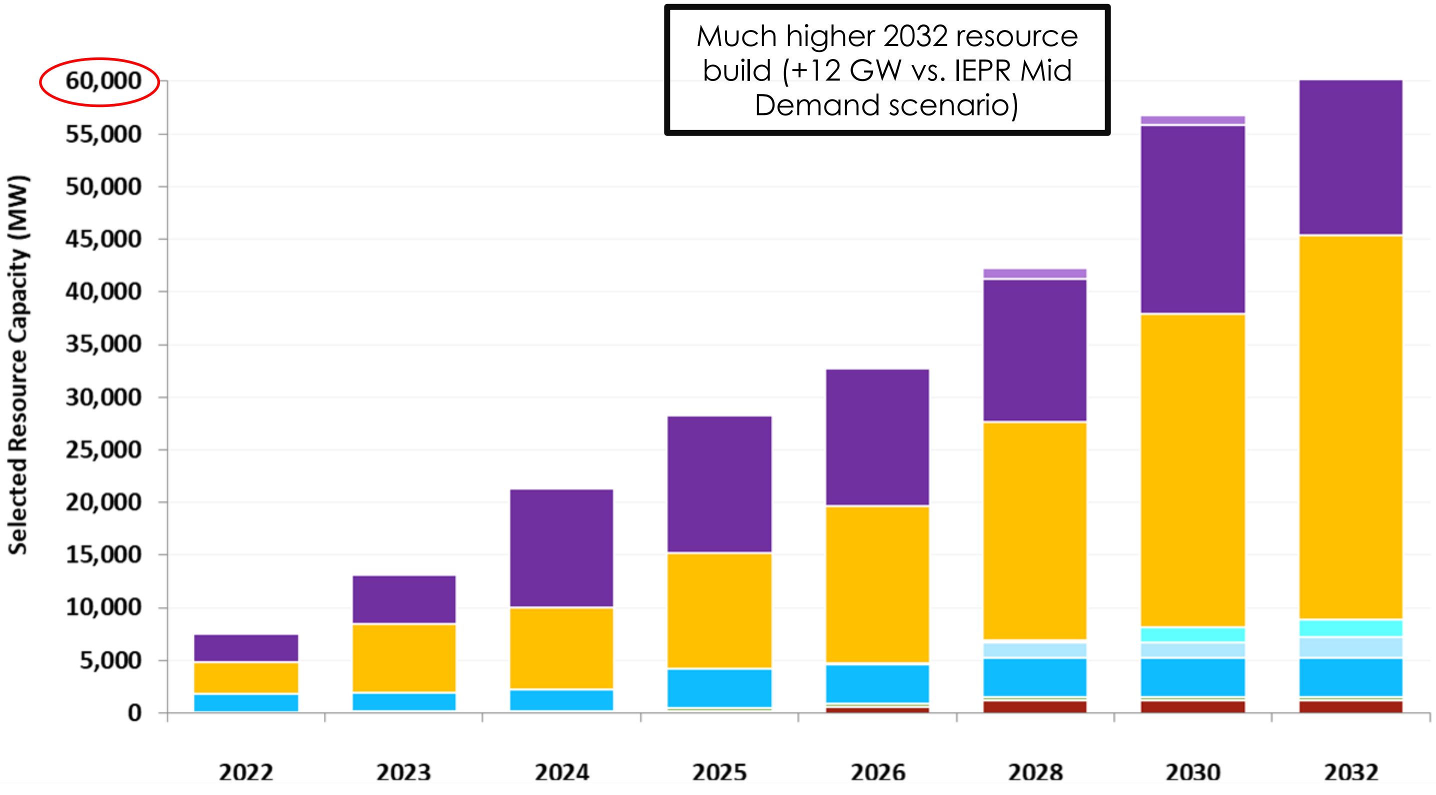
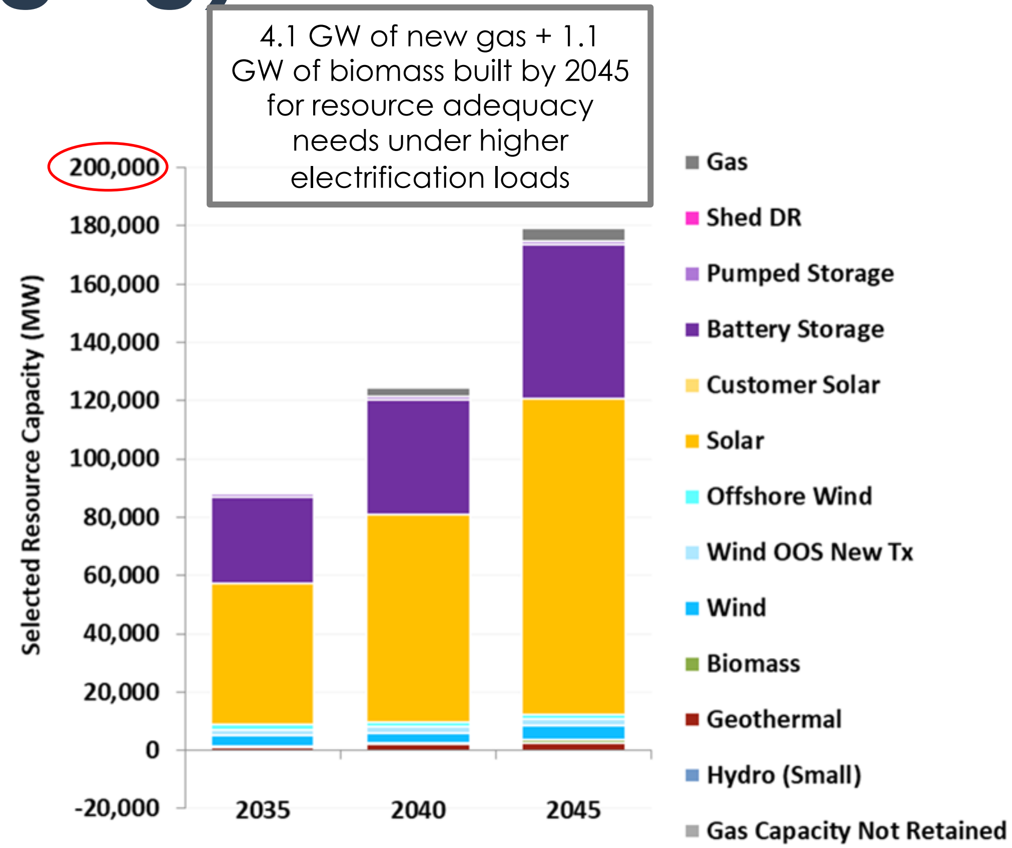
Selected resources – 38 MMT w/ High Electrification (Managed Charging)





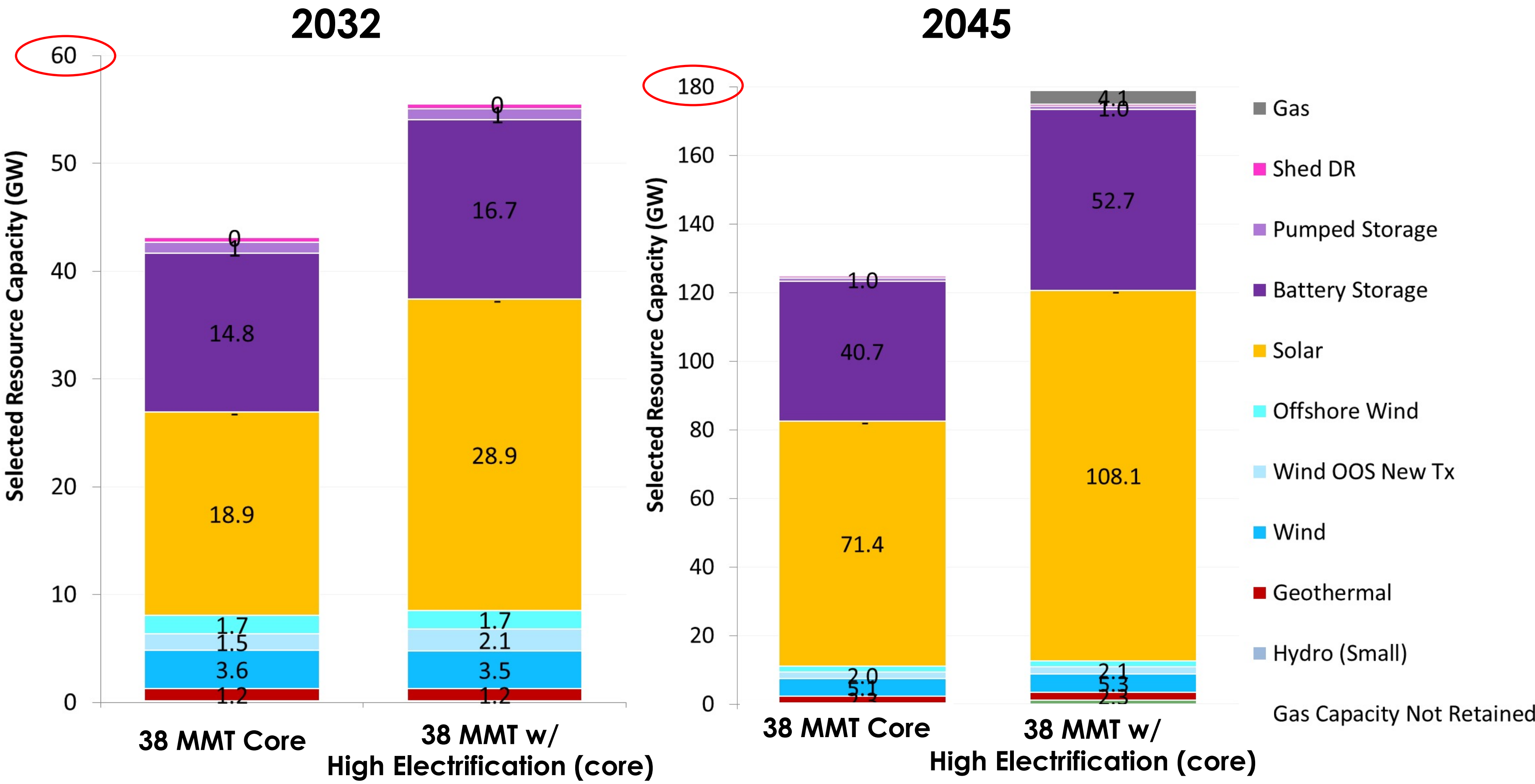
Selected resources – 38 MMT w/ High Electrification (Managed Charging)

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	0	0	0	0	2,578	4,120
Biomass	*MW*	34	65	83	107	107	134	134	134	134	134	1,147
Geothermal	*MW*	14	114	114	114	184	1,162	1,162	1,162	1,162	1,162	2,332
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,458	3,458	3,458	3,458	3,458	3,458	3,458	5,319
Wind OOS New Tx	*MW*	-	-	-	-	0	1,595	1,596	2,066	2,066	2,066	2,066
Offshore Wind	*MW*	-	-	-	-	120	195	1,431	1,708	1,728	1,728	1,749
Solar	*MW*	3,094	6,549	7,750	11,000	11,000	12,407	21,659	28,872	42,378	70,974	108,076
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,565	4,604	10,906	12,877	12,877	13,277	14,899	16,664	25,252	38,510	52,702
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	*MW*	151	151	353	441	441	441	441	441	441	441	441
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	-	-	-	(0)
Storage + DR	*MW*	**2,716**	**4,755**	**11,258**	**13,318**	**13,514**	**14,718**	**16,340**	**18,105**	**26,693**	**39,951**	**54,143**
Total Resources (Renewables + Storage + DR)	*MW*	**7,577**	**13,224**	**21,277**	**27,997**	**28,383**	**33,671**	**45,780**	**55,505**	**77,620**	**122,051**	**178,951**

- Through 2032 the increased load is mostly served by additional solar PV and battery resources
- By 2040 and 2045, the model selects more diversity and additional firm generation (shown in the selection of new gas and biomass resources) in addition to the increased solar PV and batteries

38 MMT Core vs. High Electrification (Managed Charging)

- High electrification scenarios lead to more resources, including OSW, solar, batteries, and new “gas”*

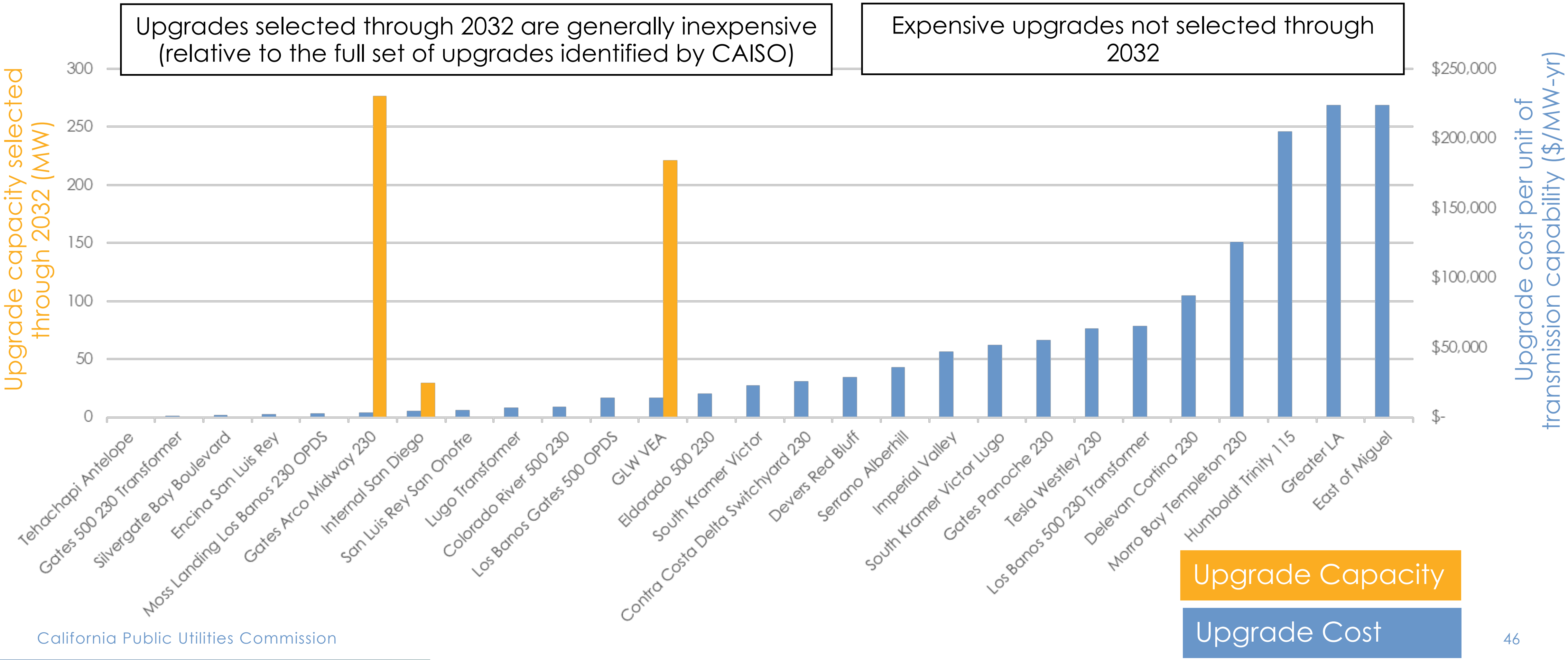


* In theory new “gas” built by RESOLVE could be non-emitting (e.g. H2 CTs), but is modeled with natural gas fuel

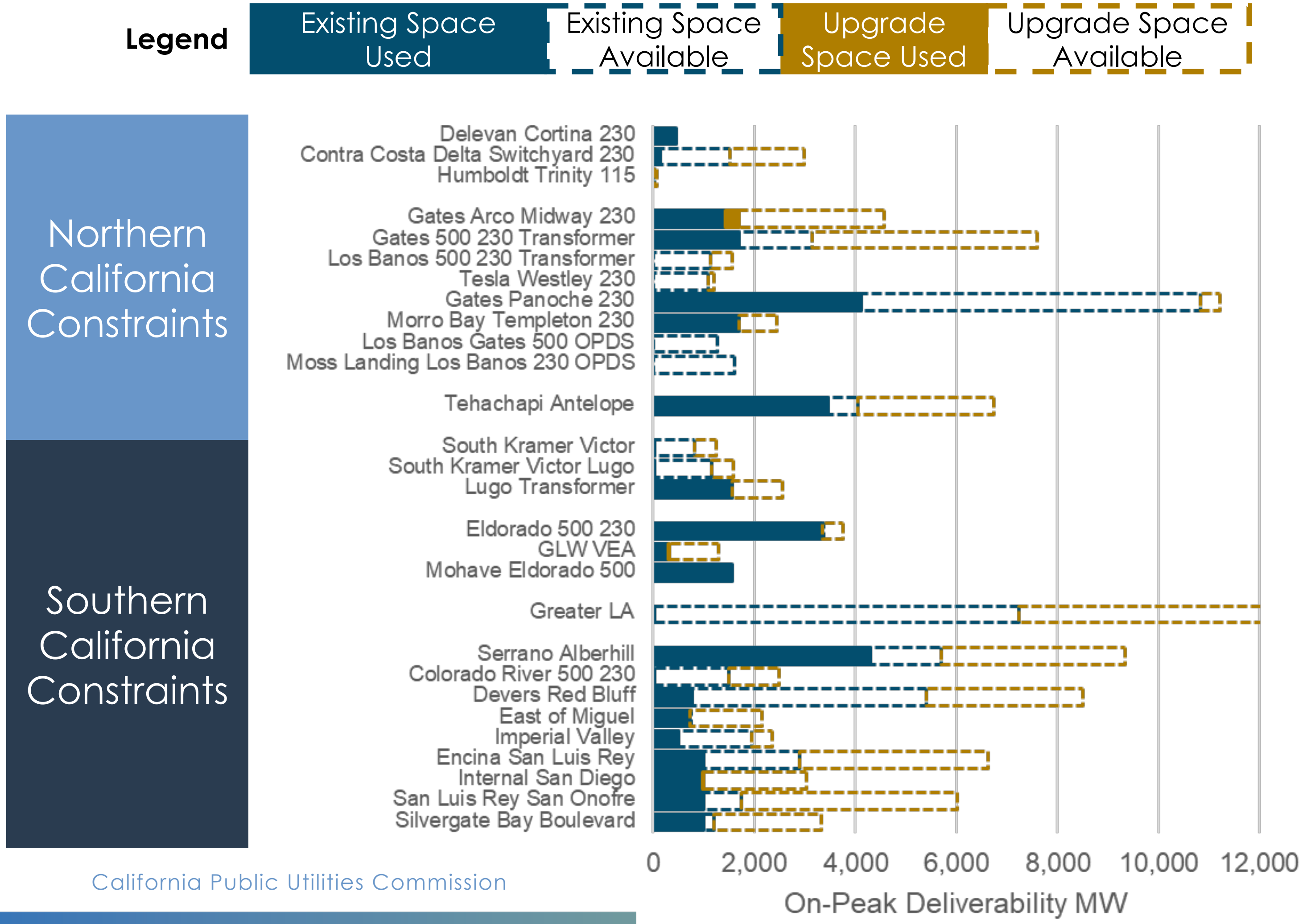
38 MMT w/ High Electrification (Managed Charging) – Transmission and Resource Interactions

- CAISO's transmission limits set an upper bound on the amount of solar + storage that could be deployed in the CAISO grid
  - Transmission upgrades create additional, but not infinite, space on the transmission system
- The 38 MMT high electrification case requires a substantial buildout of GHG-free resources, especially solar and batteries, above the core 38 MMT case
- It becomes increasingly difficult for RESOLVE to place solar and batteries in the 2040-2045 timeframe, resulting in many transmission upgrades
- It becomes particularly hard to deploy solar in this timeframe because solar becomes very limited by off-peak deliverability constraints
- As a modeling tool to explore high electrification scenarios, E3 has expanded the resource potential of Distributed PV, which in the current version of RESOLVE does not take up space in CAISO's transmission constraints
  - In the 38 MMT high electrification case, 34 GW of Distributed PV is selected in 2045; none is selected in earlier years. Further analysis would be necessary to determine interactions with CAISO's transmission constraints.
- E3 has also included a very high-cost transmission upgrade in the Greater LA area – this is for modeling purposes and is not an upgrade identified by CAISO.
  - RESOLVE will only select this upgrade as a last resort to locate additional batteries
  - However even under the high electrification case, RESOLVE does not select this upgrade
- *The amount of transmission needed for solar and batteries in the 2045 timeframe is uncertain*

Transmission upgrades 2032 – 38 MMT w/ High Electrification (Managed Charging)

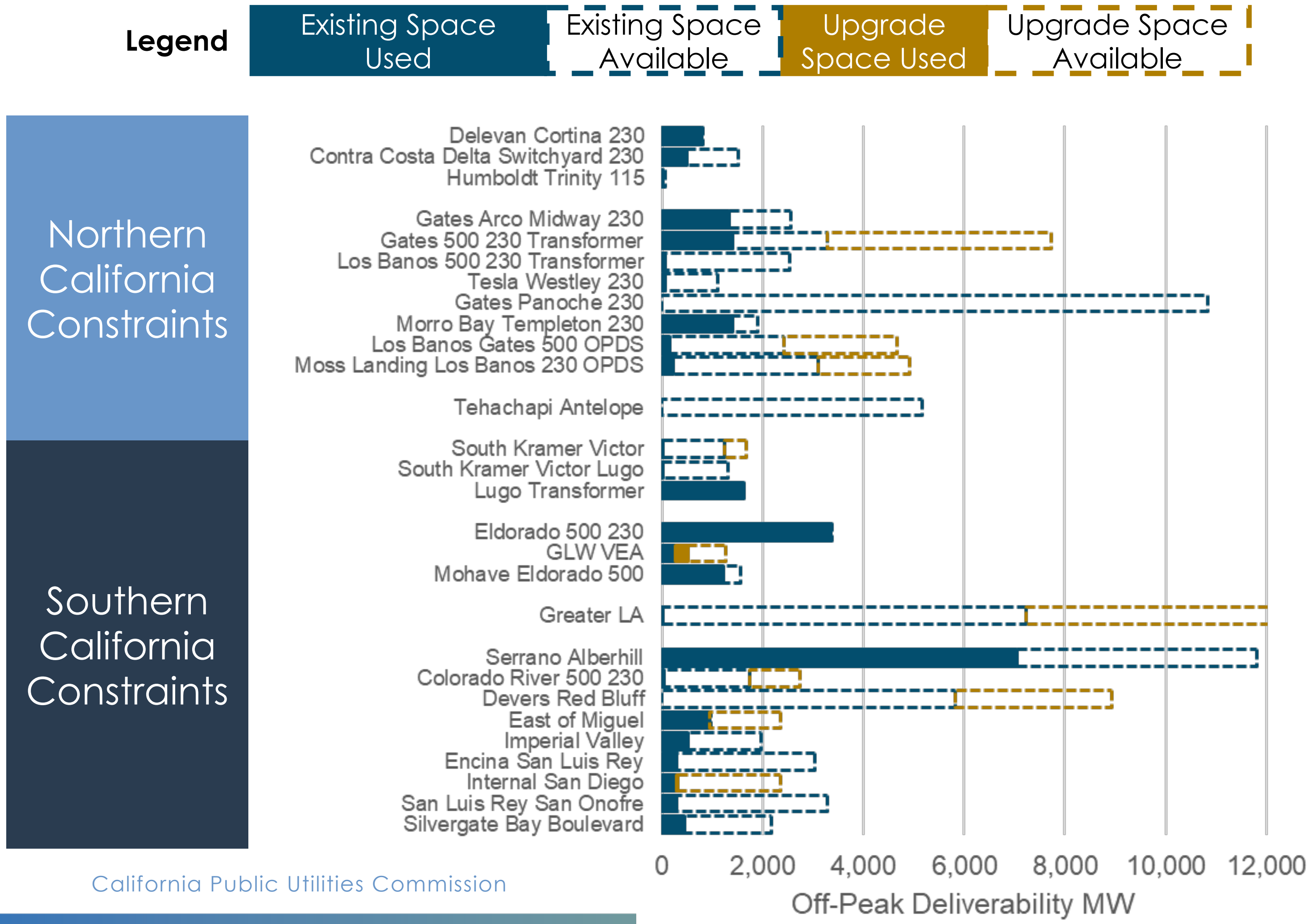


On-Peak Transmission utilization and upgrades: 2032 – 38 MMT w/ High Electrification (Managed Charging)



- Under the high electrification scenario transmission build in the 2032 timeframe is very similar because the effects of the electrification are greater beyond 2032
  - There are small increases in on-peak deliverability need in the Tehachapi antelope, Mohave Eldorado, and San Diego constraint areas
  - There is a slight decrease in on-peak deliverability need in the GLW VEA constraint area

Off-Peak Transmission utilization and upgrades: 2032 – 38 MMT w/ High Electrification (Managed Charging)



- Off peak generally less limiting than on-peak in 2032 timeframe
  - Battery deployment expands off-peak transmission capability (via charging)

Transmission upgrades (MW) annual summary – 38 MMT w/ High Electrification (Managed Charging)

