Valuation of Long-Duration Storage in Resource Planning

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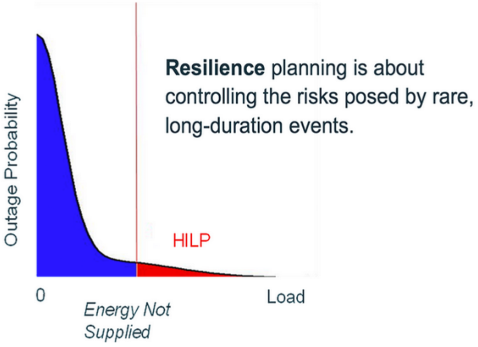
Grid Integration Group – LBNL

Power system operations, planning and economics

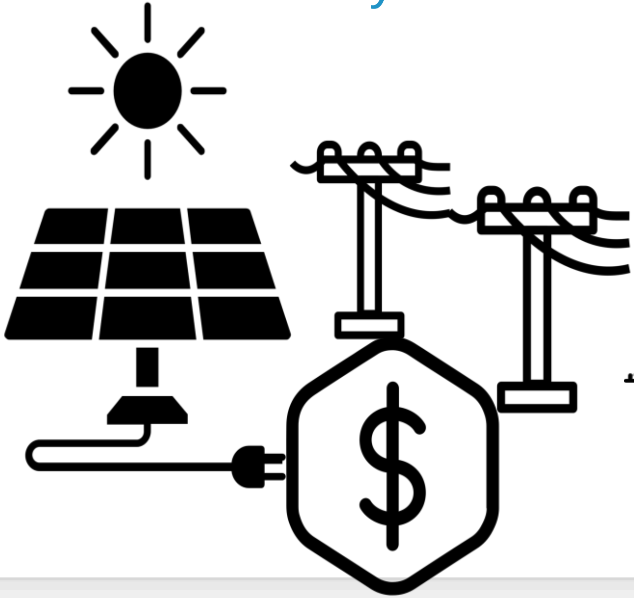
REPAIR project

Reliability planning is about mitigating outages caused by routine events.

- Expected value of interruptions.



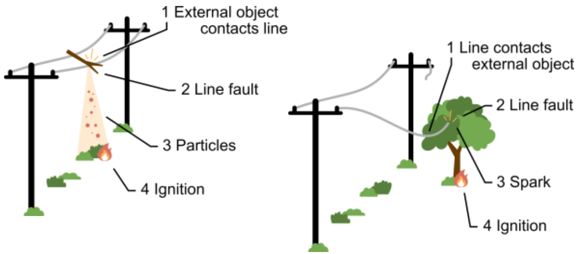
Community solar



ARPA-E Competition

arpa·e
GRID OPTIMIZATION (GO) COMPETITION

Planning for wildfires



Motivation & Research Questions

- Current methodologies calculate the future value of long-duration energy storage (LDES) to the Grid based on scenarios of LDES technology costs projected many decades ahead (2040, 2050, 2070).
- Current research questions on LDES valuation:
  - *Given LDES costs projected, what is the value that LDES can bring to a future system?*
- However, for technologies that **are not matured** yet, long-term cost cannot be projected. Instead, they are driven by policy decisions (e.g., DOE “earthshot” storage), which can shape the R&D, supply chains, etc.
- So, we ask a different question:
  - ***Given a decarbonization target, what is the LDES technology cost that will turn it into a viable solution?***
- Support cost policy (government “earthshots”, industry R&D targets) of unmatured technologies.

LDES Liftoff

Improvements Needed

LDES technology cost reduction of 45-55% and Round Trip Efficiency (RTE) improvement of 7-15% by 2030 to attract sustained investment.

To be competitive with alternative options, LDES technology costs should come down by 45–55% by 2028-2030 relative to costs reported by leading technologies today, and both the performance (measured by roundtrip efficiency – RTE) and the working lifetime of LDES technologies would also improve.

	Today (for best-in-class technology)	2030 Target*
Intra-day LDES	$1,100–1,400 per kW 69% RTE	$650 per kW 75% RTE
Multi-day LDES	$1,900–2,500 per kW 45% RTE	$1,100 per kW 55–60% RTE

** Technology improvement and compensation goals outlined in this report are in-line with existing DOE Energy Storage Grand Challenge (ESGC) goals of $0.05/kWh for long-duration stationary applications.*

Inter-day LDES

10–36 hours

Multi-day / week LDES

36–160 hours

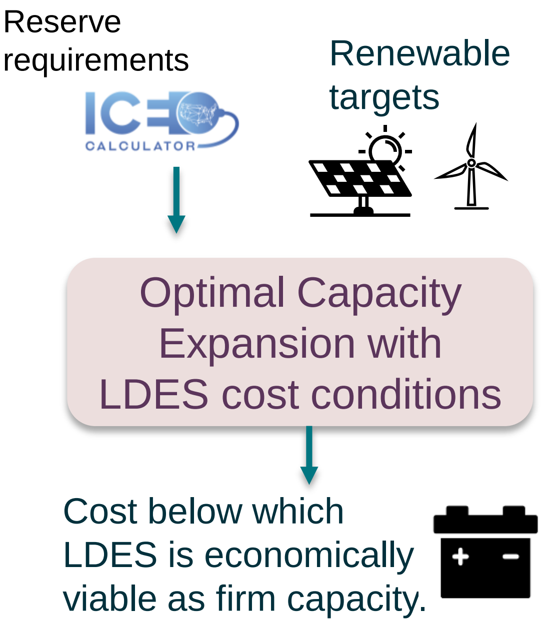
https://liftoff.energy.gov/long-duration-energy-storage/

