The California 2030 Low-Carbon Grid Study (LCGS)

Phase I Results Summary

September 2014

LCGS Overview

Premise:

- The California electric grid should be reassessed through the framework of low carbon at low cost, rather than a higher renewables portfolio standard (RPS), to achieve affordable greenhouse gas (GHG) reductions.
- A 2030 low carbon grid represents a critical strategy for success in meeting California's 2050 GHG targets.

Tools:

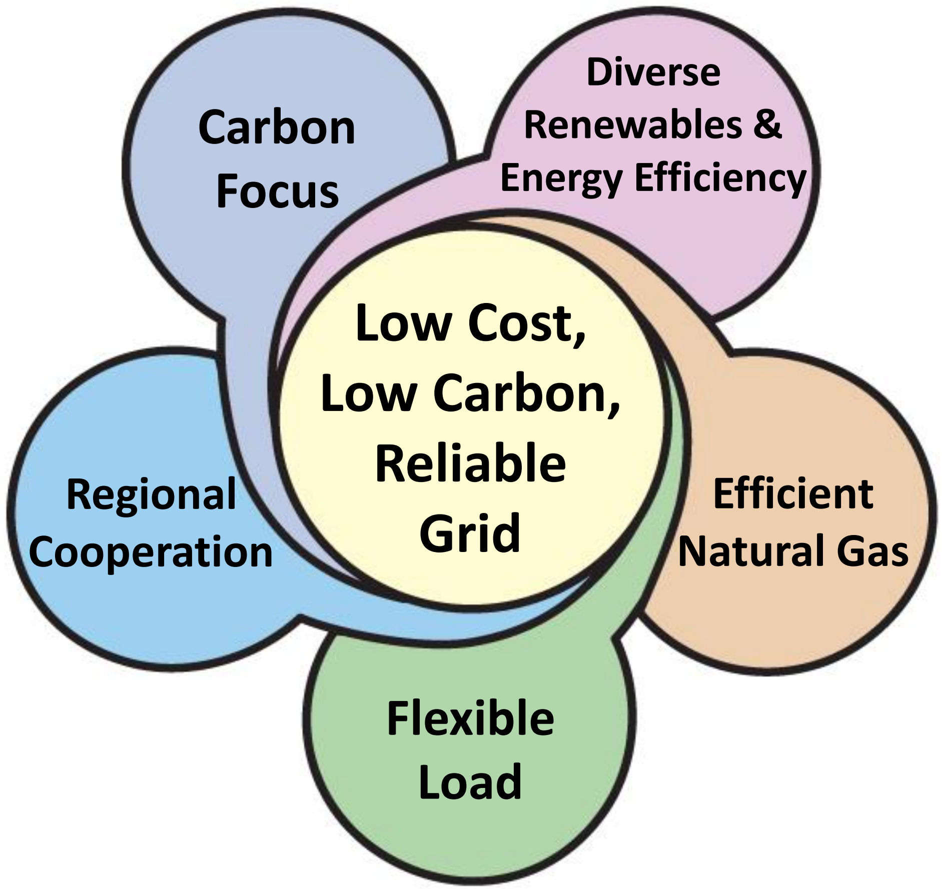
- Detailed modeling of California and Western Electricity Coordinating Council (WECC) electrical systems
- Economic analysis of overall system cost

Results:

- The LCGS analyzed California's grid with a carbon focus, flexible load, regional cooperation, efficient use of natural gas, and diverse renewable generation
- With this portfolio, the California electric sector can reduce greenhouse gas (GHG) emissions by more than 50% below 2012 levels in 2030:
  - With minimal rate impact
  - Without compromising reliability
  - With minimal curtailment of renewable energy
  - With a stable gas fleet that is dispatched with minimum cycling

The LCGS Approach

The LCGS, with a diverse portfolio of energy generation and resource flexibility, demonstrates the feasibility of deep, low cost emissions reductions in California.



LCGS Study Design

Study Components

- Phase I, *August 2014*
  - Two emissions-reductions cases for 2030, with one baseline case for comparison
  - One "low-mitigation" sensitivity, to demonstrate the effectiveness of flexibility measures
  - Estimate of revenue requirement
- Phase II, *January 2015*
  - Additional scenarios and sensitivities, vetted by independent Technical Review Committee
  - Revenue requirement analysis by JBS Energy Inc.
  - Check dispatch for compliance with regional reliability obligations.[1]
  - Final report

Participants

- Modeling: National Renewable Energy Laboratory (NREL)
- Supporting analysis: General Electric Systems (GE) (Phase II)
- Revenue Requirement Analysis: JBS Energy Inc. (Phase II)
- Peer Review: Independent Technical Review Committee
- Funding/Steering Committee: Over twenty-five companies, organizations, and foundations

[1] *Compliance with WECC Frequency Response Obligation (RFO) and NERC Standard BAL -003, Frequency Response and Bias*

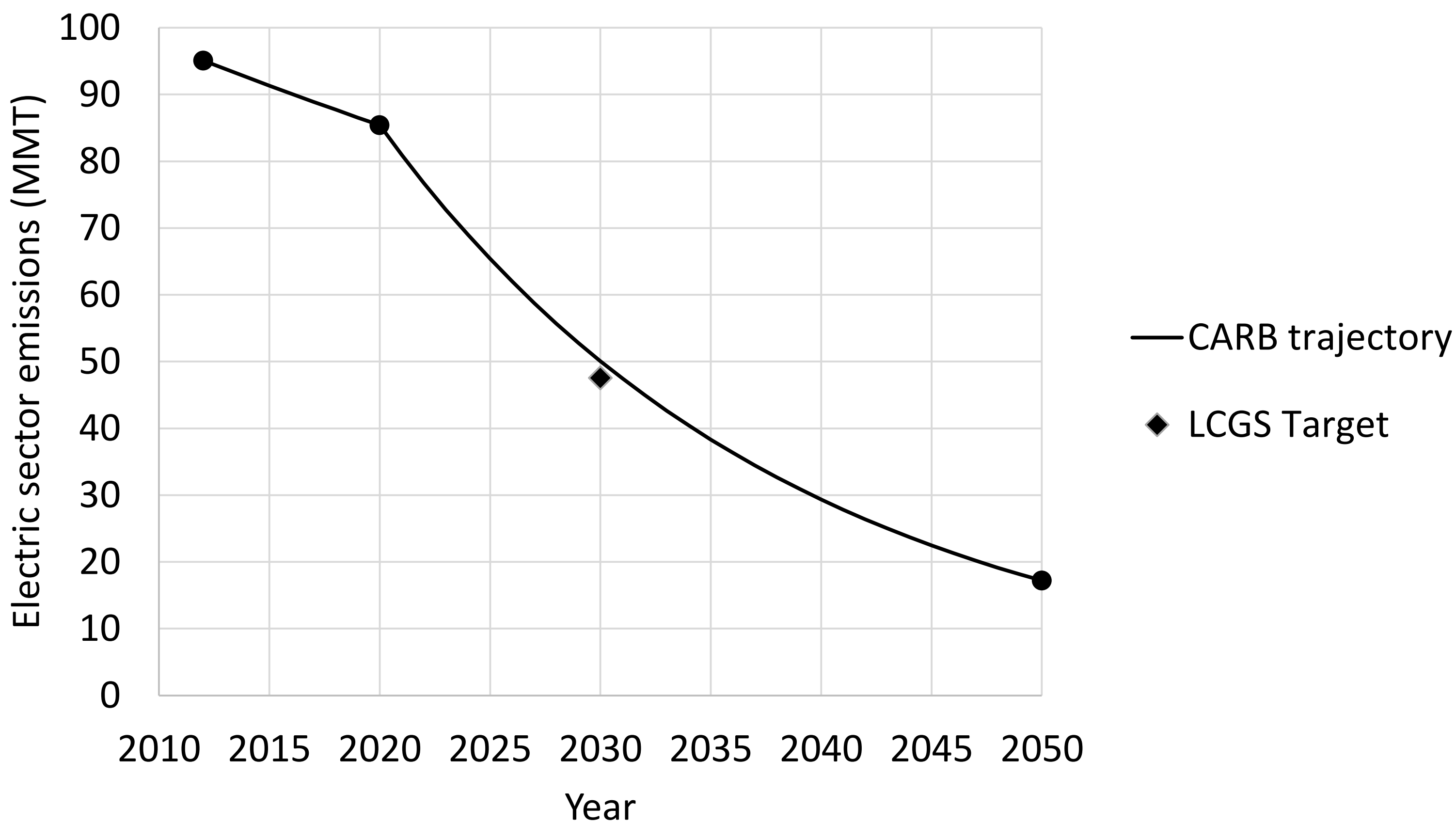
LCGS Phase I: Methodology

1. Determined 2030 GHG reductions needed to be on track for 2050 targets, using assumptions[1] from CPUC, CARB, CEC, & WECC about load forecasts, energy efficiency, customer-sited solar, electric vehicles, etc. The reductions needed were 50% below 2012 GHG levels.
2. Identified LCGS Cases:
   - **Baseline Case:** Assumes existing policies stay in place and are maintained through 2030, but implements no additional low-carbon measures.
   - **Target Case:** Based on these assumptions, a "net short" of low-carbon energy need was identified to meet the 2030 load forecasts and carbon reduction goals, in conjunction with flexibility measures.
   - **Accelerated Case:** A second, larger "net short" was identified to demonstrate that the LCGS approach can scale up toward the deeper GHG reductions needed by 2050.
3. Developed resource portfolios for each respective case, which were run in NREL's PLEXOS production cost model.
4. Analyzed investments and savings associated with implementing the Target Case instead of the Baseline Case to identify net ratepayer costs and the cost of the carbon reductions.

