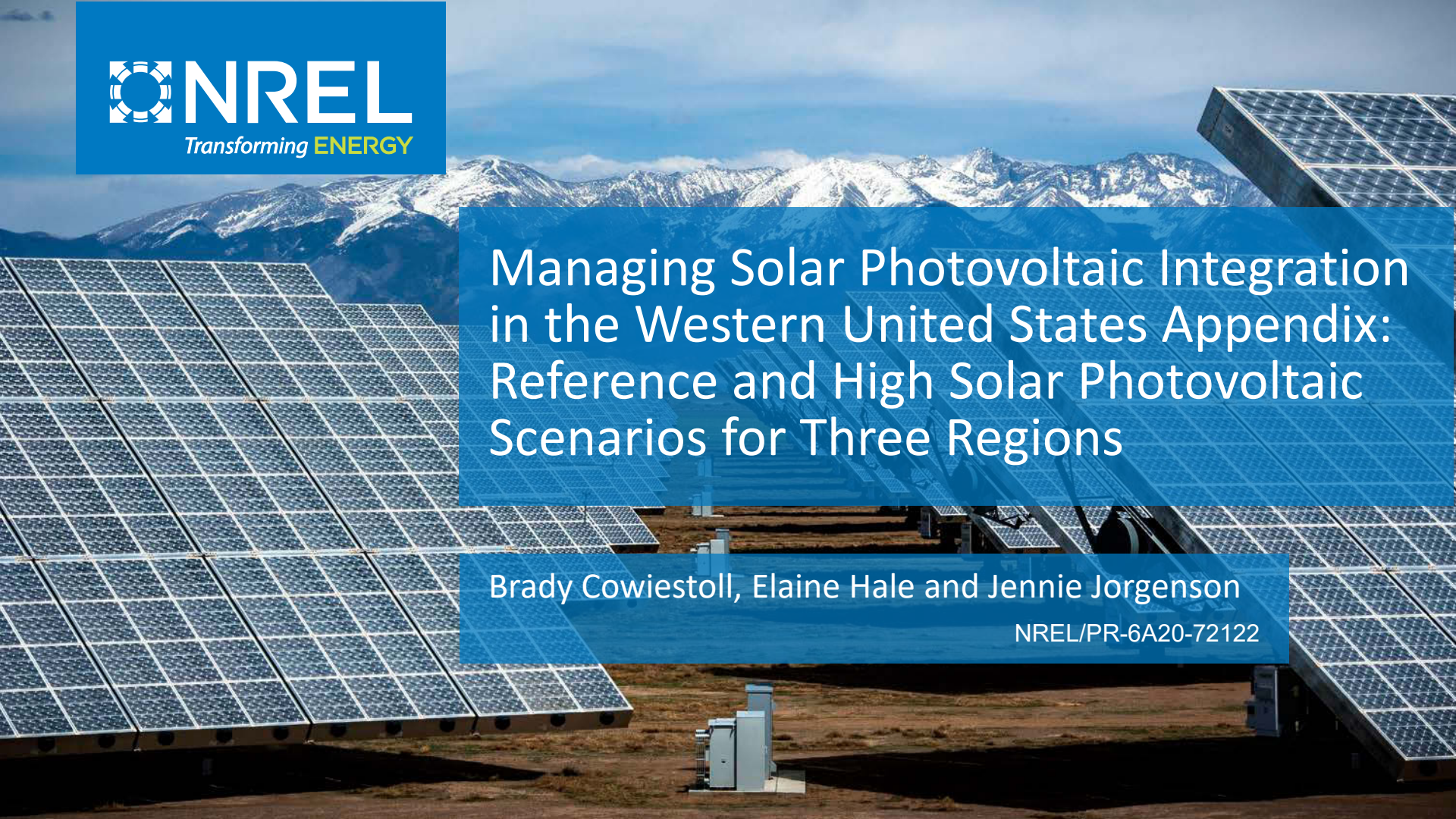

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Managing Solar Photovoltaic Integration in the Western United States Appendix: Reference and High Solar Photovoltaic Scenarios for Three Regions

Brady Cowiestoll, Elaine Hale and Jennie Jorgenson

NREL/PR-6A20-72122

Preface

This slide deck is an appendix to a paper series that examines potential challenges related to planning future power systems with higher solar photovoltaic (PV) penetrations. The series uses the western U.S. power system for these investigations because it is a region the authors and their colleagues have already extensively studied. We are therefore well-suited to analyze even higher PV penetrations and then examine the results in multiple models to determine whether our current approaches are missing key details that only emerge at higher PV penetrations. This deck details the systems underlying those analyses and how they were modeled using the Resource Planning Model (RPM), a capacity expansion modeling tool. We examine both Western Interconnection-wide and regional results for three regions in the Western U.S. with significantly different existing power systems and connections to neighboring regions; this provides a more balanced picture as to how power systems with high PV penetration might emerge in different contexts and what the resulting grid challenges, if any, might be.

The four publications in this series are listed and described in the table at the right.

Title	Description
Managing Solar Photovoltaic Integration in the Western United States: Power System Flexibility Requirements and Supply	Assessment of net load ramping needs and what resources are available to provide upward and downward ramping at different timescales
Managing Solar Photovoltaic Integration in the Western United States: Resource Adequacy Considerations	Probabilistic resource adequacy assessment of high PV penetration scenarios and comparison to planning reserve margin approaches using capacity value approximation methods
Behind-the-meter Solar Accounting in Renewable Portfolio Standards	An exploration of how two RPS design elements can influence the interaction of behind-the-meter PV and total renewable generation
Managing Solar Photovoltaic Integration in the Western United States Appendix: Reference and High Solar Photovoltaic Scenarios for Three Regions	**Resource Planning Model (RPM) inputs, scenario framework, and results for RPM-AZ, RPM-CO, and RPM-OR; two of the papers in the series use these scenarios as their starting point for analysis**

This report is listed in **bold type.**

This report series was commissioned by the Western Interstate Energy Board (WIEB) as part of the Enhanced Distributed Solar Photovoltaic Deployment via Barrier Mitigation or Removal in the Western Interconnection project funded by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Solar Energy Technologies Office (SETO). For more information, including links to other reports, see https://www.westernenergyboard.org/western-interstate-energy-board/barrier-mitigation-to-enhanced-distributed-solar-photovoltaic/.

Disclaimer

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Acronyms

AEO	Annual Energy Outlook
APS	Arizona Public Service Company
ATB	Annual Technology Baseline
CC	natural gas combined-cycle
CSP	concentrating solar power
CT	natural gas combustion turbine
DOE	U.S. Department of Energy
DPV	distributed photovoltaics
EERE	Energy Efficiency and Renewable Energy
EIA	U.S. Energy Information Association
GW	gigawatt
MW	megawatt
NEVP	Nevada Power Company
NG	natural gas
NREL	National Renewable Energy Laboratory
PACW	PacificCorp West
PGN	Portland General Electric Company
PSC	Public Service Company of Colorado
PV	photovoltaic
REC	renewable energy credit
RPM	Resource Planning Model
RPS	renewable portfolio standard
SETO	Solar Energy Technologies Office
SRP	Salt River Project
TEP	Tucson Electric Power company
TWh	terawatt hours
VG	variable generation
WACM	Western Area Power Administration: Colorado Missouri
WALC	Western Area Power Administration, Lower Colorado Region
WI	Western Interconnection
WIEB	Western Interstate Energy Board

Introduction

RPM Overview

Scenario Framework

Examining plausible pathways to high-PV futures in three Western regions

The Resource Planning Model (RPM) was used to create plausible pathways to reaching high penetrations of PV

- RPM is a capacity expansion model that simulates least-cost investments in and operation of a generation and transmission system
- RPM is designed for analysis of a *regional* electric system over a utility planning horizon (10-20 years)
  - Includes hourly chronological dispatch
  - High spatial resolution of existing and new resources
  - Real-world transmission system

This slide deck presents detailed RPM results for the three regions – RPM-AZ, RPM-CO, and RPM-OR – our "focus models" for this study. Each focus model includes higher resolution representation of transmission and generation assets within a focus region defined by a set of balancing authorities (BAs), and aggregated information about the rest of the Western Interconnection (WI).

Regional Grid Models Studied

Regional Grid Models Studied

Arizona Focus Model (RPM-AZ)

- Arizona Public Service Company (APS)
- Nevada Power Company (NEVP)
- Salt River Project (SRP)
- Tuscon Electric Power Company (TEP)
- Western Area Power Administration, Lower Colorado Region (WALC)

Colorado Focus Model (RPM-CO)

- Public Service Company of Colorado (PSC)
- Western Area Power Administration, Colorado Missouri (WACM)

Oregon Focus Model (RPM-OR)

- PacificCorp West (PACW)
- Portland General Electric Company (PGN)

High PV Penetration Scenarios

Reference

DPV, Gas Price, PV Cost, Storage Cost, and RPS

- Midline DPV projections
- Midline assumptions from the NREL 2018 ATB and the EIA AEO 2018
- Existing RPS policy as of 2018

These assumptions are used in all scenarios and locations unless stated otherwise

Focus Goal

DPV and RPS, within Focus Region only

- RPS with no REC trading to replicate the 2017 NREL Standard Scenarios' National 80% RPS case within the focus region
- More-aggressive DPV in the focus region in line with low NREL 2018 ATB PV cost projections

National Goal

PV Cost, DPV, and RPS

- RPS replicating the 2017 NREL Standard Scenarios' National 80% RPS case, applied across the whole WI
- More-aggressive DPV in line with low NREL 2018 ATB PV cost projections
- Low NREL 2018 ATB PV cost projections for all PV technologies

These assumptions are also used in the two National Goal sensitivity scenarios, Low Natural Gas Price and Low Storage Cost

Low Natural Gas Price

Gas Price

- Lower gas prices from EIA AEO 2018 "high oil and gas resource and technology" scenario

Low Storage Cost

Storage Cost

- Low NREL 2018 ATB cost projections for battery storage

DPV = distributed photovoltaics
RPS = renewable portfolio standard
REC = renewable energy credit
WI = Western Interconnection

RPM Scenario Results

Capacity

- WI
- RPM-OR
- RPM-CO
- RPM-AZ

Dispatch

- RPM-OR
- RPM-CO
- RPM-AZ

Notes about Results

- These scenarios were designed to explore systems with high PV penetrations, and do not represent forecasts or expectations about the generation mix of a future system for WI or the focus regions examined.
- The scenarios explored include very high PV penetrations, which may be unlikely to be observed under real-world market conditions, particularly in the near-term; however, they are useful in exploring the potential modeling, analytical, and planning challenges that may be associated with high PV penetration power systems.
- The results and/or views expressed in this presentation do not necessarily represent the views of the NREL, DOE, or the U.S. Government.