Transmission Constraint	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Silvergate Bay Boulevard	-	-	-	-	-	-	-	-	-	1,833	1,833
San Luis Rey San Onofre	-	-	-	-	-	-	-	-	-	1,287	1,287
Internal San Diego	-	-	-	-	-	29	29	29	29	2,067	2,067
Encina San Luis Rey	-	-	-	-	-	-	-	-	-	134	134
Imperial Valley	-	-	-	-	-	-	-	-	-	-	-
East of Miguel	-	-	-	-	-	-	-	-	-	-	503
Devers Red Bluff	-	-	-	-	-	-	-	-	-	-	-
Colorado River 500 230	-	-	-	-	-	-	-	-	-	-	-
Serrano Alberhill	-	-	-	-	-	-	-	-	-	2,807	3,648
Greater LA	-	-	-	-	-	-	-	-	-	-	-
Mohave Eldorado 500	-	-	-	-	-	-	-	-	-	-	-
GLW VEA	-	-	-	-	-	221	221	221	221	221	221
Eldorado 500 230	-	-	-	-	-	-	-	-	-	400	400
Lugo Transformer	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	0	0	980	980
South Kramer Victor Lugo	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-
South Kramer Victor	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-
Tehachapi Antelope	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	2,700	2,700
Moss Landing Los Banos 230 OPDS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-
Los Banos Gates 500 OPDS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-
Morro Bay Templeton 230	-	-	-	-	-	-	-	-	-	-	-
Gates Panoche 230	-	-	-	-	-	-	-	-	-	-	378
Tesla Westley 230	-	-	-	-	-	-	-	-	-	-	-
Los Banos 500 230 Transformer	-	-	-	-	-	-	-	-	-	-	-
Gates 500 230 Transformer	-	-	-	-	-	-	-	-	-	-	-
Gates Arco Midway 230	-	-	-	-	-	-	-	277	277	277	277
Humboldt Trinity 115	-	-	-	-	-	-	-	-	-	-	21
Contra Costa Delta Switchyard 230	-	-	-	-	-	-	-	-	-	-	-
Delevan Cortina 230	-	-	-	-	-	-	-	-	41	41	2,838

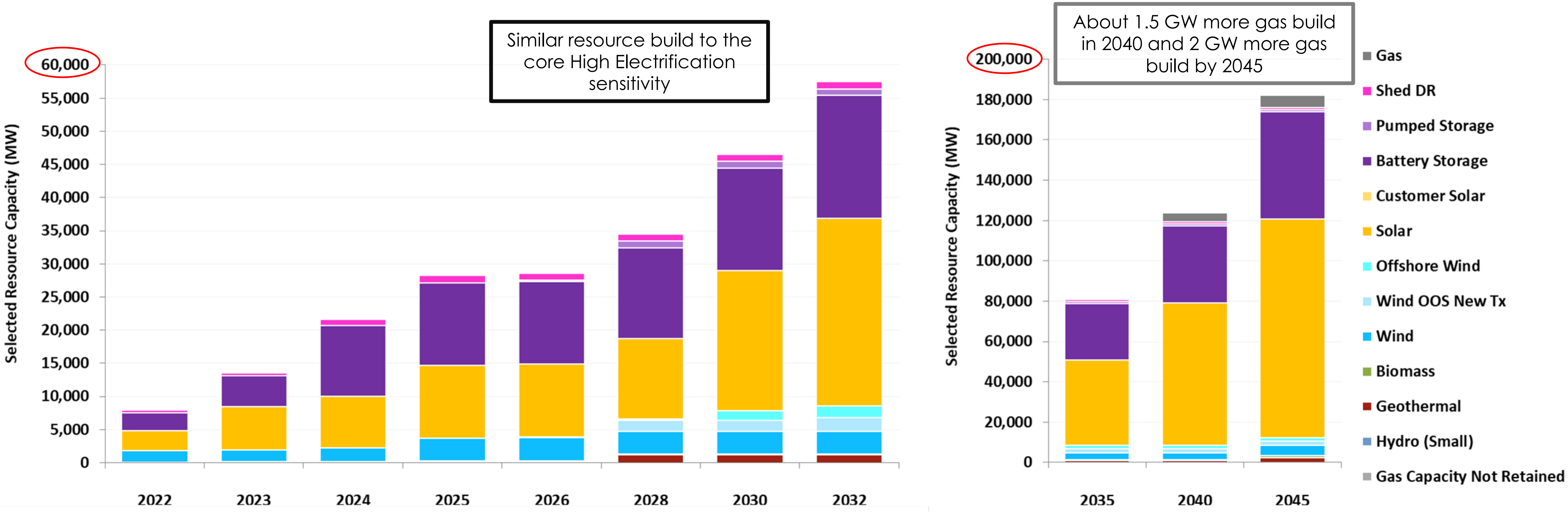
There are still few upgrades through 2032 even under the high electrification scenario

By 2040-5 most upgrades are selected, albeit with large uncertainty on transmission needs for incremental solar and batteries

38 MMT with High Electrification (Unmanaged Charging EV Profile)

With LSE Plans

Selected resources – 38 MMT with High Electrification (Unmanaged Charging)



Selected resources – 38 MMT with High Electrification (Unmanaged Charging)

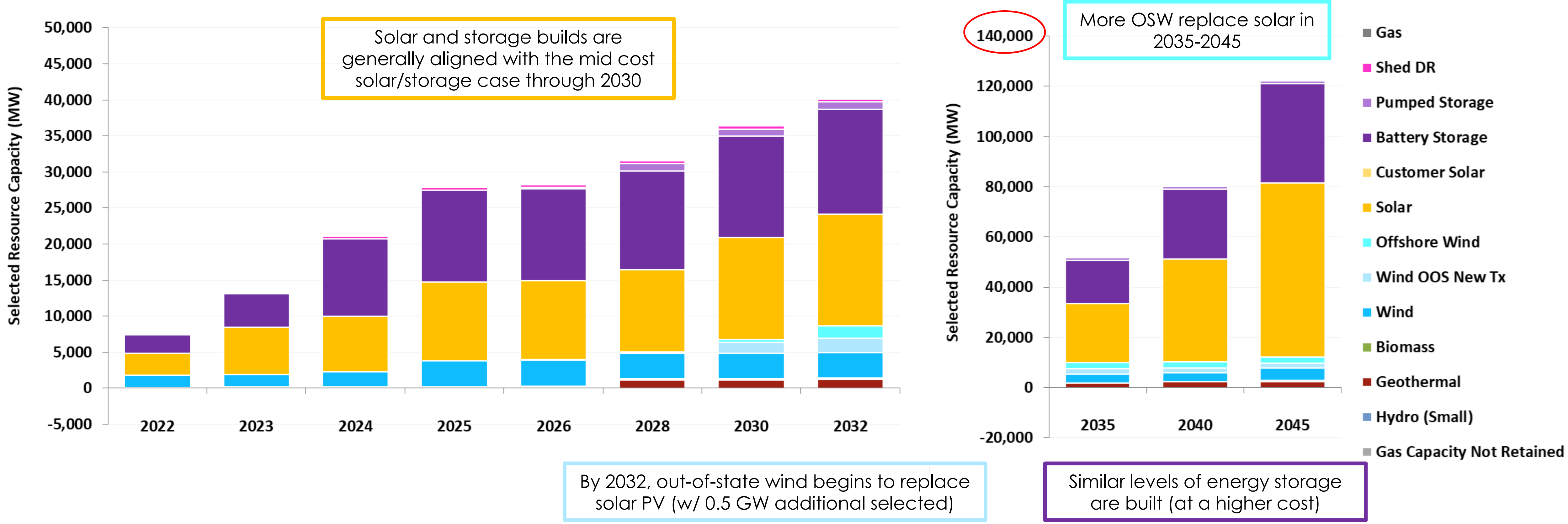
	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	3	3	3	267	4,443	6,071
Biomass	*MW*	34	65	83	107	107	134	134	134	134	134	1,147
Geothermal	*MW*	14	114	114	114	184	1,162	1,162	1,162	1,162	1,162	2,332
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,458	3,458	3,458	3,458	3,458	3,458	3,458	5,006
Wind OOS New Tx	*MW*	-	-	-	-	0	1,595	1,595	2,066	2,066	2,066	2,066
Offshore Wind	*MW*	-	-	-	-	120	195	1,431	1,708	1,728	1,728	1,749
Solar	*MW*	3,094	6,549	7,750	11,000	11,000	12,202	21,238	28,322	42,372	70,605	108,558
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,630	4,604	10,687	12,436	12,436	13,675	15,410	18,543	27,744	38,225	52,961
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,001	1,001	1,001	1,001	1,001
Shed DR	*MW*	444	444	889	1,111	1,111	1,111	1,111	1,111	1,111	1,111	1,111
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	-	-	-	-
Storage + DR	*MW*	**3,075**	**5,048**	**11,576**	**13,547**	**13,743**	**15,786**	**17,522**	**20,655**	**29,856**	**40,337**	**55,073**
Total Resources (Renewables + Storage + DR)	*MW*	**7,936**	**13,517**	**21,595**	**28,227**	**28,613**	**34,536**	**46,544**	**57,508**	**81,044**	**123,933**	**182,002**

- By 2032, the lack of managed charging results in about 2 GW more battery storage in this sensitivity relative to the High Electrification (core) sensitivity
  - New gas capacity additions of the order of 5 MW are within the margins of error for PSP RESOLVE model runs.
- In the 2040-2045 period, 1.5 GW – 2 GW more gas resources are also added relative to the High Electrification (core) sensitivity, likely due to an increased peak impact from the EV loads in 2045 without any managed charging.

38 MMT High Solar + Storage Costs

With LSE Plans

Selected resources – 38 MMT w/ high solar PV and battery storage costs

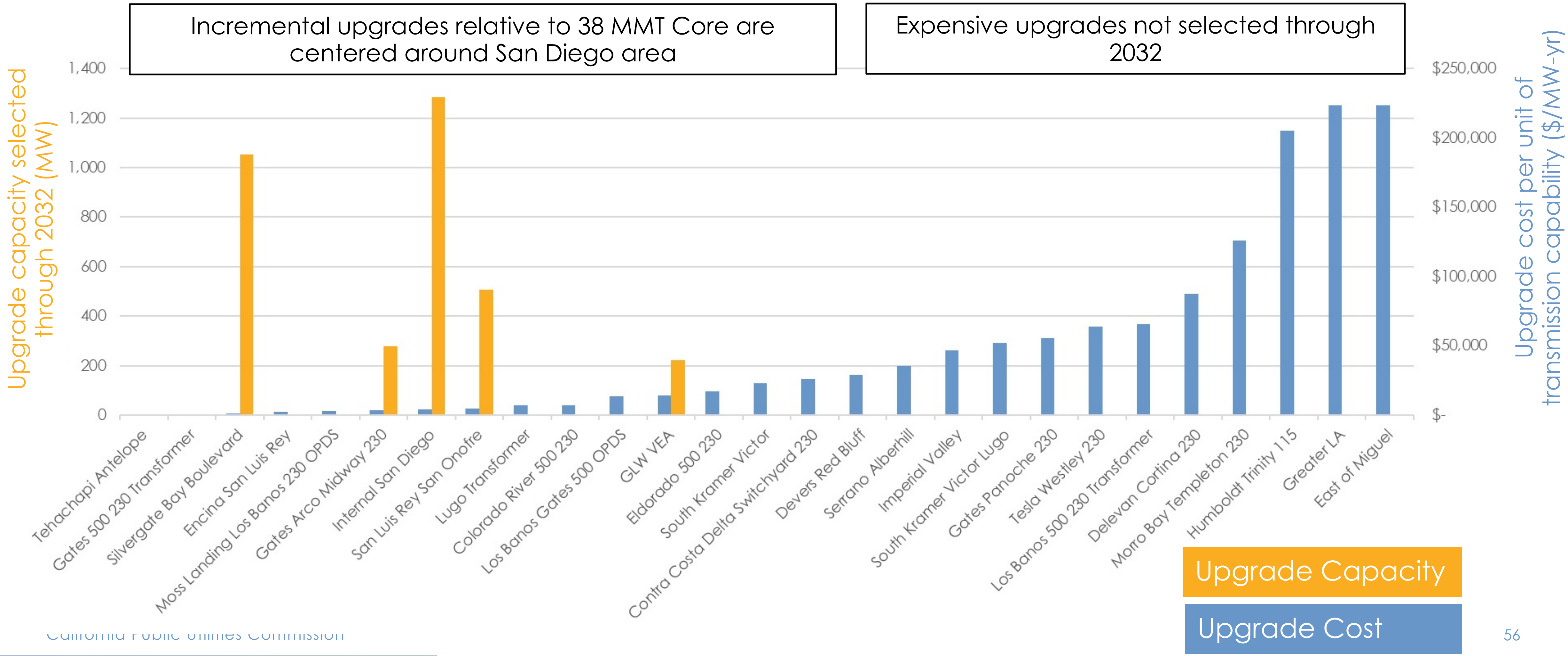


Selected resources – 38 MMT with high solar PV and battery storage costs

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	1	1	1	1	1	1
Biomass	*MW*	34	65	83	107	107	134	134	134	134	134	462
Geothermal	*MW*	14	114	114	114	184	1,160	1,160	1,238	1,805	2,298	2,332
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	*MW*	-	-	-	-	0	0	1,500	1,970	1,970	1,970	1,970
Offshore Wind	*MW*	-	-	-	-	120	195	358	1,708	2,441	2,441	2,441
Solar	*MW*	3,094	6,549	7,750	11,000	11,000	11,397	14,171	15,543	23,463	40,727	69,186
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,565	4,603	10,699	12,652	12,652	13,708	14,056	14,562	17,276	27,926	39,628
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,001	1,001	1,001	1,001	1,001
Shed DR	*MW*	151	151	353	441	441	441	441	441	441	441	441
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	(0)	(152)	(393)	(393)
Storage + DR	*MW*	**2,716**	**4,755**	**11,051**	**13,093**	**13,289**	**15,149**	**15,497**	**16,003**	**18,718**	**29,368**	**41,069**
Total Resources (Renewables + Storage + DR)	*MW*	**7,577**	**13,224**	**21,070**	**27,867**	**28,254**	**31,589**	**36,374**	**40,150**	**51,932**	**80,099**	**122,121**

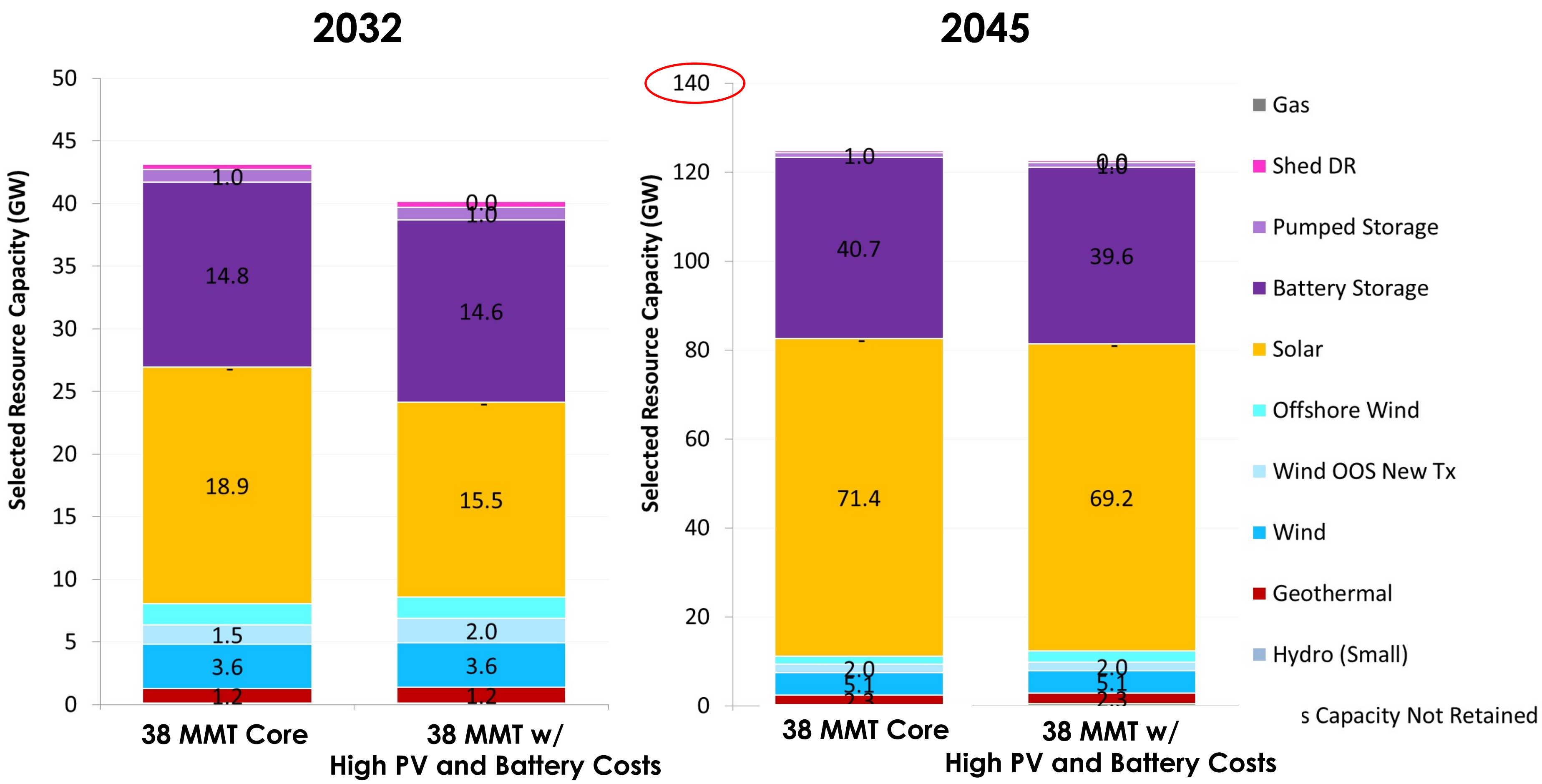
- High solar and battery buildout is relatively insensitive to solar and battery storage costs until 2032 – 2040, when additional out-of-state wind and offshore wind is selected in place of solar and battery storage
  - New gas capacity additions of the order of 5 MW are within the margins of error for PSP RESOLVE model runs. Transmission upgrades are triggered largely to accommodate more OOS wind and to offset the reduced expansion of the off-peak transmission capability due to reduced battery storage selection
- Larger upgrades in the Internal San Diego constraint, and two new upgrades at the Silvergate Bay Boulevard constraint and the San Luis Rey San Onofre constraint

Transmission upgrades 2032
38 MMT with high solar PV and battery storage costs



38 MMT Core vs. High solar PV and battery costs

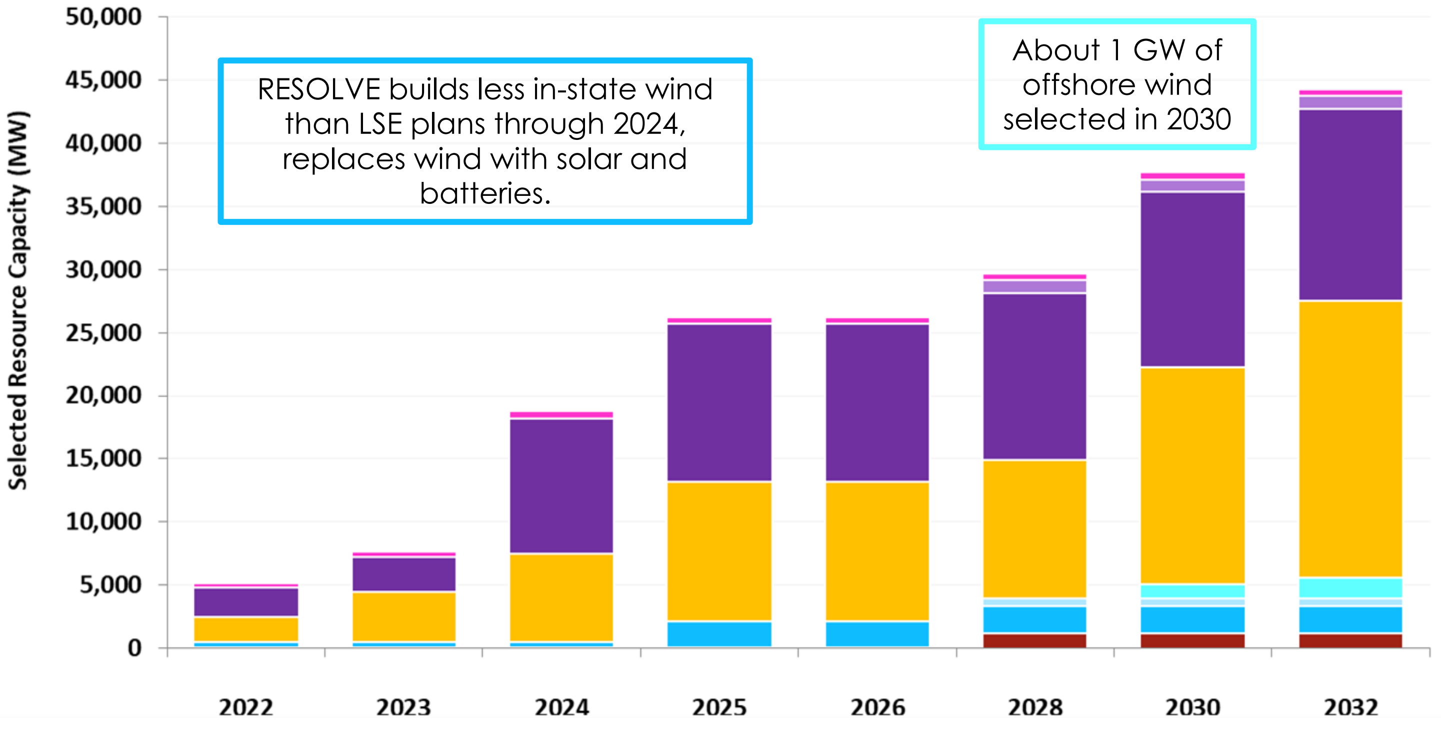
- High solar PV and battery storage costs leads to similar resource builds with less solar and a little more resource diversity

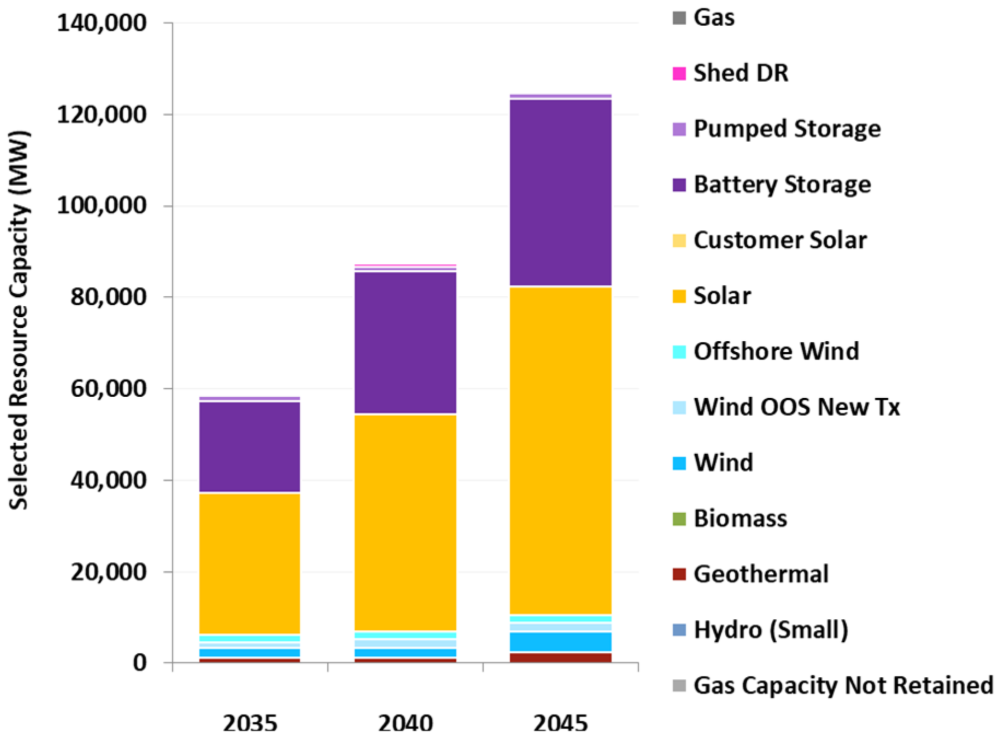


38 MMT No LSE Plans

Without any LSE Plans

Selected resources – 38 MMT without LSE Plans





Out-of-state wind on new transmission not selected in large amounts until ~2040. 605 MW selected in 2028

