Supporting the Changing Grid: Grid-Interactive Water Heaters

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Q2 PROJECT UPDATE

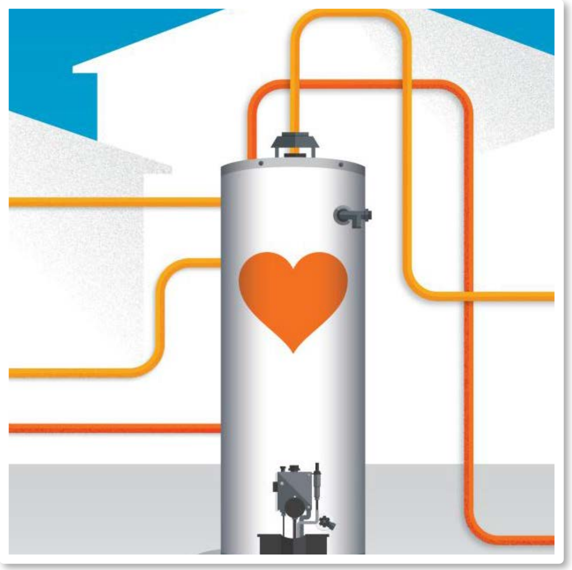


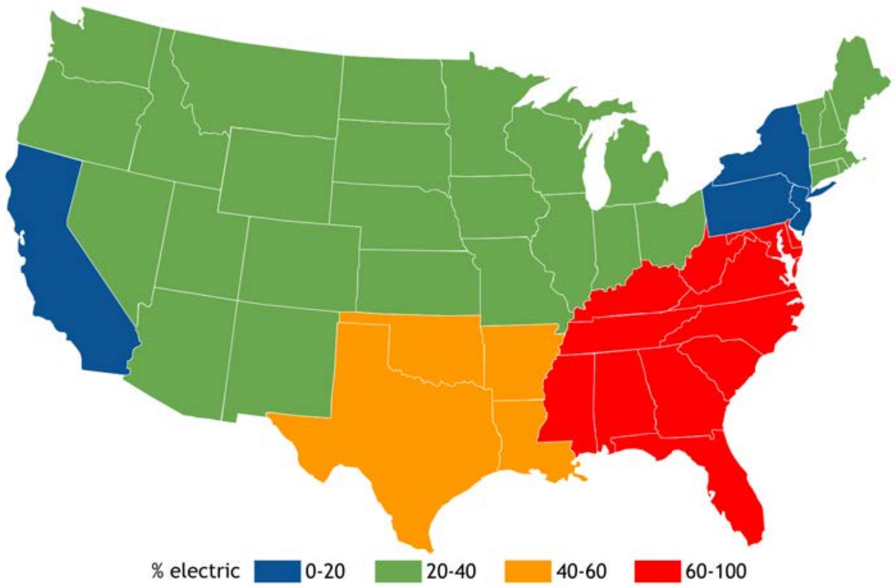
Image from:
PG&E's 2013 - 2014 Residential Water Heater Strategy. at <http://aceee.org/files/pdf/conferences/hwf/2013/4C-wilhelm.pdf>

Outline

- Introduction
  - How many water heaters are there?
  - How do water heaters work?
  - Value, ability, policy
  - Project summary
- Study of GIWH sensitivity to capacity and technology
  - Large capacity vs small capacity
  - Heat pump vs electric resistance
- Valuation of GIWH energy storage
- Next steps
- Conclusions and partnerships

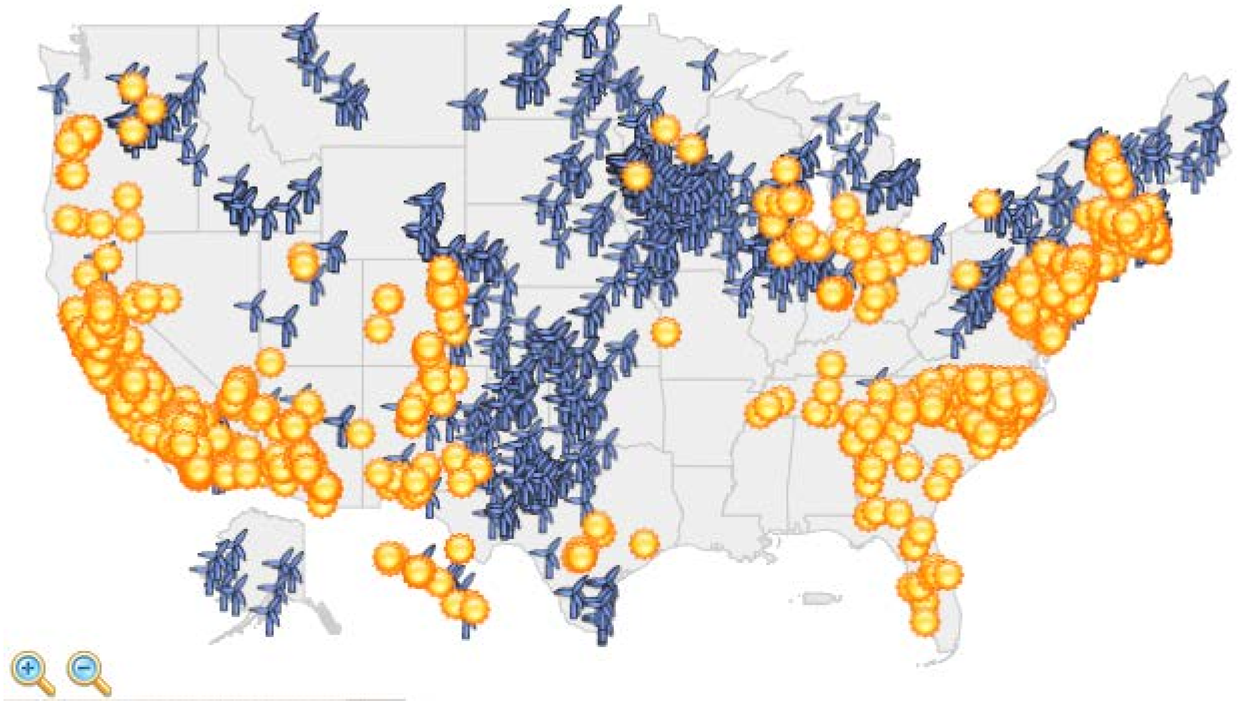
Electric water heaters are 200GW of opportunity on the grid