PV Penetration Results from RPM for each of the Focus Models (in 2035, as % of Generation)

	RPM-AZ				RPM-CO				RPM-OR			
	DPV		All PV		DPV		All PV		DPV		All PV	
Scenario	**AZ**	**WI**	**AZ**	**WI**	**CO**	**WI**	**CO**	**WI**	**OR**	**WI**	**OR**	**WI**
Reference	5.8	3.2	30.1	15.5	2.0	3.2	11.5	13.7	1.3	3.2	10.4	15.0
Focus Goal	7.5	3.4	49.7	19.1	3.5	3.3	24.1	14.6	1.4	3.2	75.4	17.3
National Goal	7.2	3.7	48.1	30.8	3.8	3.7	18.7	25.0	2.0	3.7	75.6	27.2
National Goal + Low Storage Costs	7.6	3.7	49.9	32.8	3.9	3.7	32.8	30.6	2.0	3.7	77.3	32.5
National Goal + Low Natural Gas Price	7.2	3.7	49.1	31.6	3.7	3.7	19.5	25.6	2.0	3.7	73.2	27.3

DPV = distributed (behind-the-meter) photovoltaics
WI = Western Interconnection

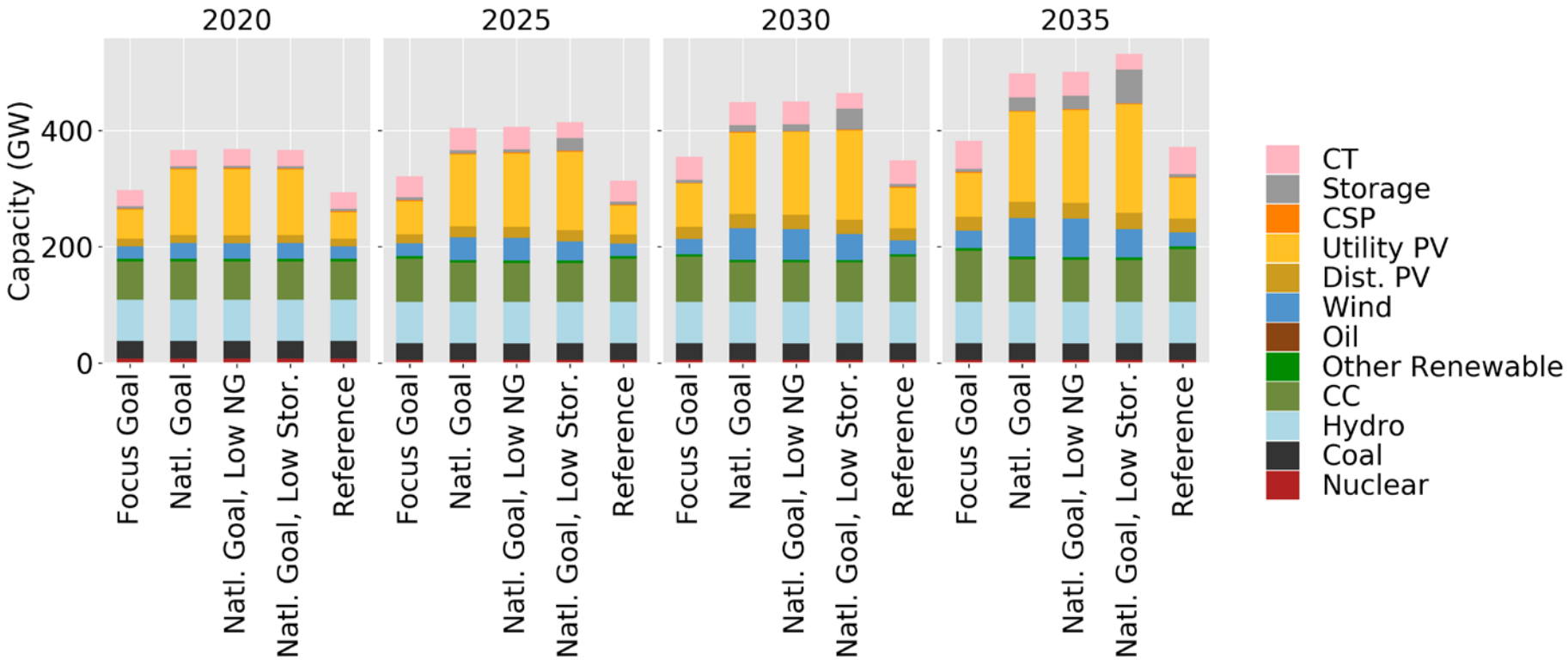
RPM Model Key

- Abbreviations
  - CC = Gas Combined Cycle
  - CT = Gas Combustion Turbine
  - CSP = Concentrating Solar Power
  - Other Renewable = Geothermal and Biomass
  - DPV = Distributed PV

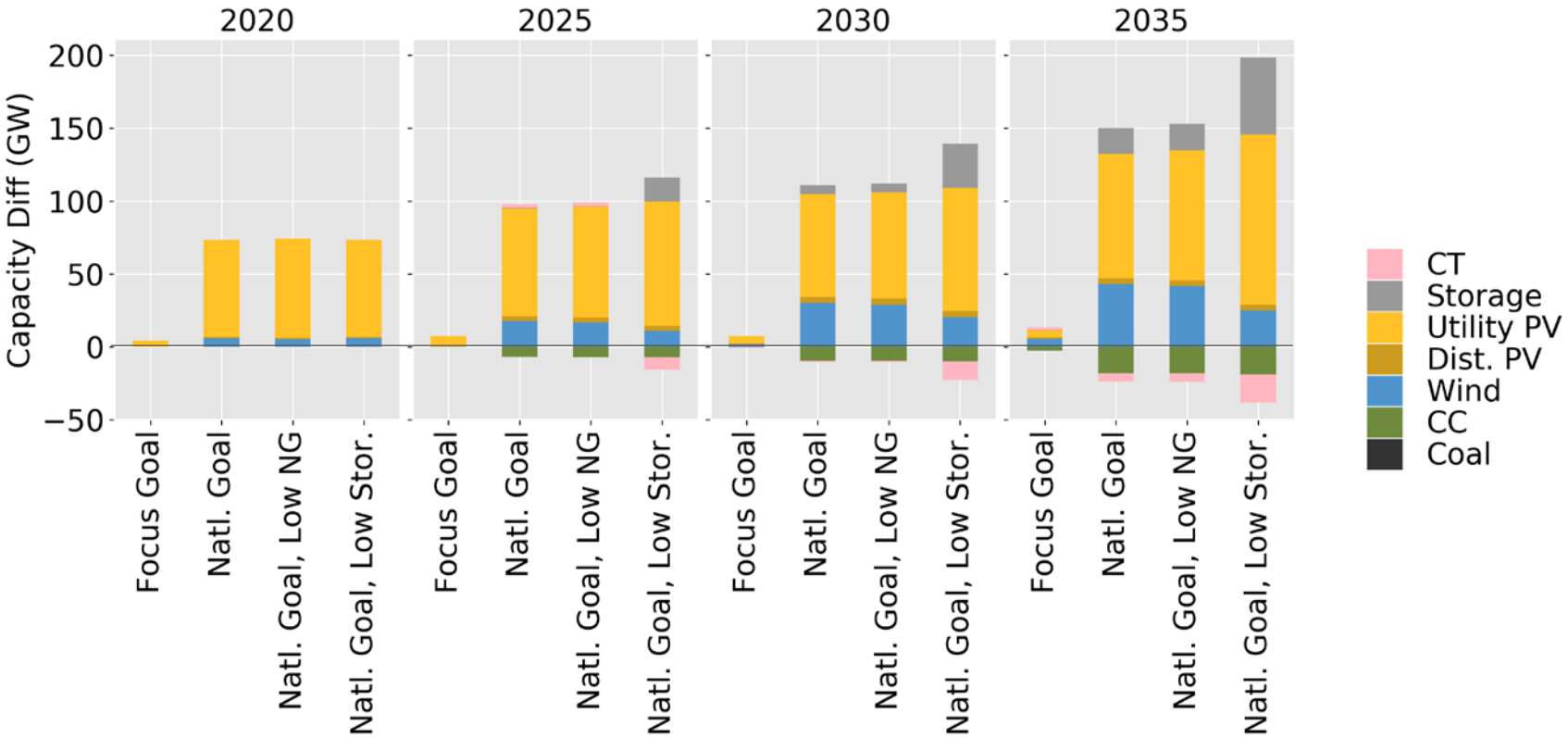
- Dispatch Periods
  - Four representative days are chosen from a load clustering algorithm performed prior to optimization
  - Days are chosen to be most representative of Low, Mid, High load periods; the peak load day is also represented

- WI-wide results are shown from the Colorado Focus Model. Each focus region has slightly different results for all of the WI due to the different region modeled in detail and subsequent changes in model optimization. These differences tend to be small; however we note the focus model the WI results are taken from for completeness.

WI Capacity (from RPM-CO)

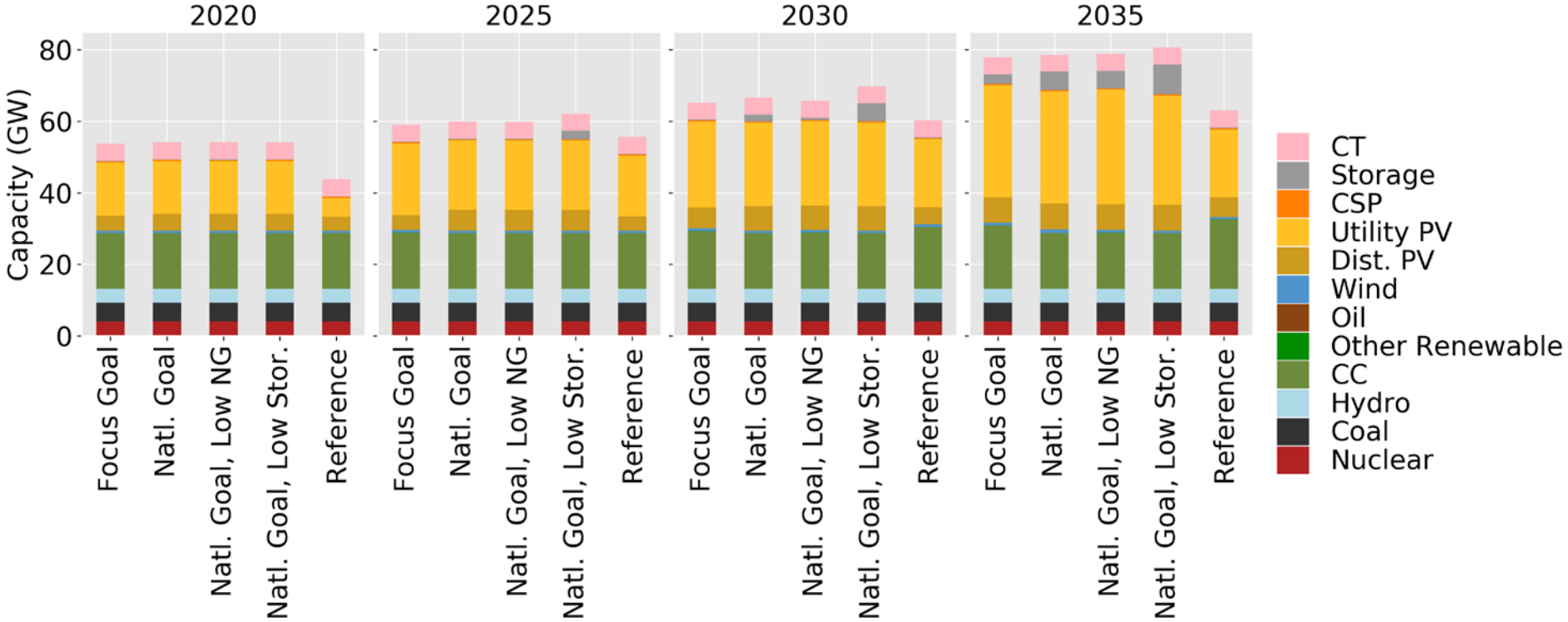


WI Capacity Difference (from RPM-CO)