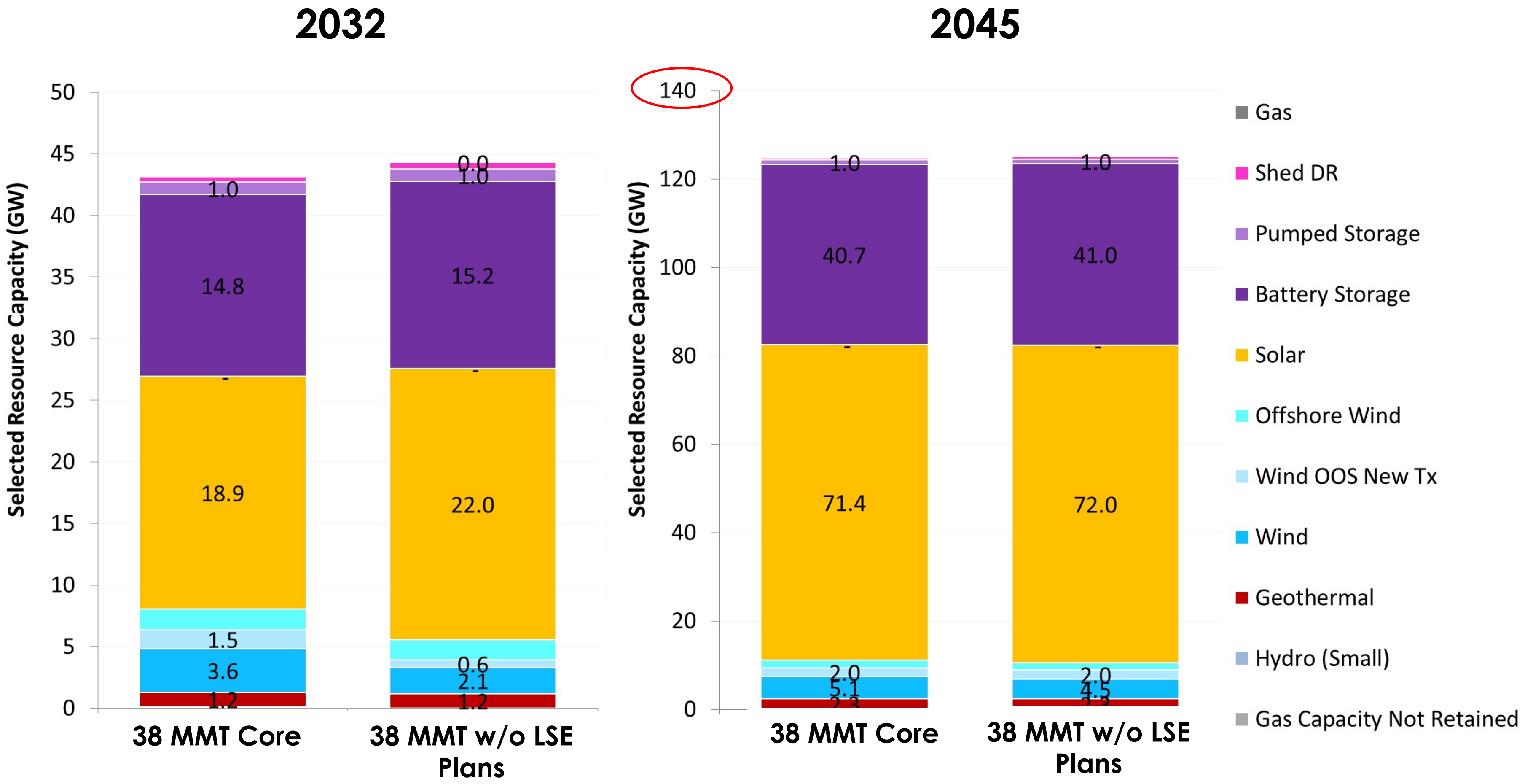
Selected resources – 38 MMT without LSE Plans

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	0	0	0	0	0	0
Biomass	*MW*	15	15	15	15	15	15	15	15	15	15	15
Geothermal	*MW*	14	14	14	14	14	1,175	1,175	1,175	1,175	1,175	2,332
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	431	431	431	2,118	2,118	2,118	2,118	2,118	2,118	2,118	4,519
Wind OOS New Tx	*MW*	-	-	-	-	-	605	605	605	1,191	1,970	1,970
Offshore Wind	*MW*	-	-	-	-	-	-	1,177	1,662	1,662	1,662	1,662
Solar	*MW*	2,000	4,000	7,000	11,000	11,000	11,000	17,165	21,995	31,111	47,533	71,958
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,315	2,781	10,761	12,575	12,575	13,256	13,907	15,184	20,119	31,277	41,045
Pumped Storage	*MW*	-	-	-	-	0	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	*MW*	362	450	538	538	538	538	538	538	538	538	538
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	-	-	-	-
Storage + DR	*MW*	**2,676**	**3,231**	**11,299**	**13,113**	**13,113**	**14,794**	**15,445**	**16,722**	**21,657**	**32,815**	**42,583**
Total Resources (Renewables + Storage + DR)	*MW*	**5,136**	**7,691**	**18,759**	**26,260**	**26,260**	**29,708**	**37,701**	**44,293**	**58,930**	**87,289**	**125,040**

- Without the LSE plans about 2.6 GW of total wind is selected by 2032, compared to 5.1 GW with the LSE plans in the 38 MMT Core scenario

38 MMT Core vs. Without LSE Plans

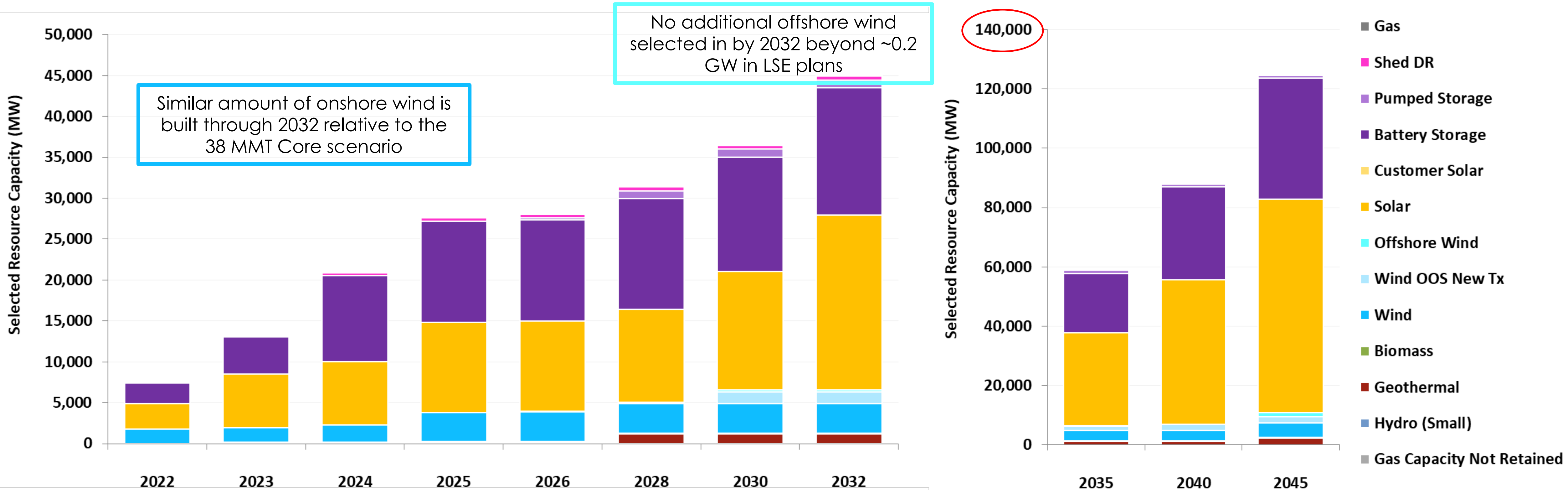
- Less wind and OOS wind are selected by 2032
  - Replaced largely by solar PV, causing an a slightly larger total selected resource relative to the 38 MMT Core
- By 2045 the selected portfolios are largely similar with a little less wind and a little more solar PV



38 MMT with No Offshore Wind ITC Extension

With LSE Plans

Selected resources – 38 MMT with No Offshore Wind ITC Extension



Similar amounts of out-of-state wind on new transmission selected as in the 38 MMT Core scenario through 2045; maxes out at ~2 GW

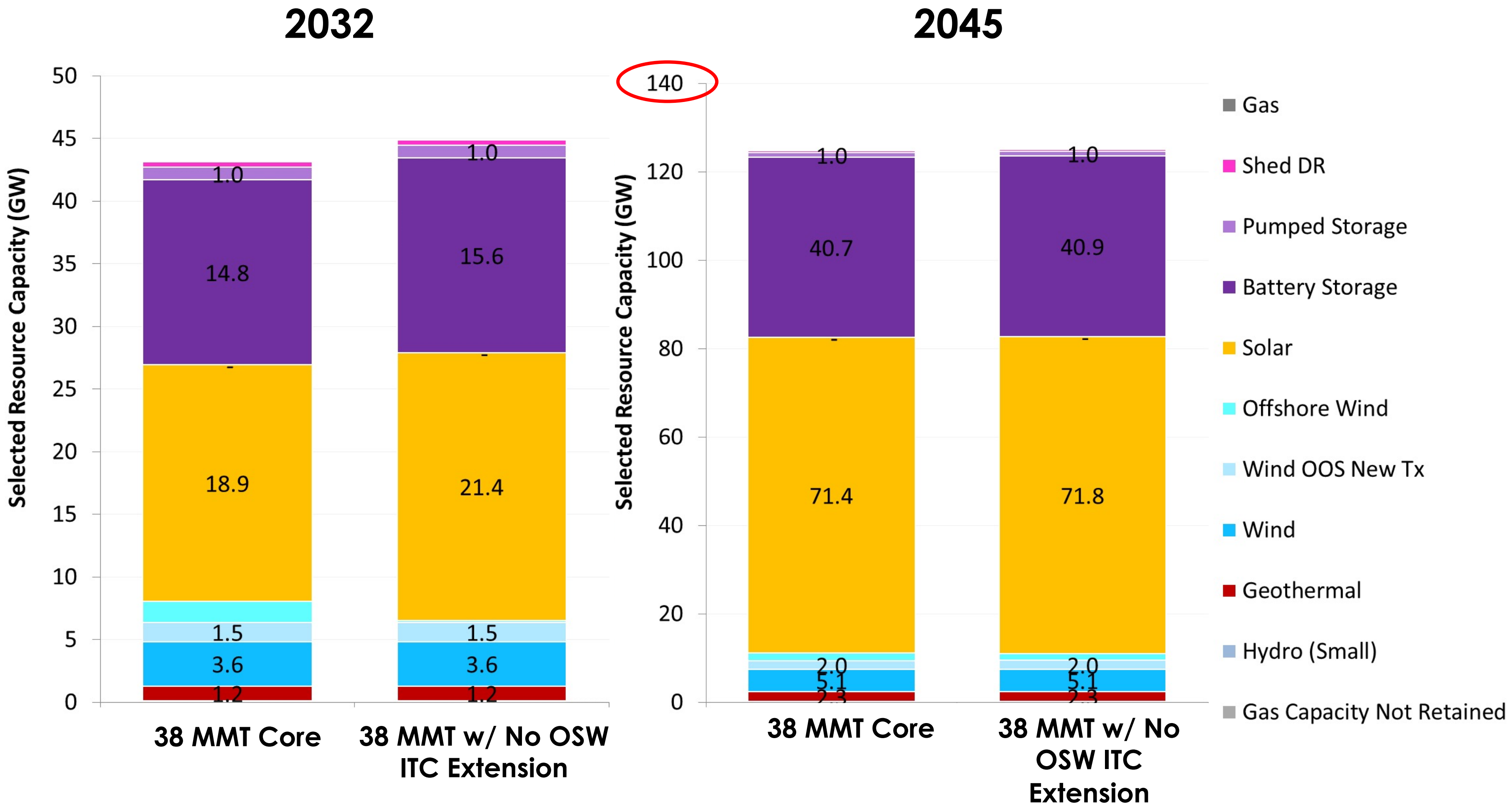
Selected resources – 38 MMT with No Offshore Wind ITC Extension

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	0	0	0	0	0	30
Biomass	*MW*	34	65	83	107	107	134	134	134	134	134	134
Geothermal	*MW*	14	114	114	114	184	1,160	1,160	1,160	1,160	1,160	2,273
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	*MW*	-	-	-	-	0	0	1,500	1,500	1,500	1,970	1,970
Offshore Wind	*MW*	-	-	-	-	120	195	195	195	195	195	1,539
Solar	*MW*	3,094	6,549	7,750	11,000	11,000	11,397	14,491	21,363	31,217	48,654	71,754
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,565	4,604	10,505	12,415	12,415	13,472	13,966	15,551	20,065	31,296	40,893
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	*MW*	151	151	353	441	441	441	441	441	441	441	441
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	*(0)*	(0)	(0)	(0)	(0)
Storage + DR	*MW*	**2,716**	**4,755**	**10,858**	**12,856**	**13,052**	**14,913**	**15,407**	**16,992**	**21,506**	**32,737**	**42,334**
Total Resources (Renewables + Storage + DR)	*MW*	**7,577**	**13,224**	**20,876**	**27,631**	**28,017**	**31,353**	**36,441**	**44,898**	**59,265**	**88,404**	**125,087**

- Without access to the offshore wind ITC extension via safe harbor, offshore wind is only selected in 2045 (beyond the LSE plans amount)
- The amount of out-of-state wind is similar to the 38 MMT Core scenario, further underscoring the deduction that this resource is likely maxed out at 2 GW due to transmission constraints

38 MMT Core vs. with No Offshore Wind ITC Extension

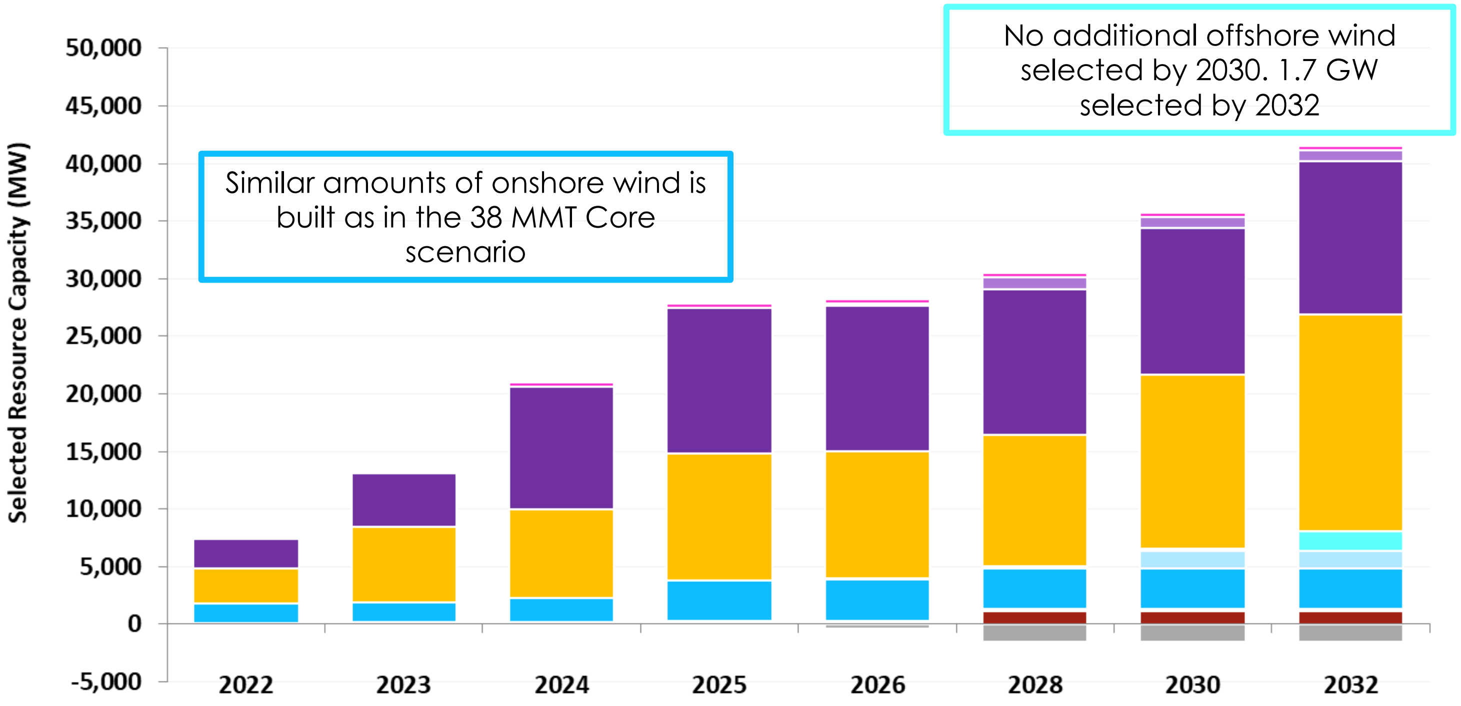
- Significantly less offshore wind is selected by 2032
  - Replaced largely by solar PV and batteries
- By 2045 the selected portfolios are largely similar

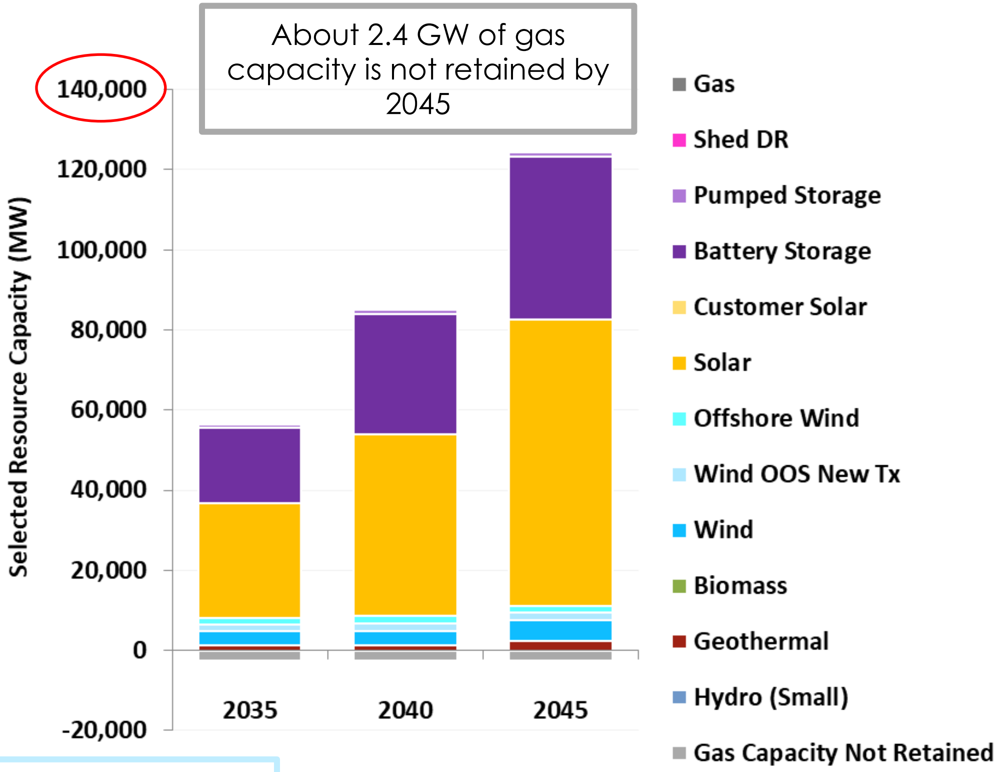


38 MMT with MTR Non-Persistence

With LSE Plans

Selected resources – 38 MMT with MTR Non-Persistence





~300 MW of gas capacity is not retained starting in 2026; 1.5 GW by 2032

Similar amounts of out-of-state wind on new transmission selected as in the 38 MMT core scenario

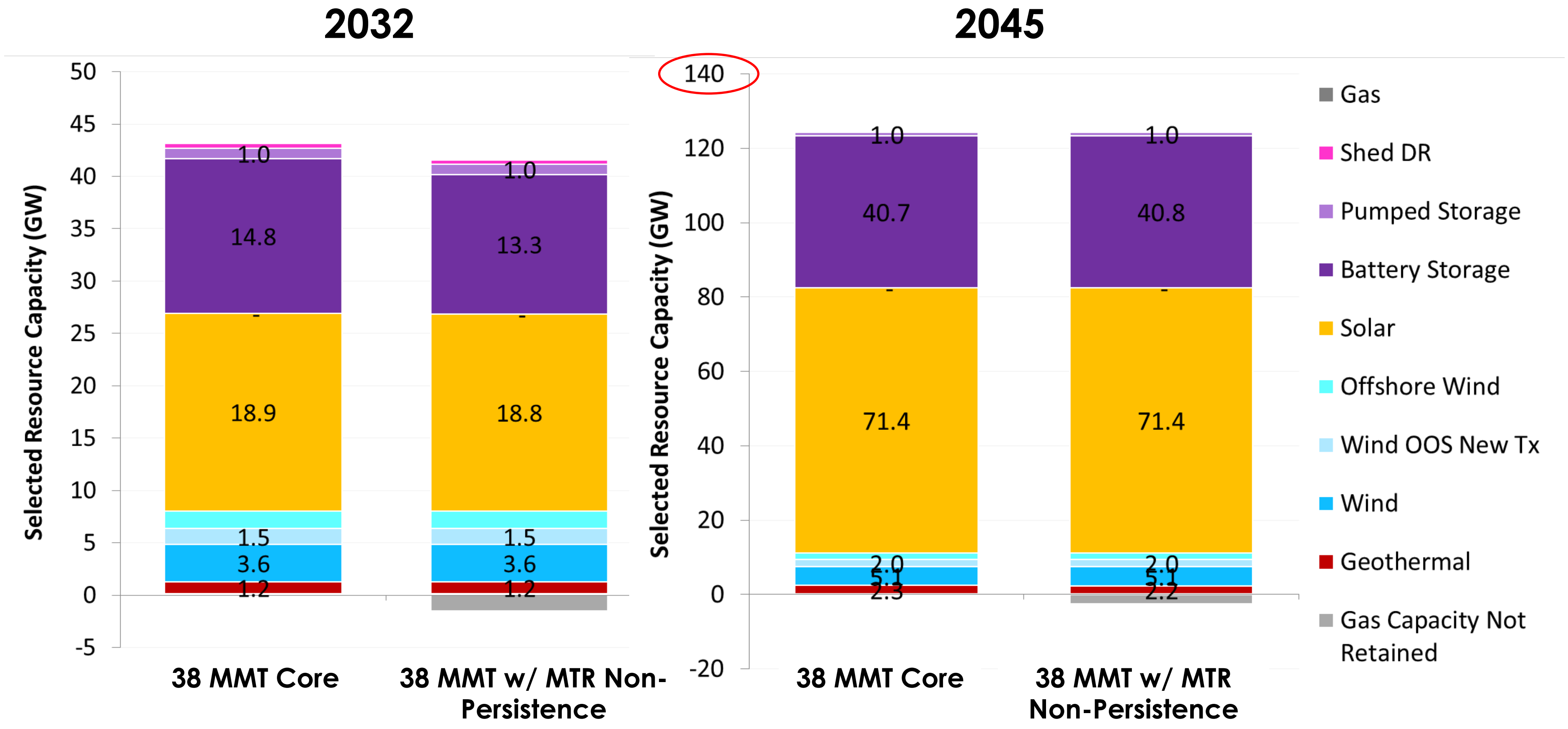
Selected resources – 38 MMT with MTR Non-Persistence

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	MW	-	-	-	-	-	0	0	0	0	0	0
Biomass	MW	34	65	83	134	134	134	134	134	134	134	134
Geothermal	MW	14	114	114	114	184	1,160	1,160	1,160	1,160	1,160	2,244
Hydro (Small)	MW	-	-	-	-	-	-	-	-	-	-	-
Wind	MW	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	MW	-	-	-	-	0	0	1,500	1,500	1,500	1,970	1,970
Offshore Wind	MW	-	-	-	-	120	195	195	1,708	1,728	1,728	1,728
Solar	MW	3,094	6,549	7,750	11,000	11,000	11,397	15,162	18,809	28,675	45,319	71,430
Customer Solar	MW	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	MW	2,565	4,604	10,629	12,677	12,677	12,677	12,677	13,323	18,718	30,076	40,783
Pumped Storage	MW	-	-	-	-	196	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	MW	151	151	353	353	353	353	353	353	353	353	353
Gas Capacity Not Retained	MW	-	-	-	-	*(341)*	*(1,487)*	*(1,487)*	(1,539)	(2,447)	(2,447)	(2,447)
Storage + DR	MW	**2,716**	**4,755**	**10,982**	**13,029**	**13,225**	**14,029**	**14,030**	**14,676**	**20,071**	**31,429**	**42,136**
Total Resources (Renewables + Storage + DR)	MW	**7,577**	**13,224**	**21,000**	**27,831**	**27,876**	**28,982**	**34,247**	**40,001**	**54,375**	**82,847**	**122,249**

- Without the continuation of the D.21-06-035 requirements beyond 2026, about 1.5 GW of gas capacity is not retained starting in 2028 and growing to 2.4 GW by 2045
  - Other portfolio selections are similar to the 38 MMT Core scenario