Resistance water heaters are prevalent…[1]



Overall there are ~53 million electric water heaters, and ~4 million are replaced annually.

… in some regions where renewables penetration increases the need for ancillary services[2]

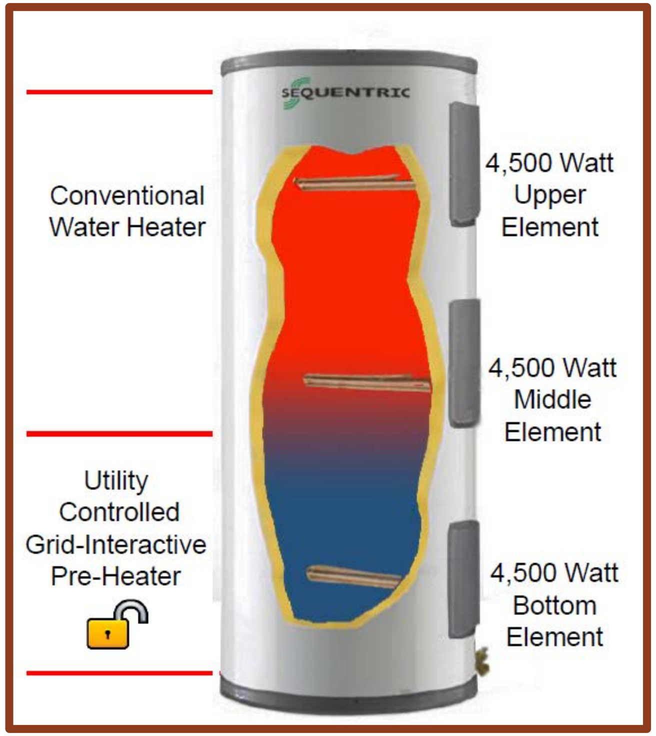


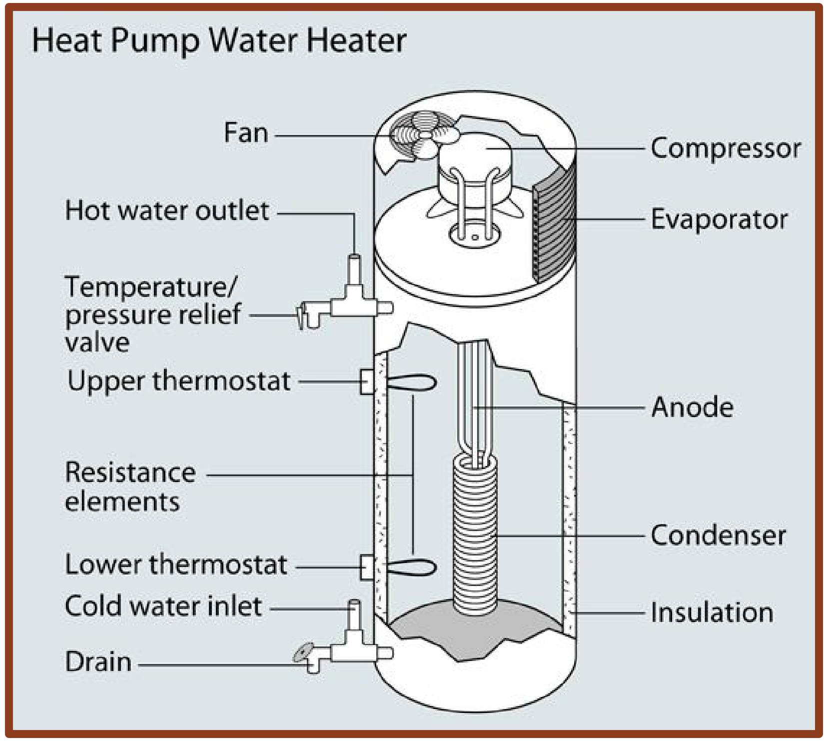
1 http://www.eia.gov/consumption/residential/data/2005/hc/hc8waterheating/pdf/tablehc13.8.pdf
http://c.ymcdn.com/sites/www.peakload.org/resource/resmgr/2014FallArchive/ConnettGIWH.pdf (53m/4m)
2 http://www.nrdc.org/energy/renewables/energymap.asp
http://www.demandresponsedirectory.com/get_DRD_file.php?file=Emerging%20Market%20for%20Grid-Interactive%20Water%20Heating.pdf