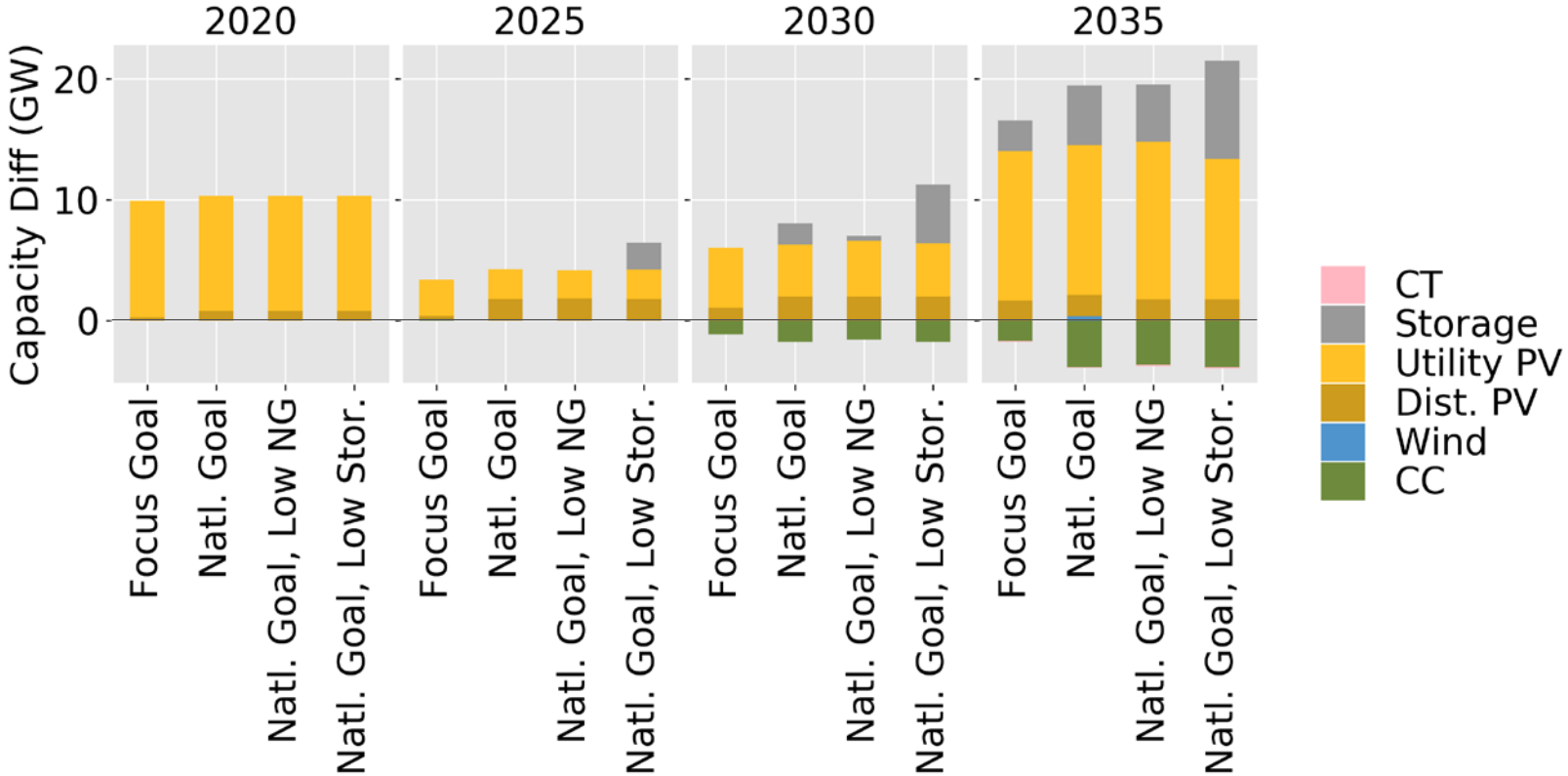


All differences are with respect to the Reference case

RPM-AZ Capacity

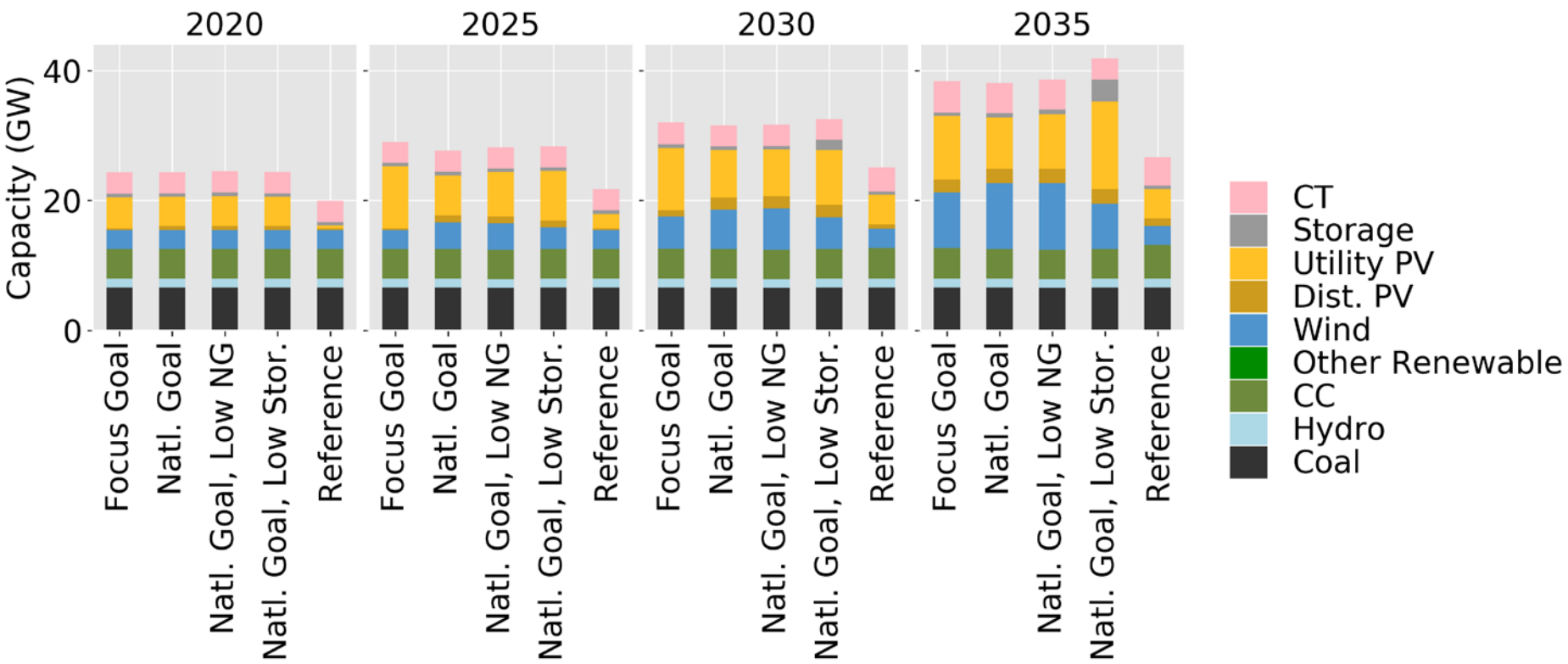


RPM-AZ Capacity Difference

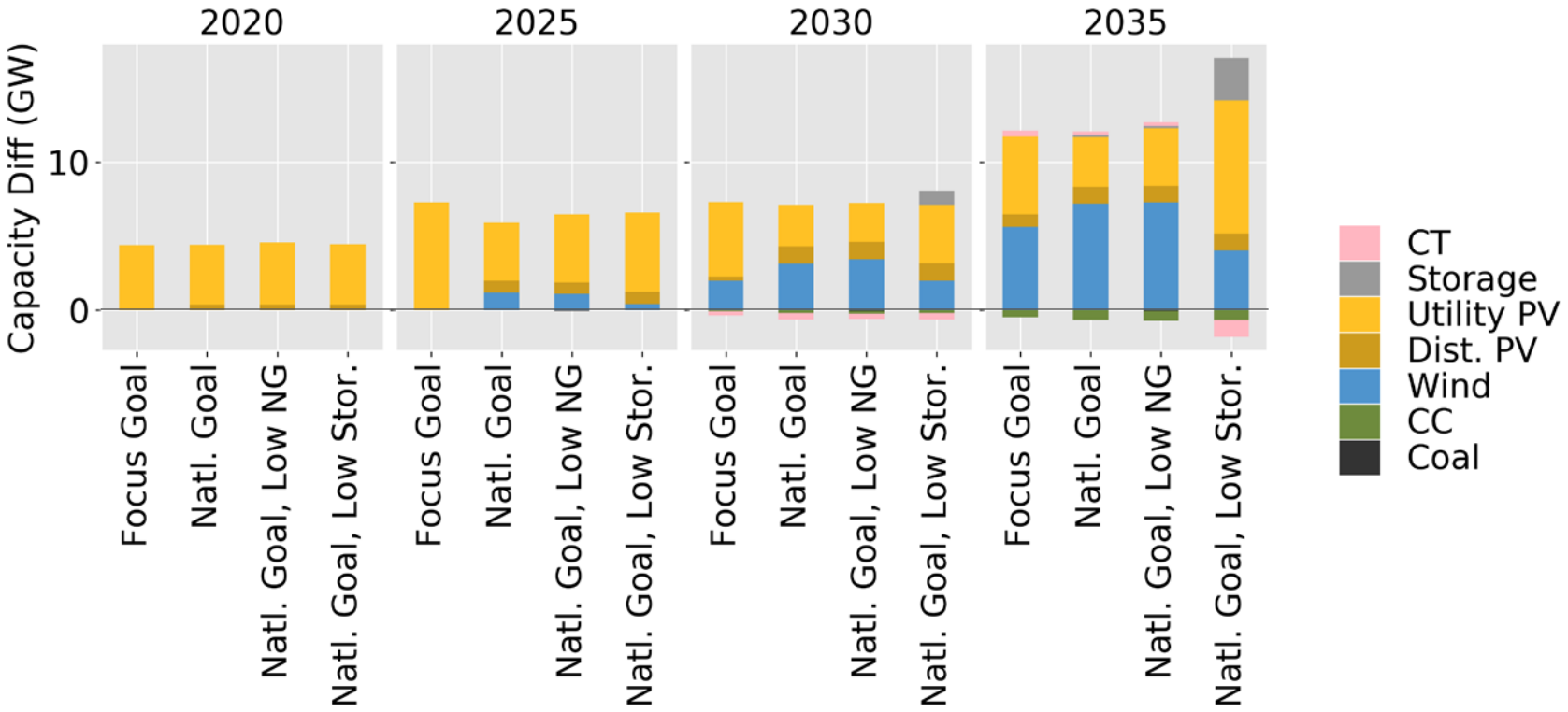


All differences are with respect to the Reference case

RPM-CO Capacity

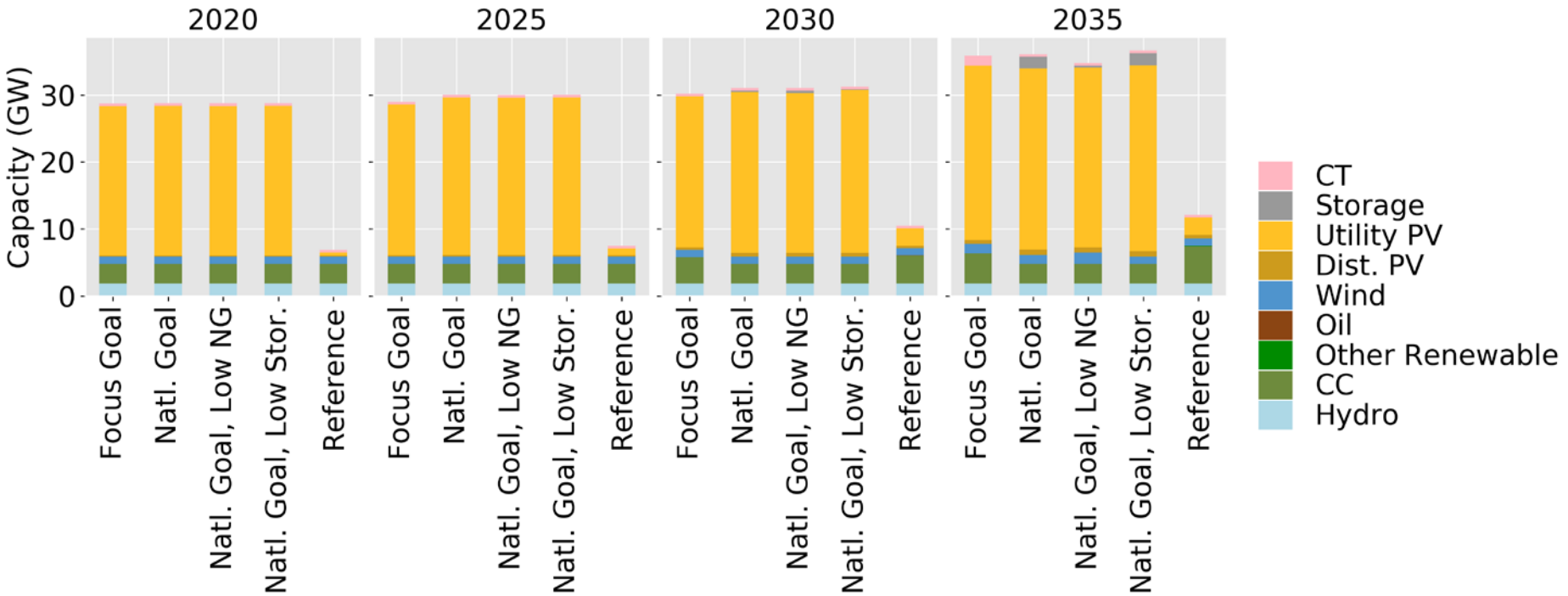


RPM-CO Capacity Difference



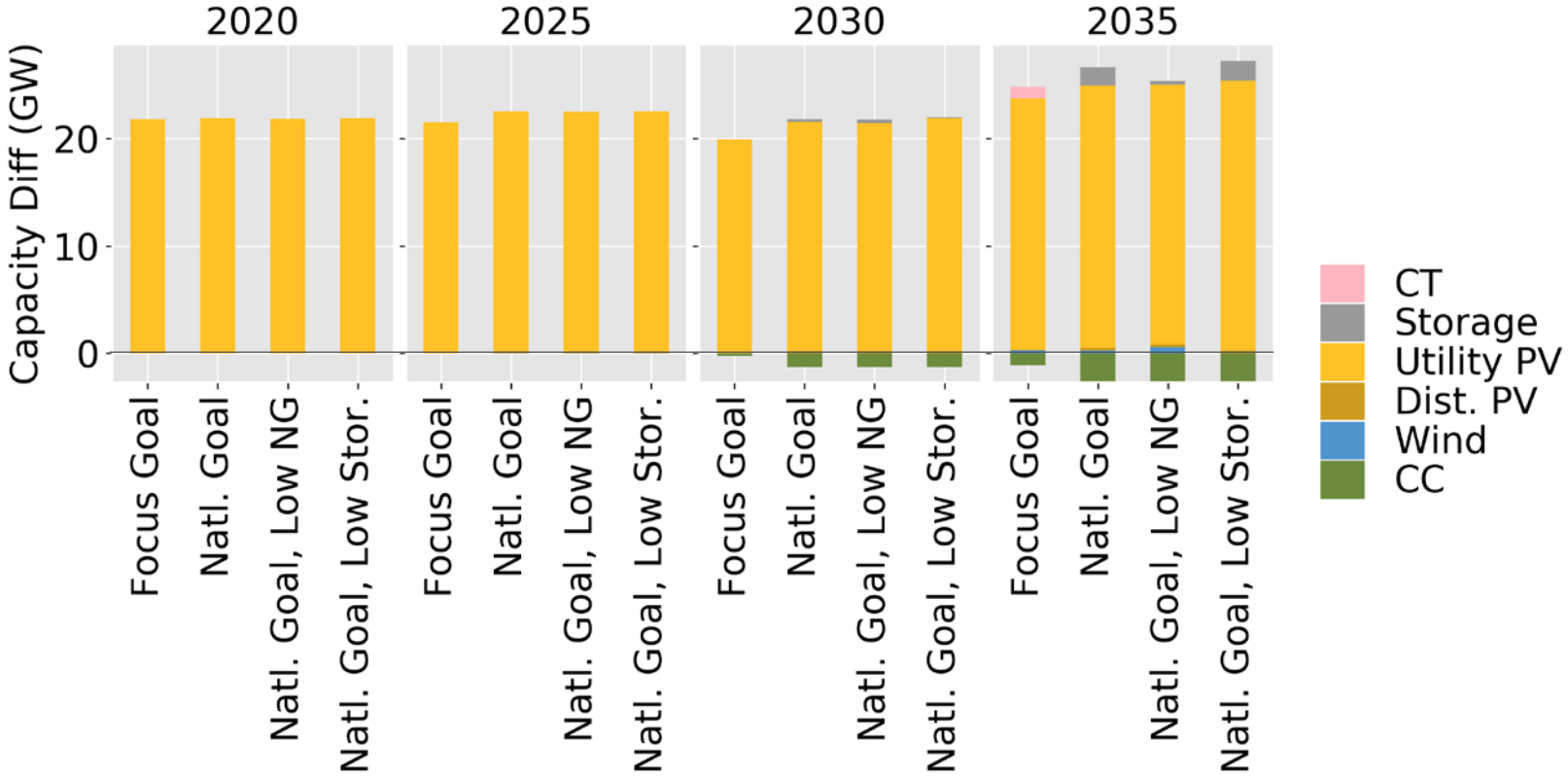
All differences are with respect to the Reference case

RPM-OR Capacity



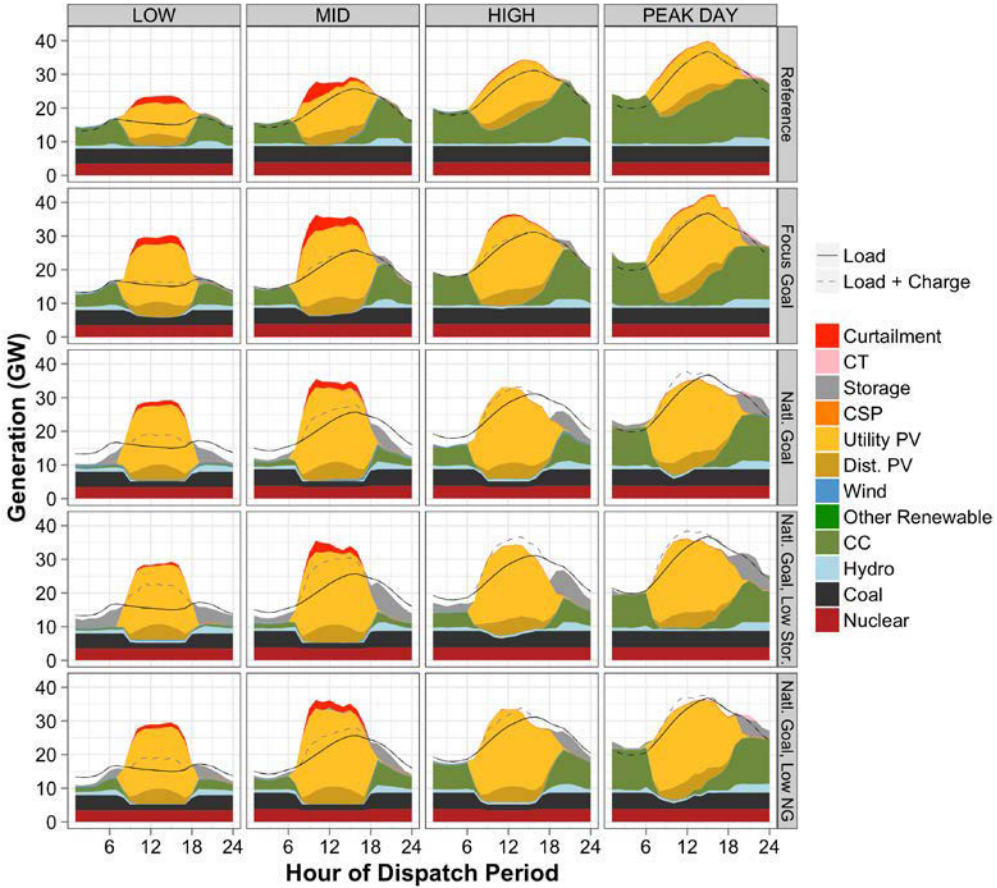
Note – The Standard Scenarios 80% RPS case-derived RPS targets for Oregon are quite high beginning in 2020. In order to explicitly capture the Standard Scenarios results, REC trading was disallowed. Given that the Oregon focus region within the model currently imports a substantial amount of electricity to meet load, prohibiting REC trading has the effect of requiring a large amount of new renewable capacity within the focus region. The policy implemented is thus purely hypothetical, and allows for the exploration of the system under an extreme case in which a stringent RPS is met primarily with solar.