LDES Types

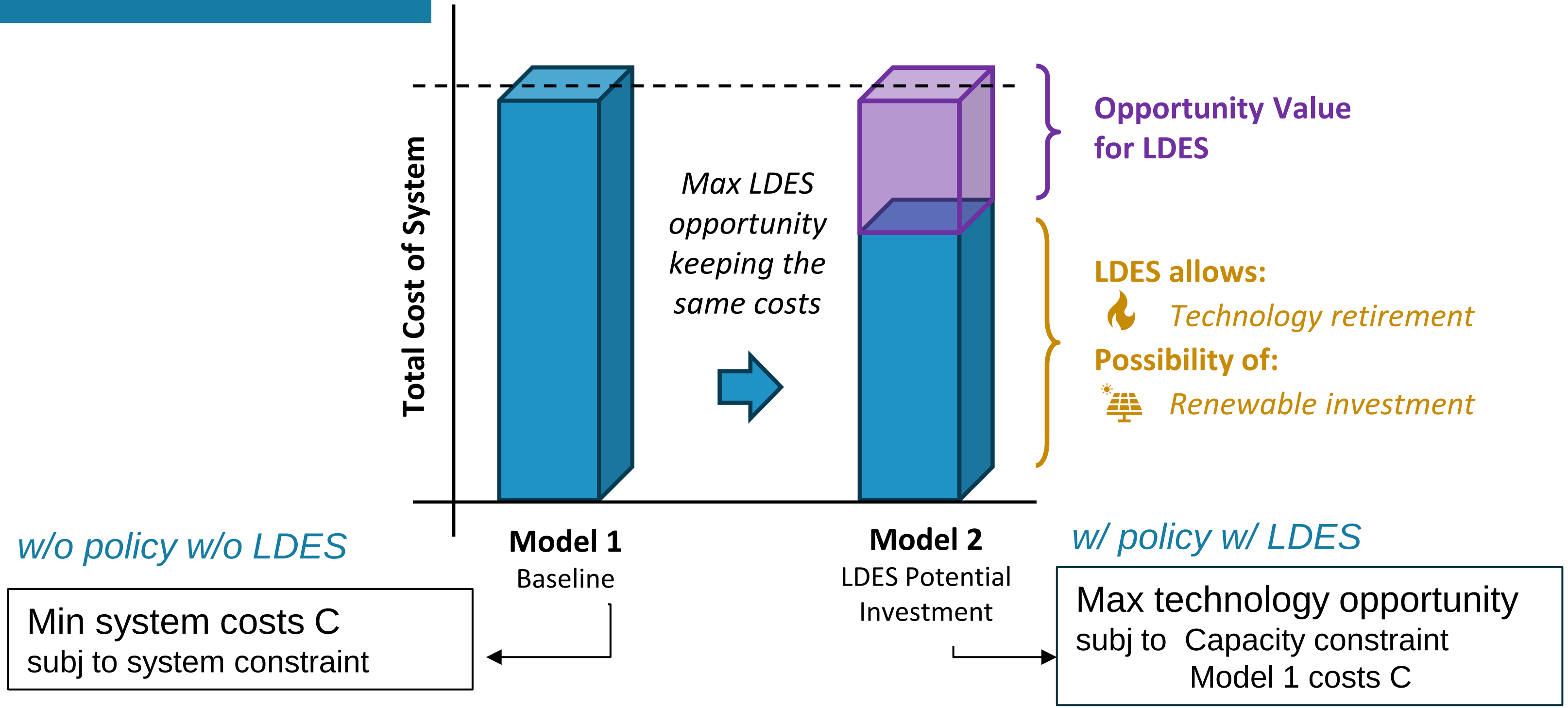
	Mechanical	Electrochemical	Thermal	Chemical
Description	Solutions that store energy as a kinetic, gravitational potential or compression/pressure medium.	Energy storage systems generate electrical energy from chemical reactions.	Solutions stocking thermal energy by heating or cooling a storage medium.	Chemical energy storage systems store electricity through the creation of chemical bonds.
Examples	• Pumped Hydroelectric Storage (PHS), • Compressed Air Energy Storage (CAES).	• Zinc or vanadium flow batteries, • Lithium-ion, • Sodium, • Iron-air batteries.	• Concentrating solar power (CSP) plants.	• Hydrogen storage.
Duration category by DOE	Inter-day (10–36 hours).	Multi-day/week (36–160 hours).	Multi-day/week (36–160 hours).	Multi-day/week (36–160 hours) and Seasonal shifting (160+ hours).
RTE	40 — 85%	50 — 90%	20 — 90%	30 — 50%

Objective & Approach

- Develop an **innovative valuation framework** that captures the value of LDES in long-term decarbonization.
- The objective is to capture the cost ($/MWh) below which LDES becomes **economically viable as a firm capacity technology** to compensate renewables variability.
- We use as an example of decarbonization target, the **replacement of Gas** power plants in 2040, 2045, 2050.



Methodology



Learnings: Costs

A California case study

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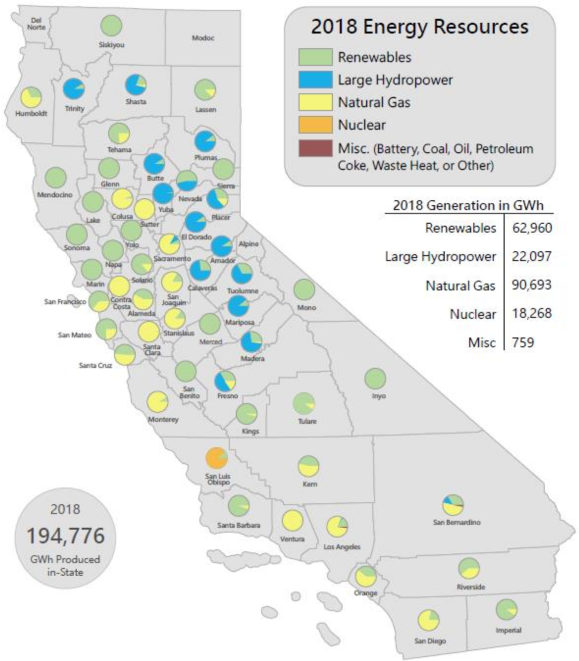
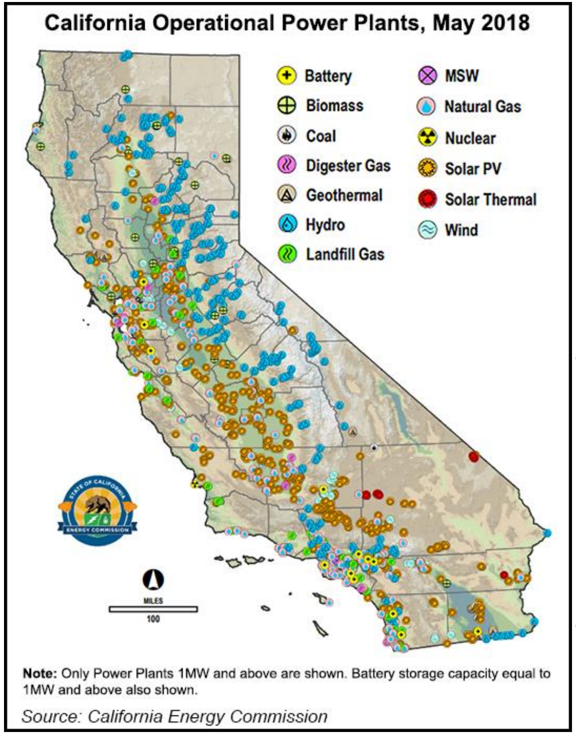
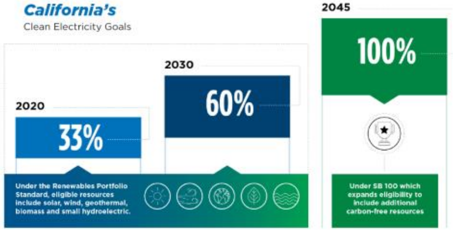
CA context



Source: CEC





- Gas currently provides firm generation and flexibility
- LDES can be an alternative

Case Study

Balancing areas used in Cambium, ReEDS

Existing Generators

Renewable Tech: Biopower; Geothermal; Hydropower; Distributed/ Utility PV; On/offshore Wind