[1] *For a full list of assumptions and model designs, see LCGS Work Paper 1: Assumptions, available at www.lowcarbongrid2030.org*

LCGS 2030 Target on Emissions Reduction Path to 2050

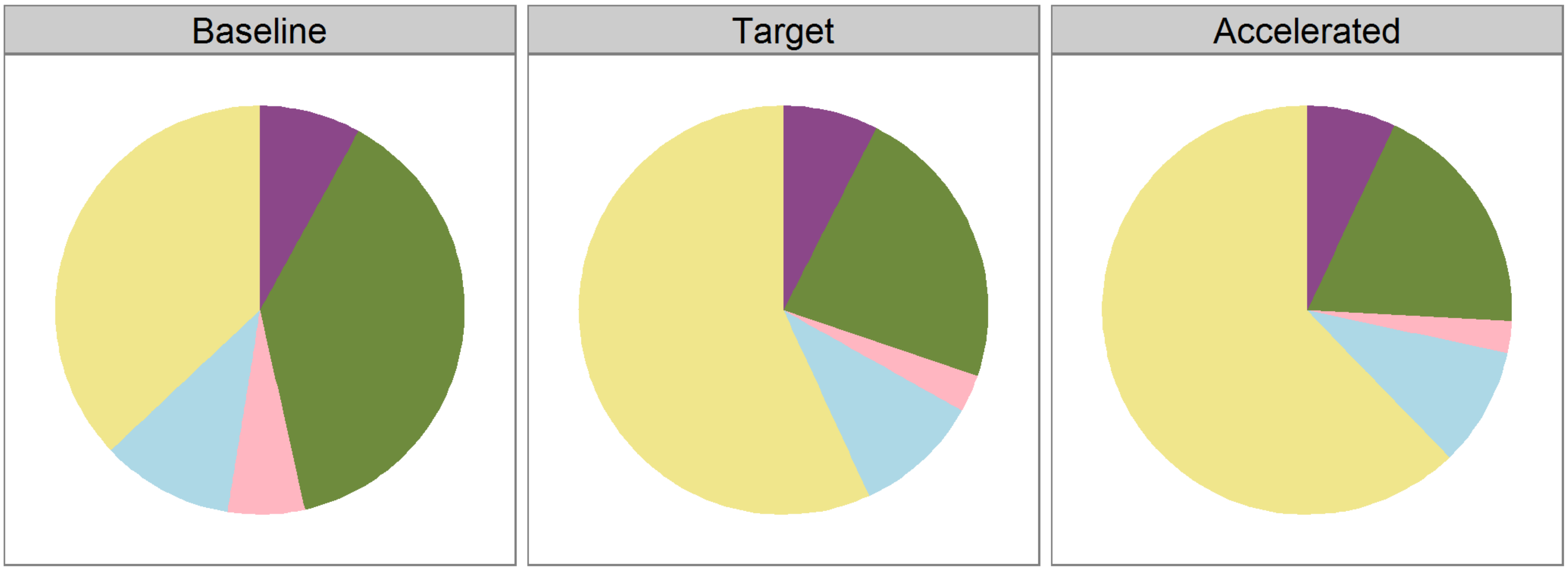
- The LCGS target of 47 MMT (50% below 2012 levels) was chosen for 2030. This sets California on the California Air Resources Board's (CARB) constant percentage reductions trajectory[1] from 2020 to 2050.



Also shown: actual 2012 emissions from California's electric sector, AB 32 emissions target in 2020, executive order S-3-05 emissions target in 2050.

[1]See California Air Resources Board's *First Update to the Climate Change Scoping Plan*, p. 33.
[2]This plot assumes that the electric sector produces 20% of statewide emissions.

LCGS Phase I: Portfolio Cases



110 TWh zero-carbon energy; Some energy efficiency, demand response, and storage; Load: 341 TWh

177 TWh zero-carbon energy; Accelerated levels of energy efficiency and demand response; More storage than Baseline Case; Load: 321 TWh

205 TWh zero-carbon energy; Accelerated levels of energy efficiency and demand response; More storage than Target Case; Load: 321 TWh

Phase I: Results Summary

1. Carbon Reductions

- **Target Case:** More than 50% reduction from 2012 CO_2 emissions.
- **Accelerated Case:** Greater reductions than Target Case. Demonstrates that the existing grid can scale up for deeper reductions beyond 2030.

Slide 10

2. Rate Impact

- **Cost Savings:** New infrastructure and program costs are balanced by savings from reduced fuel purchases, more efficient use of grid resources, avoided emissions costs.
- **New Development:** ~$58 Billion investment in infrastructure serves as an economic stimulus (~80% in California).
- **Marginal Impact:** Using the LCGS approach, utility revenue requirements needed to implement a low-carbon grid vs. a business as usual strategy are minimal.

Slides 11-14

3. Import Flows

- **Trading Patterns:** Import patterns and regional flows are not drastically different from 2012. Significant net exports in some hours. Annual import quantity is roughly one half of today.
- **Fuel Type:** Regional trading is mostly renewable, rather than carbon-intensive fossil energy.

Slides 15 - 17

4. Natural Gas/Grid Operations

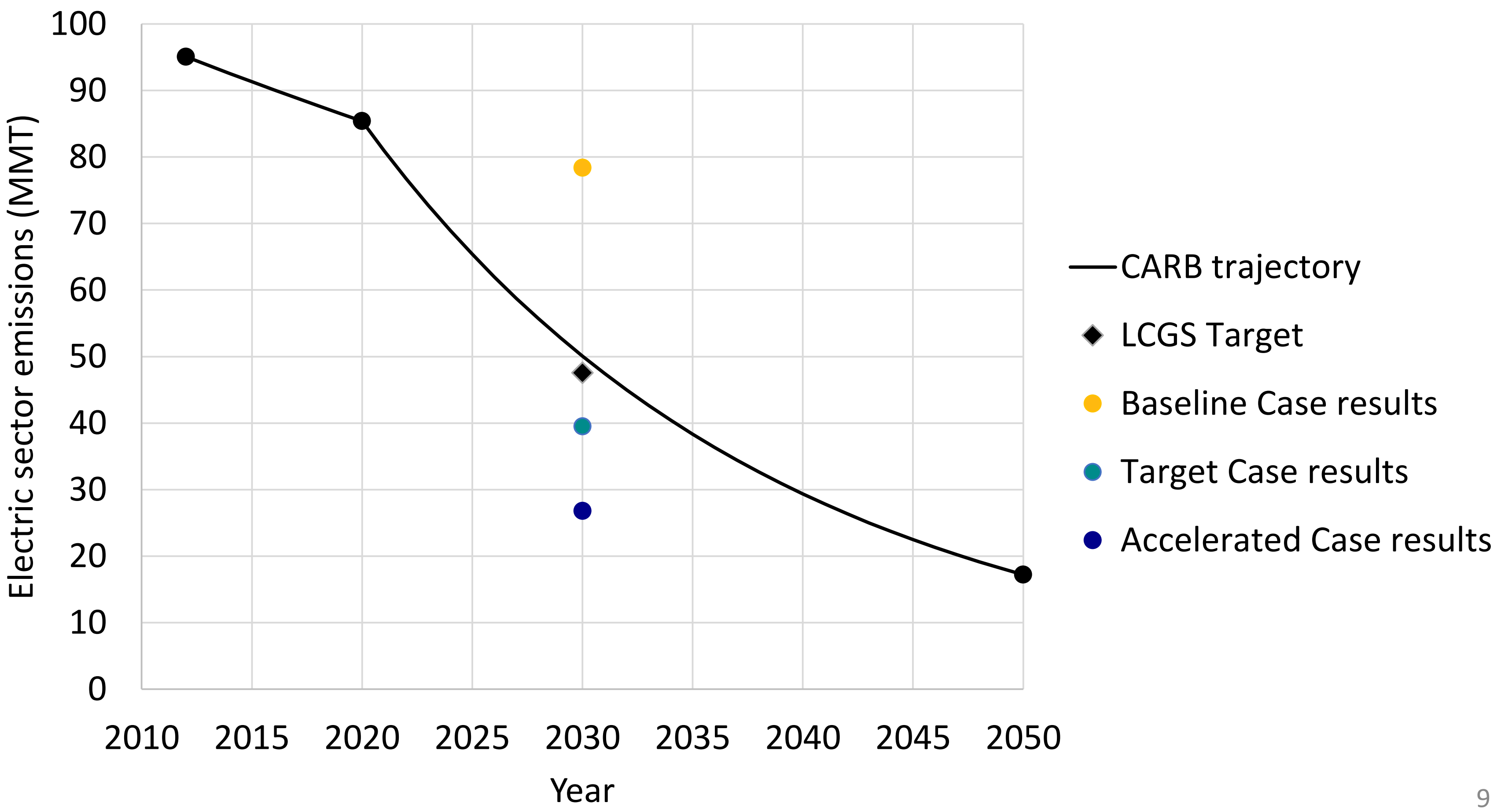
- **Ancillary Services:** Short term system flexibility and regulation is served primarily by imports, exports, demand response, dispatchable hydro, and energy storage including pumped hydro and concentrating solar; frees up natural gas to serve primarily as block-loaded intermediate generation.
- **Efficient Dispatch:** Because natural gas is needed less often as a flexible resource, gas facilities start and stop less frequently, and operate more often at full capacity. This increases fuel efficiency and decreases operational cost.