38 MMT Core vs. MTR Non-Persistence

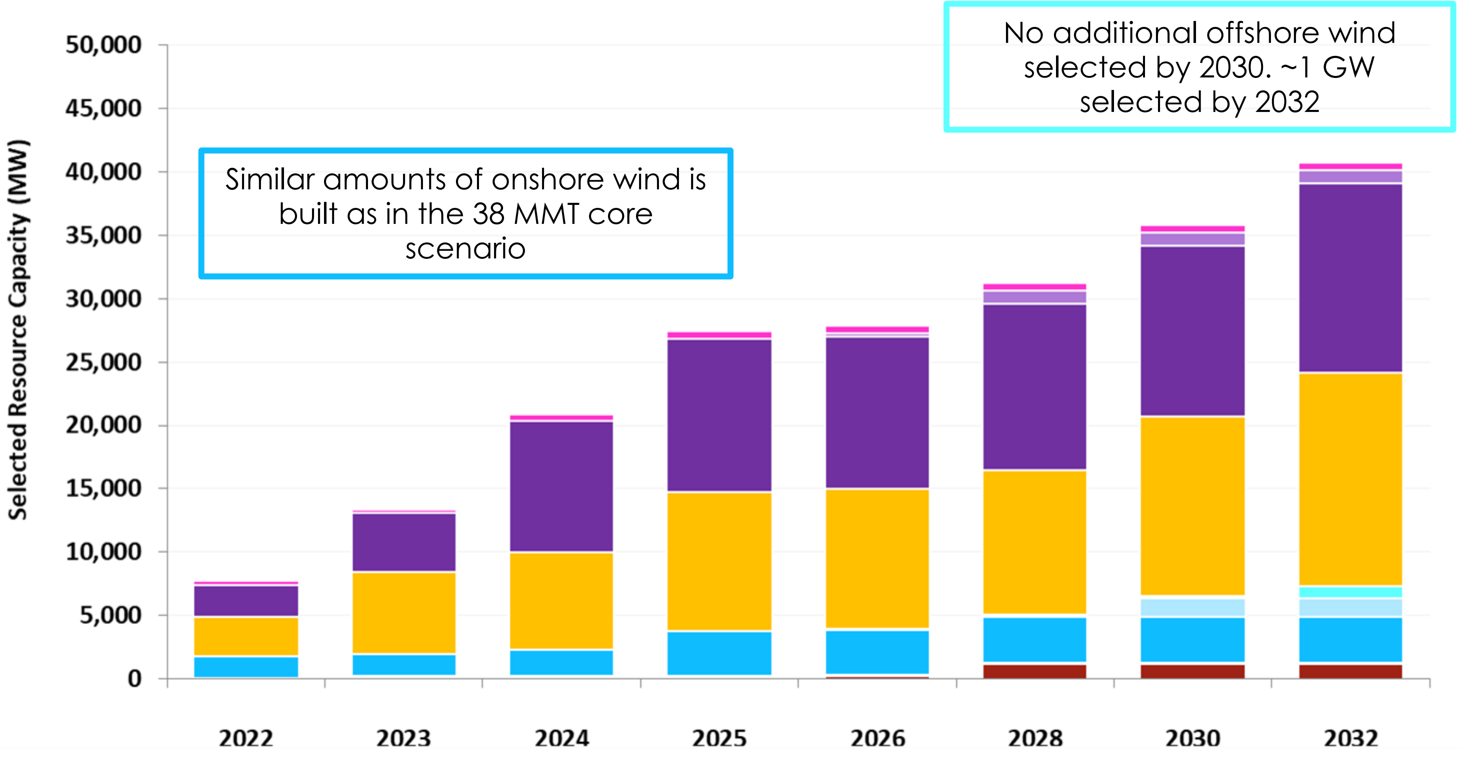
- The selected portfolio is very similar between the two scenarios
- Discontinuing the D.21-06-035 requirements allows for not retaining some gas capacity

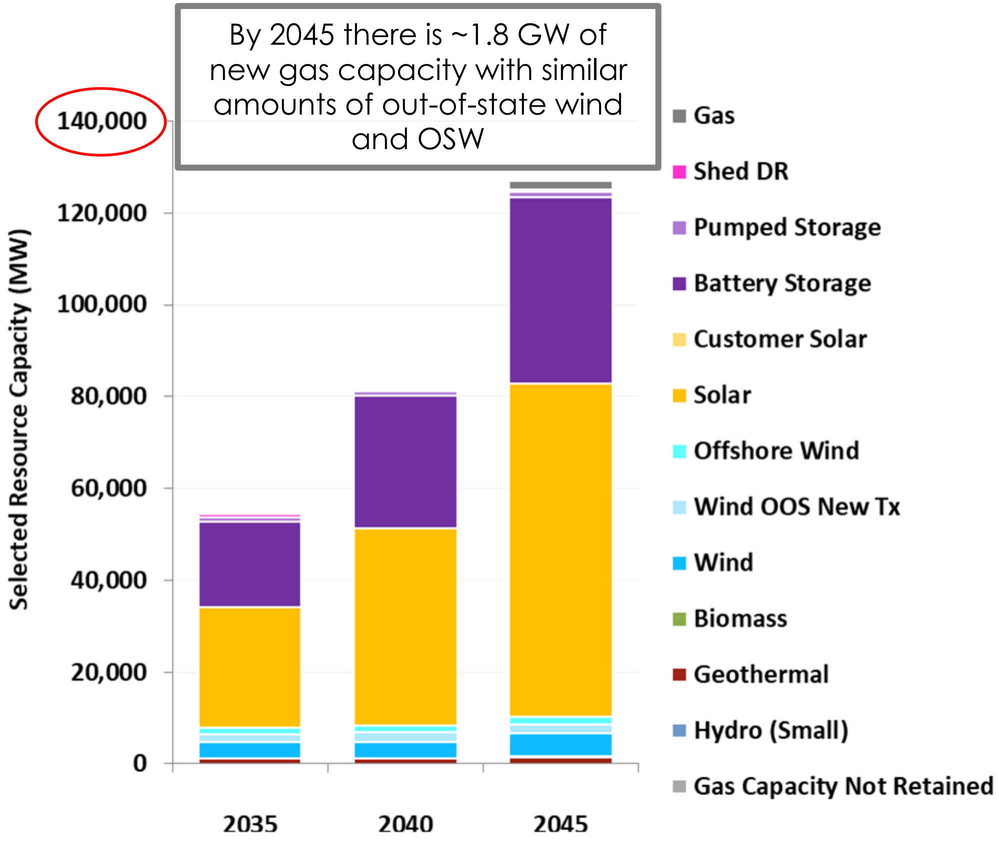


38 MMT with 2020 IEPR

With LSE Plans

Selected resources – 38 MMT with 2020 IEPR





Similar amounts of out-of-state wind on new transmission selected as in the 38 MMT core scenario

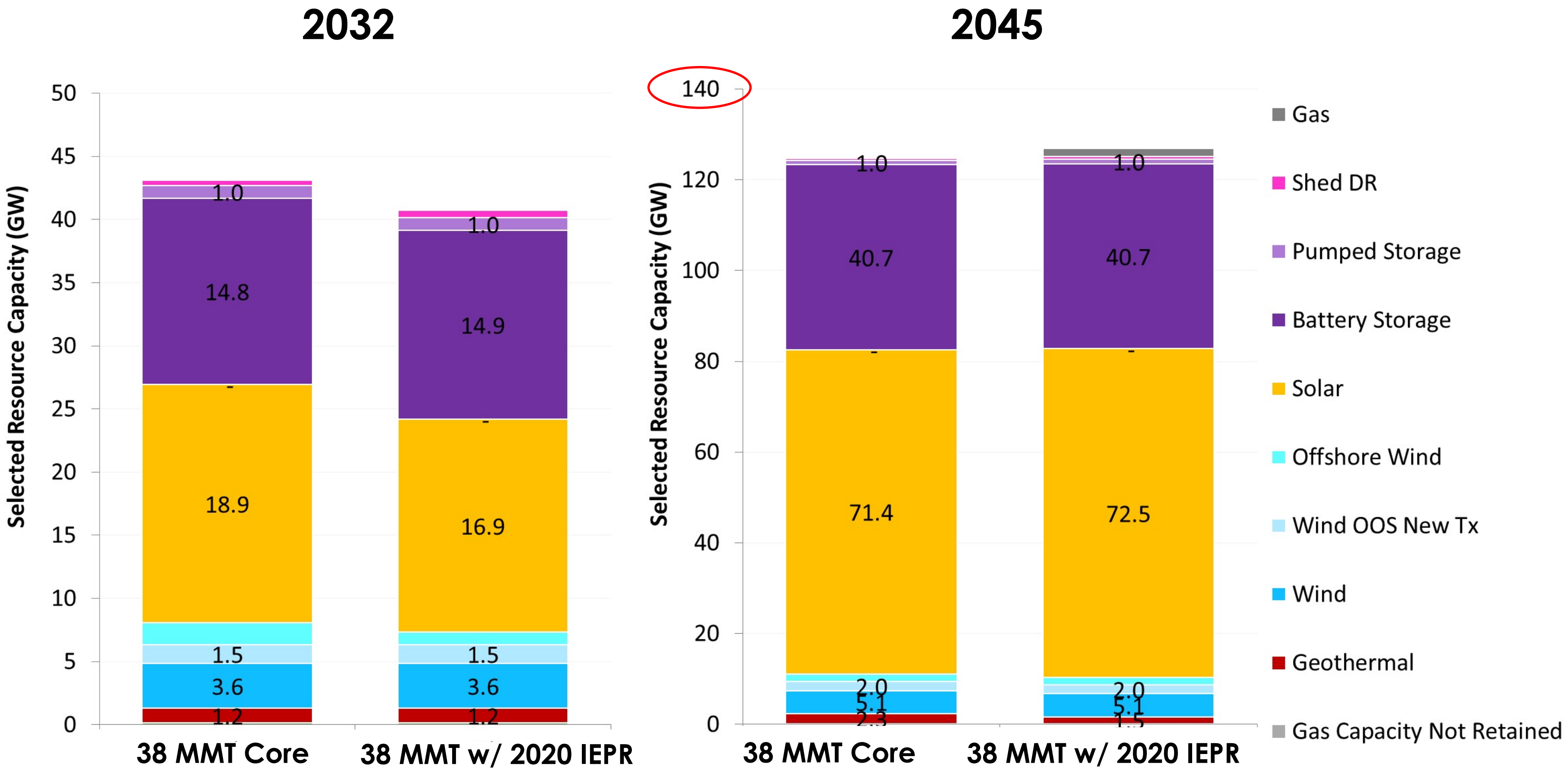
Selected resources – 38 MMT with 2020 IEPR

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	MW	-	-	-	-	-	1	1	1	1	1	1,801
Biomass	MW	34	65	83	107	107	134	134	134	134	134	134
Geothermal	MW	14	114	114	114	184	1,160	1,160	1,160	1,160	1,160	1,521
Hydro (Small)	MW	-	-	-	-	-	-	-	-	-	-	-
Wind	MW	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	MW	-	-	-	-	0	0	1,500	1,500	1,500	1,970	1,970
Offshore Wind	MW	-	-	-	-	120	195	195	964	1,613	1,613	1,613
Solar	MW	3,094	6,549	7,750	11,000	11,000	11,397	14,171	16,873	26,177	42,939	72,482
Customer Solar	MW	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	MW	2,571	4,604	10,349	12,082	12,082	13,202	13,466	14,944	18,626	28,724	40,749
Pumped Storage	MW	-	-	-	-	196	1,000	1,001	1,001	1,001	1,001	1,001
Shed DR	MW	299	299	529	617	617	617	617	617	617	617	617
Gas Capacity Not Retained	MW	-	-	-	-	-	-	-	-	-	-	-
Storage + DR	MW	**2,870**	**4,903**	**10,878**	**12,699**	**12,895**	**14,819**	**15,084**	**16,561**	**20,244**	**30,342**	**42,366**
Total Resources (Renewables + Storage + DR)	MW	**7,730**	**13,372**	**20,896**	**27,474**	**27,860**	**31,259**	**35,798**	**40,746**	**54,382**	**81,712**	**126,942**

- By 2032 there is about 1 GW less solar PV resources and about 700 MW less of offshore wind resources relative to the 38 MMT Core scenario
- By 2045 there's about 1.8 GW more new gas resources in this sensitivity and 700 MW less of geothermal relative to the 38 MMT Core scenario

38 MMT Core vs. 38 MMT with 2020 IEPR

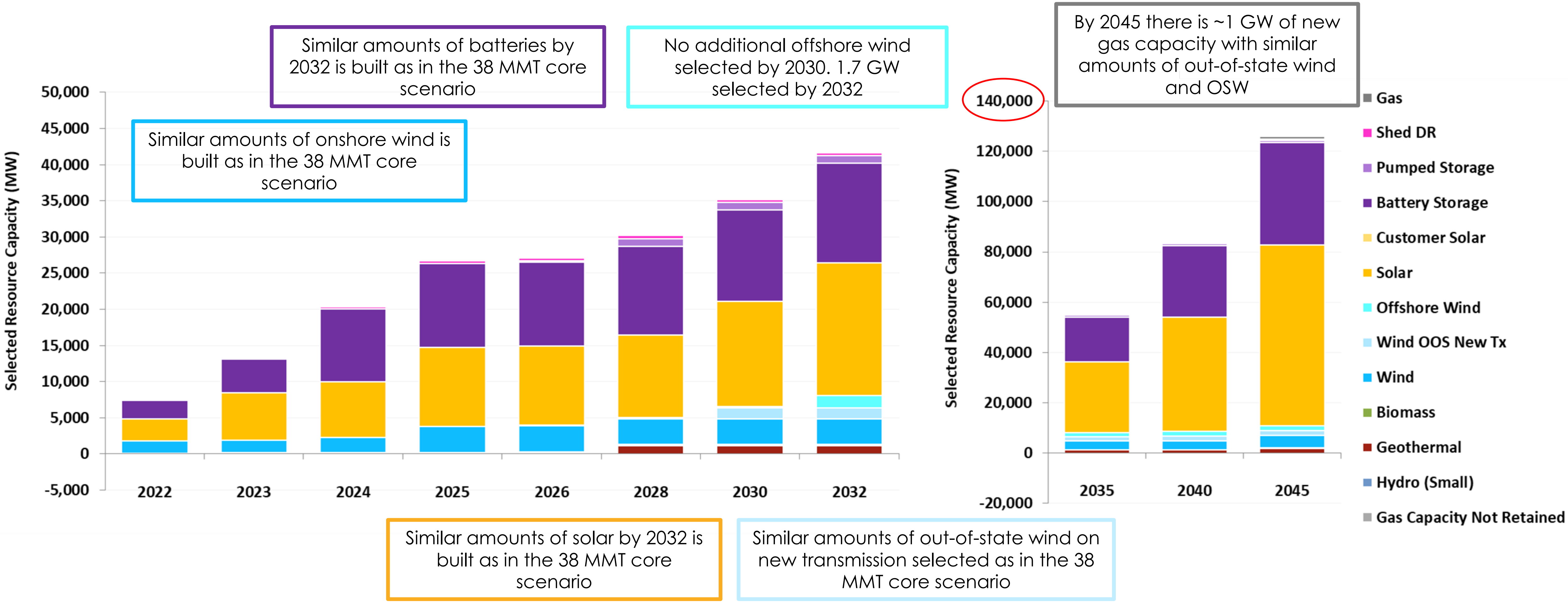
- The selected portfolio is very similar between the two scenarios
  - ~2 GW less solar is selected in the 2020 IEPR sensitivity by 2032
  - ~1 GW of new gas capacity is added by 2045 in the 2020 IEPR sensitivity



38 MMT with 2020 IEPR + 2020 IEPR High EV (Managed Charging EV Profile)

With LSE Plans

Selected resources – 38 MMT with 2020 IEPR + 2020 IEPR High EV (Managed Charging)



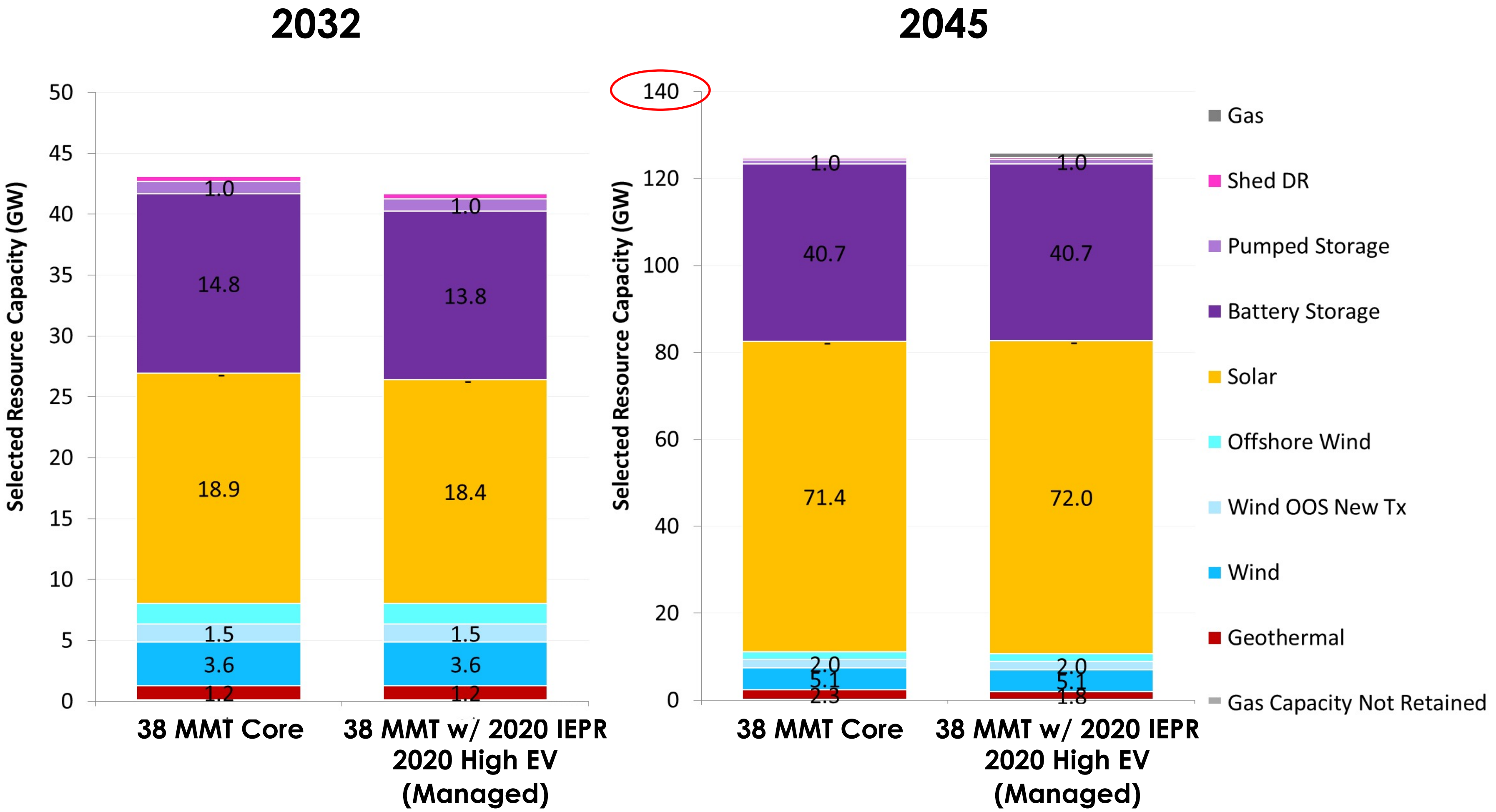
Selected resources – 38 MMT with 2020 IEPR + 2020 IEPR High EV (Managed Charging)

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	MW	-	-	-	-	-	1	1	1	1	1	980
Biomass	MW	34	65	83	107	107	134	134	134	134	134	134
Geothermal	MW	14	114	114	114	184	1,160	1,160	1,160	1,160	1,160	1,823
Hydro (Small)	MW	-	-	-	-	-	-	-	-	-	-	-
Wind	MW	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	MW	-	-	-	-	0	0	1,500	1,500	1,500	1,970	1,970
Offshore Wind	MW	-	-	-	-	120	195	195	1,708	1,728	1,728	1,728
Solar	MW	3,094	6,549	7,750	11,000	11,000	11,397	14,589	18,373	28,259	45,349	71,976
Customer Solar	MW	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	MW	2,565	4,604	10,012	11,528	11,528	12,303	12,621	13,814	17,610	28,459	40,737
Pumped Storage	MW	-	-	-	-	196	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	MW	151	151	353	436	436	436	436	436	436	436	436
Gas Capacity Not Retained	MW	-	-	-	-	-	-	-	-	(0)	(0)	(0)
Storage + DR	MW	**2,716**	**4,755**	**10,365**	**11,964**	**12,160**	**13,739**	**14,057**	**15,251**	**19,046**	**29,896**	**42,174**
Total Resources (Renewables + Storage + DR)	MW	**7,577**	**13,224**	**20,383**	**26,739**	**27,125**	**30,179**	**35,190**	**41,679**	**55,381**	**83,791**	**125,839**

- By 2032 there is about 500 MW less solar PV resources and about 1 GW less of battery storage resources relative to the 38 MMT Core scenario
- By 2045 there's about 950 MW more new gas resources in this sensitivity and 430 MW less of geothermal relative to the 38 MMT Core scenario

38 MMT Core vs. 38 MMT with 2020 IEPR + 2020 IEPR High EV (Managed Charging)

- The selected portfolio is very similar between the two scenarios
  - ~500 MW less solar is selected in the 2020 IEPR + 2020 IEPR High EV sensitivity by 2032
  - ~1 GW of new gas capacity is added by 2045 in the 2020 IEPR + 2020 IEPR High EV sensitivity



38 MMT with 2020 IEPR + 2020 IEPR High EV (Unmanaged Charging EV Profile)

With LSE Plans

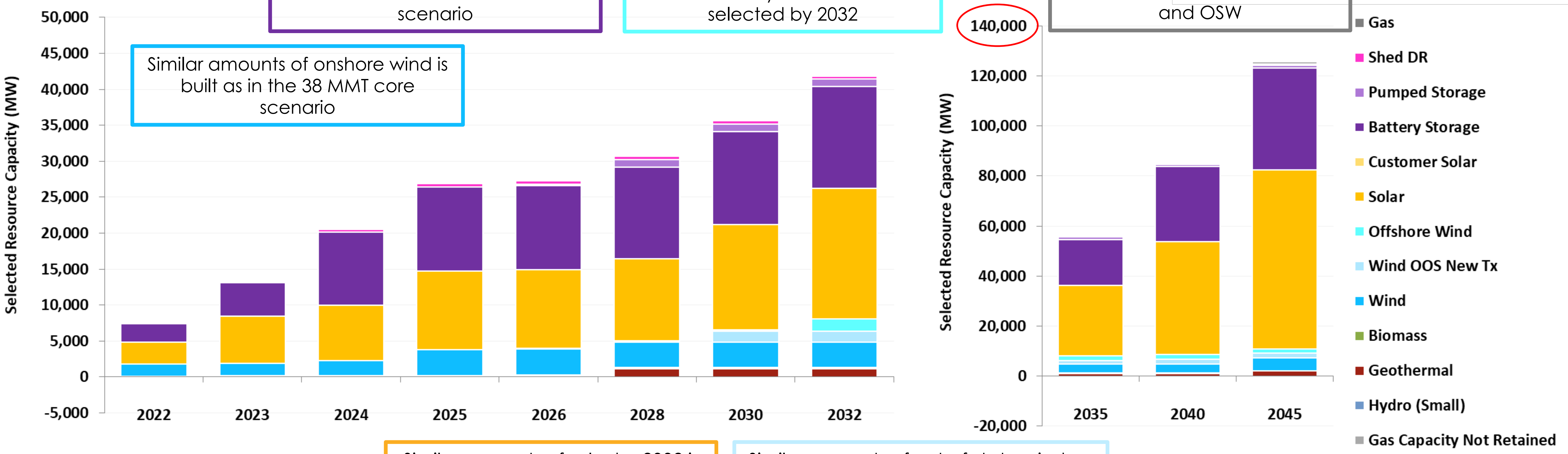
Selected resources – 38 MMT with 2020 IEPR + 2020 IEPR High EV (Unmanaged Charging)

Similar amounts of batteries by 2032 is built as in the 38 MMT core scenario

No additional offshore wind selected by 2030. 1.7 GW selected by 2032

By 2045 there is ~ 1GW of new gas capacity with similar amounts of out-of-state wind and OSW

Similar amounts of onshore wind is built as in the 38 MMT core scenario



Similar amounts of solar by 2032 is built as in the 38 MMT core scenario

Similar amounts of out-of-state wind on new transmission selected as in the 38 MMT core scenario