- **Short-duration Tech**: 2-8 hours; PHS
  - **Fossil**: Oil/Gas

- Hourly (8760) resolution
- 15% Reserve Criterion

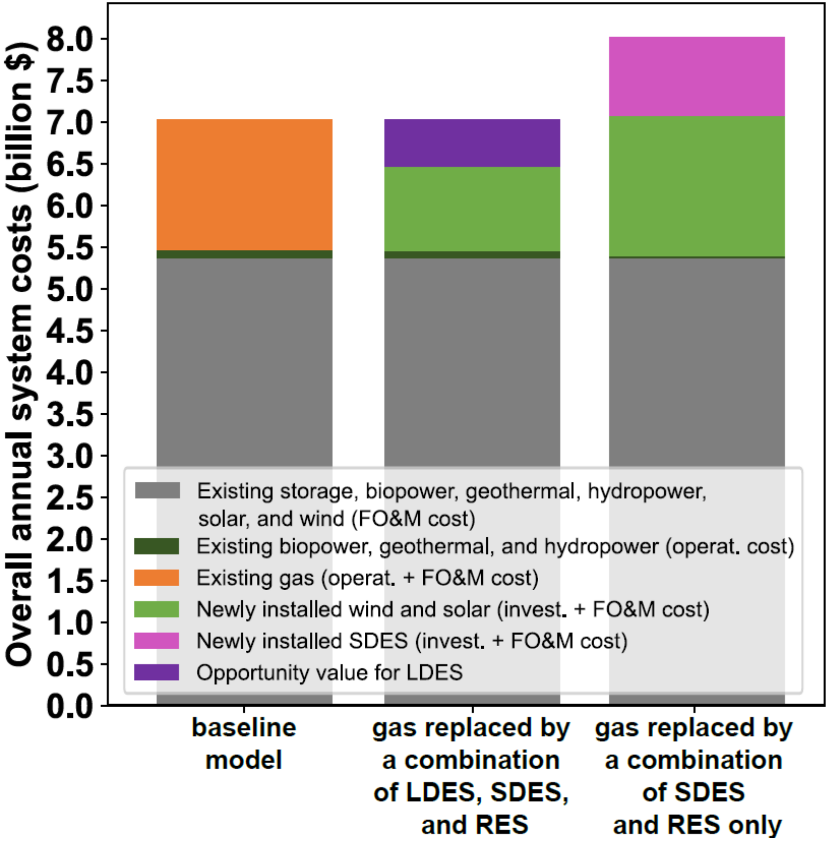
- **The Model 1 considers:**
  - All existing generators do not change.
  - No investment.
- **The Model 2 considered:**
  - The retirement of 100% gas power.
  - Candidate LDES.
    - Power quantity = Max of 75 GW
    - Number of periods = 100h
    - RTE = 42.5% (Round trip efficiency of an **Ion-air battery** proposed by Form Energy).
  - Candidate SDES.
    - Power quantity = Max of 45 GW
    - Number of periods = 4h
    - RTE = 85%

Learnings
2050 California

If gas generators are replaced by SDES and renewables only, overall costs will be higher.

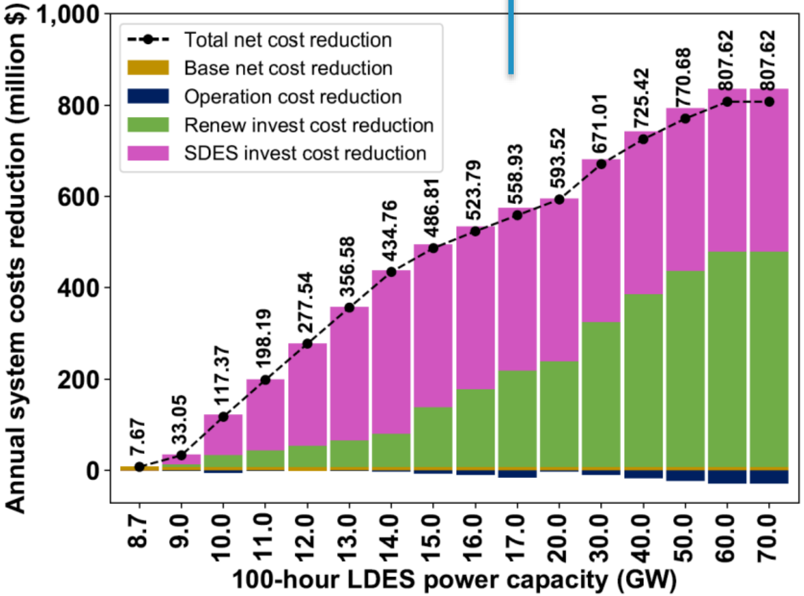
17 GW of 100-h LDES power capacity can support the system to maintain the same baseline costs

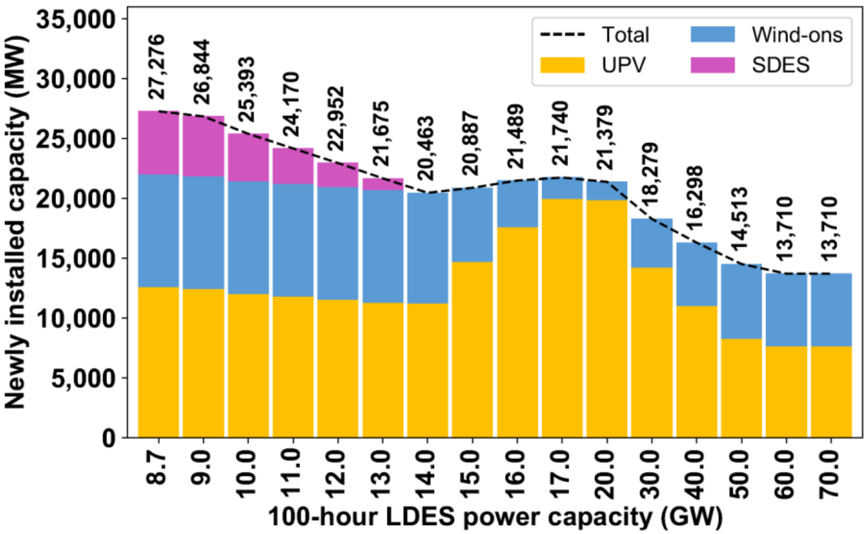
Associated boundary cost would be US$ 512.54kW^{-1}



Learnings
2050 California

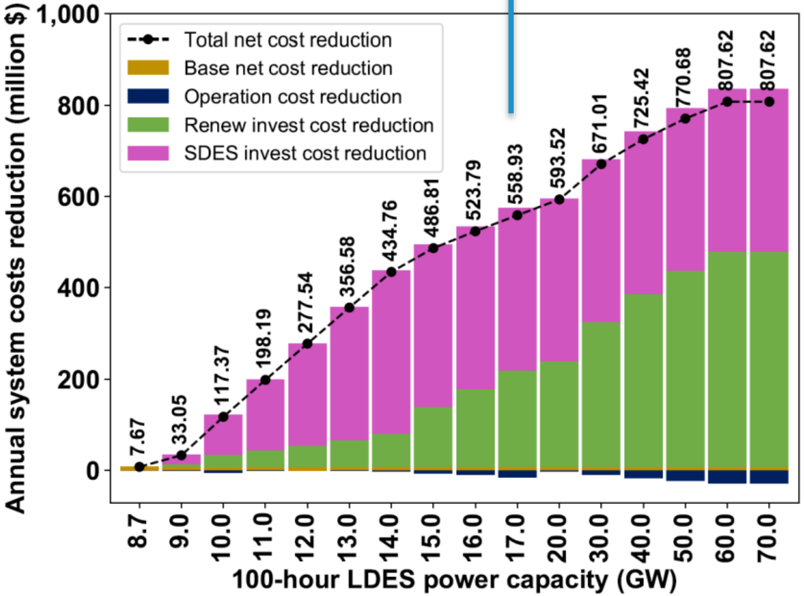
Investment cost reduction achieved via cheaper renewable mix as more LDES is present