Slides 18-28

Results: 1. Carbon Reductions

LCGS 2030 Cases on Emissions Reduction Path to 2050

- Emissions reductions in Target and Accelerated Cases exceed LCGS target of 50% reductions below 2012 levels by 2030.



Results: 1. Carbon Reductions

Emissions in Each Case (all values in MMT in 2030)			
	Baseline	Target	Accelerated
CO_2 from gas generation in CA	67.2	43.7	39.5
CO_2 from unspecified imports[1]	11.8	3.0	0.2
Total CO_2 from gas generation and imports	**79.0**	**46.7**	**39.7**
CO_2 credited to exports[2]	-0.6	-7.2	-12.9
Net CO_2 including export credits	**78.4**	**39.5**	**26.8**
% reductions below 2012 levels[3]	**18%**	**58%**	**72%**

- Emissions from imports have generally historically made up at least half of California's total emissions
- The Target and Accelerated Cases yield dramatic carbon reductions because:
  - Coal imports are essentially eliminated (including economy energy)
  - Most California imports are zero-carbon energy
  - Efficient grid dispatch enables significant integration of renewable energy without curtailment of zero carbon resources and replacement by fossil energy
  - Natural gas is efficiently "block-loaded" rather than run frequently at partial capacity, because short-term ancillary services are provided by low-carbon resources, demand response and energy storage

[1] *"Unspecified imports" are system power that is not California-owned or under long-term contract from specific facilities*
[2] *Exports include: California generation used to serve out of state load and California-contracted zero-carbon specified imports that are used to serve out of state load*
[3] *2012 actual emissions were 95.1 MMT*

Results: 2. Rate Impact

Revenue Requirements for the Year 2030[1]	
Target Case Costs	+ $5,300 Million
Target Case Savings	- $5,500 Million
Reduction in Revenue Required	**- $200 Million**
Savings per Megawatt Hour (MWh) Percent of 2012 rates	- $0.6/MWh - 0.4%

- Forecasted prices:
  - Natural gas $6.18/MMBtu (EIA reference case)
  - Carbon $31.41/MMTCO$_2$ (CEC low case)
  - Capacity $40/kw-yr
  - Weighted Average Cost of Capital (WACC) 7%
- Selecting a diverse portfolio of energy generation and flexibility resources helps reduce net revenue requirement.
- Cost savings from reduced fossil fuel use and avoided emissions costs balance out the cost to implement a low-carbon grid.
- Lower gas use leads to lower consumer price risk.

[†] *See slide 14 for details*

Results: 2. Rate Impact

Investment portfolio, 2020 – 2030: supply-side

Portfolio Element	2020 zero-carbon portfolio[1]	Incremental additions, 2020-2030			
		Baseline Case		Target Case	
	Capacity, MW	Capacity, MW	Capex, $million	Capacity, MW	Capex, $million
Biomass	1,348	-	-	269	1,220
Geothermal	2,744	-	-	1,500	9,260
Wholesale solar PV	9,950	4,110	10,400	5,445	14,470
Solar Thermal	1,400	-	-	1,670	8,680
Wind	10,400	-	-	9,480	17,540
CC Gas		600	740	-	-
Storage	4,800	175[2]	700	2,375	4,270
Transmission			250		2,600
Total			**12,090**		**57,940**

[1]Based on 2012 LTPP. This includes contracted renewables both in and out of state.

[2]Represents small-scale storage built after 2020 (same in both cases).

Results: 2. Rate Impact

Investment portfolio, 2020 – 2030: demand-side

Portfolio Element	2020 portfolio	Incremental additions, 2020-2030		Difference in levelized utility program costs (in 2030)
		Baseline Case	Target Case	
	Capacity, MW	Capacity, MW	Capacity, MW	
Customer Sited PV	6,090	2,800	8,500	
Energy Efficiency	4,350[1]	4,350	8,950	$155 million
Demand Response	2,176[2]	2,624	7,424	$25 million[3]

[1]*Average of "mid" and "high mid" CEC efficiency forecasts for 2020*
[2]*CPUC 2014 LTPP planning assumption (for the year 2024)*
[3]*Placeholder for Phase I, will analyze in Phase II*

Results: 2. Rate Impact

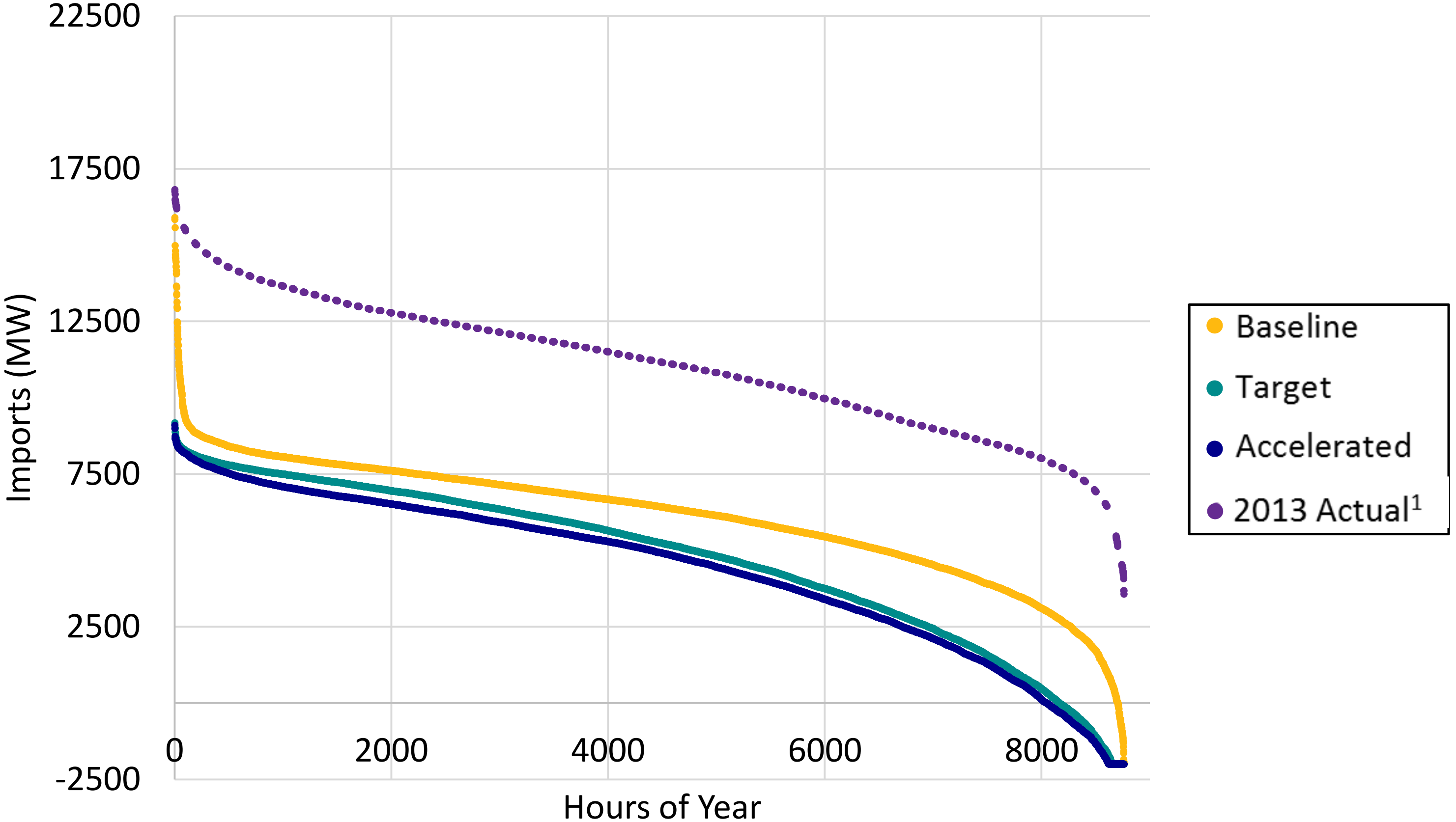
Phase I Estimated 2030 Revenue Requirement Impact

Revenue requirement and savings associated with the Target Case, calculated relative to the Baseline Case.

2030 Revenue Requirement (million $)		
Levelized Capex[1]		4,391
Fixed O&M		690
EE Program Charges		155
DR Program Charges		25
Capacity payments to DR providers[2]		192
Capacity payments to gas fleet[2]		(124)
	Total	**5,329**
2030 Production Cost Savings (million $)		
Fuel[3]		4,235
Variable O&M/start & shutdown[3]		371
CO_2 emissions credits[3]		946
	Total	**5,551**

[1]Levelized capital charge calculated using capital expenditure from slide 12 and converted to levelized capital charge using WECC spreadsheet tool with 7% WACC.
[2]Capacity payments calculated by: taking the difference between DR use or peak gas dispatch between the Target and Baseline Cases and multiplying $40/kw-yr RA payment
[3]Production cost savings are outputs of NREL's production cost model

Results: 3. Import Flows
California Net Imports



- Import patterns show little variability between Cases.
- Regional flows are not dramatically different from 2013.
- 2030 imports are approximately 50% of 2013 imports
- Most imports and WECC trading in Target and Accelerated cases are zero-carbon energy, rather than coal and natural gas.