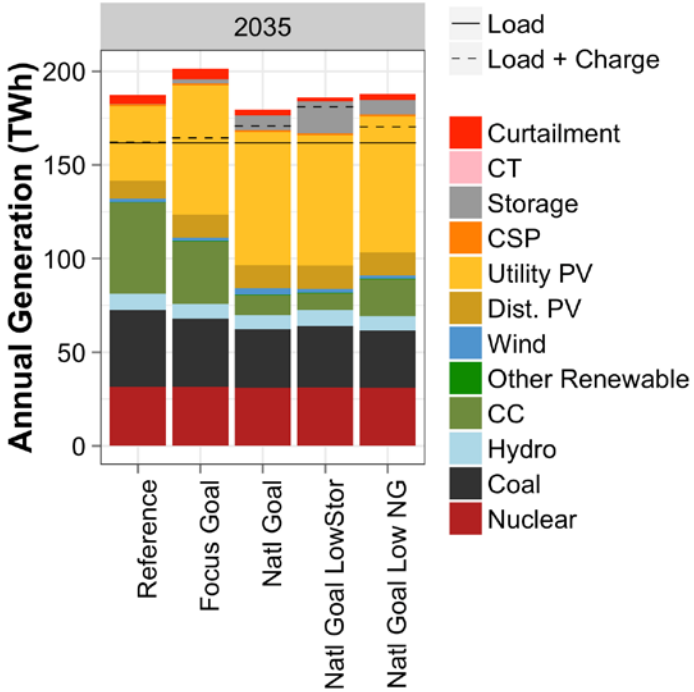
RPM-OR Capacity Difference



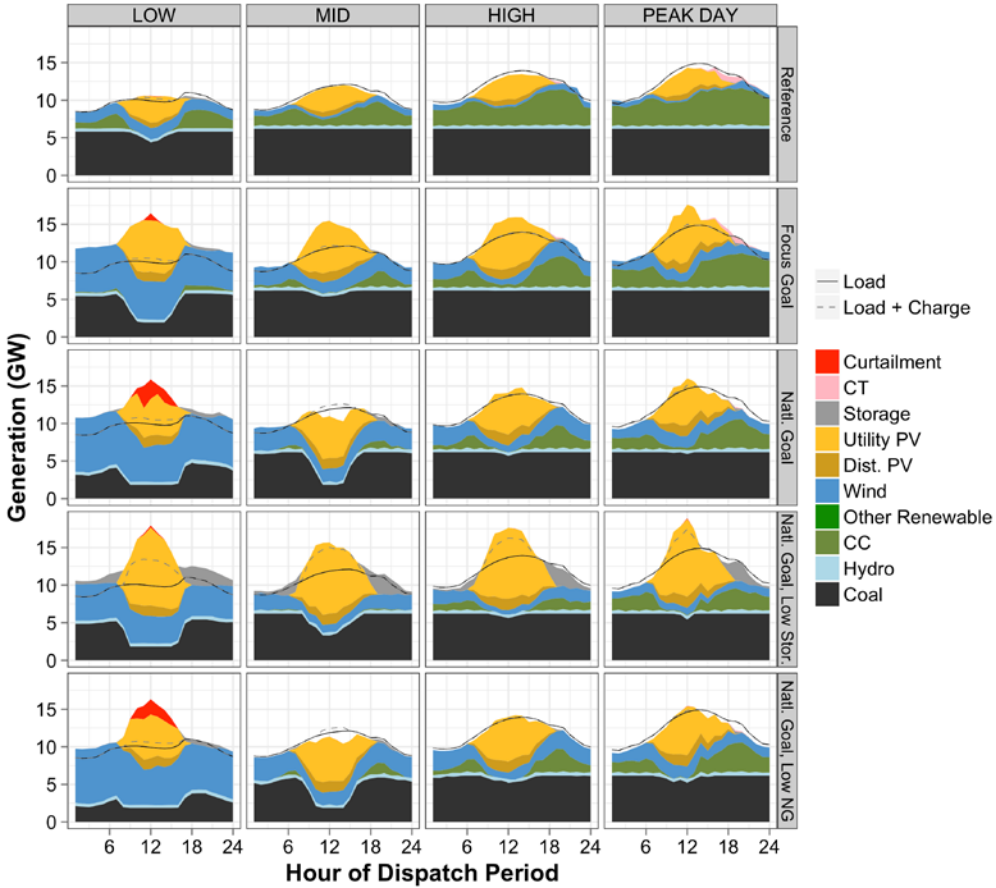
All differences are with respect to the Reference case