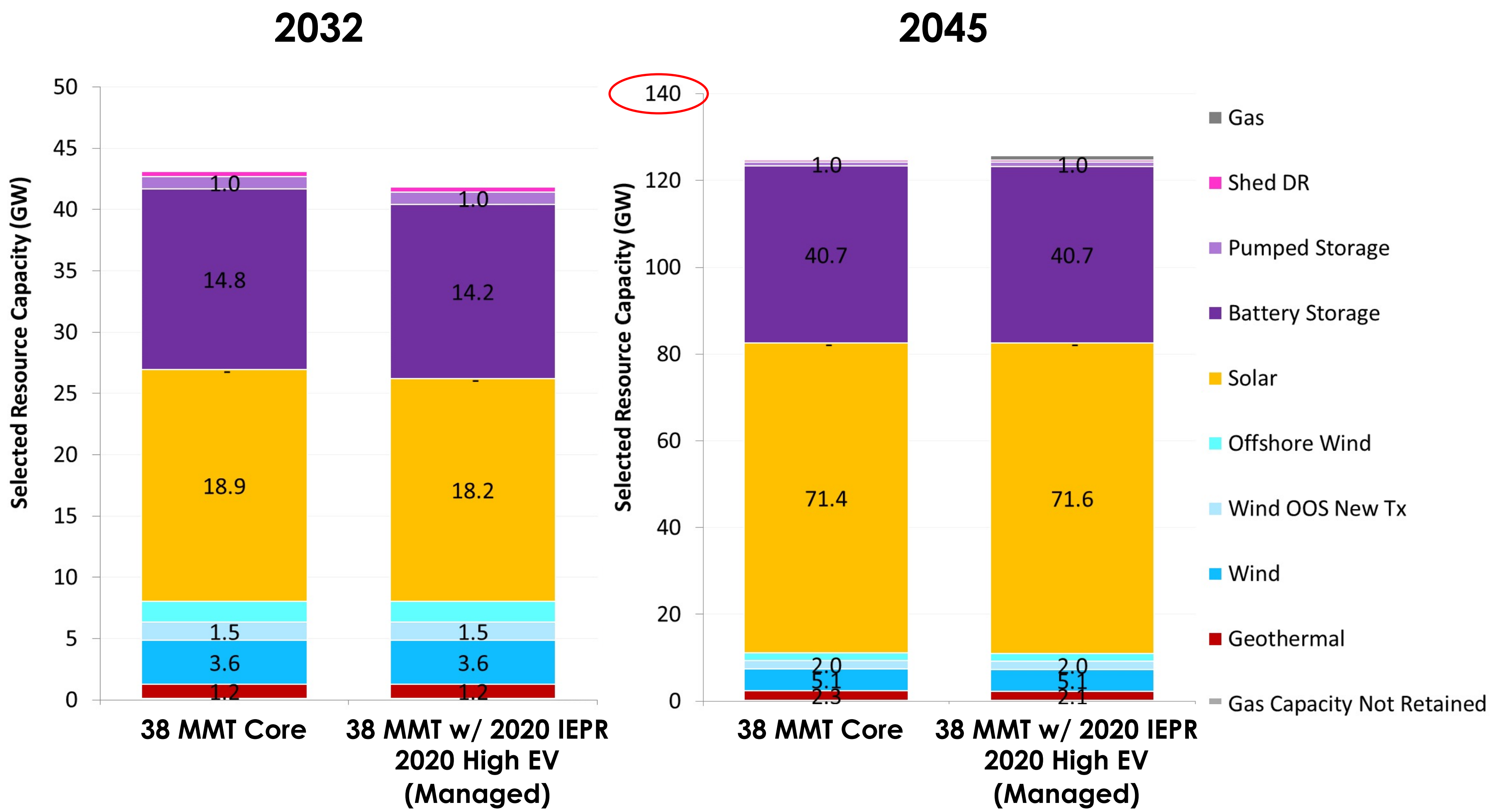
Selected resources – 38 MMT with 2020 IEPR + 2020 IEPR High EV (Unmanaged Charging)

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	MW	-	-	-	-	-	1	1	1	1	1	1,009
Biomass	MW	34	65	83	107	107	134	134	134	134	134	134
Geothermal	MW	14	114	114	114	184	1,160	1,160	1,160	1,160	1,160	2,109
Hydro (Small)	MW	-	-	-	-	-	-	-	-	-	-	-
Wind	MW	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	MW	-	-	-	-	0	0	1,500	1,500	1,500	1,970	1,970
Offshore Wind	MW	-	-	-	-	120	195	195	1,708	1,728	1,728	1,728
Solar	MW	3,094	6,549	7,750	11,000	11,000	11,397	14,678	18,160	28,157	45,194	71,563
Customer Solar	MW	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	MW	2,571	4,604	10,147	11,661	11,661	12,780	12,948	14,204	18,386	29,940	40,705
Pumped Storage	MW	-	-	-	-	196	1,000	1,001	1,001	1,001	1,001	1,001
Shed DR	MW	151	151	353	441	441	441	441	441	441	441	441
Gas Capacity Not Retained	MW	-	-	-	-	-	-	-	-	-	(0)	(0)
Storage + DR	MW	**2,722**	**4,755**	**10,499**	**12,101**	**12,297**	**14,221**	**14,389**	**15,645**	**19,827**	**31,381**	**42,146**
Total Resources (Renewables + Storage + DR)	MW	**7,583**	**13,224**	**20,518**	**26,876**	**27,262**	**30,662**	**35,610**	**41,862**	**56,060**	**85,122**	**125,713**

- By 2032 there is about 700 MW less solar PV resources and about 550 MW less of battery storage resources relative to the 38 MMT Core scenario
  - About 50 MW less solar and 450 MW more batteries selected relative to the Managed Charging sensitivity
- By 2045 there's about 980 MW more new gas resources in this sensitivity and 140 MW less of geothermal relative to the 38 MMT Core scenario
  - About 300 MW more geothermal relative to the Managed Charging sensitivity

38 MMT Core vs. 38 MMT with 2020 IEPR + 2020 IEPR High EV (Unmanaged Charging)

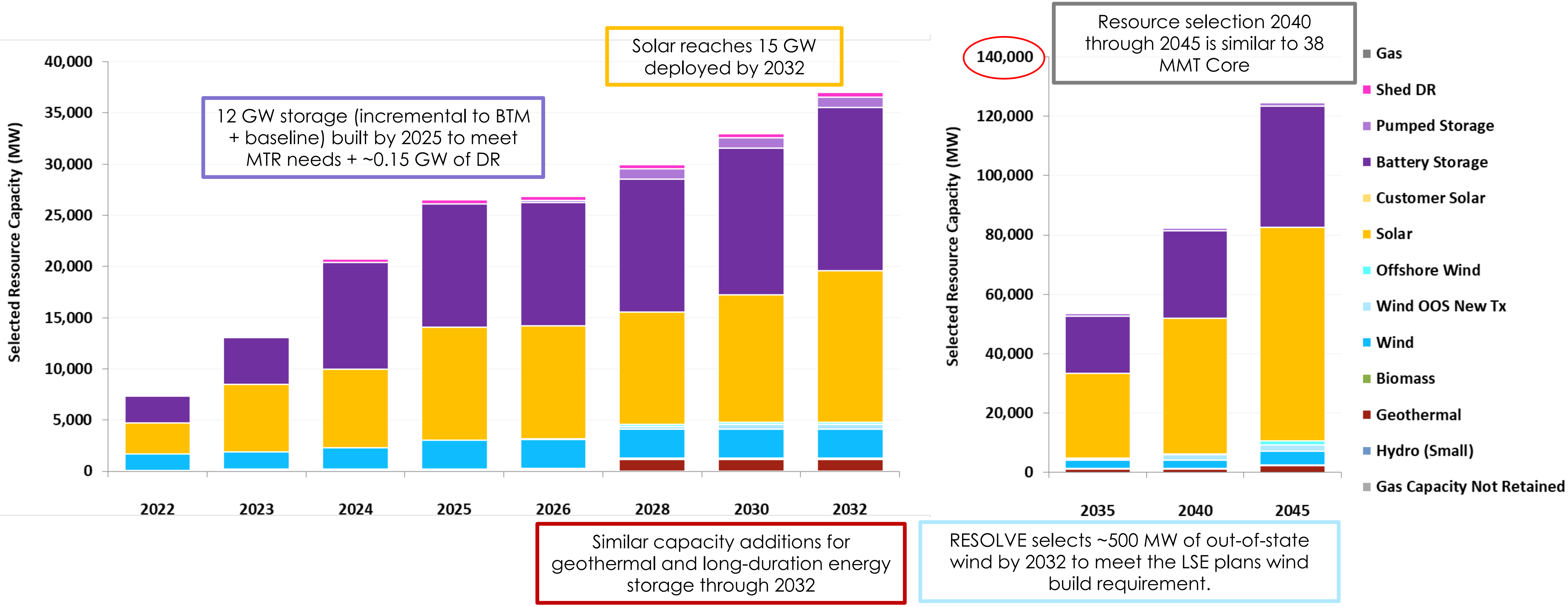
- The selected portfolio is very similar between the two scenarios
  - ~500 MW less solar is selected in the 2020 IEPR + 2020 IEPR High EV sensitivity by 2032
  - ~1 GW of new gas capacity is added by 2045 in the 2020 IEPR + 2020 IEPR High EV sensitivity



46 MMT Core

With 46 MMT LSE Plans

Selected resources: 46 MMT Core



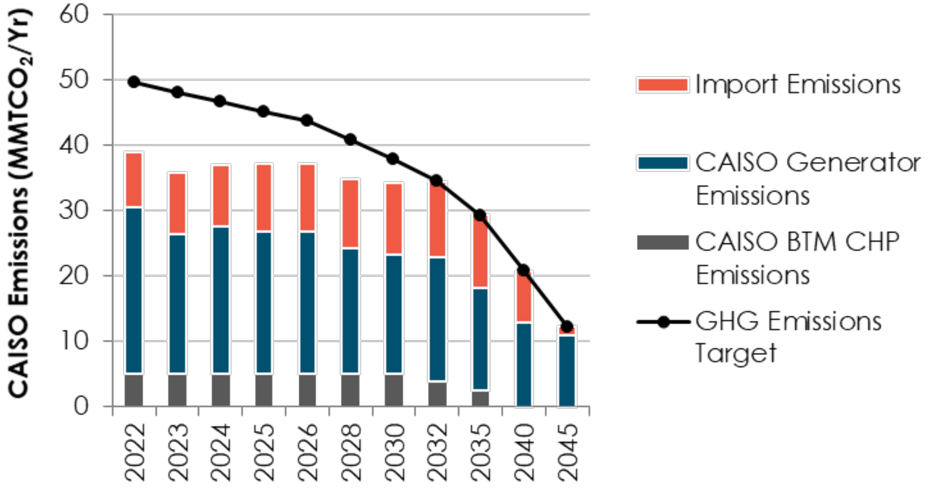
Selected resources – 46 MMT Core

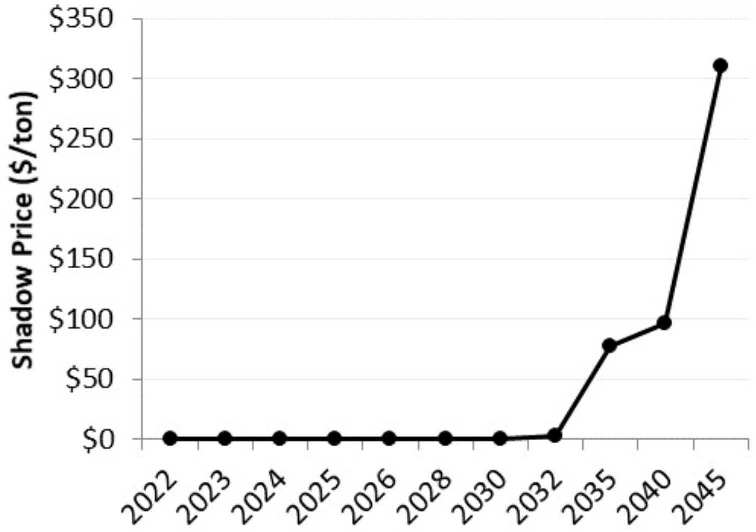
	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	MW	-	-	-	-	-	0	0	0	0	0	0
Biomass	MW	34	65	83	107	107	129	129	129	129	129	129
Geothermal	MW	14	114	114	114	149	1,173	1,173	1,173	1,173	1,173	2,332
Hydro (Small)	MW	-	-	-	-	-	-	-	-	-	-	-
Wind	MW	1,640	1,704	2,070	2,819	2,819	2,819	2,819	2,819	2,839	2,839	4,784
Wind OOS New Tx	MW	-	-	-	-	0	254	492	492	492	1,970	1,970
Offshore Wind	MW	-	-	-	-	120	195	195	195	195	195	1,382
Solar	MW	3,058	6,593	7,689	11,000	11,000	11,000	12,412	14,789	28,506	45,695	71,976
Customer Solar	MW	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	MW	2,565	4,573	10,409	12,060	12,060	12,951	14,333	15,950	19,217	29,422	40,879
Pumped Storage	MW	-	-	-	-	185	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	MW	151	151	353	441	441	441	441	441	441	441	441
Gas Capacity Not Retained	MW	-	-	-	-	-	-	-	-	(0)	(83)	(83)
Storage + DR	MW	**2,716**	**4,725**	**10,762**	**12,501**	**12,686**	**14,392**	**15,774**	**17,391**	**20,657**	**30,863**	**42,320**
Total Resources (Renewables + Storage + DR)	MW	**7,462**	**13,201**	**20,718**	**26,541**	**26,881**	**29,963**	**32,996**	**36,990**	**53,994**	**82,782**	**124,811**

- The reduced GHG emissions target by 2032 causes RESOLVE to select about 6 GW less resources than in the 38 MMT Core scenario

GHG constraint: 46 MMT Core

GHG constraint is binding starting only in 2032 – a few years later than the 38 MMT which is binding in 2026





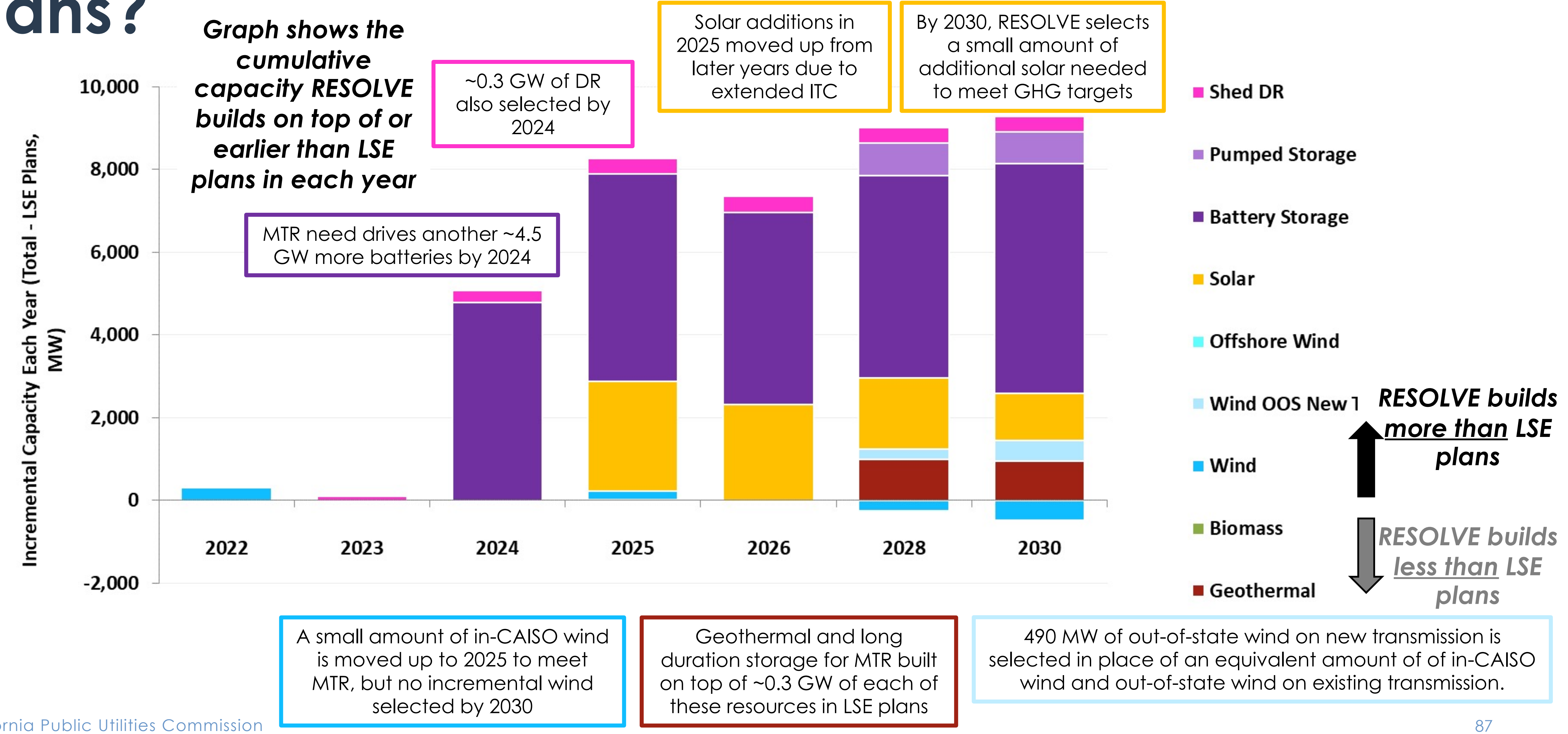
What Does RESOLVE pick on top of 46 MMT LSE Plans?

Incremental Capacity Addition On Top of LSE Planned Resources

Technology Class	Unit	2022	2023	2024	2025	2026	2028	2030
Battery Storage	MW	-	-	4,771	4,998	4,648	4,898	5,561
Pumped Storage	MW	-	-	-	-	-	783	751
Biomass	MW	-	-	-	12	-	-	-
Shed DR	MW	-	89	288	375	375	376	376
Geothermal	MW	-	-	-	-	-	988	952
Solar	MW	-	-	-	2,662	2,317	1,711	1,143
Wind	MW	308	2	2	210	2	(252)	(490)
Offshore Wind	MW	-	-	-	-	-	-	-
Wind OOS New Tx	MW	-	-	-	-	-	254	492

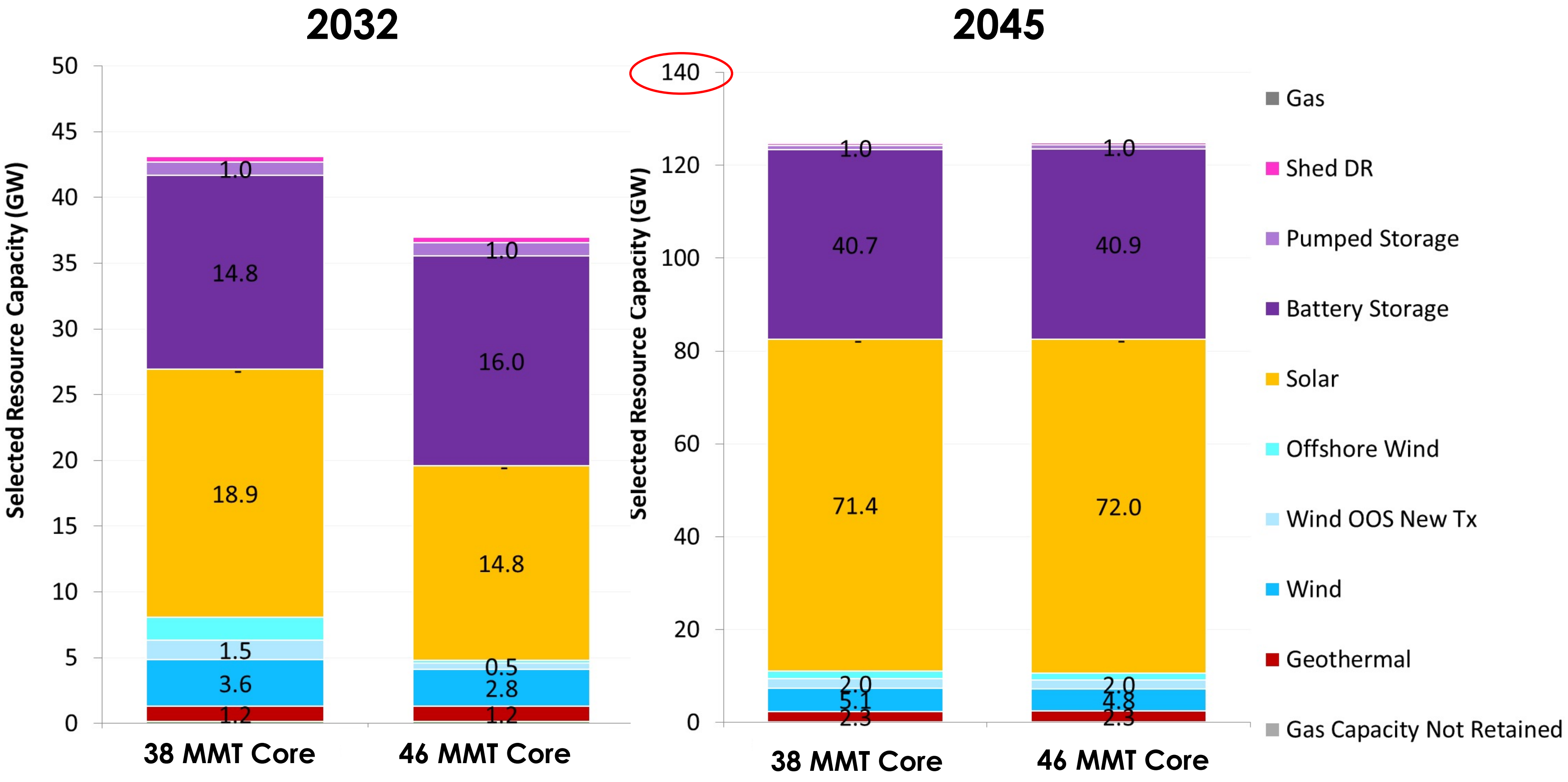
What Does RESOLVE pick on top of 46 MMT LSE Plans?

Graph shows the cumulative capacity RESOLVE builds on top of or earlier than LSE plans in each year



38 MMT Core vs. 46 MMT Core

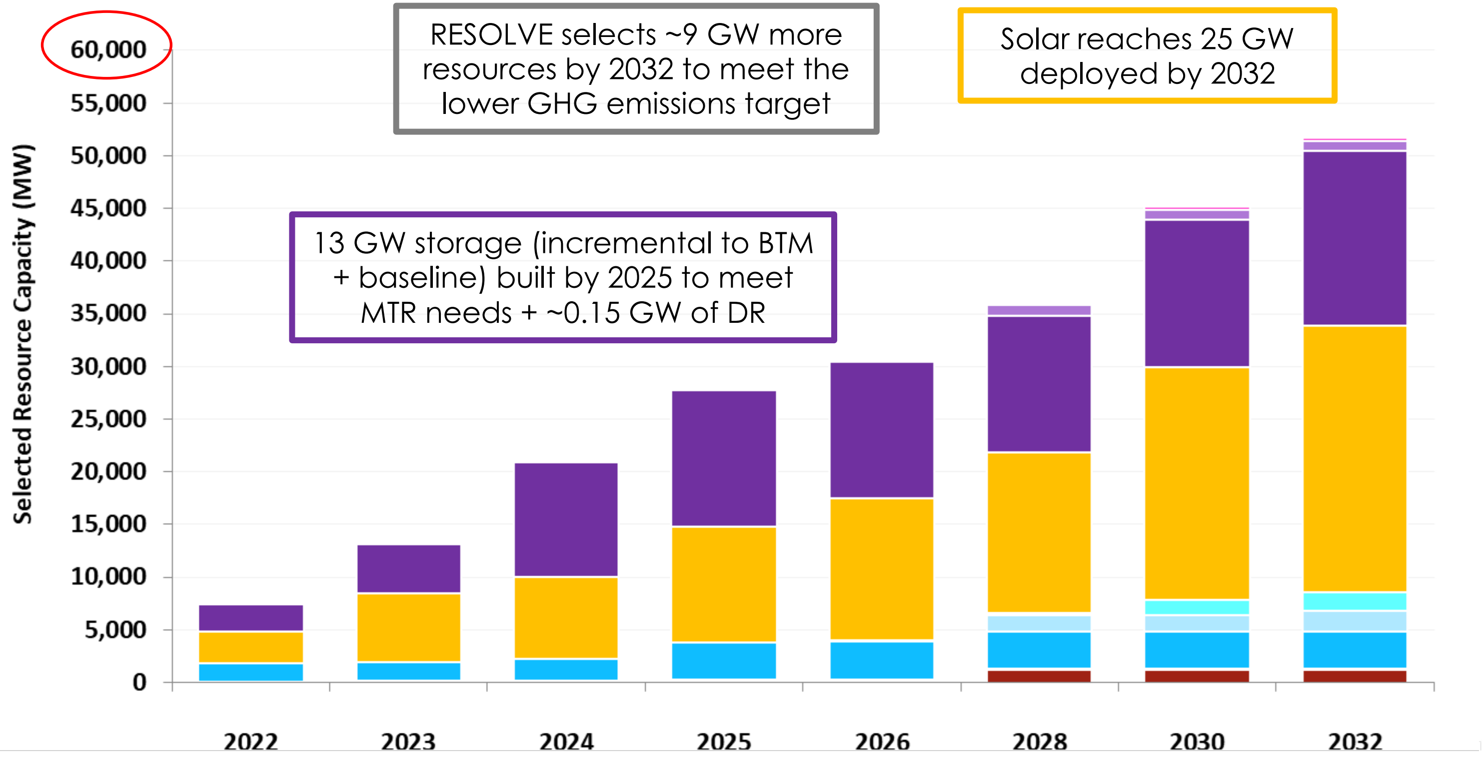
- The combination of the higher GHG limit and smaller LSE plans causes a significantly lower quantity of resources to be selected by 2032