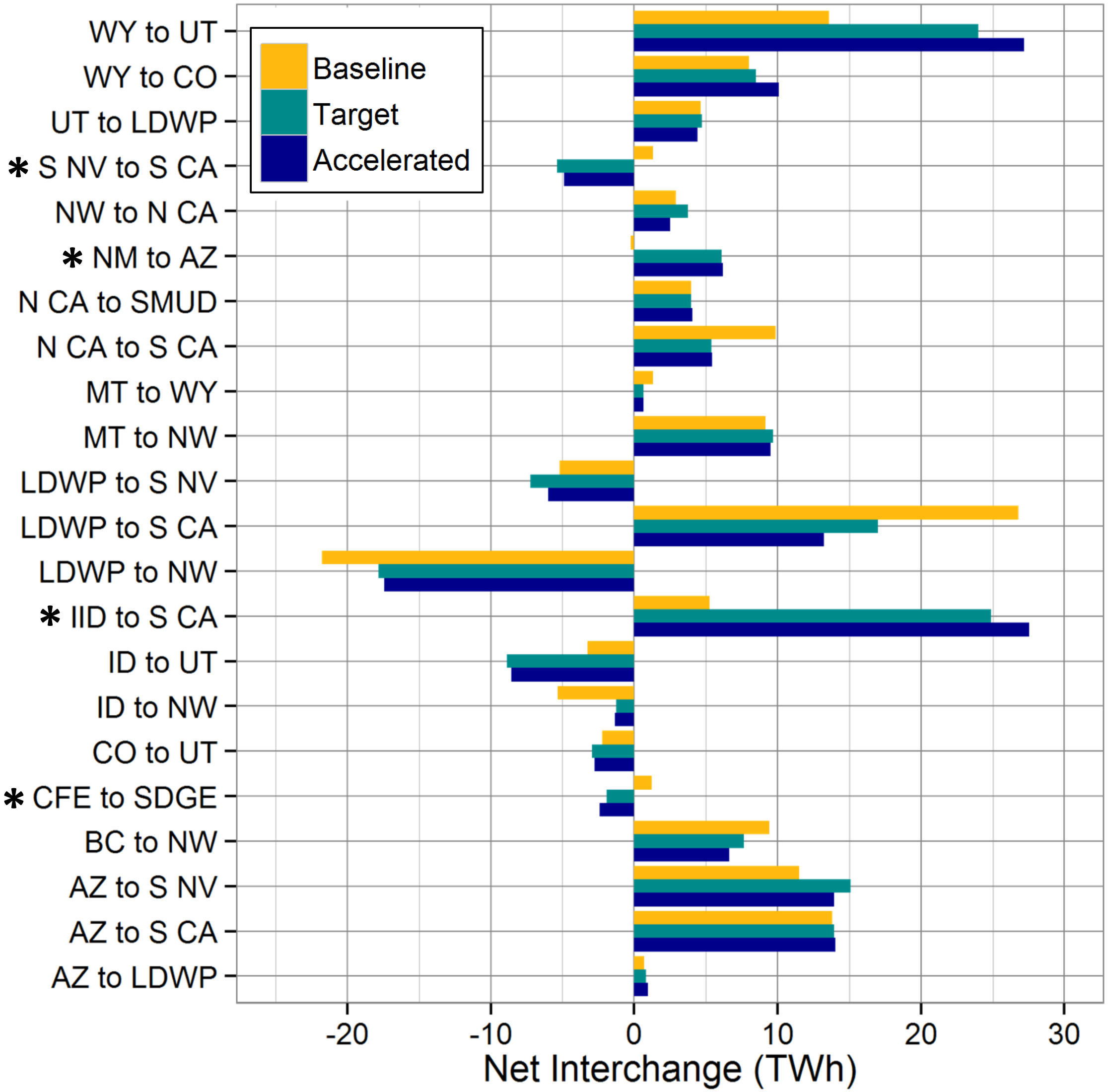
[1] *2013 total imports from Today's Outlook page on CAISO website; POU imports estimated based on total CA net imports*

Results: 3. Import Flows
California Net Imports

	Case		
	Baseline	Target	Accelerated
CA annual net imports (TWh)	**53.2**	**41.4**	**38.3**
Exports	-0.04	-0.6	-0.8
Total imports	53.2	42.0	39.1
Contracted imports (Palo Verde + OOS RE for CA)	8.6 (Palo) + 18.6 (RPS)	8.6 + 42.4	8.6 + 59.1
Contracted imports that are used inside CA	25.8	35.0	38.7
Contracted imports which are not imported to CA	**1.4**	**16.0**	**29.0**
Unspecified imports (Not counting specified imports used outside CA)	27.4	7.0	0.4

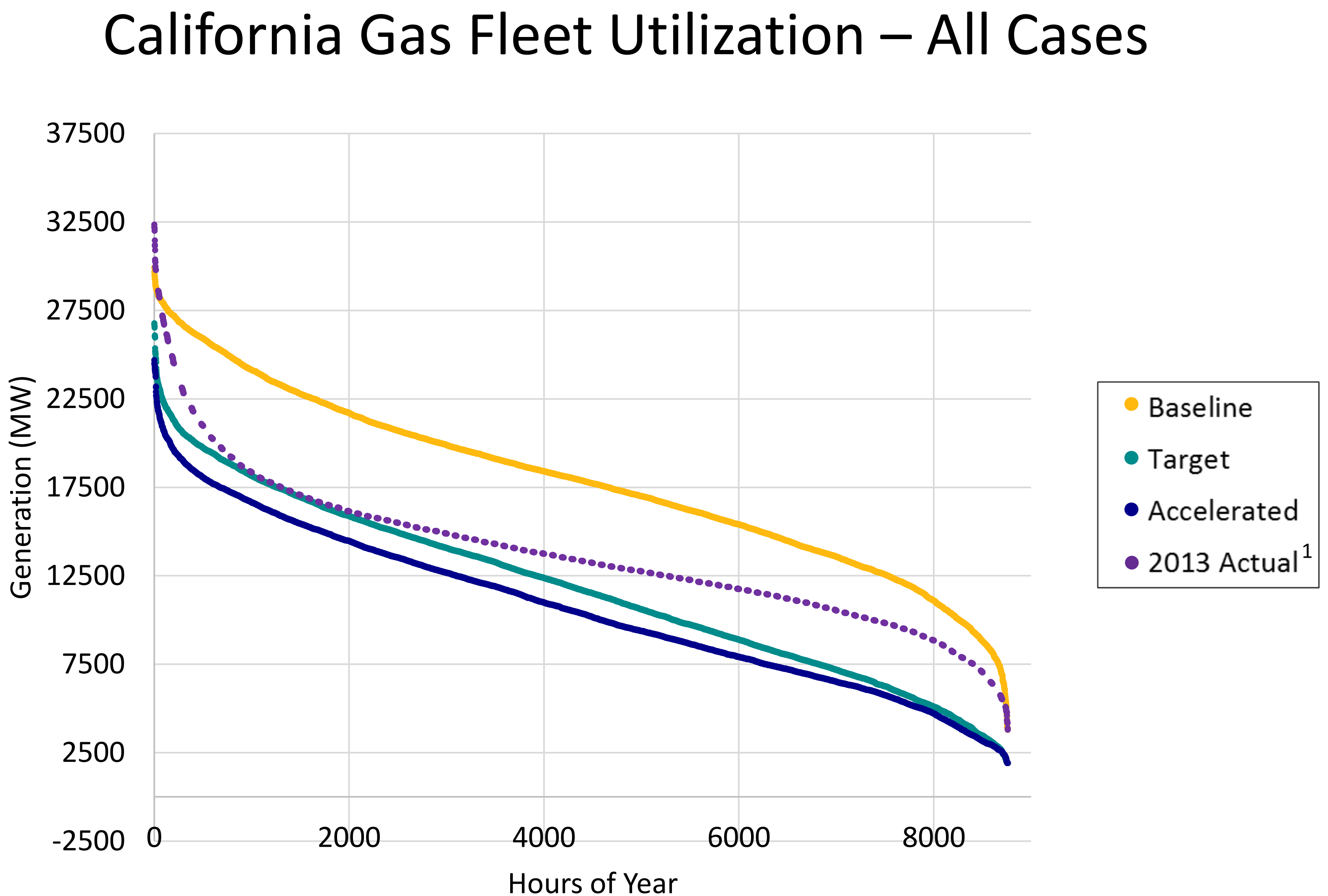
Contracted imports are imports that come from a specific source outside CA (e.g., Palo Verde AZ nuclear plant, Wyoming wind, New Mexico wind)

Results: 3. Import Flows
Annual Net Interchange Between Regions



- Flows throughout the Western Interconnection change significantly on only a few interfaces
  - *Note starred flows*
- Across many interfaces, flows that were from coal/gas generation are replaced with out-of-state renewables