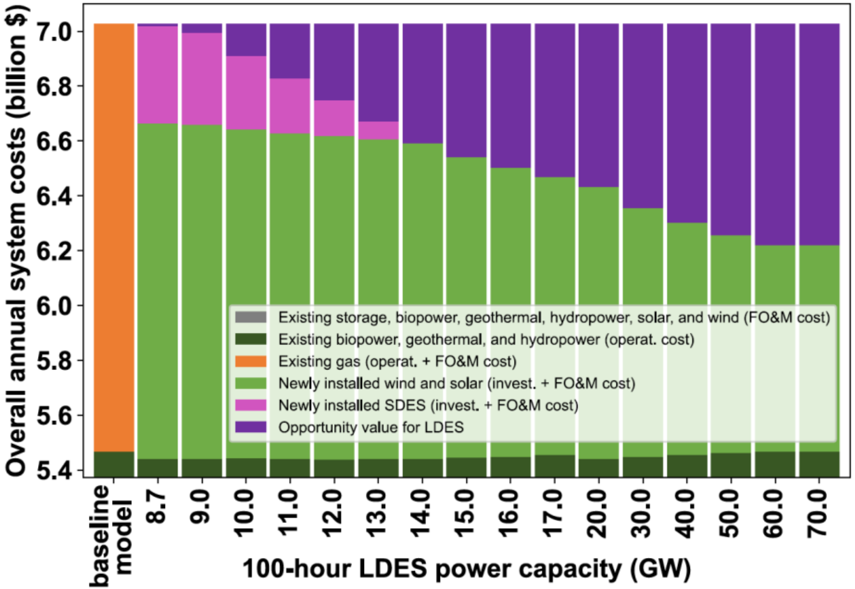




Learnings
2050 California

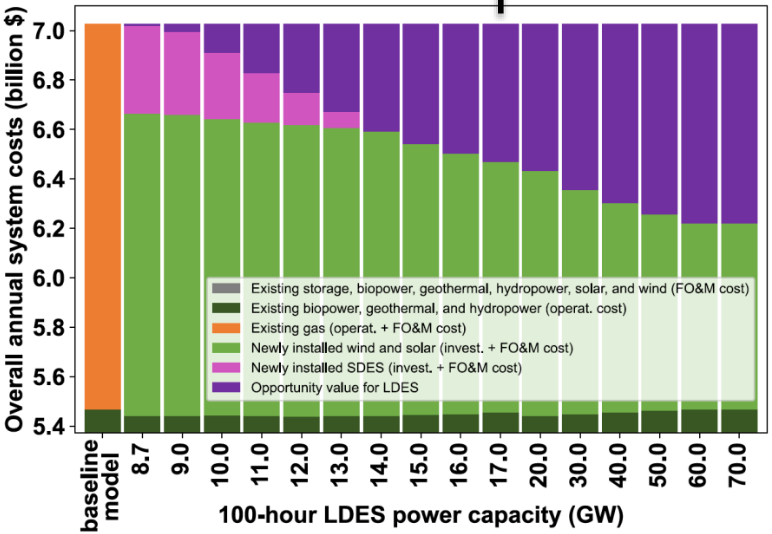
Opportunity value for LDES comes from avoided investments

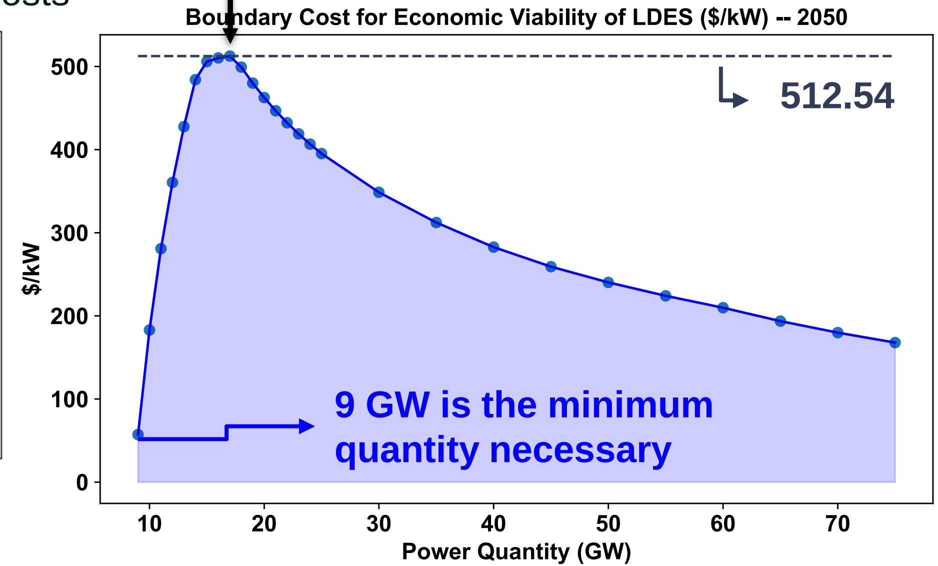




Learnings
2050 California

Opportunity value for LDES results in boundary costs





- We cannot replace gas if we do not have at least 9 GW of 100h LDES
- LDES has to cost between 100-515 $/kW to be viable in California system
- The quantity of LDES more favorable to technology costs is around 17 GW