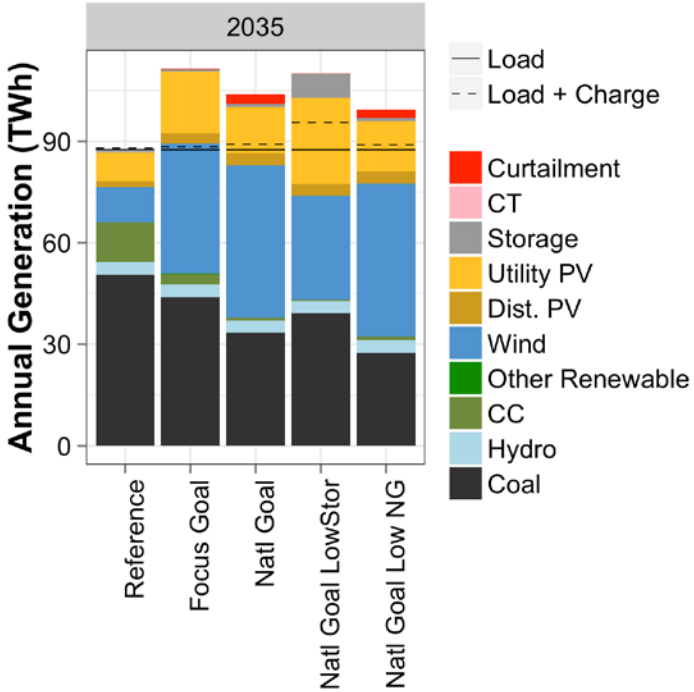
RPM-AZ Representative Dispatch



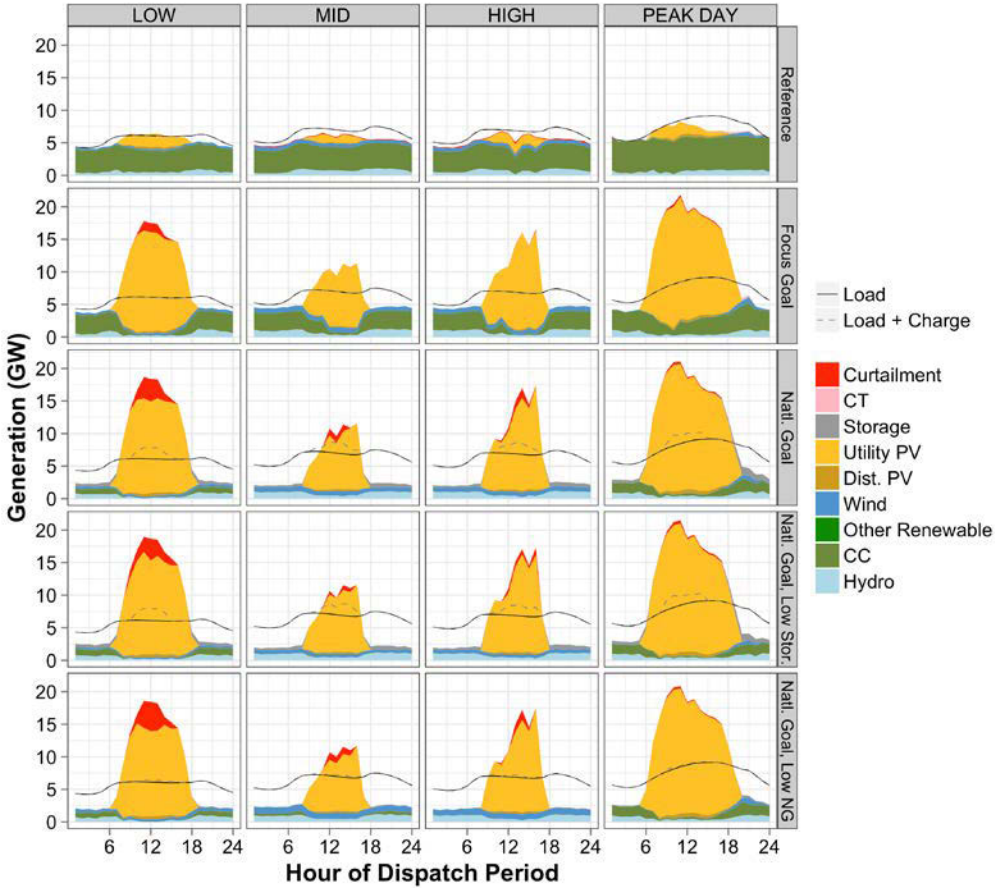


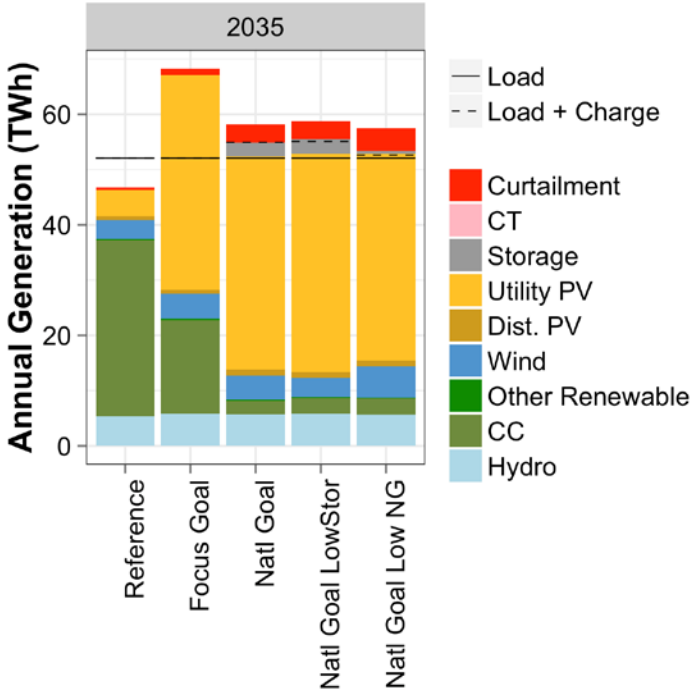
RPM-CO Representative Dispatch





RPM-OR Representative Dispatch



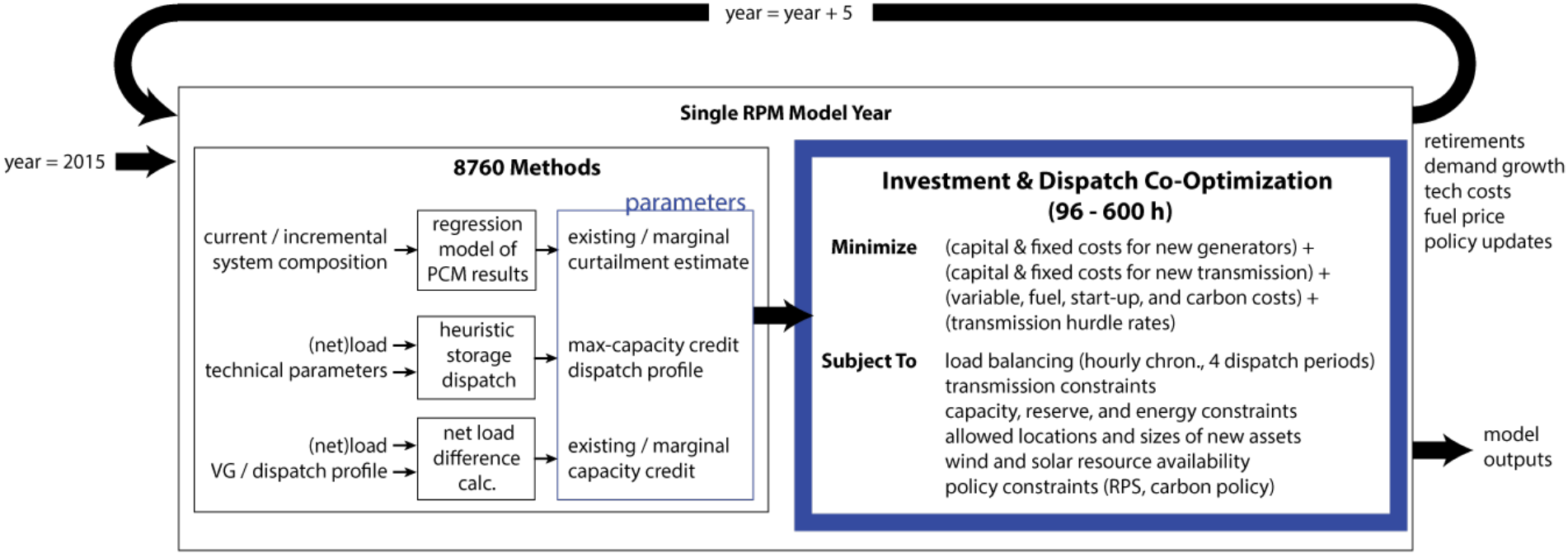


Modeling Details

Focus Region Capacity

Data Sources

RPM Algorithmic Structure



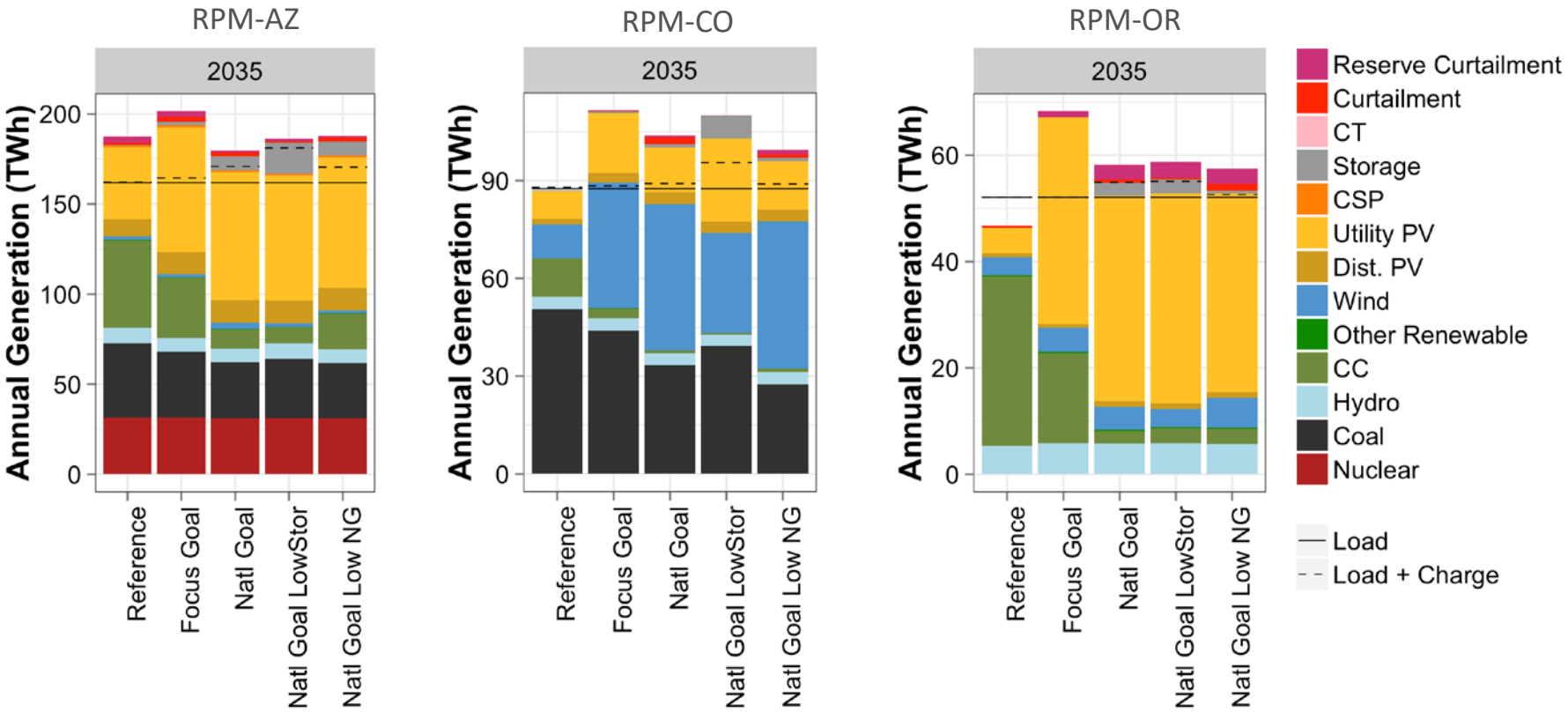
- Linear Model: Sequentially solves for resources that meet system needs at least cost
- 8,760 methods adjust reduced-order co-optimization to dynamically account for capacity value of variable generation and energy storage, and curtailment impacts.

Reserves Provision from Utility-Scale PV in RPM

- Increased variability increases reserve requirements, but variable resources can also provide reserves if they are being curtailed
- Providing reserves is typically only economic if PV is being curtailed
  - At high PV penetrations, providing reserves with curtailed energy can be a valuable grid service
- RPM assumes that beginning in 2020 all newly built utility-scale wind and solar resources will include the capability to provide reserves from curtailed energy.
- RPM may underestimate the value of providing reserves, as it is an hourly model and cannot capture sub-hourly variability

Reserves Provision from Variable Generation (VG)

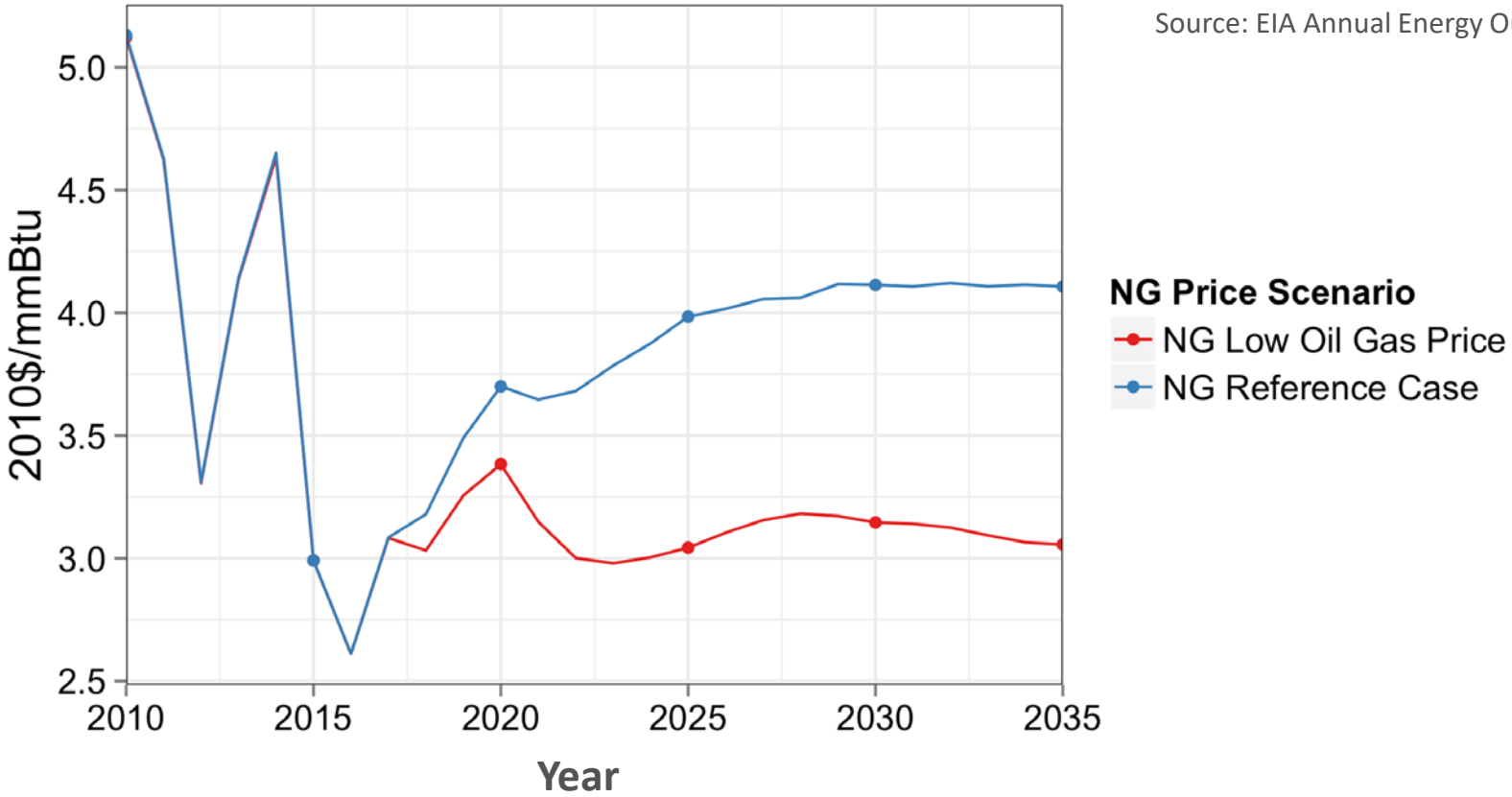
Reserve Curtailment is the VG capacity that is pre-curtailed in order to provide reserves