Results: 4. Natural Gas/Grid Operations

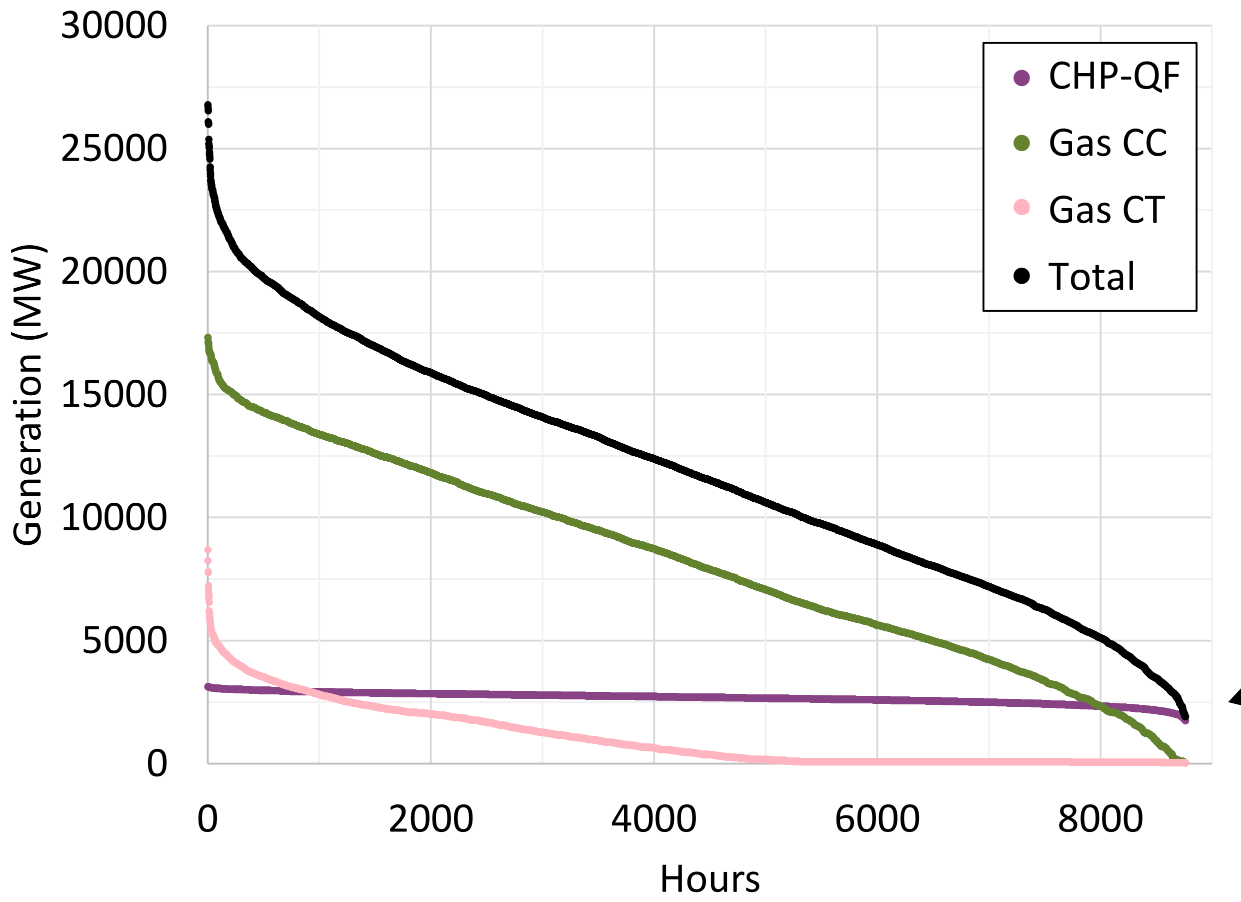


[1]2013 CAISO gas usage from Today's Outlook page on CAISO website; POU gas usage estimated based on total CA gas usage

Results: 4. Natural Gas/Grid Operations

California Gas Fleet Utilization – Target Case Only

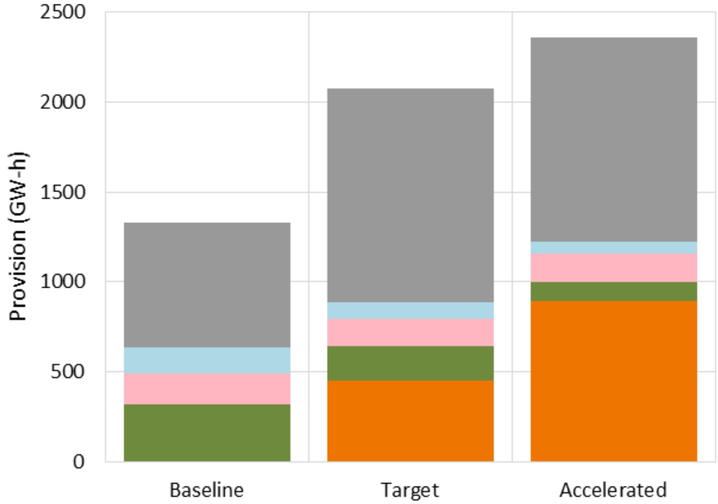
- Breakdown of three types of gas generation in 2030



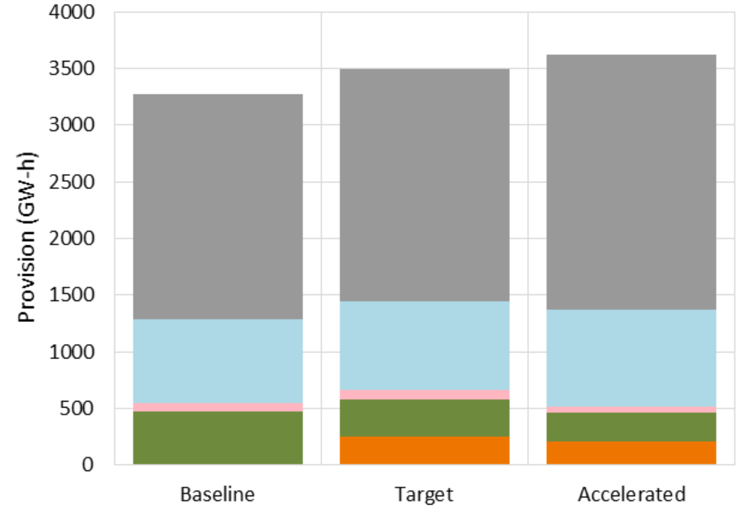
Hours when in-state must-take gas (CHP) generation is below ~2500 MW is some combination of CHP "curtailment" or maintenance and forced outages