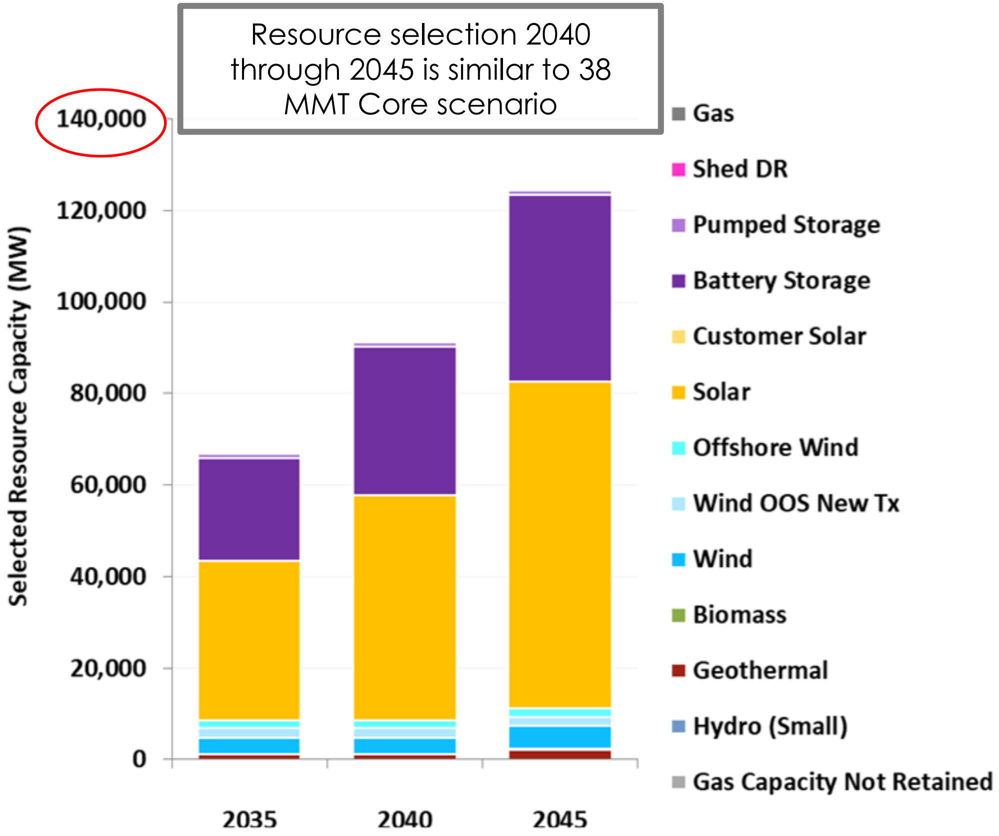


30 MMT Core

With 38 MMT LSE Plans

Selected resources: 30 MMT Core





Similar capacity additions for geothermal and long-duration energy storage through 2032 as in the 38 MMT Core scenario

RESOLVE builds ~500 MW more OOS wind by 2032 to meet the lower GHG emissions target relative to the 38 MMT Core scenario

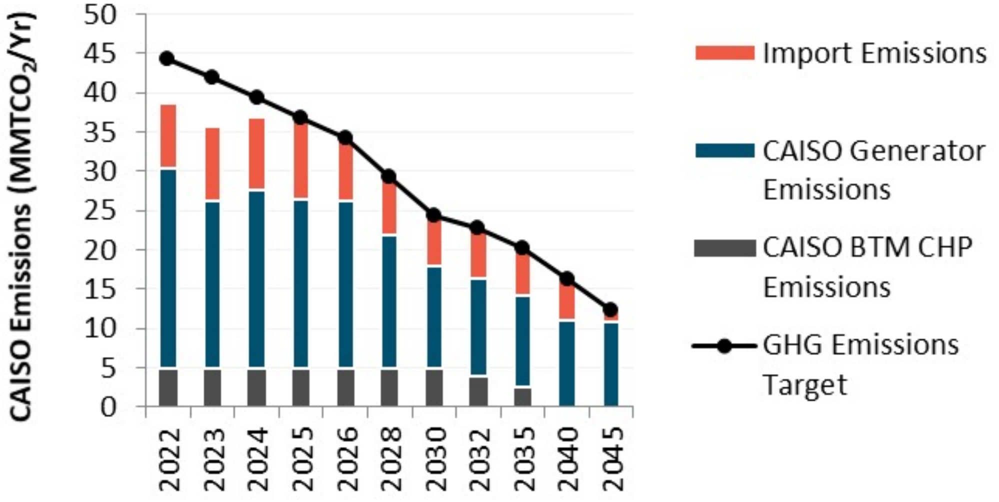
Selected resources – 30 MMT Core

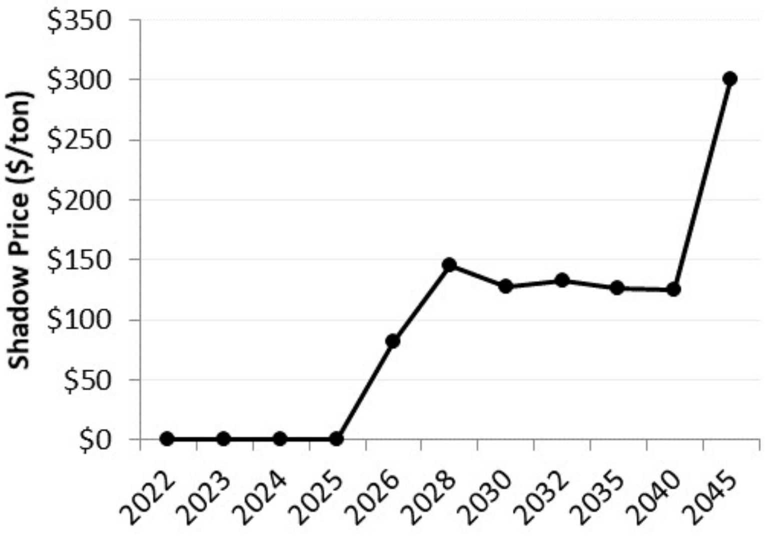
	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	0	0	0	0	0	279
Biomass	*MW*	34	65	83	107	107	134	134	134	134	134	134
Geothermal	*MW*	14	114	114	114	184	1,158	1,158	1,158	1,158	1,158	2,222
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,553	3,553	3,553	3,553	3,553	3,553	3,553	5,053
Wind OOS New Tx	*MW*	-	-	-	-	0	1,500	1,500	1,970	1,970	1,970	1,970
Offshore Wind	*MW*	-	-	-	-	120	195	1,452	1,728	1,728	1,728	1,728
Solar	*MW*	3,094	6,549	7,750	11,000	13,537	15,266	22,076	25,270	34,854	49,317	71,433
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,565	4,603	10,840	12,960	12,960	12,993	14,003	16,624	22,517	32,296	40,784
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,000	1,000	1,000	1,000	1,000
Shed DR	*MW*	151	151	244	244	244	244	244	244	244	244	244
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	-	-	-	-
Storage + DR	*MW*	**2,716**	**4,755**	**11,084**	**13,204**	**13,400**	**14,237**	**15,247**	**17,868**	**23,761**	**33,540**	**42,028**
Total Resources (Renewables + Storage + DR)	*MW*	**7,577**	**13,224**	**21,102**	**27,979**	**30,901**	**36,044**	**45,121**	**51,682**	**67,158**	**91,401**	**124,849**

- To achieve the reduced GHG targets through 2032, additional solar, battery storage resources, and a little out-of-state wind are added relative to the 38 MMT Core
  - 9 GW more resources in total are added by 2032.

GHG constraint: 30 MMT Core

GHG constraint is binding starting in 2026 – a few years earlier than cases with higher GHG targets. Target is close to binding in 2025.



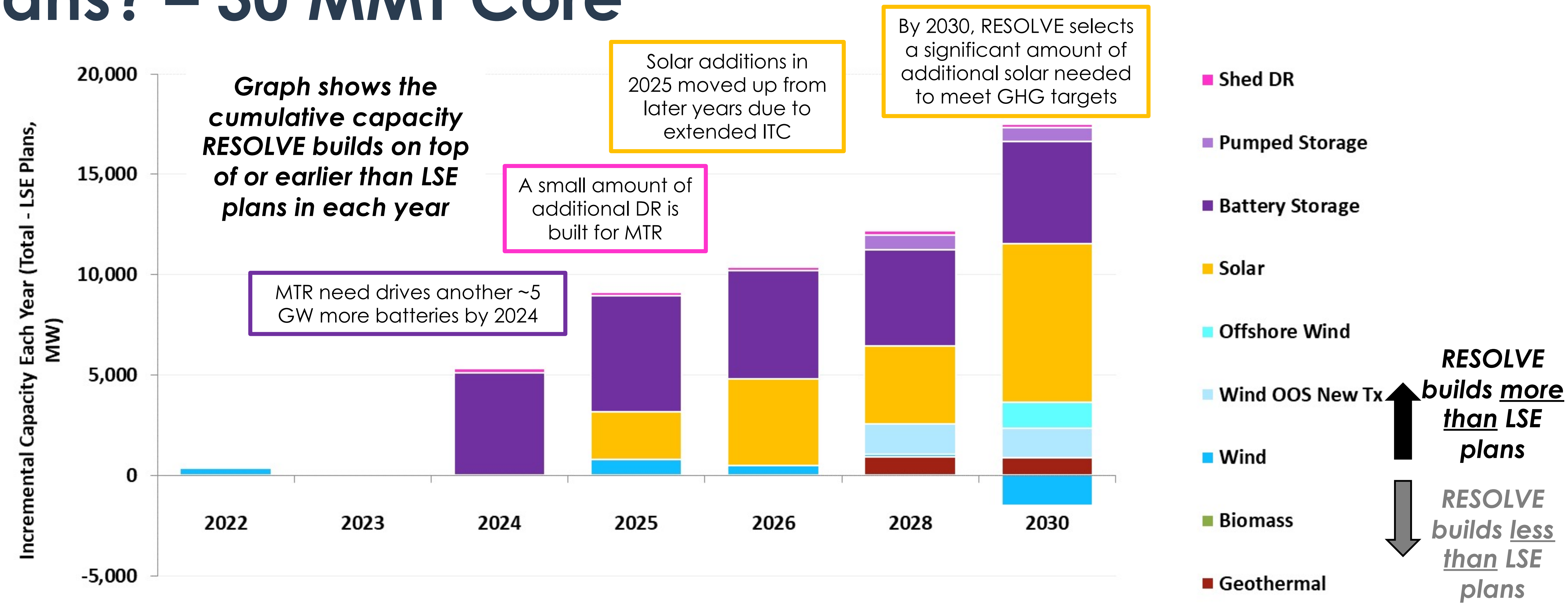


What Does RESOLVE pick on top of 38 MMT LSE Plans? – 30 MMT Core

Incremental Capacity Addition On Top of LSE Planned Resources

Technology Class	Unit	2022	2023	2024	2025	2026	2028	2030
Battery Storage	MW	-	-	5,105	5,784	5,417	4,791	5,101
Pumped Storage	MW	-	-	-	-	-	764	692
Biomass	MW	-	-	-	12	-	-	-
Shed DR	MW	-	89	180	178	178	179	179
Geothermal	MW	-	-	-	-	-	938	867
Solar	MW	-	-	-	2,344	4,330	3,869	7,905
Wind	MW	365	22	22	796	475	134	(1,478)
Offshore Wind	MW	-	-	-	-	-	-	1,257
Wind OOS New Tx	MW	-	-	-	-	-	1,500	1,500

What Does RESOLVE pick on top of 38 MMT LSE Plans? – 30 MMT Core



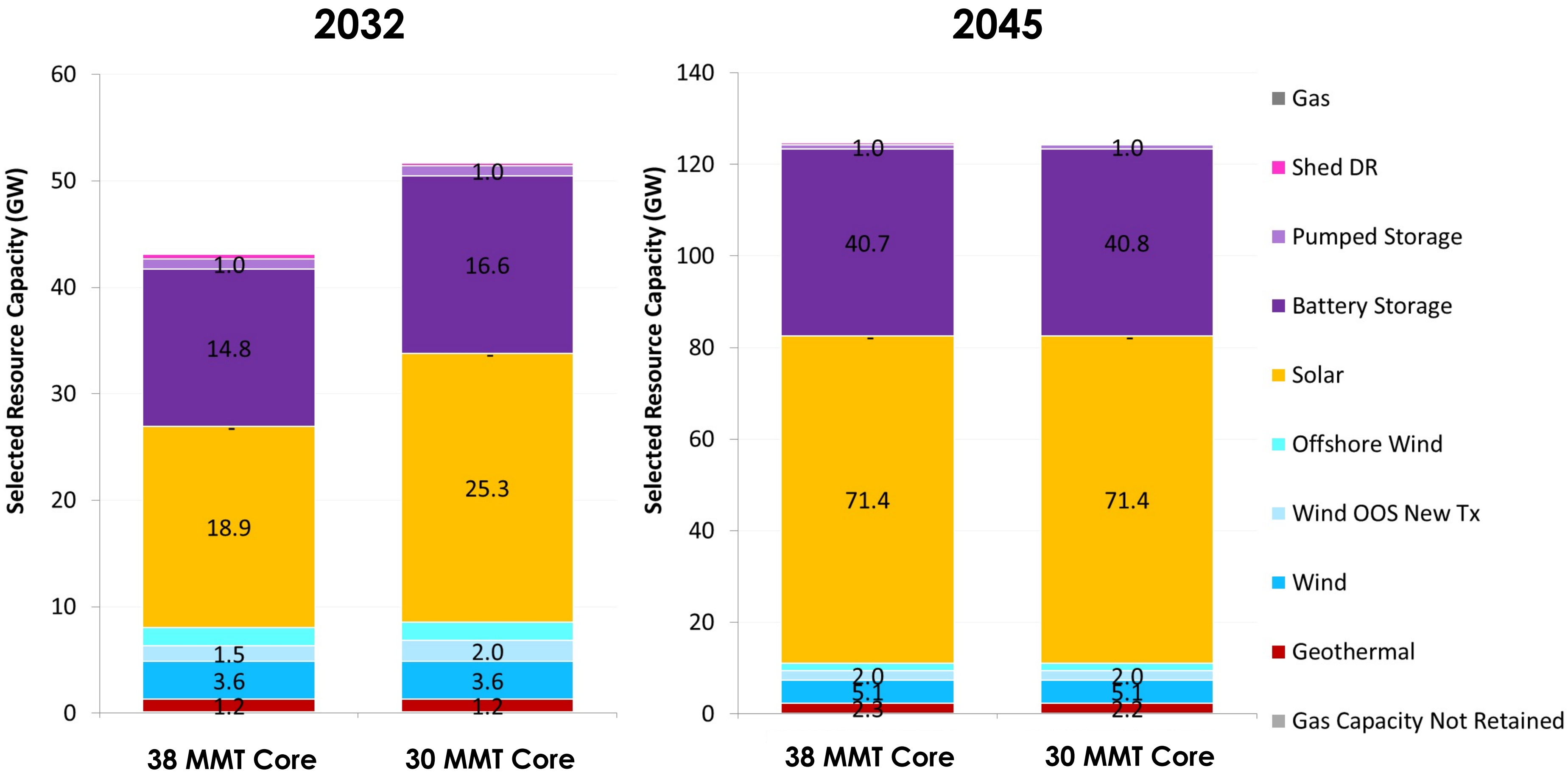
A small amount of in-CAISO wind is moved up to 2025 to meet MTR but no incremental wind selected by 2030

Like in the 38 MMT core, geothermal and long duration storage for MTR are built on top of ~0.3 GW of each of these resources in LSE plans

1.5 GW of out-of-state wind on new transmission is selected in 2028, earlier than the LSE plans for new wind in 2030; this OOS wind still replaces about 1.7 GW of in-CAISO wind and out-of-state wind on existing transmission

38 MMT Core vs. 30 MMT Core

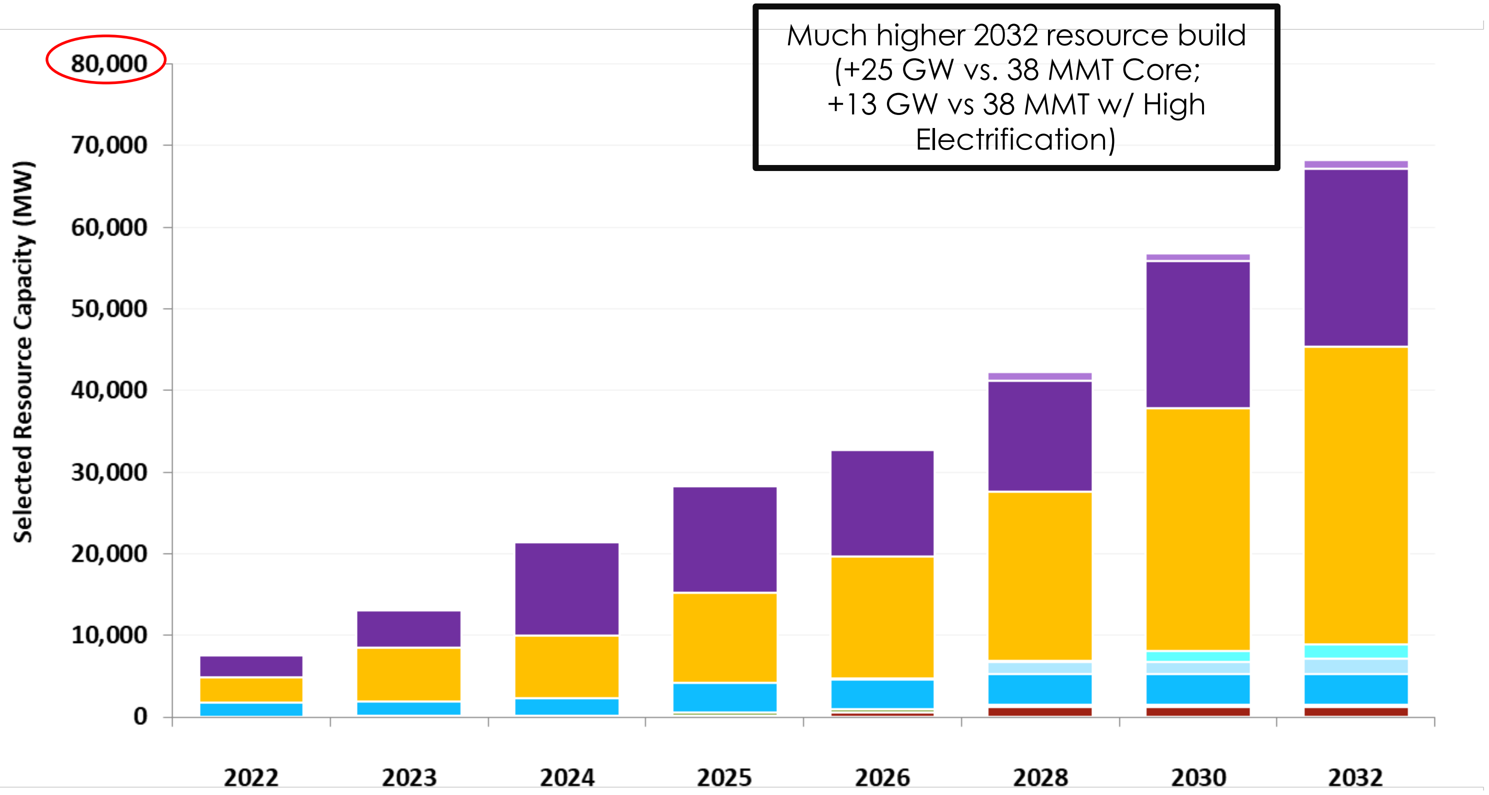
- The lower GHG target by 2032 largely leads to additional solar and battery storage builds, also additional out-of-state wind
  - 8.7 GW of additional resources relative to the 38 MMT Core

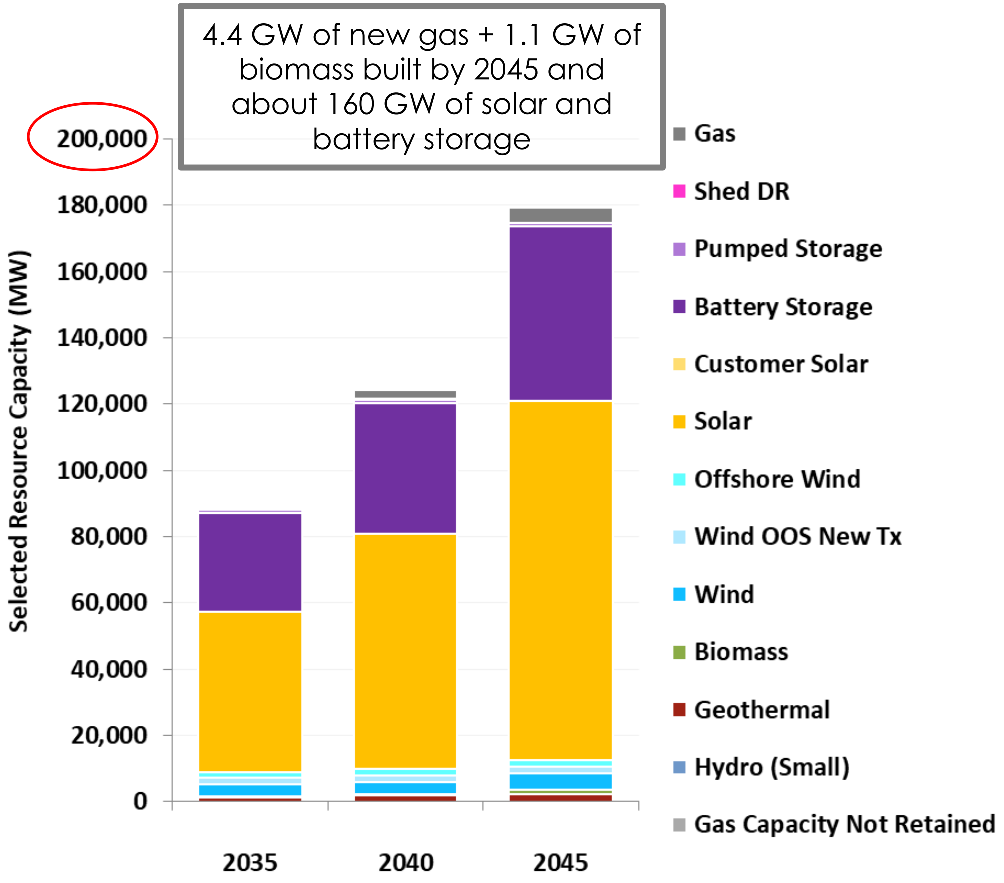


30 MMT High Electrification (Managed EV Profile)

With 38 MMT LSE Plans

Selected resources – 30 MMT w/ High Electrification (Managed)





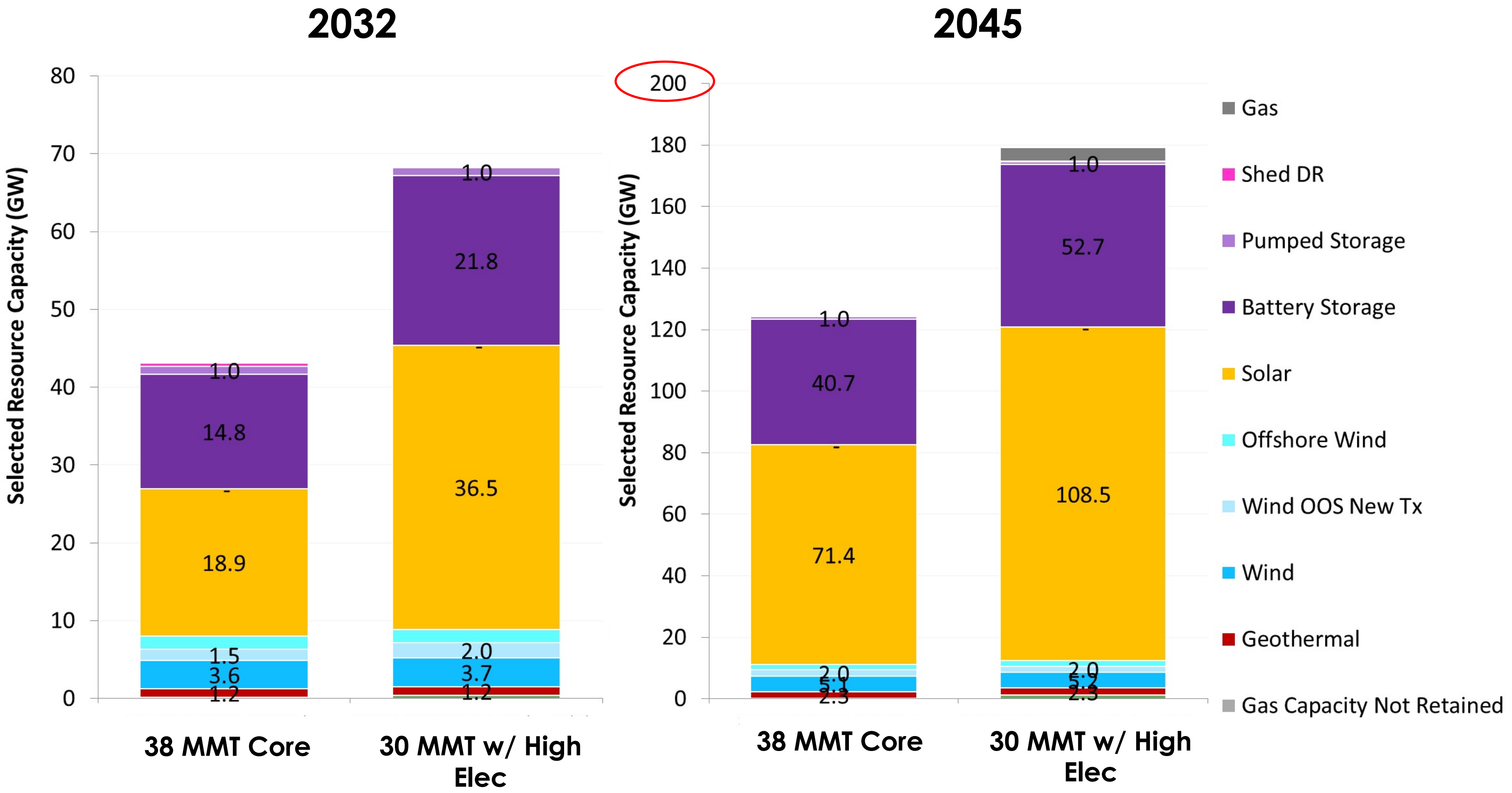
Selected resources – 30 MMT PSP w/ High Electrification