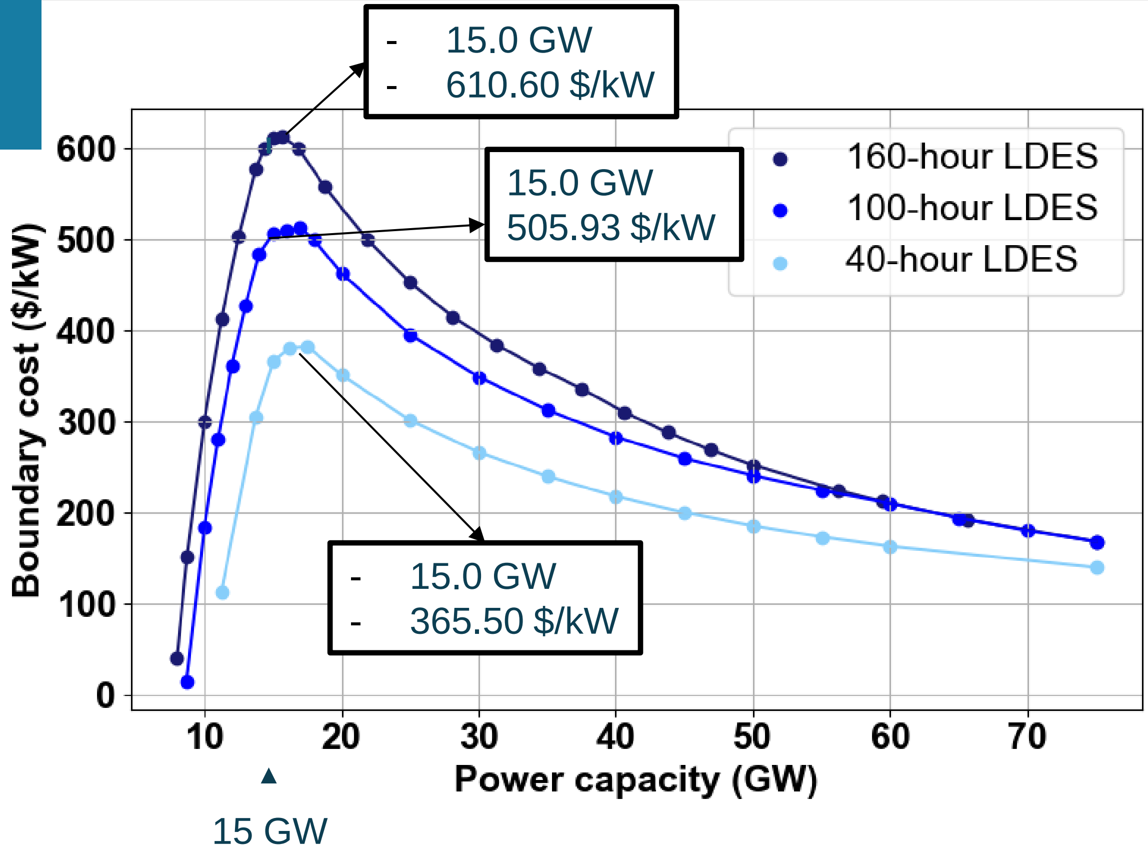
Sensitivity Duration

The boundary cost increases with the duration of the LDES.

The minimum capacity decreases with the LDES duration.

The boundary cost peaks at ~15 GW for all durations.

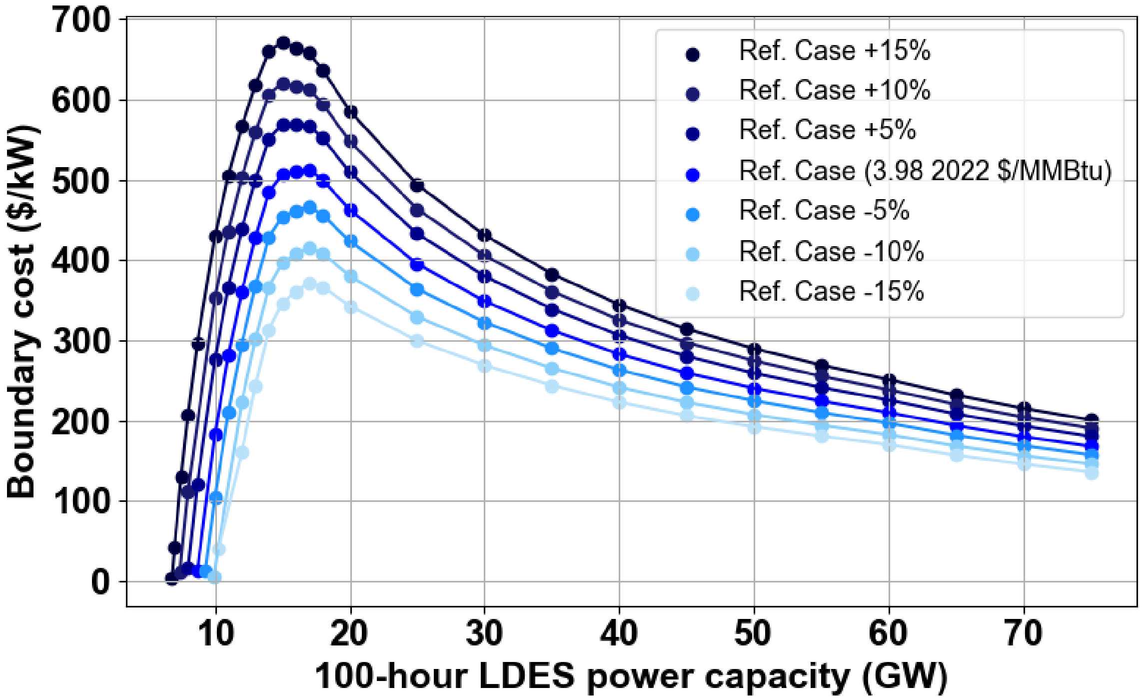
For higher quantities storage duration does not affect value.



Sensitivity
Gas Prices

The analysis looks at natural gas prices being 5%, 10%, and 15% higher or lower in 2050 compared to the Reference case.

The boundary cost peaks at ~15 GW for all durations.



Sensitivity
Gas Prices and Solar Investment Costs

The higher the gas price, the higher the boundary cost

The lower the solar investment cost, the higher the boundary cost

Natural gas fuel price fluctuations (rows), Ref. case: 3.98 $/MMBtu; Solar investment cost fluctuations (columns), Ref. case: 701.16 $/kW

	-30%	-25%	-20%	-15%	-10%	-5%	Ref. Case	+5%	+10%	+15%	+20%	+25%	+30%
-30%	366.21	343.30	320.39	297.55	274.77	252.04	229.36	207.12	185.32	163.55	141.84	120.20	98.71
-25%	417.23	394.32	371.41	348.57	325.79	303.06	280.38	258.14	236.34	214.57	192.86	171.22	149.73
-20%	462.08	439.17	416.26	393.43	370.65	347.92	325.24	303.00	281.20	259.43	237.72	216.08	194.59
-15%	508.42	485.51	462.60	439.76	416.98	394.25	371.57	349.33	327.53	305.76	284.05	262.41	240.92
-10%	552.42	529.51	506.60	483.77	460.99	438.25	415.58	393.33	371.53	349.76	328.05	306.41	284.92
-5%	603.28	580.37	557.46	534.62	511.84	489.11	466.43	444.19	422.39	400.62	378.91	357.27	335.78
Ref. Case	649.38	626.47	603.56	580.73	557.95	535.22	512.54	490.30	468.50	446.73	425.02	403.38	381.89
+5%	704.44	681.53	658.62	635.78	613.00	590.27	567.59	545.35	523.55	501.78	480.07	458.43	436.94
+10%	749.67	726.76	703.85	681.02	658.24	635.51	612.83	590.59	568.79	547.02	525.31	503.67	482.17
+15%	794.34	771.43	748.52	725.69	702.91	680.18	657.50	635.26	613.46	591.68	569.98	548.33	526.84
+20%	839.98	817.07	794.16	771.33	748.55	725.82	703.14	680.90	659.10	637.33	615.62	593.97	572.48
+25%	881.61	858.70	835.79	812.96	790.18	767.45	744.77	722.53	700.73	678.96	657.25	635.61	614.12
+30%	926.77	903.86	880.95	858.12	835.34	812.61	789.93	767.69	745.89	724.12	702.41	680.77	659.27