Results: 4. Natural Gas/Grid Operations

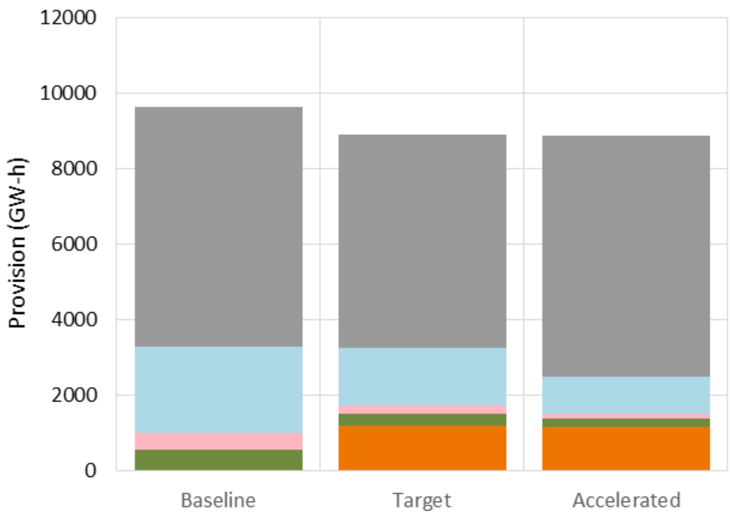
Sources of Load Following Reserves

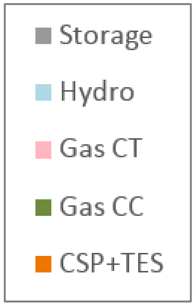


Sources of Regulation



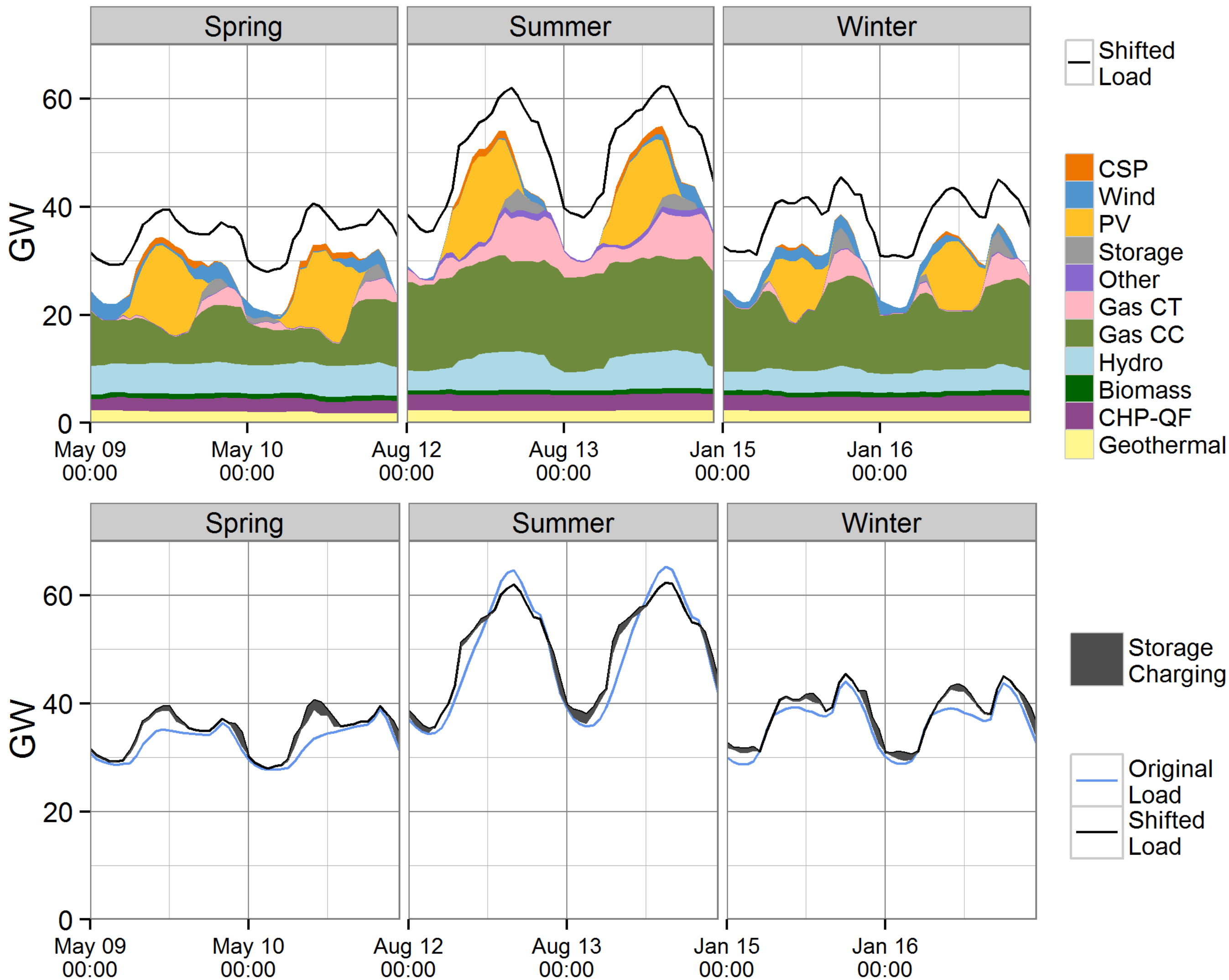
Sources of Contingency Reserves





- Storage includes: pumped hydro, compressed air energy storage (CAES), and small storage under CPUC mandate
- Zero-carbon sources provide most load following reserves and ancillary services, instead of the natural gas fleet

Results: 4. Natural Gas/Grid Operations
Dispatch stacks (example)

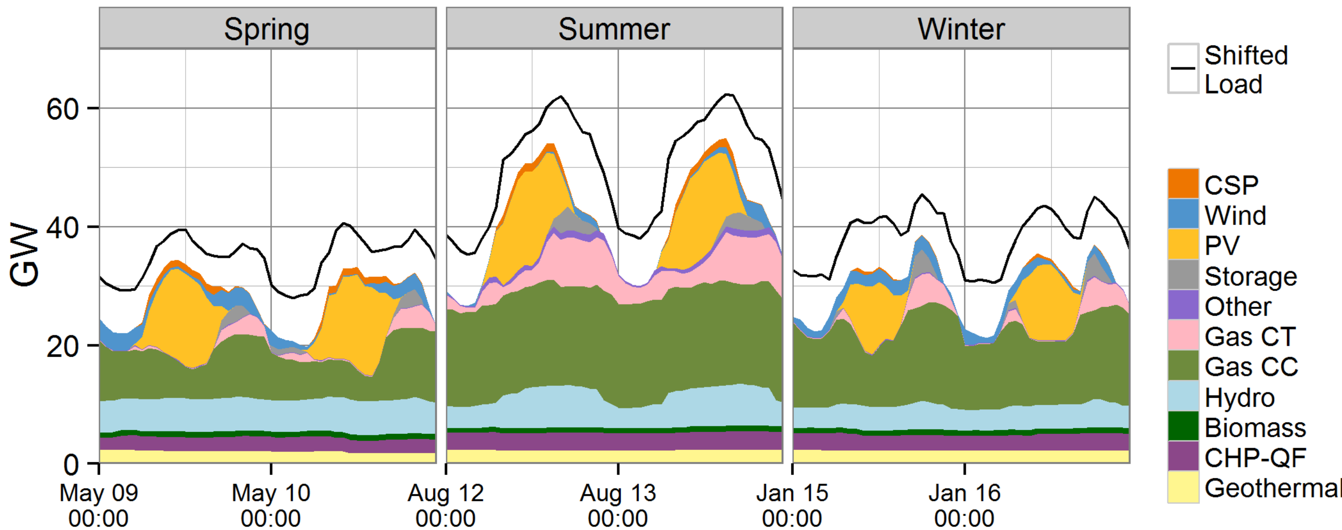


CC: combined cycle; CT: combustion turbine; CHP: combined heat and power

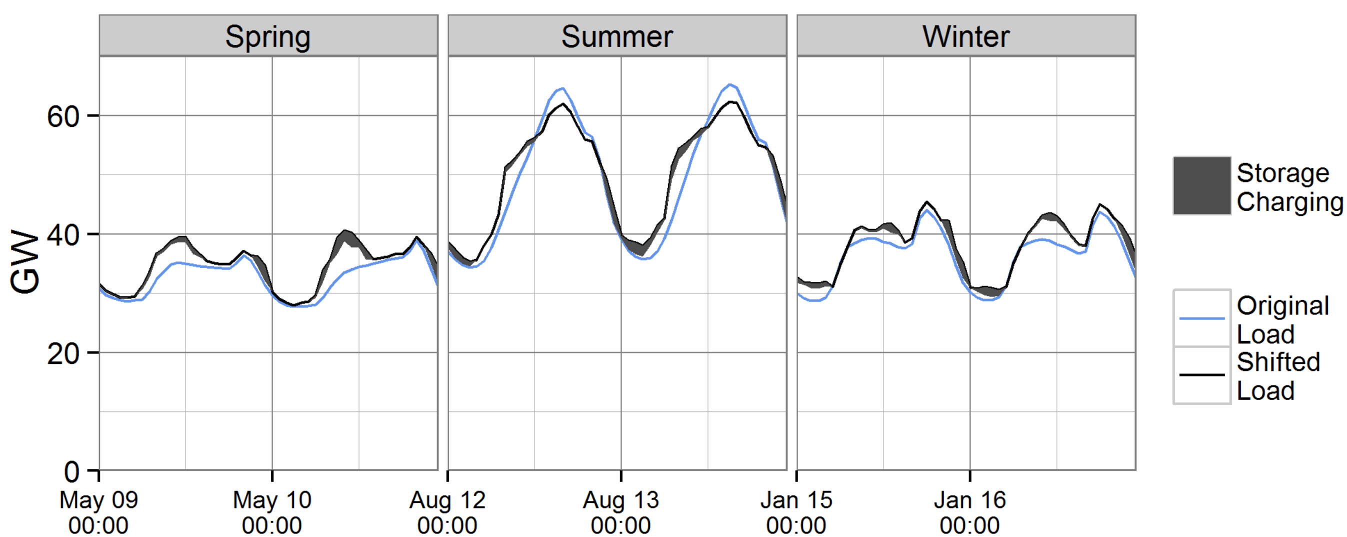
Example: how to read dispatch stacks

- Top graph shows supply-side dispatch and the shifted load
- Difference between dispatch stack and load line represents imports and/or exports
- Bottom graph shows load, demand-side flexibility, and storage charging
- Difference between blue and black lines is load shifting/demand response. Grey shaded region is storage charging or pumping

Results: 4. Natural Gas/Grid Operations
Dispatch stacks (Baseline)