	Unit	2022	2023	2024	2025	2026	2028	2030	2032	2035	2040	2045
Gas	*MW*	-	-	-	-	-	0	0	0	0	2,677	4,497
Biomass	*MW*	34	65	83	373	373	373	373	373	373	373	1,147
Geothermal	*MW*	14	114	114	114	527	1,156	1,156	1,156	1,156	1,995	2,332
Hydro (Small)	*MW*	-	-	-	-	-	-	-	-	-	-	-
Wind	*MW*	1,719	1,741	2,071	3,687	3,687	3,687	3,687	3,687	3,687	3,687	5,187
Wind OOS New Tx	*MW*	-	-	-	-	0	1,500	1,500	1,970	1,970	1,970	1,970
Offshore Wind	*MW*	-	-	-	-	120	195	1,431	1,708	1,728	1,728	1,749
Solar	*MW*	3,094	6,549	7,750	11,000	14,963	20,726	29,736	36,522	48,405	71,064	108,472
Customer Solar	*MW*	-	-	-	-	-	-	-	-	-	-	-
Battery Storage	*MW*	2,626	4,604	11,345	13,085	13,085	13,584	17,938	21,775	29,679	39,615	52,744
Pumped Storage	*MW*	-	-	-	-	196	1,000	1,000	1,001	1,001	1,001	1,001
Shed DR	*MW*	176	176	176	176	176	176	176	176	176	176	176
Gas Capacity Not Retained	*MW*	-	-	-	-	-	-	-	-	-	-	(0)
Storage + DR	*MW*	**2,803**	**4,780**	**11,521**	**13,262**	**13,458**	**14,761**	**19,115**	**22,952**	**30,856**	**40,791**	**53,921**
Total Resources (Renewables + Storage + DR)	*MW*	**7,663**	**13,249**	**21,540**	**28,436**	**33,128**	**42,398**	**56,999**	**68,368**	**88,176**	**124,286**	**179,274**

- Through 2032 the increased load is mostly served by additional solar PV and battery resources
  - About 100 MW of additional onshore wind is selected in 2025 through 2040.
- By 2040 and 2045, the model selects more diversity and additional firm generation (shown in the selection of additional geothermal, new gas, biomass resources) in addition to the increased solar PV and batteries

38 MMT Core vs. 30 MMT w/ High Electrification

- The combination of lower GHG targets and higher loads due to electrification lead to significant additional solar and battery storage builds, and firm resources
  - About 25 GW more by 2032 and 55 GW more by 2045



Appendix A: Overview of RESOLVE

RESOLVE Model Overview

- RESOLVE is a capacity expansion model designed to inform long-term planning questions around renewables integration
- RESOLVE co-optimizes investment and dispatch for a selected set of days over a multi-year horizon in order to identify least-cost portfolios for meeting specified GHG targets and other policy goals
- Scope of RESOLVE optimization in the 2021 PSP and 2022-2023 TPP:
  - Covers the CAISO balancing area including POU load within the CAISO
  - Optimizes dispatch but not investment outside of the CAISO
    - Resource capacity outside of CAISO cannot be changed by the optimization
- The RESOLVE model used to develop the Preferred System Plan results, along with accompanying documentation of inputs and assumptions, model operation, and results will be available for download from the CPUC's website.
- The role of the RESOLVE model in IRP is to select portfolios of new resources that are expected to meet policy goals at least cost while ensuring reliability

General Assumptions Components Used in 2021 PSP Modeling

- IRP seeks to use standardized modeling inputs in both capacity expansion (RESOLVE) and production cost modeling (SERVM)
- Generally, these assumptions pertain to use of demand forecasts and the definition of what baseline resources to consider in both models
- An overview of core modeling inputs for 2021 modeling is included in this section
  - Descriptions of demand forecast and baseline resource inputs
- Additional updates for resource costs and transmission model are covered in Appendix B and Appendix C respectively

Core Modeling Input: Demand Forecast

- Per the 2013 joint agency leadership agreement to use a single forecast set*, current IRP modeling uses the Energy Commission's 2019 IEPR Update Forecast as a core input
- Uncertainty in future electricity demand considered:
  - 1998-2017 weather scenarios and 5 weighted levels of load forecast uncertainty in SERVM
  - Sensitivity and scenario modeling (e.g. high EV load, high electrification) in RESOLVE
- IEPR forecast annual projections of electricity consumption and demand modifiers are used to scale corresponding hourly shapes in RESOLVE and SERVM

* See February 25, 2013 CPUC-CEC-CAISO Letter to Senators Padilla and Fuller and more information available on CPUC's webpage; Also see Final 2018 Integrated Energy Policy Report Update, Volume II- Clean Version

Core Modeling Input: Baseline Resources

- **<u>Baseline resources</u>** are resources that are included in a model run as an assumption rather than being selected by the model as part of an optimal solution
- Within CAISO, the baseline resources are intended to capture:
  - Existing resources, net of planned retirements (e.g. once-through-cooling plants)
  - "Steel-in-the-ground" new resources that are deemed sufficiently likely to be constructed, usually because of being LSE-owned or contracted, with CPUC and/or LSE governing board approval
    - e.g. CPUC- or LSE governing board-approved renewable power purchase agreements, CPUC-approved gas plants, CPUC storage procurement target (i.e., AB 2514)
  - Projected achievement of demand-side programs under current policy
    - e.g. forecast of EE achievement, BTM PV adoption under NEM tariff

Core Modeling Input: Baseline Resources (continued)

- In external zones (e.g., BANC), where RESOLVE does not optimize the portfolios, the baseline resources are derived from the WECC Anchor Data Set, which includes each external BA's plans to add/retire resources to meet assumed policy and reliability goals
- RESOLVE optimizes the selection of additional resources in the CAISO area needed to meet policy goals, such as RPS, a GHG target, or a planning reserve margin; these resources that are selected by RESOLVE are *not* baseline resources
- The same baseline resources are assumed in the 46, 38, and 30 MMT Core and sensitivity scenarios
- Baseline resources for the 2021 PSP analysis include previously proposed ground truthing updates and have been updated to align with LSE plan data and MTR baseline with the NQC percentages matching the 2021 CPUC NQC List

Baseline Resource Assumptions: Retirements, Repowering, Risk Adjustments

- Retirements
  - Power plants with announced retirements are modeled as retired. Compliance with Once-Thru-Cooled Water Board policy is assumed and Diablo Canyon Power Plant is retired in 2024/2025
  - Of the remaining existing plants, RESOLVE uses economic retention functionality to examine what portion of the existing gas-fired generation fleet may need to be retained or allowed to retire within the IRP planning horizon
- Repowering
  - Staff is aware that a significant fraction of California's wind capacity may need to be repowered to remain online through 2032
  - Further data gathering and RESOLVE development will be needed to explicitly consider repowering in modeling

Candidate Resource Assumptions

- "Candidate" resources represent the menu of options from which RESOLVE can select to create an optimal portfolio
- Publicly-available data on cost, potential, and operations are used to the maximum extent possible to develop candidate resource assumptions
- Both supply and demand-side resources are included as candidate resources
- Supply-side Candidate Resources:
  - Natural gas: CCGT, CT
  - Renewables: Solar PV, Wind, Geothermal, Biomass
  - Utility-Scale battery storage: Li-ion, Flow
  - Pumped storage
- Demand-side Candidate Resources:
  - Behind-the-meter PV (Distributed Solar PV)
  - Behind-the-meter Li-ion Storage
  - Shed Demand Response

Portfolio Selection: Costs and Benefits

- The optimal mix of candidate resources in RESOLVE is a function of the costs and characteristics of the candidate resources and the constraints that the portfolio must meet.
- When choosing a resource, RESOLVE weighs:
  - Costs of building and operating each resource
    - Fixed costs: capital, fixed O&M, transmission upgrades
    - Variable costs: fuel, variable O&M, start
  - The system benefits of adding each resource to the portfolio
    - Hourly energy and reserve value
    - Contribution to GHG and RPS policy goals
    - Contribution to system resource adequacy (planning reserve margin)
    - Contribution to local capacity requirements (if any - none modeled in 2019 IRP)
- Capital costs are typically the largest cost category for renewable resources.

Appendix B: Resource Cost and Build Updates

Summary of cost and build updates

- **Update to NREL 2020 ATB as data source for most technology costs**
  - Exceptions are batteries (Lazard) and offshore wind (NREL OCS study) – see below
- **Battery costs**
  - Update to Lazard v6.0
  - Including capex, fixed O&M, annual warranty and augmentation costs (% of capex)
- **Offshore wind costs**
  - Update to incorporate final numbers from NREL OCS Study BOEM 2020-048
- **ITC/PTC schedules**
  - Update to reflect statute and IRS guidance as of Dec 2020
  - Solar (PV, thermal), wind (onshore, offshore), battery with ITC (hybrid with solar PV)
- **Updated solar annual build constraints to reflect updated ITC schedule**
  - 2021 – 3.1 GW; 2022 – 3.5 GW; 2023 – 1.2 GW, 2025 – 3.2 GW
- **Financing lifetimes**
  - Update to align with latest E3 assumptions based on recent LBNL studies
  - Utility and commercial solar PV, onshore wind, and gas
- **Solar PV inverter loading ratios**
  - Align with latest E3 assumptions based on recent LBNL research
  - Specifically, utility solar PV changed from 1.35 to 1.3 to align with assumption used for solar profile simulation
- **Interconnection cost for storage**
  - Utility-scale Li-ion, flow batteries, pumped hydro

ITC/PTC schedules

- **Solar (commercial PV, utility PV, solar thermal)**
  - ITC extends for projects coming online through 2025 (ITC drops to 10% afterward – same as previous)
- **Residential solar**
  - ITC drops to 0% after 2025
- **Onshore wind**
  - PTC extends through 2025; values adjusted for inflation
- **Offshore wind**
  - ITC extends through 2035 (to reflect assumption that developers will access 10-year safe harbor by end 2025 for projects on federal land / waters)
- **Battery with ITC (hybrid with solar PV) - not used for PSP model runs**
  - ITC extends through 2025 (to be consistent with solar PV)

Financing lifetimes

Technology	Before	After	Source of E3 proforma
Solar - Commercial	35	30	LBNL, 2020, Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals
Solar - Utility Tracking	35	30	LBNL, 2020, Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals
Wind - Onshore	25	30	LBNL, 2019, Benchmarking Anticipated Wind Project Lifetimes: Results from a Survey of U.S. Wind Industry Professionals
Gas CC/CT	20	25	E3

Solar PV inverter loading ratio

Technology	Before	After	Source of E3 proforma
Solar - Residential	1.35	1.15	LBNL, 2019, Tracking the Sun
Solar - Commercial	1.35	1.15	LBNL, 2019, Tracking the Sun
Solar - Utility Tracking	1.35	1.3	E3 assumptions for profile simulation

Storage interconnection costs

- **Apply $100/kW interconnection cost to utility-scale Li-ion batteries, flow batteries, and pumped hydro storage**
  - <u>Rationale for including interconnection cost:</u> Previously assumed zero interconnection cost for storage. Given the low and aggressive storage cost estimates in Lazard v6.0, interconnection costs were included to be conservative.
  - <u>Rationale for $100/kW:</u> A lot of storage will be connected at low costs at existing solar or gas points of interconnection. The interconnection cost for solar in the Resource Costs & Build workbook is $200/kW based on the Black & Veatch study. The $200/kW for storage is currently considered to be rather high and could mean that solar + storage is effectively double paying for interconnection. Therefore, the interconnection cost of new gas resources was adopted as a proxy, which is $100/kW in the Resource Costs & Build workbook.
  - Same interconnection cost applied to pumped hydro for consistency
- **$100/kW interconnection cost ~ $10/kW-yr cost increase on a levelized basis**
  - For utility-scale Li-ion batteries, $10/kW-yr in 2020 → $8/kW-yr in 2029 and onward

Overview of resource cost comparison

<u>High-level takeaways:</u> Resource cost vintage (e.g., NREL 2020 vs. 2018 ATB, Lazard v6.0 vs. v5.0) has the highest impacts on costs. Most of the recent ("2022-23 TPP") updates only affect levelized costs and have relatively small impacts.

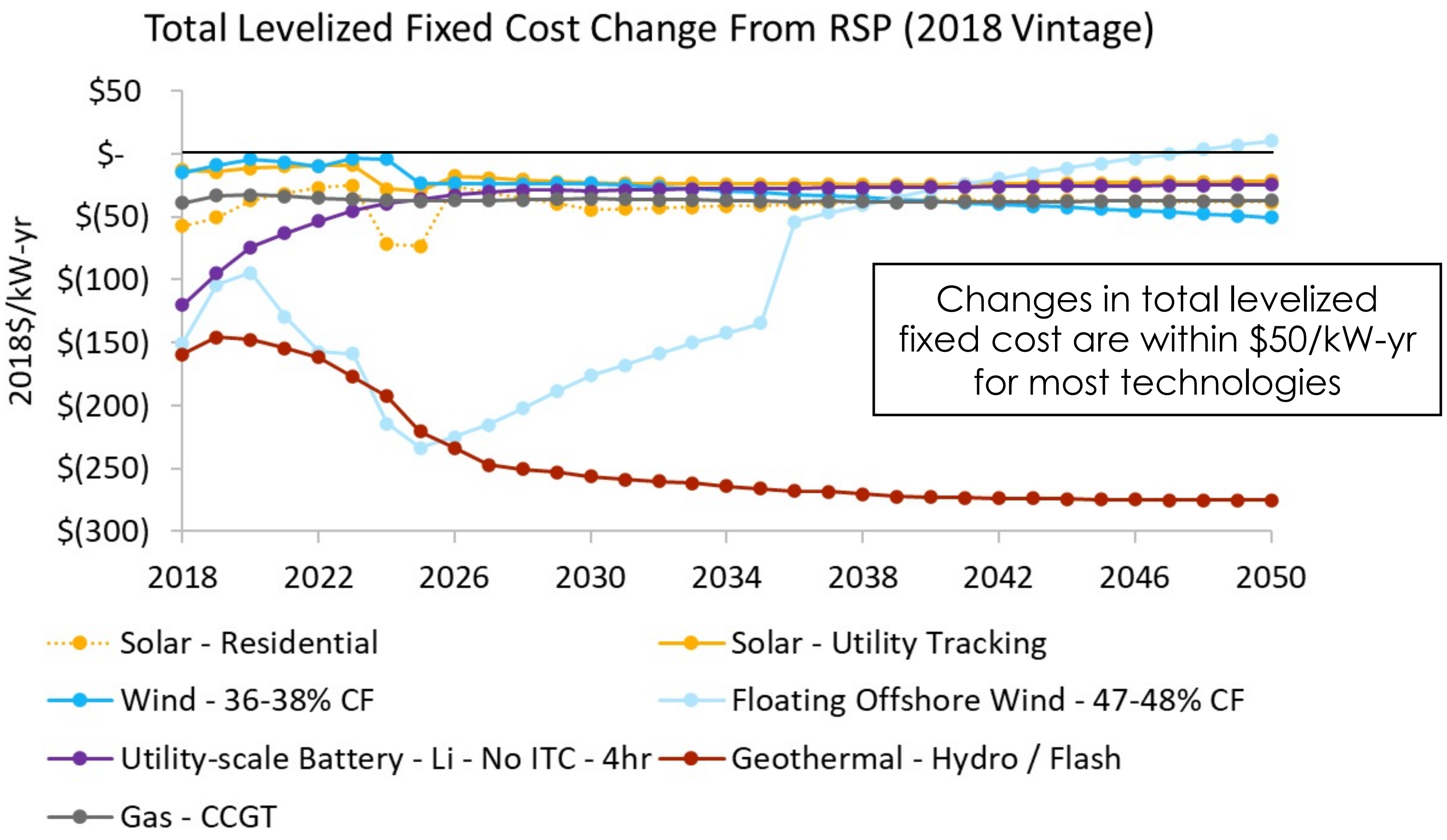
Three sets of resource costs are compared:

- **"2018"**
  - Resource costs prior to summer 2020 updates
  - 2018 vintage (NREL 2018 ATB, Lazard 4.0)
- **"2020"**
  - Resource costs updated (and presented to CPUC) in summer 2020
  - 2020 vintage (NREL 2020 ATB, Lazard 5.0)
- **"2021 PSP / 2022-23 TPP"**
  - Updates for TPP and PSP runs, summer 2021
  - Changes described in previous section (slides 11-14) are relative to "2020" costs

Note: LCOEs shown here are illustrative. All-in levelized costs are the primary cost inputs for new resources in RESOLVE. LCOEs are inferred from dispatch results.

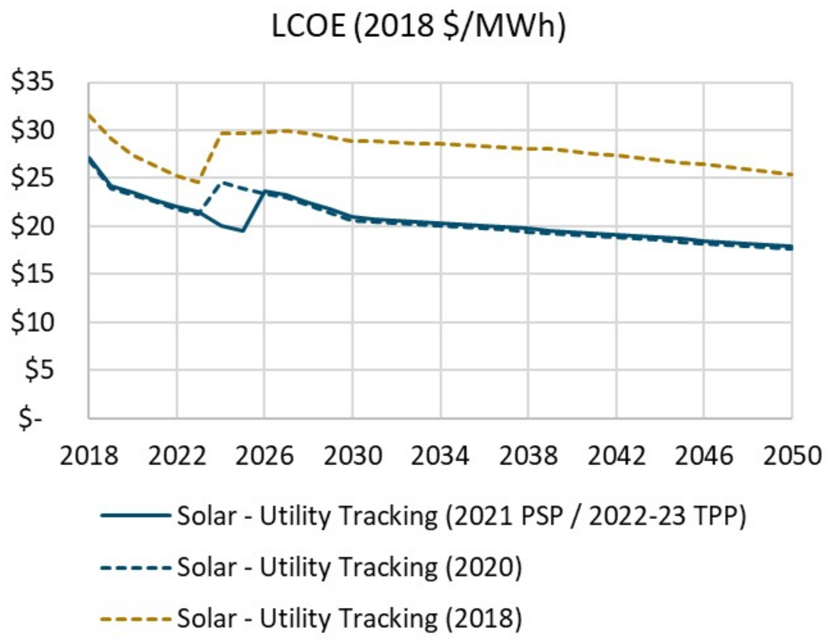
Changes in total levelized fixed cost

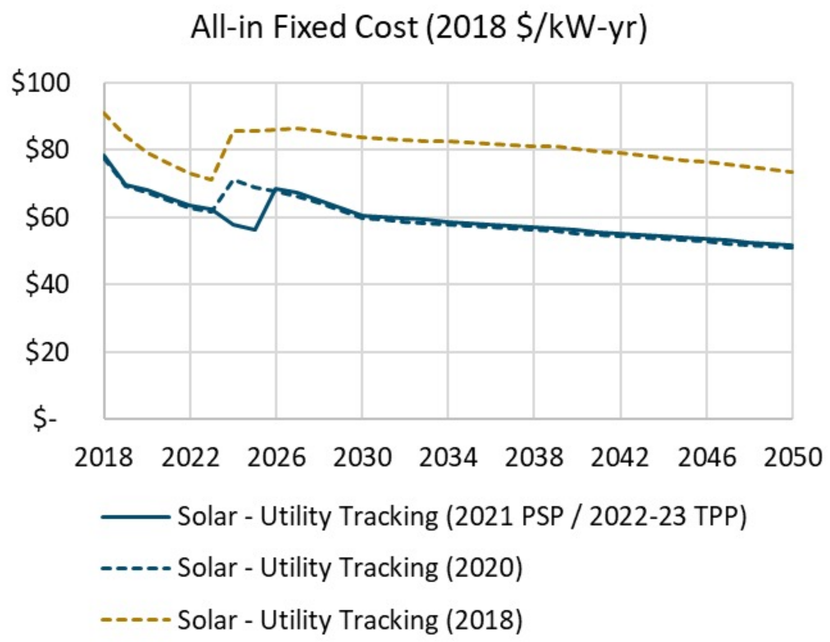
2021 PSP / 2022-23 TPP vs. RSP (2018 vintage)



Utility-scale solar PV

- Biggest differences due to resource cost vintage (2020 vs. 2018 NREL ATB)
- Among the other updates, ITC schedule had the biggest impact

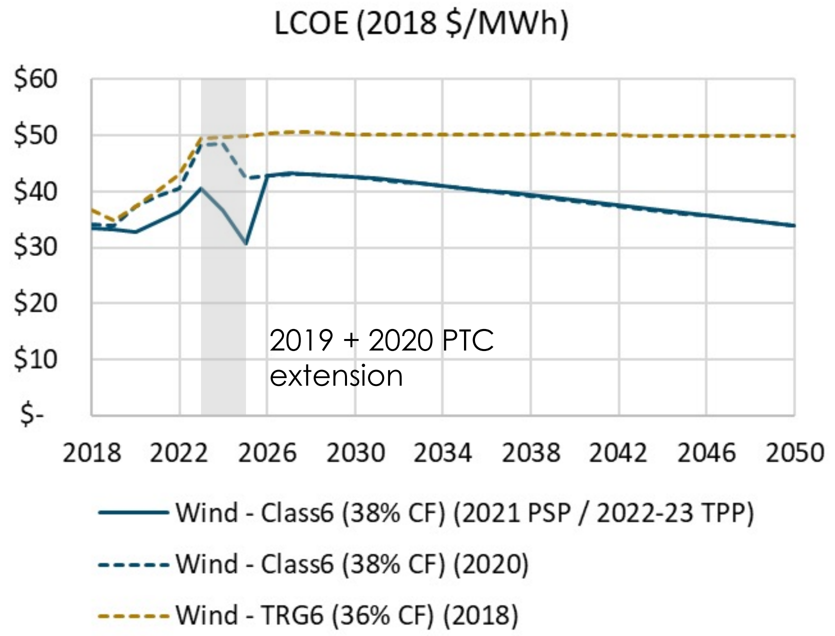




Onshore wind, Class 6 (36-38% capacity factor)

- Biggest differences due to resource cost vintage (2020 vs. 2018 NREL ATB)
- Among the other updates, PTC schedule had the biggest impact

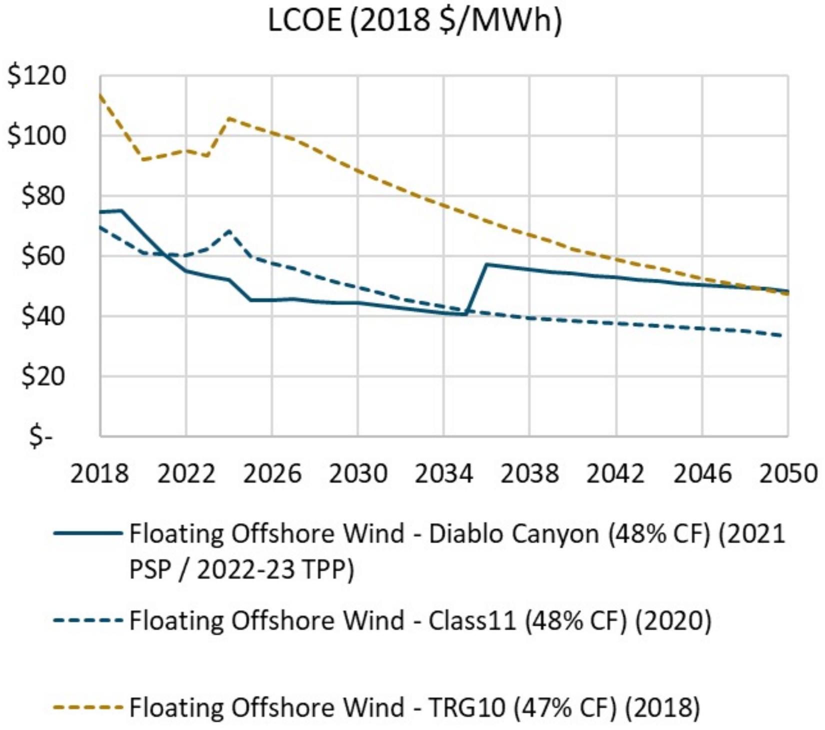
PTC timeline:
- <u>Previous legislation:</u> PTC decreases to **40%** by the end of **2023** (online date)
- <u>Dec 2019:</u> PTC extension at **60%** to the end of **2024** (online date)
- <u>Dec 2020:</u> PTC extension at **60%** to the end of **2025** (online date)

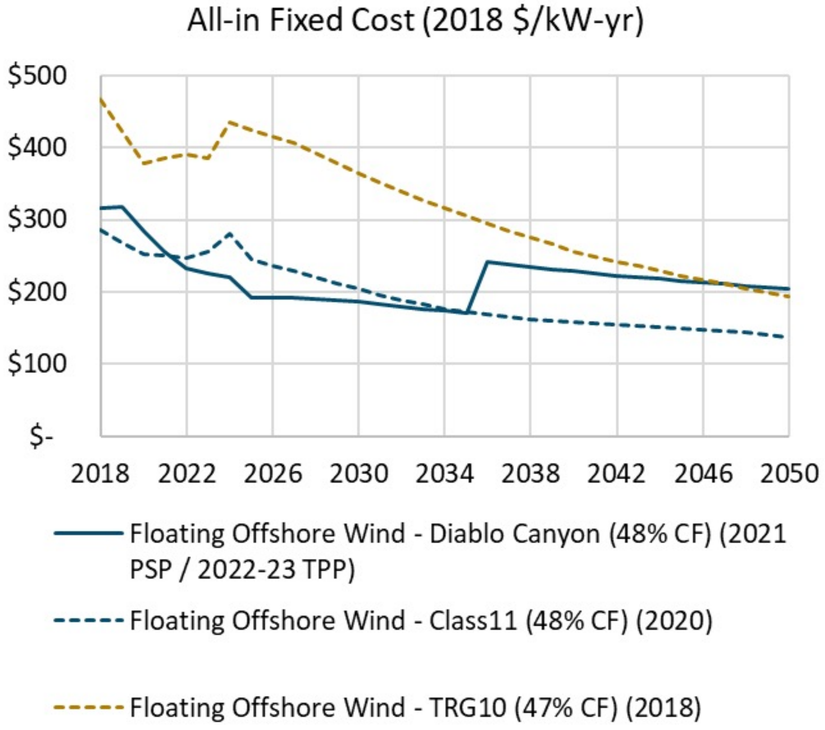


Note: wind bins (Techno-Resource Groups or Classes) changed between 2019 and 2020 ATB, resulting in small differences in capacity factor.