Initial System Capacity for Each Focus Model (MW)

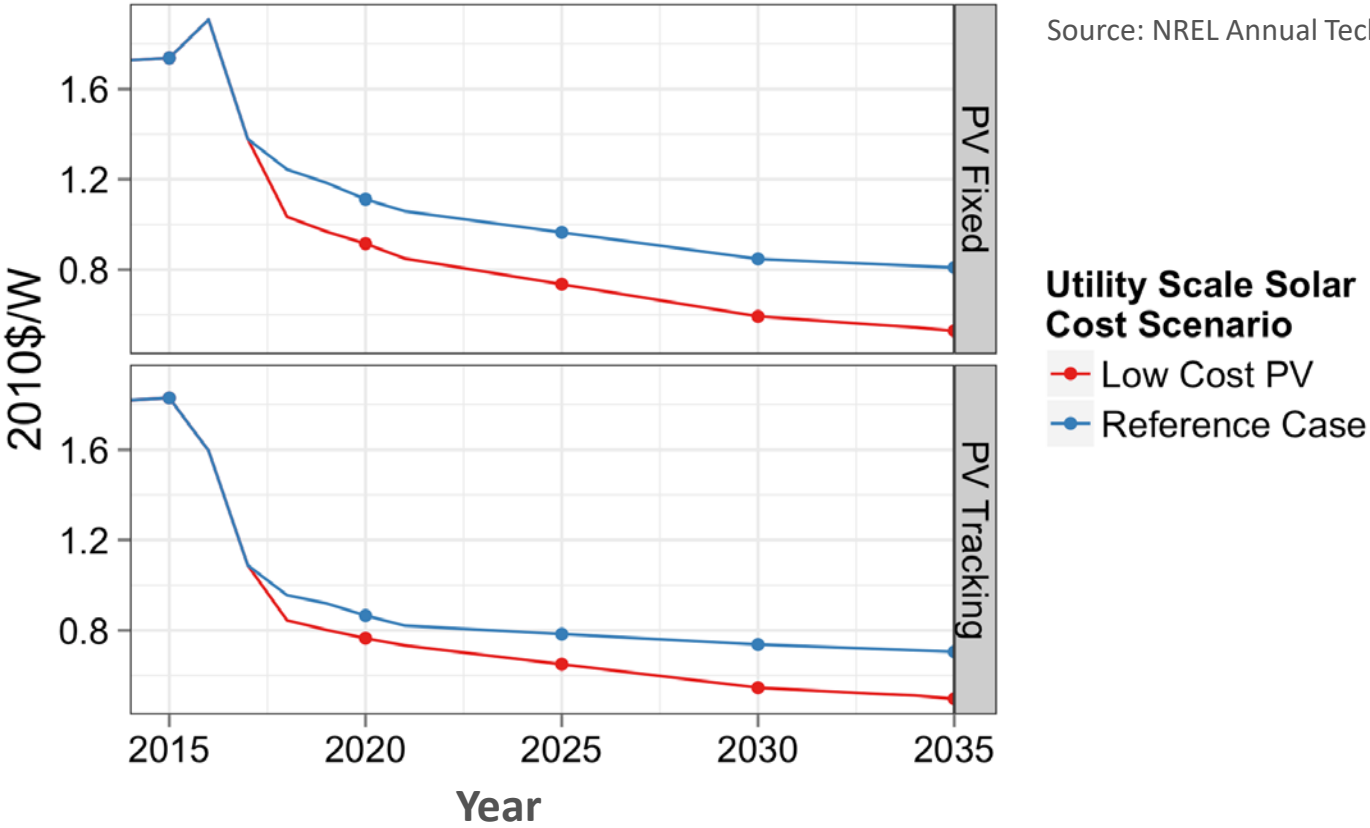
	WI			RPM-AZ			RPM-CO			RPM-OR		
	2010	Planned	Retiring	2010	Planned	Retiring	2010	Planned	Retiring	2010	Planned	Retiring
CT	39,742	6,857	19,229	3,747	1,235	360	3,645	--	412	479	50	124
Storage	3,787	40	--	146	20	--	560	--	--	--	--	--
CSP	426	--	--	72	250	--	--	--	--	--	--	--
PV	1,170	34,850	--	22	8,368	--	12	1,567	--	6	656	--
Wind	11,624	10,009	114	--	696	--	1,405	1,552	--	1,002	88	--
Oil	--	8	--	--	2	--	--	--	--	--	1	--
CC	64,403	3,756	3,096	15,427	144	25	3,752	1,007	207	2,479	440	--
Hydro	70,164	1,852	118	3,884	3	--	1,345	1	5	1,883	--	62
Coal	38,818	405	10,984	8,836	--	3620	7,332	376	1,099	510	--	510
Nuclear	9,681	--	4,486	4,035	--	--	--	--	--	--	--	--
Other Renewable	4,614	521	641	30	4	--	--	2	--	37	0	--
Total	**244,430**	**58,298**	**38,667**	**36,199**	**10,722**	**4,005**	**18,050**	**4,504**	**1,722**	**6,396**	**1,236**	**696**