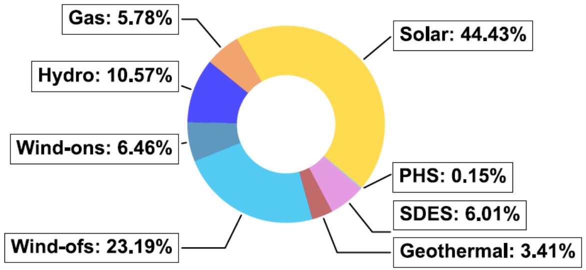
Color scale: 100, 200, 300, 400, 500, 600, 700, 800, 900

Learnings: Operations

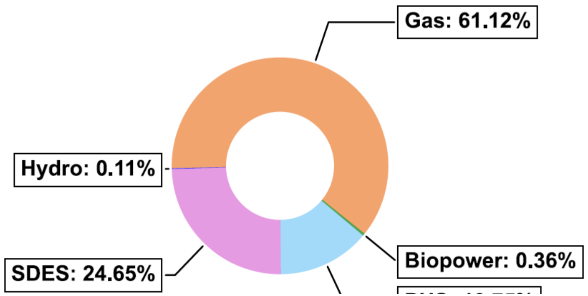
A California case study

Generation and Reserves

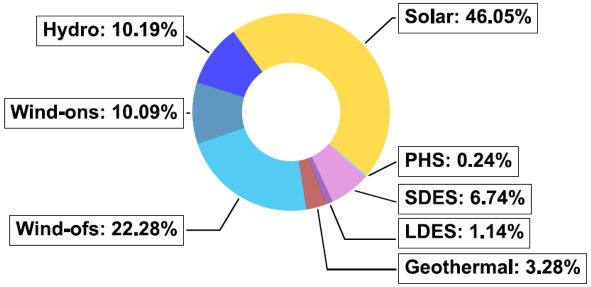
Baseline model – Generation



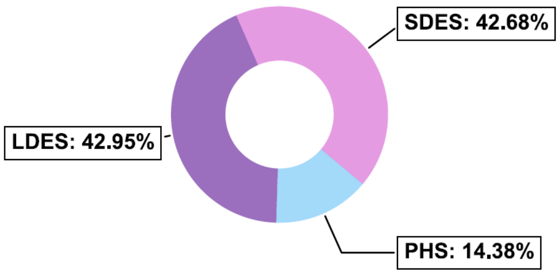
Baseline model – Reserves



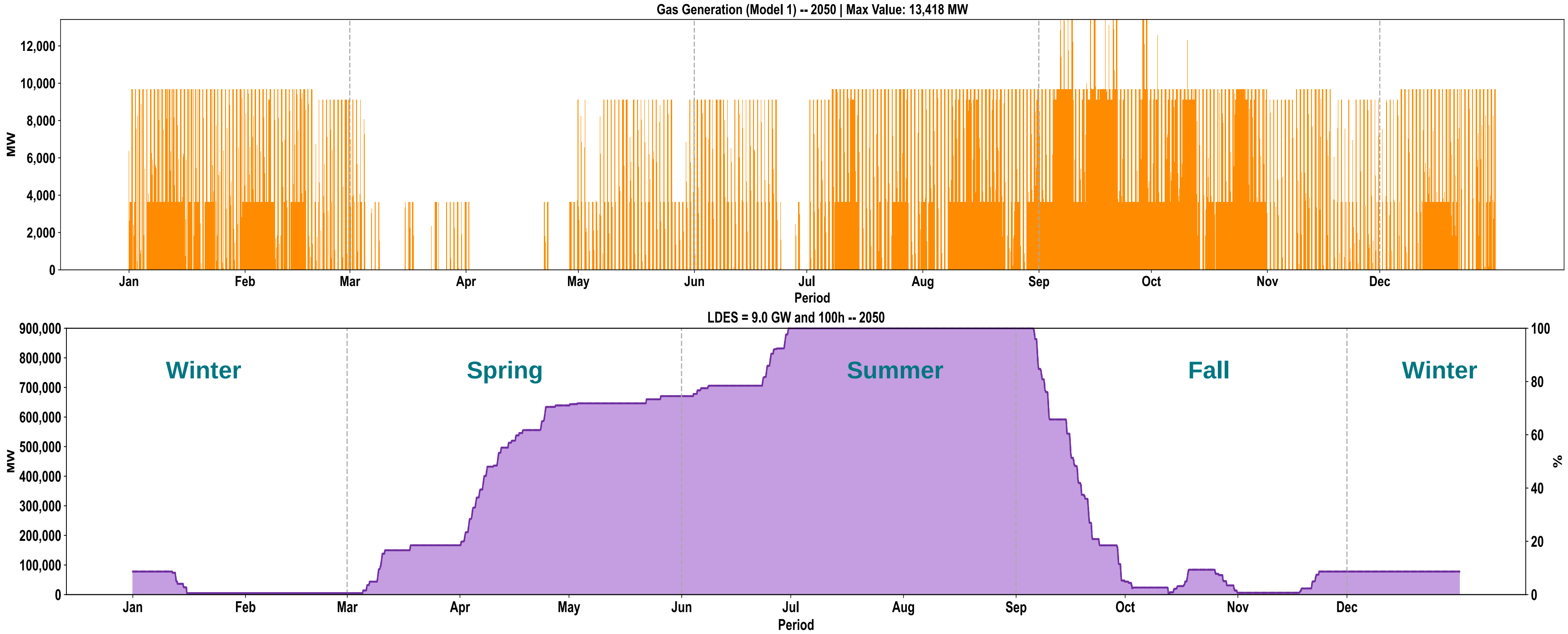