Floating offshore wind, 47-48% capacity factor

- Biggest differences due to resource cost data source (NREL OCS Study vs. NREL ATB/E3)
- Among the other updates, ITC schedule had the biggest impact

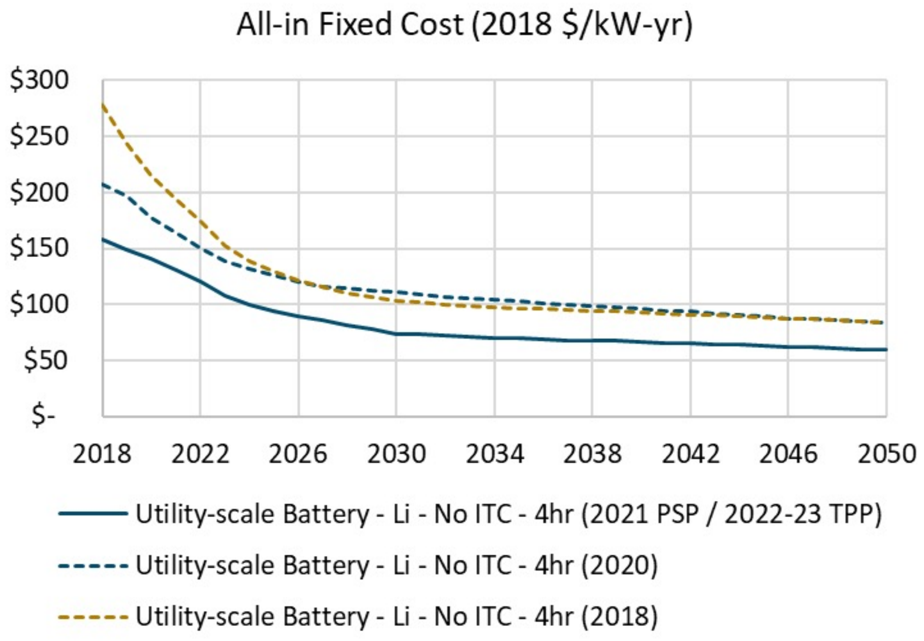




Note: wind bins (Techno-Resource Groups or Classes) changed between 2019 and 2020 ATB, resulting in small differences in capacity factor.

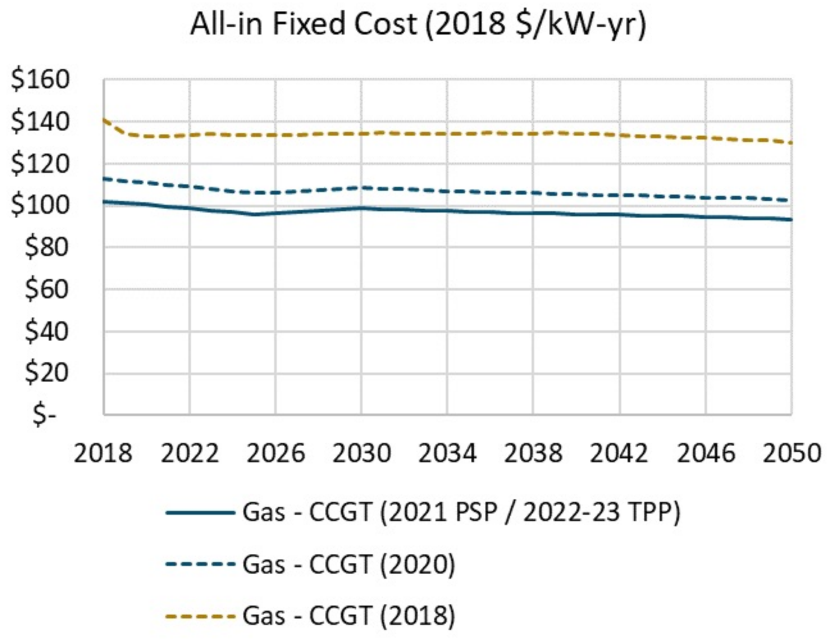
Utility-scale standalone Li-ion battery

- Biggest differences come from resource cost vintage
  - Lazard 6.0 assumed substantial cost reductions



Gas CCGT

- Biggest differences due to resource cost vintage (2020 vs. 2018 NREL ATB)
- Assumption for financing lifetime had relatively small impacts



Note: LCOE not shown because the capacity factor of gas resources is a RESOLVE output. The capacity factor can change over time and cannot be predicted prior to each model run.

Appendix C: Transmission Updates

Objective of RESOLVE Transmission Updates

- E3 updated RESOLVE to incorporate additional technology-specific and location-specific transmission deliverability information in order to refine location information of resources selected in RESOLVE portfolios
- The RESOLVE updates use new and updated data described in CAISO's white paper, which includes:
  - More detail on how generation and storage resources and transmission constraints interact via resource output factors
  - Additional detail on the timing of peak needs via highest and secondary on-peak transmission constraints
  - An expanded set of transmission constraints
  - Details of how transmission upgrades impact on-peak and off-peak capability
  - Estimates of time to construct transmission upgrades

White paper available at http://www.caiso.com/Documents/WhitePaper-2021TransmissionCapabilityEstimates-CPUCResourcePlanningProcess.pdf

Transmission Capability Update Approach

1. Create transmission capability constraint equations
2. Input new transmission capability data
   - Existing transmission capabilities
   - Upgrade cost and first available year
   - Upgrade effectiveness at increasing on-peak and off-peak deliverability
3. Assign RESOLVE resources to each constraint
   - Use CAISO's resource output factors for deliverability
     - Offshore and out of state wind data not provided by CAISO; E3 scaled land-based CAISO wind resource output factors by capacity factor

- Implementation of all three approaches relies on RESOLVE's new "custom constraint" functionality, enabled by an updated code base

EODS = Energy Only Deliverability Status
FCDS = Full Capacity Deliverability Status

Fully Deliverable vs. Energy Only

Total Renewable Capacity Selected

Capacity:
For solar, wind, and geothermal resources, RESOLVE selects deliverability status

Energy:
All capacity contributes to dispatch on 37 representative days (no direct link between deliverability status and dispatch)

Fully Deliverable (FCDS) capacity contributes to resource adequacy (the planning reserve margin)

Energy Only (EODS) capacity does NOT contribute to resource adequacy (the planning reserve margin)

Transmission Deliverability Constraints

On-Peak HSN: Highest System Need

On-Peak SSN: Secondary System Need

Off-Peak

Fully Deliverable renewable capacity must "fit" within both on-peak transmission capability limits (including upgrades)

All renewable capacity requires off-peak transmission capability

Transmission Constraint – On-Peak HSN Example

Constraint Type	Existing Transmission System Capability Estimate (MW)	Transmission Upgrade Capacity (MW)		Non-Storage Resource (r) Capability Required (MW)	Storage Resource (sr) Capability Required (MW)
On-Peak HSN: Highest System Need	Fully Deliverable (FCDS)	Upgrade FCDS MW	$\geq$	$\sum_{r}\begin{pmatrix}\text{Fully Deliverable Capacity}_r \; * \\ \text{Resource HSN Output Factor}_r\end{pmatrix}$	$+\sum_{sr}(\text{Installed Capacity}_{sr})$

There are three different limits for each transmission constraint; HSN limit used as example here

CAISO estimates of existing network capability and how upgrade would increase capability

Each resource has an output factor ranging from 0 to 1, representing capacity factor during periods when the constraint is limiting

Storage discharge (On-Peak) requires transmission capability; Storage charging (Off-Peak) increases transmission capability

Generalized Constraint Equations

On-Peak HSN: Highest System Need	Fully Deliverable (FCDS)	Upgrade FCDS MW	≥	$\sum_{r} \begin{pmatrix} \text{Fully Deliverable Capacity}_r \ * \\ \text{Resource HSN Output Factor}_r \end{pmatrix}$	$+\sum_{sr} (\text{Installed Capacity}_{sr})$
On-Peak SSN: Secondary System Need	Fully Deliverable (FCDS)	Upgrade FCDS MW	≥	$\sum_{r} \begin{pmatrix} \text{Fully Deliverable Capacity}_r \ * \\ \text{Resource SSN Output Factor}_r \end{pmatrix}$	$+\sum_{sr} (\text{Installed Capacity}_{sr})$
Off-Peak	Energy Only (EODS)	Upgrade EODS MW	≥	$\sum_{r} \begin{pmatrix} \text{Installed Capacity}_r \ * \\ \text{Resource Off–Peak Output Factor}_r \end{pmatrix}$	$-\sum_{sr} (\text{Installed Capacity}_{sr})$

EODS = Energy Only Deliverability Status
FCDS = Full Capacity Deliverability Status

Transmission Upgrades

- CAISO provided 44 constraints of which 28 were modelled in RESOLVE
  - Upgrades without a RESOLVE candidate resource weren't modeled
  - Some RESOLVE Constraint names may differ from names in CAISO white paper
- Transmission upgrades are not made available for selection until the First Available Year
  - Ensures that upgrades can be built on a feasible development timeline

RESOLVE Transmission Constraint Name	Resource Constraint Area	First Available Year	Upgrade size - On-peak (MW)	Upgrade size - Offpeak (MW)	Levelized Cost ($2020/MW-yr)
Delevan Cortina 230	Northern California	2034	2,838	N/A	87,364
Contra Costa Delta Switchyard 230	Northern California	2030	1,476	N/A	26,009
Humboldt Trinity 115	Northern California	2031	57	N/A	205,153
Gates Arco Midway 230	Southern PGAE	2031	3,137	332	3,374
Gates 500 230 Transformer	Southern PGAE	2026	4,453	1,603	732
Los Banos 500 230 Transformer	Southern PGAE	2028	446	N/A	65,595
Tesla Westley 230	Southern PGAE	2027	114	N/A	63,617
Gates Panoche 230	Southern PGAE	2027	378	6,723	55,275
Morro Bay Templeton 230	Southern PGAE	2031	739	123	125,914
Los Banos Gates 500 OPDS	Southern PGAE	2031	N/A	2,246	2,250
Moss Landing Los Banos 230 OPDS	Southern PGAE	2031	N/A	1,822	2,773
Tehachapi Antelope	Tehachapi	2024	2,700	N/A	476
South Kramer Victor	Greater Kramer	2029	430	480	22,883
South Kramer Victor Lugo	Greater Kramer	2025	430	N/A	51,832
Lugo Transformer	Greater Kramer	2026	980	N/A	6,906
Eldorado 500 230	El Dorado SNV	2026	400	N/A	16,920
GLW VEA	El Dorado SNV	2027	1,000	1,110	14,118
Mohave Eldorado 500	El Dorado SNV	No upgrade identified			
Serrano Alberhill	SCE Eastern/SDGE	2031	3,648	N/A	35,528
Colorado River 500 230	SCE Eastern/SDGE	2026	1,000	1,000	7,155
Devers Red Bluff	SCE Eastern/SDGE	2031	3,100	1,876	28,870
East of Miguel	SCE Eastern/SDGE	2032	1,412	943	223,754
Imperial Valley	SCE Eastern/SDGE	2031	400	N/A	46,850
Encina San Luis Rey	SCE Eastern/SDGE	2032	3,718	N/A	2,355
Internal San Diego	SCE Eastern/SDGE	2024	2,067	274	4,331
San Luis Rey San Onofre	SCE Eastern SDGE	2032	4,269	N/A	4,766
Silvergate Bay Boulevard	SCE Eastern SDGE	2028	2,119	N/A	1,360
Greater LA	Greater LA	No upgrade identified *			

* Upgrade modeled in RESOLVE with an extremely high cost to act as an "overflow" zone for long-run (~2040+ timeframe) planning

Input Data: Resource Output Factors for Transmission Capability Estimates

- Transmission capability varies with:
  - Resource type
  - Time of delivery
    - Highest System Need
    - Secondary System Need
    - Offpeak
  - Location
- CAISO provided **resource output factors** to reflect this:
  - The fraction of installed resource capacity that requires transmission space under different constraint scenarios
- Storage resources expand EODS limits via charging off-peak (negative 100% in EODS table)

Resource output factors – Full Capacity Deliverability Status (FCDS) Capability Estimates

On Peak Scenario	Highest System Need (HSN)			Secondary System Need (SSN)		
Load Serving Entity	SDG&E	SCE	PG&E	SDG&E	SCE	PG&E
Solar	3.0%	10.6%	10.0%	40.2%	42.7%	55.6%
Wind	33.7%	55.7%	66.5%	11.2%	20.8%	16.3%
Pumped Hydro	100%					
Li Battery	100%*					
Geothermal	100%					

Resource output factors – Energy Only Deliverability Status (EODS) Capability Estimates

Constraint Area Type	"Wind" Area			"Solar" Area		
Load Serving Entity	SDG&E	SCE	PG&E	SDG&E	SCE	PG&E
Solar	68.0%	68.0%	68.0%	79.0%	77.0%	79.0%
Wind	69.0%	64.0%	64.0%	44.0%	44.0%	44.0%
Pumped Hydro	-100%					
Li Battery	-100% *					
Geothermal	100% **					

* Discharge power capacity used for Li storage regardless of duration
**100% of Geothermal nameplate capacity assumed to need off-peak deliverability

Data Source: CAISO Whitepaper - Transmission Deliverability Study

Resource Constraint Assignment Northern California

Resources

Transmission Constraints	Northern California Wind	Solano Wind	Humboldt Wind	Humboldt Bay Offshore Wind	Solano Geothermal	Northern California Geothermal	Northern California Solar	Northern California Li Battery	Northwest Wind on Existing Transmission
Delevan Cortina 230	1	1	1	1	1	1	1	1	1
Contra Costa Delta Switchyard 230	0	1	0	0	1	0	0	0	1
Humboldt Trinity 115	0	0	1	1	0	0	0	0	0

1 indicates that the resource is included in the constraint;
0 indicates that it is not

Resource Constraint Assignment Southern PG&E

	Kern Greater Carrizo Wind	Carrizo Wind	Central Valley North Los Banos Wind	Diablo Canyon Offshore Wind	Morro Bay Offshore Wind	Southern PGAE Solar	Southern PGAE Li Battery
Gates Arco Midway 230	1	1	0	0	1	0	0
Gates 500 230 Transformer	1	1	1	0	1	0	0
Los Banos 500 230 Transformer	0	0	1	0	0	0	0
Tesla Westley 230	0	0	1	0	0	0	0
Gates Panoche 230	0	1	0	1	1	1	1
Morro Bay Templeton 230	1	1	1	0	1	0	0
Los Banos Gates 500 OPDS	1	1	0	0	0	0	0
Moss Landing Los Banos 230 OPDS	1	1	1	0	0	0	0

Resource Constraint Assignment Tehachapi, Greater Kramer, & El Dorado

El Dorado

	Southern NV Eldorado Solar	Southern NV Eldorado Li Battery	Southern Nevada Wind	Southern Nevada Geothermal	Wyoming Wind
Eldorado 500 230	1	1	1	1	0
GLW VEA	0	0	1	1	0
Mohave Eldorado 500	0	0	0	0	1

Tehachapi

	Tehachapi Wind	Tehachapi Solar	Tehachapi Li Battery	Tehachapi Pumped Storage
Tehachapi Antelope	1	1	1	1

Greater Kramer

	Greater Kramer Solar	Greater Kramer Li Battery	Inyokern North Kramer Geothermal
South Kramer Victor	0	0	1
South Kramer Victor Lugo	0	0	1
Lugo Transformer	1	1	1

Resource Constraint Assignment SCE + Eastern SDG&E

	Riverside Solar	Riverside Li Battery	Riverside Palm Springs Geothermal	Riverside Palm Springs Wind	Arizona Solar	Arizona Li Battery	New Mexico Wind	SW Ext Tx Wind	Imperial Solar	Imperial Li Battery	Greater Imperial Geothermal	Riverside East Pumped Storage	San Diego Pumped Storage	Baja California Wind	San Diego Li Battery
Serrano Alberhill	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Colorado River 500 230	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Devers Red Bluff	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0
East of Miguel	0	0	0	0	1	1	1	1	1	1	1	0	0	1	0
Imperial Valley	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
Encina San Luis Rey	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
Internal San Diego	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
San Luis Rey San Onofre	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
Silvergate Bay Boulevard	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1

Resource Constraint Assignment Greater LA Constraint

- CAISO identified additional transmission capability near the Los Angeles area that is not included in other transmission constraints
  - The Greater LA constraint was created to include this transmission capability in RESOLVE.
- The Greater LA constraint combines the existing system capability for the following CAISO-identified constraints:
  - Orange County Area
  - Laguna Bell – Mesa Flow Limit
  - SCE Metro Area
- The Greater LA solar resource was limited to 3,000 MW based on interconnection queue activity

	Riverside West Pumped Storage	Greater LA Solar	Greater LA Li Battery
Greater LA	1	1	1

Serrano – Alberhill Transmission Constraint Example

- The following section provides an example of how resources, transmission limits, and transmission upgrades interact in RESOLVE
  - One of the largest transmission constraints is used as an example: the Serrano – Alberhill constraint in the Southern SCE area.

Serrano – Alberhill Tx Constraint Example Transmission Constraint Data

Constraint Attributes	
Full Capacity Deliverability	5,700 MW
Energy Only Deliverability	11,800 MW
Upgrade type	Adds peak deliverability
Upgrade size	3,648 MW
Upgrade cost	$1.48 Bn
Construction time	105 Months (+ 12 months for approval process)
Area constraint type (for off-peak deliverbality factors)	Solar

- Existing transmission lines provide:
  - 5.7 GW on-peak space
  - 11.8 GW off-peak space
- RESOLVE can build up to 3,648 MW of new **on peak** transmission capability
  - The upgrade creates 0 MW of off-peak capability
- Levelized cost of **35,528 $/MW-year** (2020 $)
  - This includes AFUDC* costs
- New transmission capability available from **2031** at the earliest

*Allowance for Funds Used During Construction (AFUDC)

Serrano – Alberhill Example: Resources

Resource Name	LSE Zone (Used to look up resource output factors)	Resource Type (Used to look up resource output factors)	HSN (Resource Output Factors)	SSN (Resource Output Factors)	Offpeak (Resource Output Factors)
Riverside Palm Springs Geothermal	N/A	Geothermal	100%	100%	100%
Greater Imperial Geothermal	N/A	Geothermal	100%	100%	100%
Riverside Li Battery	N/A	Li Battery	100%	100%	-100%
Arizona Li Battery	N/A	Li Battery	100%	100%	-100%
Imperial Li Battery	N/A	Li Battery	100%	100%	-100%
San Diego Li Battery	N/A	Li Battery	100%	100%	-100%
Riverside East Pumped Storage	N/A	PSH	100%	100%	-100%
San Diego Pumped Storage	N/A	PSH	100%	100%	-100%
Riverside Solar	SCE	Solar	11%	43%	77%
Arizona Solar	SCE	Solar	11%	43%	77%
Imperial Solar	SCE	Solar	11%	43%	77%
Baja California Wind	SDG&E	Wind	34%	11%	44%
New Mexico Wind	SCE	Wind	79%	29%	62%
Riverside Palm Springs Wind	SCE	Wind	61%	23%	48%
SW Ext Tx Wind	SCE	Wind	65%	24%	51%

The Serrano – Alberhill constraint has 15 associated resources in the SCE Eastern + SDG&E region

The constraint is in a solar constrained area and therefore the corresponding offpeak resource output factors are used

Serrano – Alberhill Example: On-Peak <u>HSN</u>

On-Peak HSN: Highest System Need	5,700 MW (constant)	+ Transmission Upgrade FCDS MW (RESOLVE decision variable)	≥	$0.106 * (FCDS\_Capacity_{Riverside\_Solar} + FCDS\_Capacity_{Imperial\_Solar} + FCDS\_Capacity_{Arizona\_Solar})$ + $1 * (FCDS\_Capacity_{Riverside\_Palm\_Springs\_Geothermal} + FCDS\_Capacity_{Greater\_Imperial\_Geothermal})$ + $0.607 * FCDS\_Capacity_{Riverside\_Palm\_Springs\_Wind}$ + $0.788 * FCDS\_Capacity_{New\_Mexico\_Wind}$ + $0.647 * FCDS\_Capacity_{SW\_Ext\_Tx\_Wind}$	+ $Installed\_Capacity_{Riverside\_Li\_Battery}$ + $Installed\_Capacity_{Riverside\_East\_Pumped\_Storage}$ + $Installed\_Capacity_{Imperial\_Li\_Battery}$ + $Installed\_Capacity_{Arizona\_Li\_Battery}$

Only Fully Deliverable (FCDS) renewable capacity included in On-Peak constraints.

Serrano – Alberhill Example: On-Peak SSN

On-Peak SSN: Secondary System Need	5,700 MW (constant)	+ Transmission Upgrade FCDS MW (RESOLVE decision variable)	≥	0.427 * ($FCDS\_Capacity_{Riverside\_Solar}$ + $FCDS\_Capacity_{Imperial\_Solar}$ + $FCDS\_Capacity_{Arizona\_Solar}$) + 1 * ($FCDS\_Capacity_{Riverside\_Palm\_Springs\_Geothermal}$ + $FCDS\_Capacity_{Greater\_Imperial\_Geothermal}$) + 0.227 * $FCDS\_Capacity_{Riverside\_Palm\_Springs\_Wind}$ + 0.294 * $FCDS\_Capacity_{New\_Mexico\_Wind}$ + 0.242 * $FCDS\_Capacity_{SW\_Ext\_Tx\_Wind}$	+ $Installed\_Capacity_{Riverside\_Li\_Battery}$ + $Installed\_Capacity_{Riverside\_East\_Pumped\_Storage}$ + $Installed\_Capacity_{Imperial\_Li\_Battery}$ + $Installed\_Capacity_{Arizona\_Li\_Battery}$

→ Note that the coefficients change between HSN and SSN. Solar resources here require more on-peak space in the SSN constraint than the HSN

Serrano – Alberhill Example: Off-Peak

Off-Peak	11,800 MW (constant)	+ 0 MW (The Serrano – Alberhill upgrade provides no additional off-peak deliverability)	≥	0.77 * ($\text{Installed\_Capacity}_{\text{Riverside\_Solar}}$ + $\text{Installed\_Capacity}_{\text{Imperial\_Solar}}$ + $\text{Installed\_Capacity}_{\text{Arizona\_Solar}}$) + 1*($\text{Installed\_Capacity}_{\text{Riverside\_Palm\_Springs\_Geothermal}}$ + $\text{Installed\_Capacity}_{\text{Greater\_Imperial\_Geothermal}}$) + 0.480 * $\text{Installed\_Capacity}_{\text{Riverside\_Palm\_Springs\_Wind}}$ + 0.643 * $\text{Installed\_Capacity}_{\text{New\_Mexico\_Wind}}$ + 0.511 * $\text{Installed\_Capacity}_{\text{SW\_Ext\_Tx\_Wind}}$	- $\text{Installed\_Capacity}_{\text{Riverside\_Li\_Battery}}$ - $\text{Installed\_Capacity}_{\text{Riverside\_East\_Pumped\_Storage}}$ - $\text{Installed\_Capacity}_{\text{Imperial\_Li\_Battery}}$ - $\text{Installed\_Capacity}_{\text{Arizona\_Li\_Battery}}$

Note: Many of the CAISO-identified upgrades do increase off-peak deliverability

-1 coefficient for storage resources represents charging off-peak. Storage charging decreases available energy in the constraint zone off-peak.