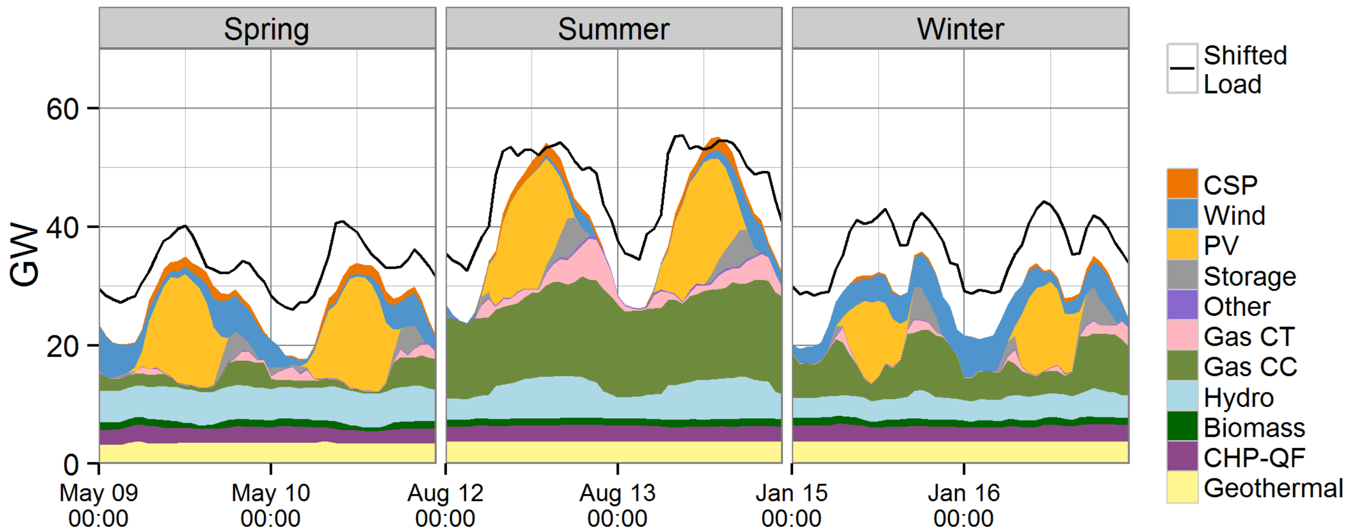


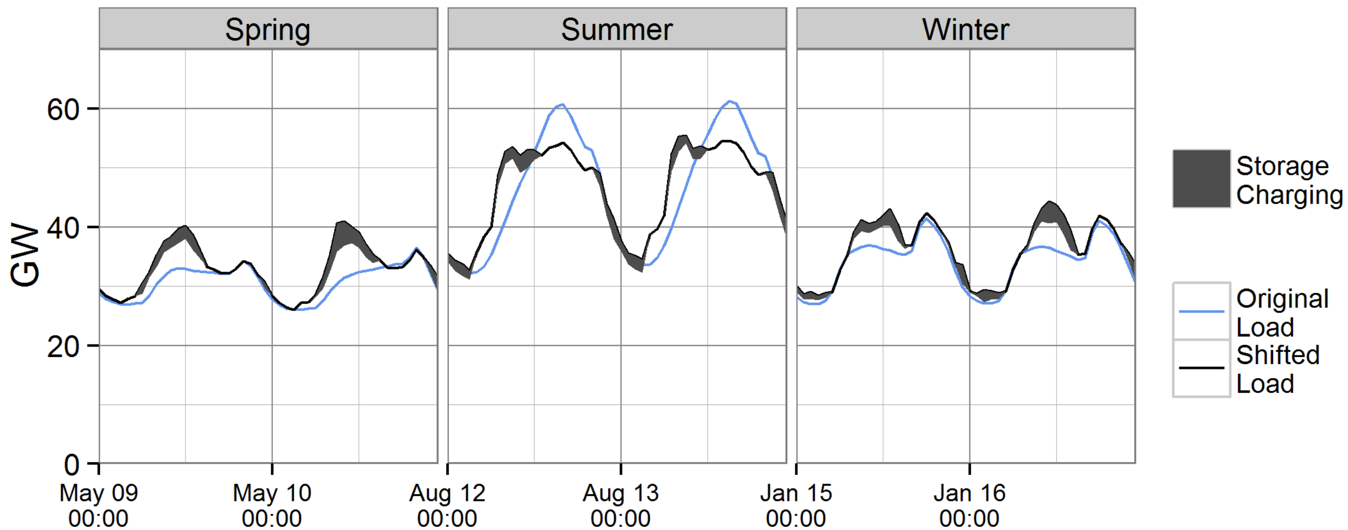
- Supply-side flexibility comes from CCs, CTs, and imports/exports



- Overall load shape changes due to arbitraging storage devices, demand response, and partially schedulable charging of electric vehicles

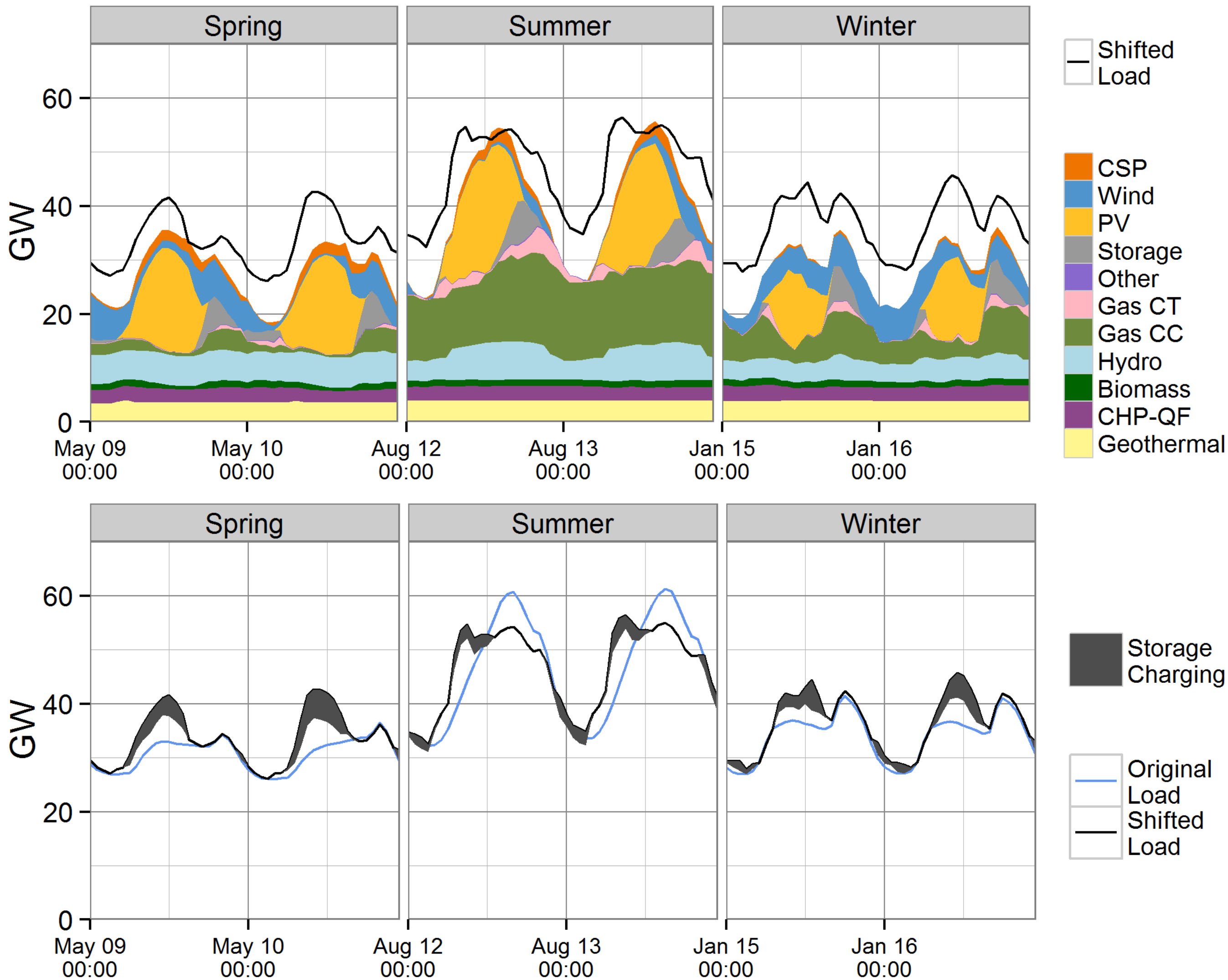
Results: 4. Natural Gas/Grid Operations
Dispatch stacks (Target)





- Imports are reduced (compared to Baseline Case); CCs are dispatched more often in spring and winter; CCs are nearly baseload in summer
- Load shifting becomes more aggressive and summer peak is reduced and moved earlier in the day to coincide with solar generation

Results: 4. Natural Gas/Grid Operations
Dispatch stacks (Accelerated)