Opportunity value model – Generation



Opportunity value model – Reserves

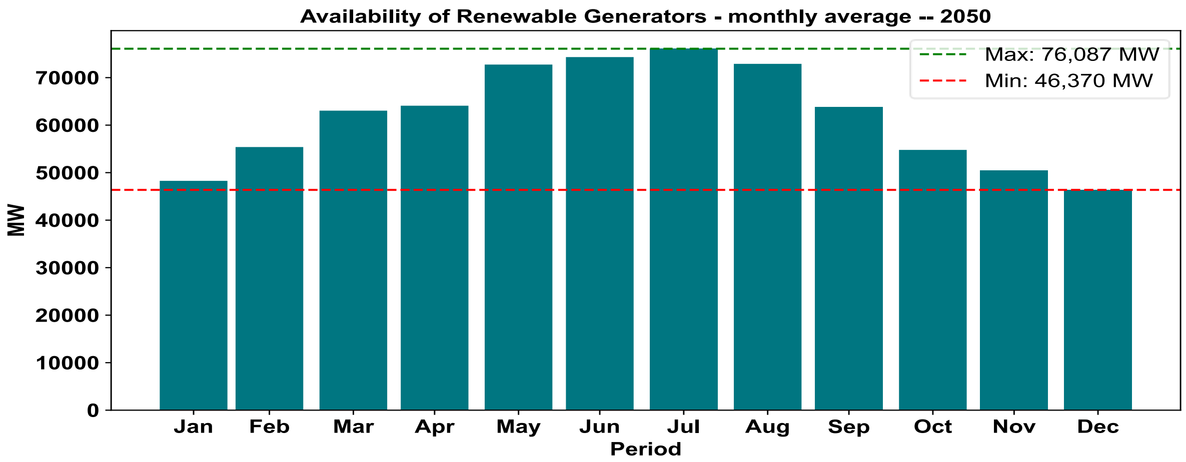


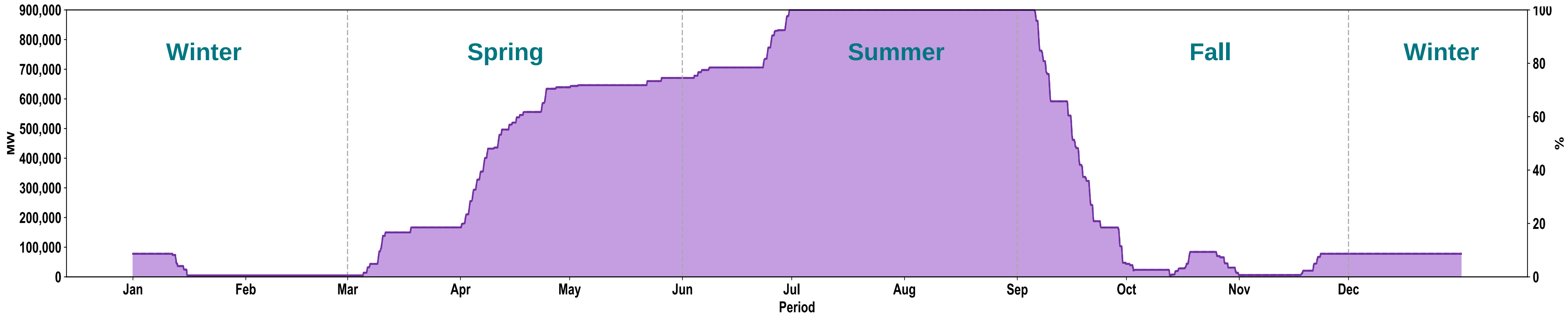
LDES vs Gas Operation



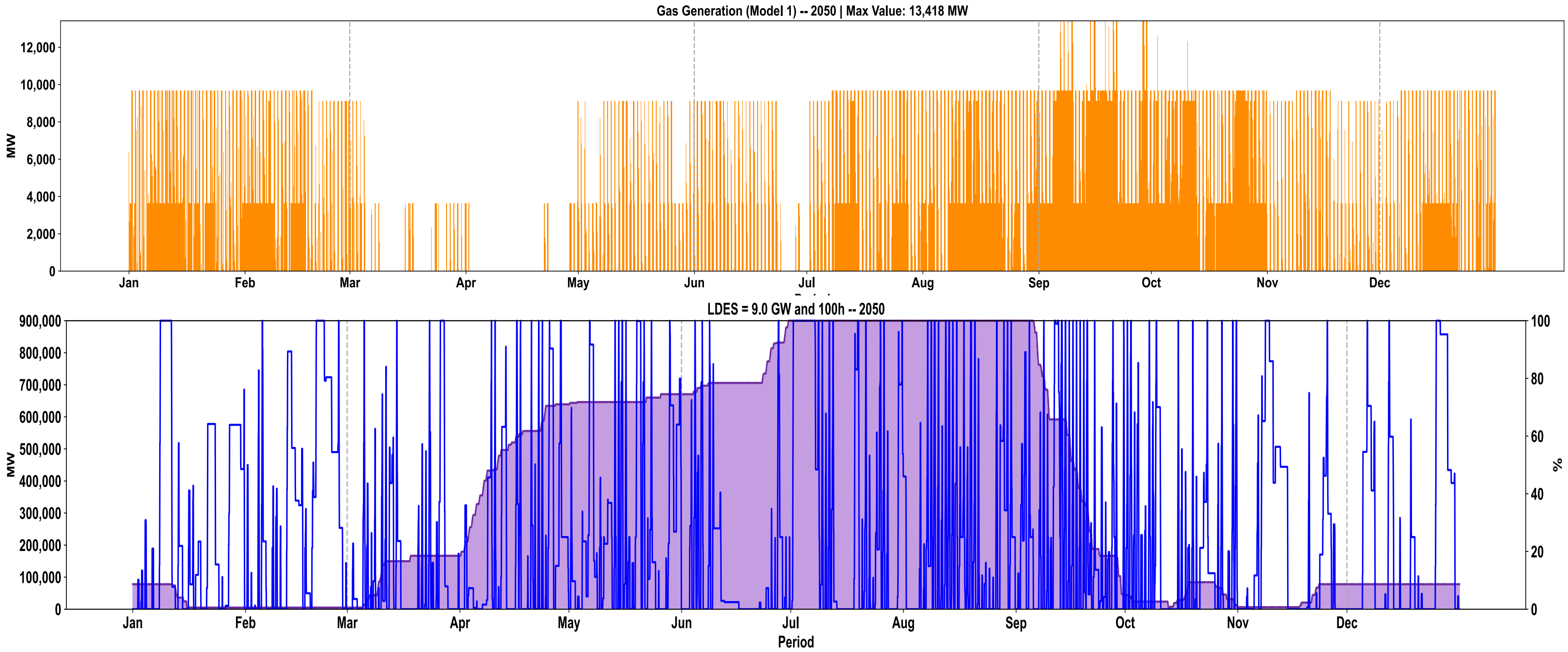
LDES vs Renewables Operation

It is easy to observe how LEDS charges with the increased availability of renewable sources and vice versa.