Natural Gas Prices



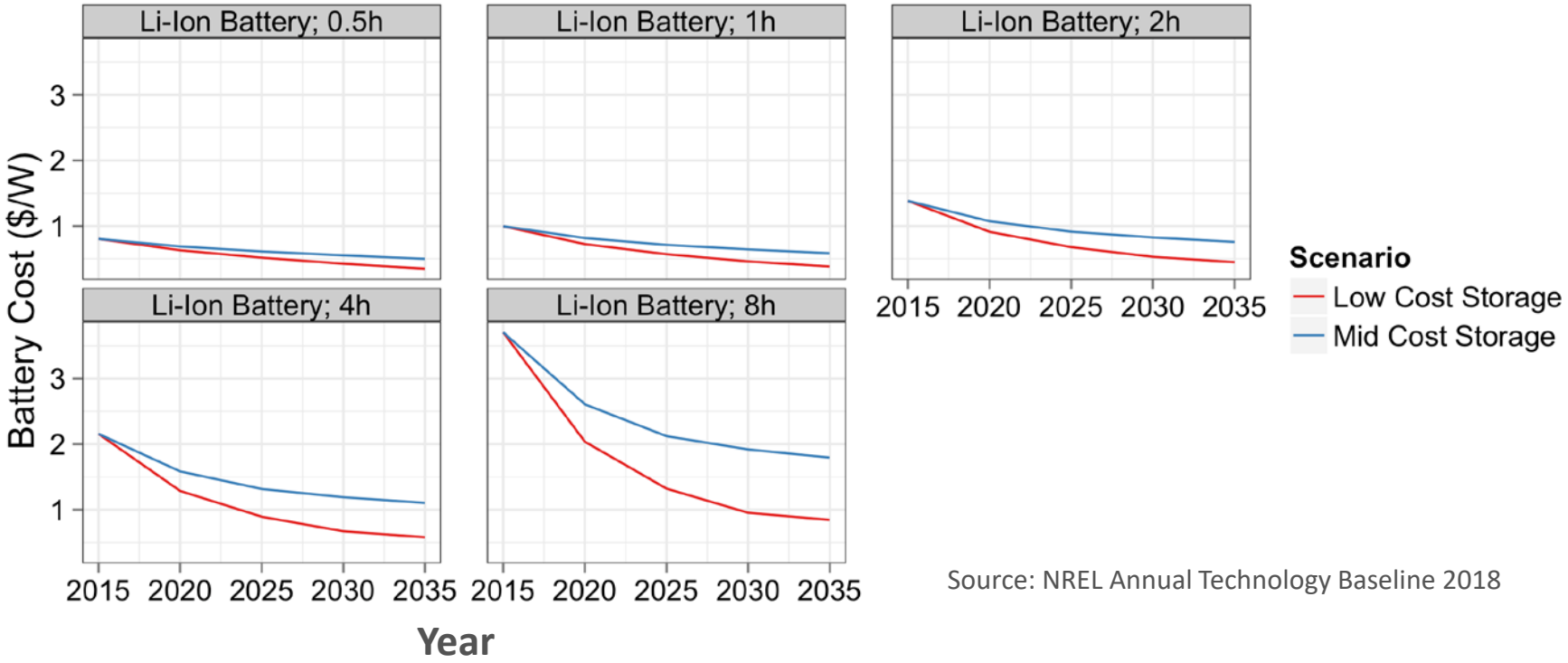
Source: EIA Annual Energy Outlook 2018

Technology Costs, Utility PV



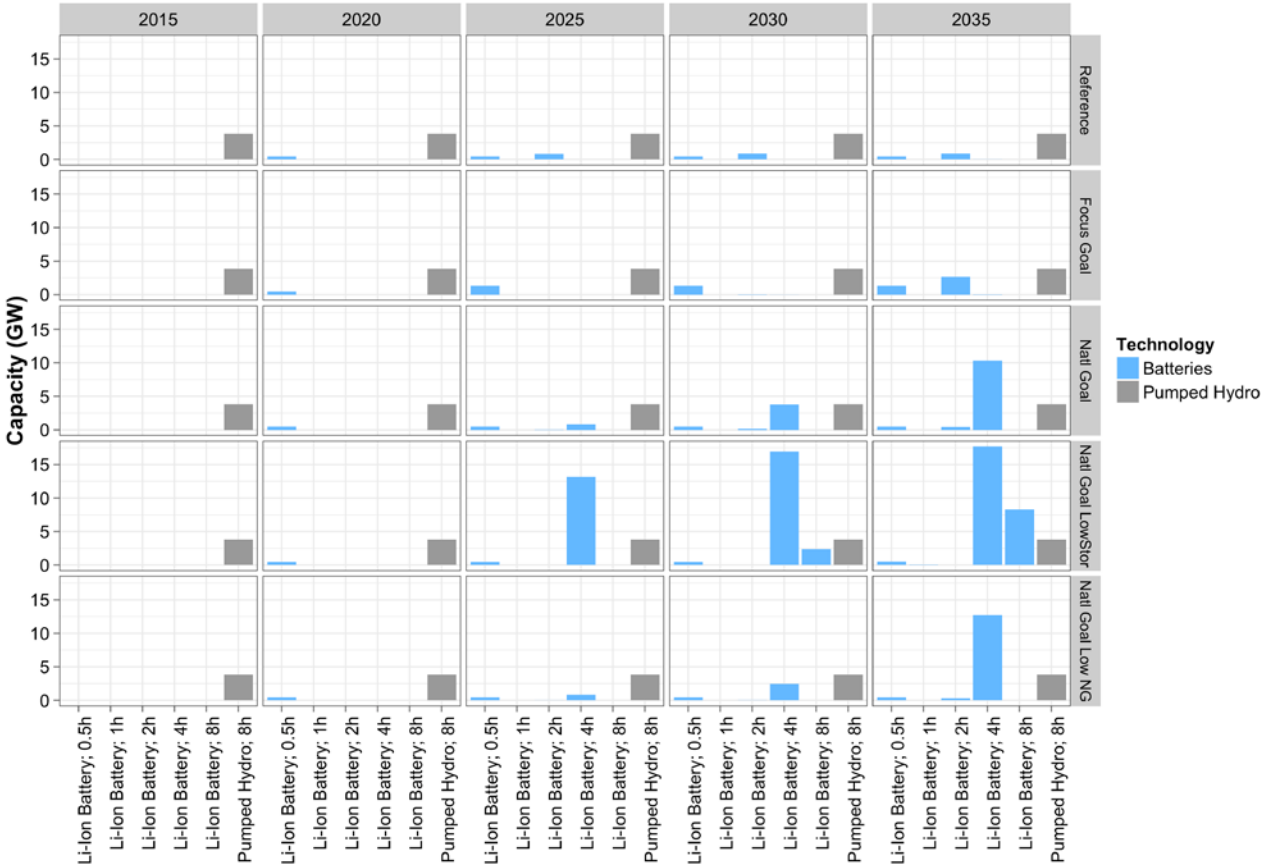
Source: NREL Annual Technology Baseline 2018

Technology Costs, Battery

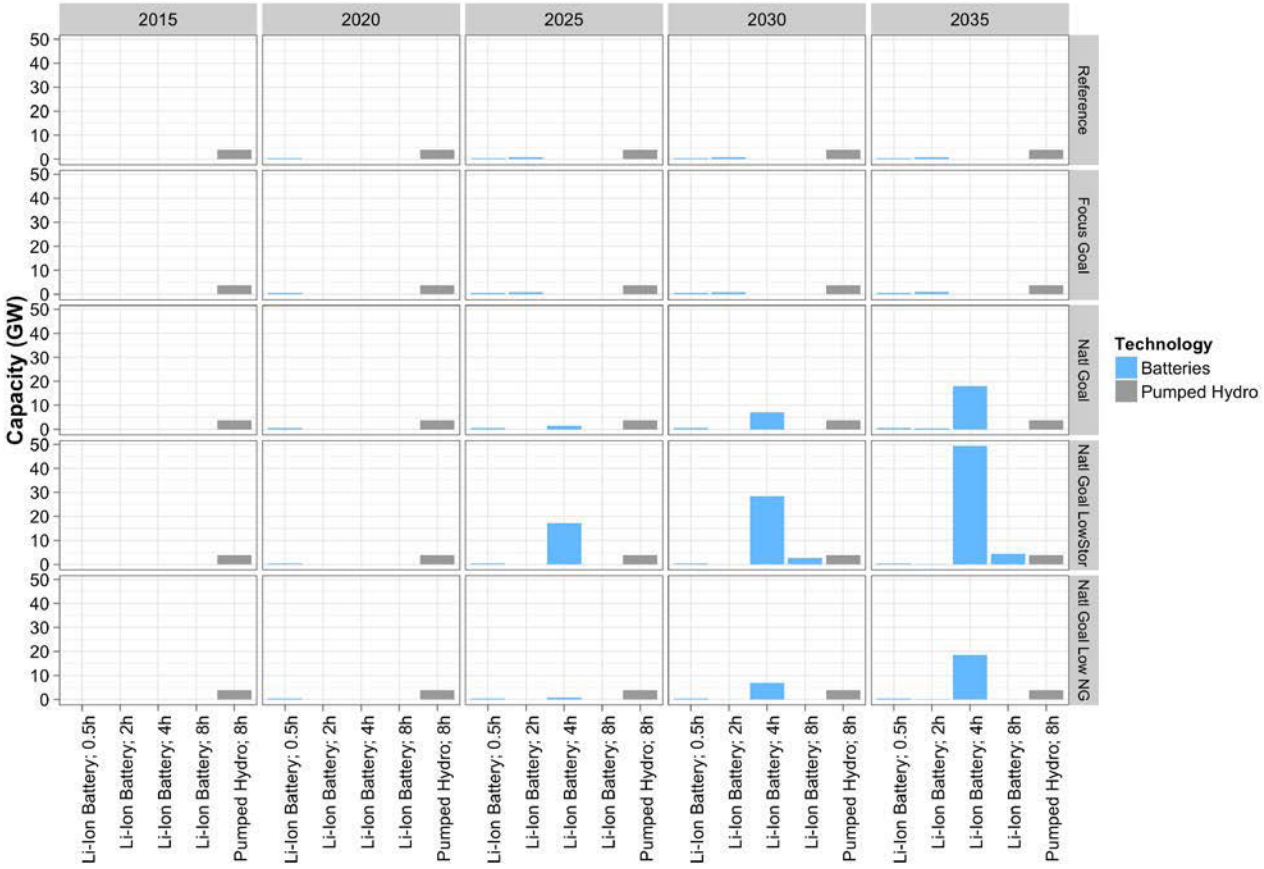


Source: NREL Annual Technology Baseline 2018

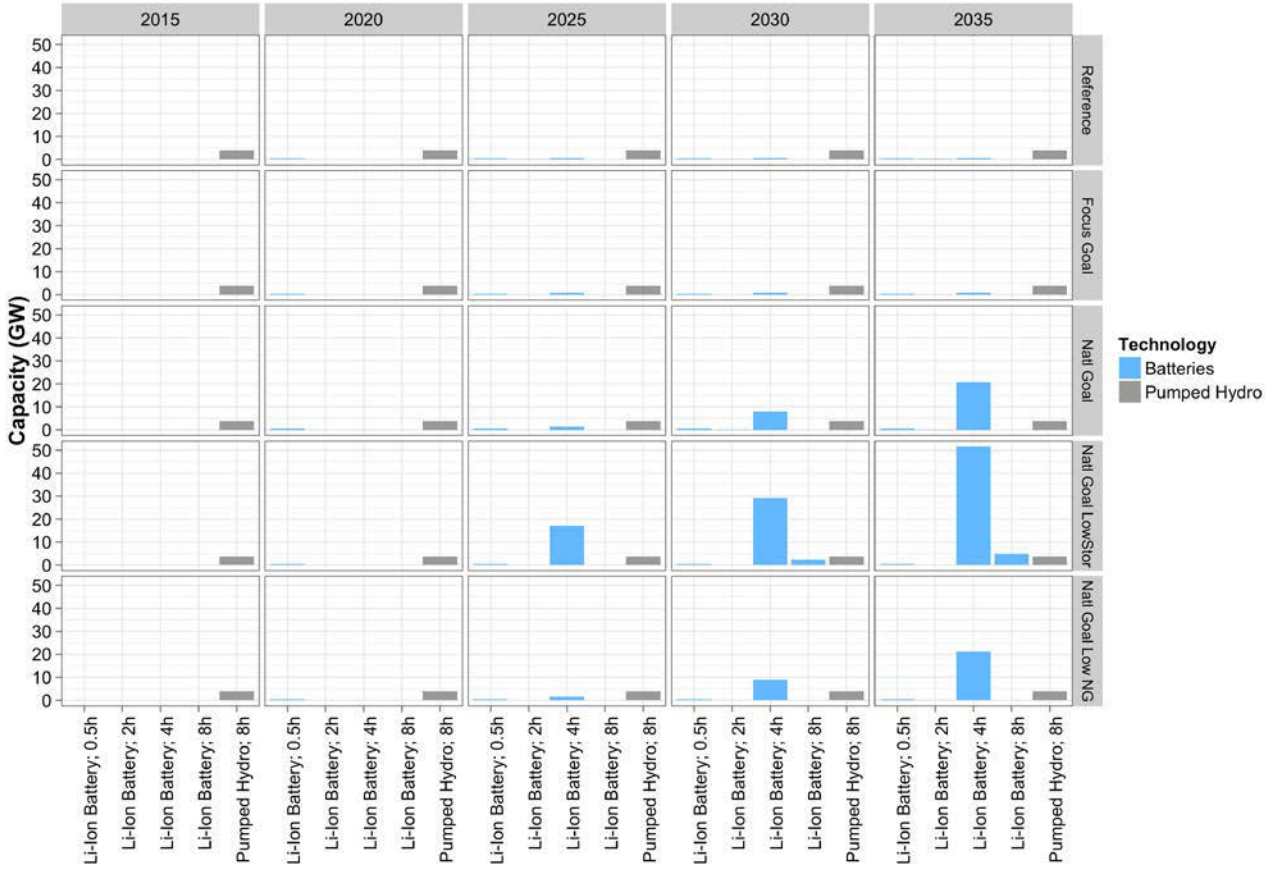
WI-wide Battery Capacity, from RPM-AZ



WI-wide Battery Capacity, from RPM-CO



WI-Wide Battery Capacity, from RPM-OR



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