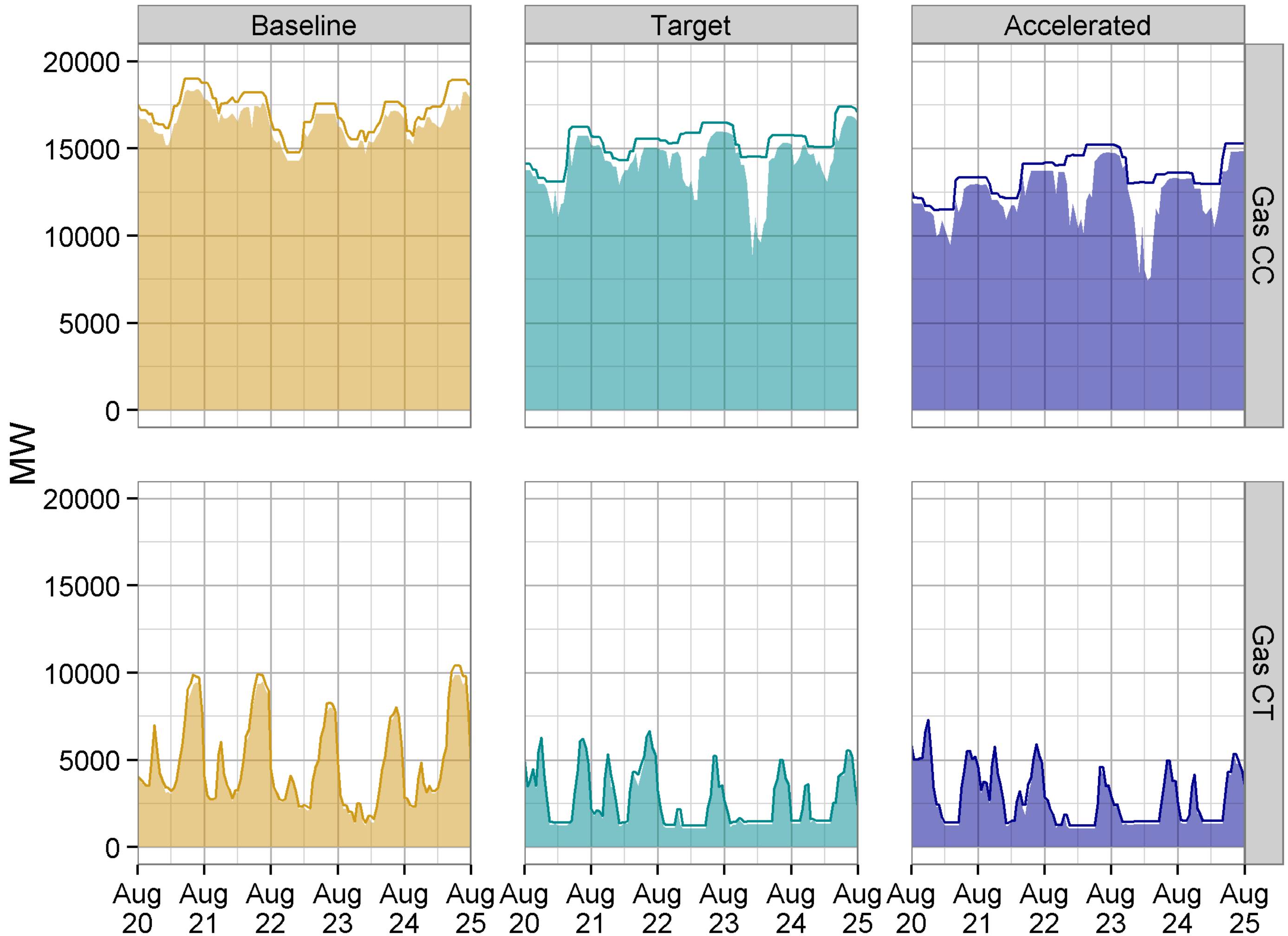


- Similar to Target Case with less imports and gas generation

- Additional storage allows for more aggressive load shifting during mid-day (high solar) hours
- Demand response acts similar to Target Case

Results: 4. Natural Gas/Grid Operations

Gas fleet utilization – summer typical five-day dispatch

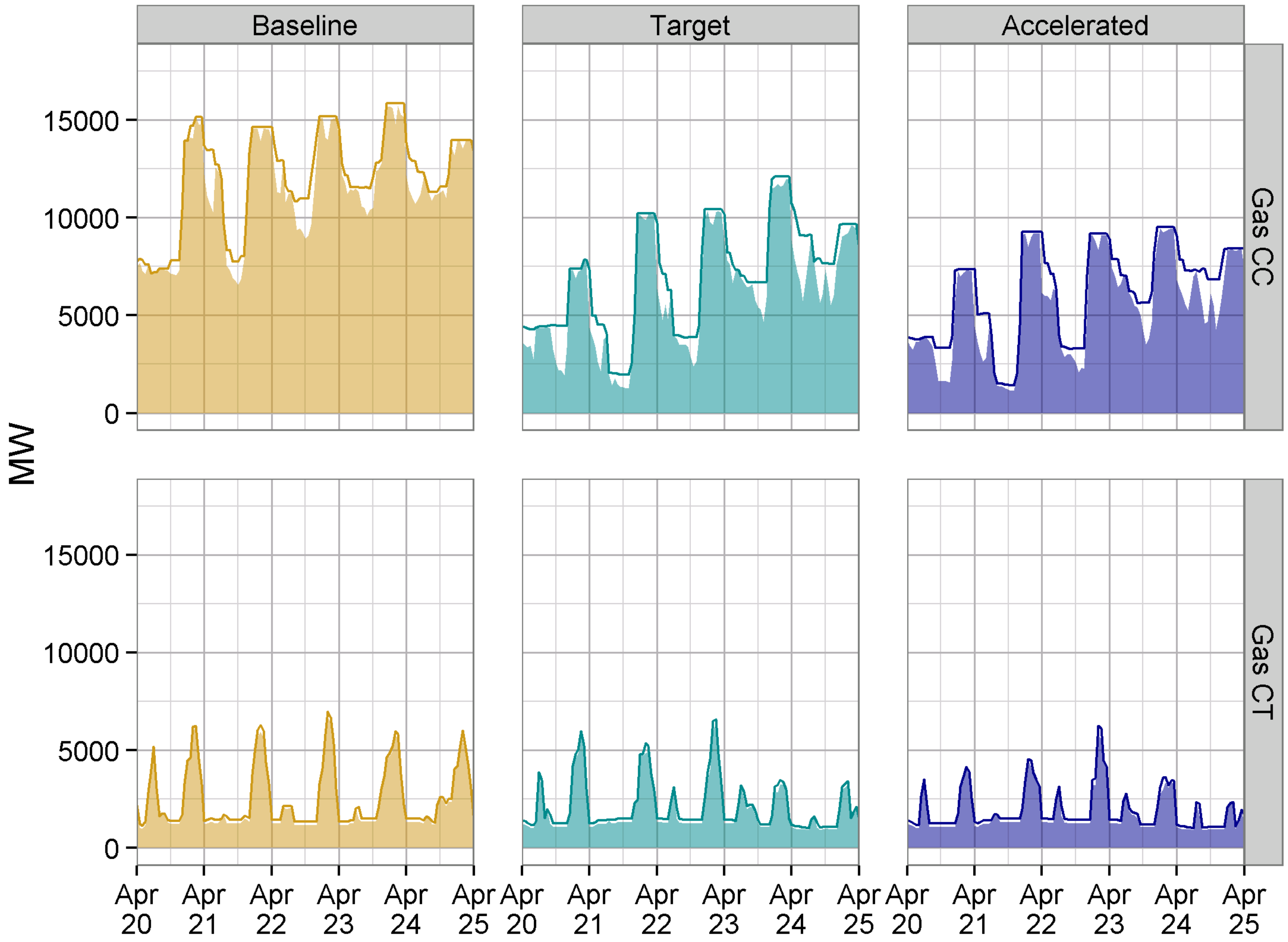


- High utilization of committed gas fleet
- The CC fleet does not do a lot of daily cycling during the summer

- Solid line shows committed capacity of each generator type
- Shaded region shows actual dispatched energy by generator type

Results: 4. Natural Gas/Grid Operations

Gas fleet utilization – spring typical five-day dispatch



- High utilization of committed gas fleet
- CC fleet sees daily cycling in Target and Accelerated Cases

Results: 4. Natural Gas/Grid Operations California Gas Generator Operation

	Baseline	Target	Accelerated
Average hours online per start			
CA Gas CCs	85	52	57
CA Gas CTs	7.3	5.7	5.6
CHP-QF	222	174	161
Average heat rate (Btu/kWh)			
CA Gas CCs	7,700	7,500	7,400
CA Gas CTs	9,800	9,500	9,600
CHP-QF	9,600	9,600	9,600

- Average fleet heat rate remains relatively constant, because while fleet capacity factor goes down, the committed fleet capacity factor remains high (see following slide)
- This indicates that gas units are turning off, rather than turning down (especially low efficiency units)
- Gas CCs are on for 2-4 days on average for each time they are started
- Gas CTs are on for 5-10 hours each time they are started

Results: 4. Natural Gas/Grid Operations California Gas Generator Operation

	Baseline	Target	Accelerated
Fleet capacity factor (%)			
CA Gas CCs	66.8	39.0	33.5
CA Gas CTs	22.2	10.8	10.4
CHP-QF	84.1	82.1	81.7
Committed fleet capacity factor (%) (Average capacity factor of each unit only counting hours when the unit is online)			
CA Gas CCs	94.9	92.0	92.0
CA Gas CTs	92.7	90.6	89.8
CHP-QF	96.0	94.1	93.7

- Committed fleet capacity factor is high for all cases, indicating that gas units are turning off, rather than turning down
  - 2013 committed capacity factor of CA CCs was ~80% and CTs was ~72% (based on EPA Continuous Emission Monitor data analysis done by the authors)

Conclusions

Phase I Results

- The LCGS analyzed California's grid with a carbon focus, flexible load, regional cooperation, efficient use of natural gas, and diverse renewable generation
- With this portfolio, the California electric sector can reduce GHG emissions by more than 50% below 2012 levels in 2030:
  - With minimal rate impact
  - Without compromising reliability
  - With minimal curtailment of renewable energy
  - With a stable gas fleet that is dispatched with minimum cycling

Significance

- The Target Case modeled in this study illustrate a feasible, reliable, affordable and practical trajectory toward meeting California's 2050 GHG goals.
- The 2030 LCGS demonstrates that California can:
  - Achieve ambitious emissions reductions;
  - Lead the Western U.S. toward a sustainable, low-carbon electric sector;
  - Deploy unprecedented energy efficiency and efficient use of natural gas;
  - De-carbonize transportation by supporting significant use of electric vehicles;
  - Spur state-wide economic development from renewable energy, transmission, and energy storage projects.

Questions?

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