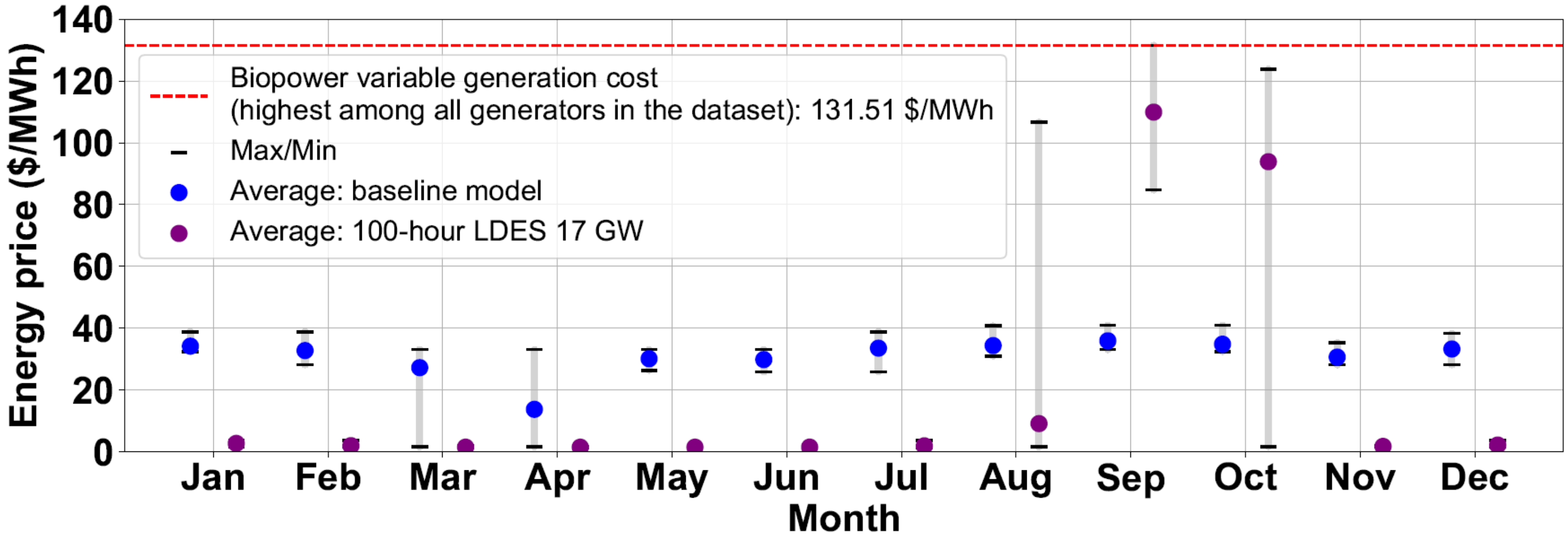


LDES vs SDES Operation



Energy Prices

- Energy prices become more frequently lower once gas generators are replaced by storage + renewables
- However, volatility is higher

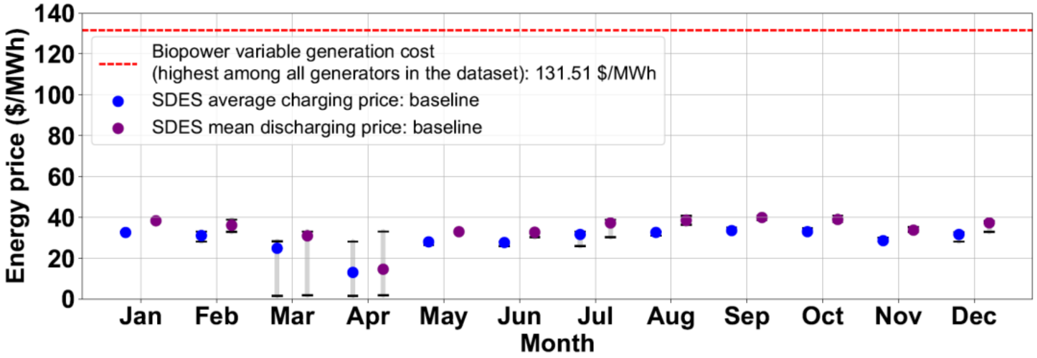


SDES Arbitrage

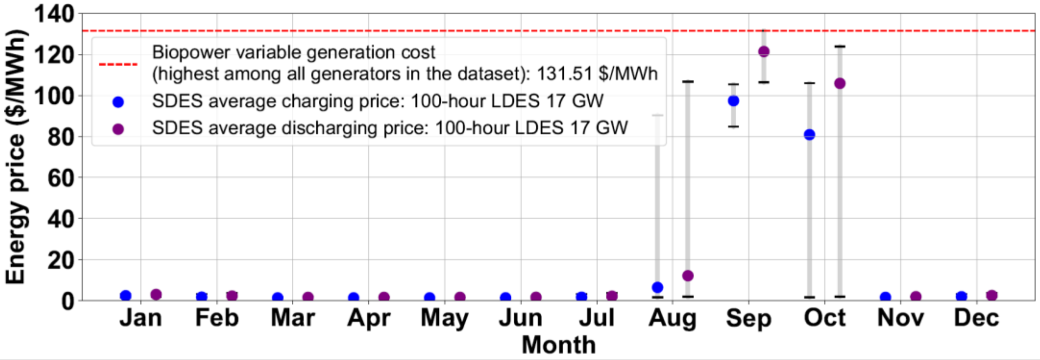
SDES arbitrage profit patterns change once gas generators are replaced by renewables +storage

Essentially, higher arbitrages profits are achieved during near scarcity situations

Baseline model

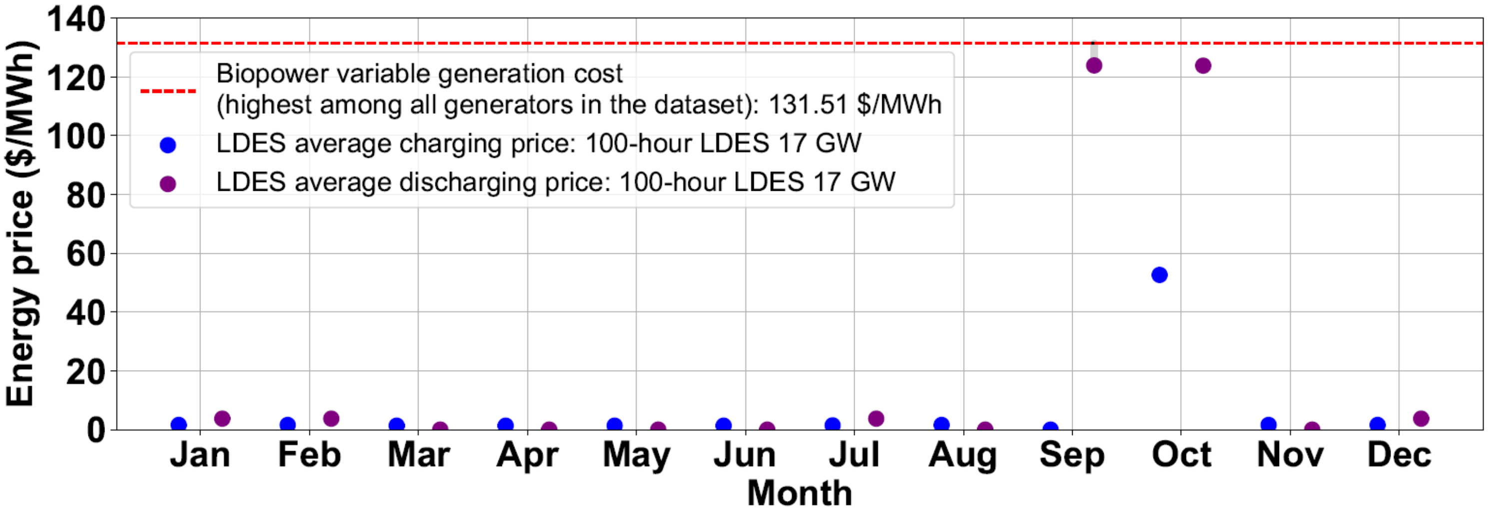


Opportunity value model



LDES Arbitrage

LDES is also more compensated during the end of summer



Paper

P. Silva, A. Moreira, M. Heleno and A. L. M. Marcato, "Boundary Technology Costs for Economic Viability of Long-Duration Energy Storage Systems in California," in *IEEE Transactions on Energy Markets, Policy and Regulation, https://ieeexplore.ieee.org/abstract/document/10638215.*

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