How do electric (storage) water heaters work?

Sequentric/Vaughn:
3-element heater
100% eff; 1-2s

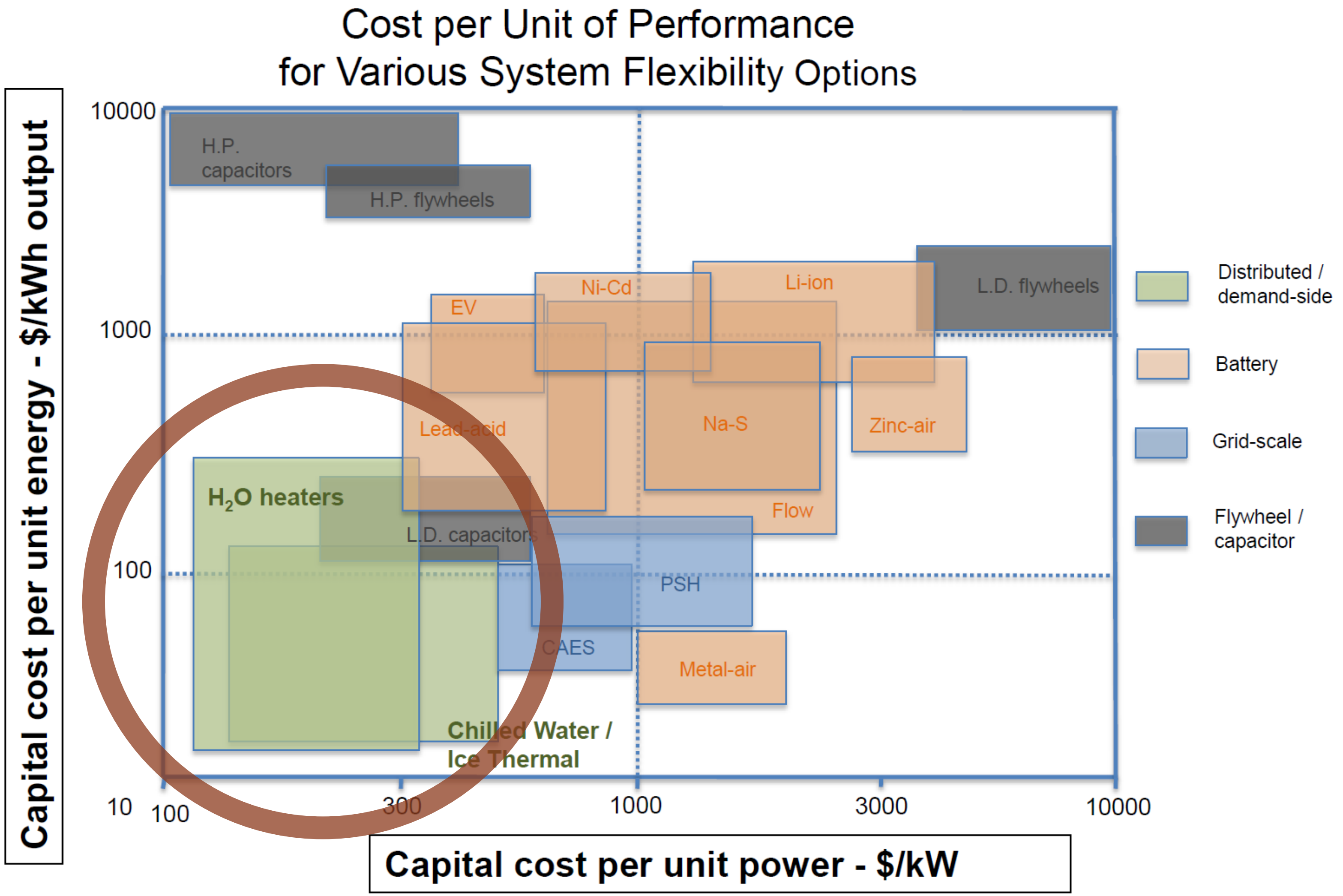
GE Appliances:
Hybrid HP
200% eff; no DEC; $4HP = 1ER$





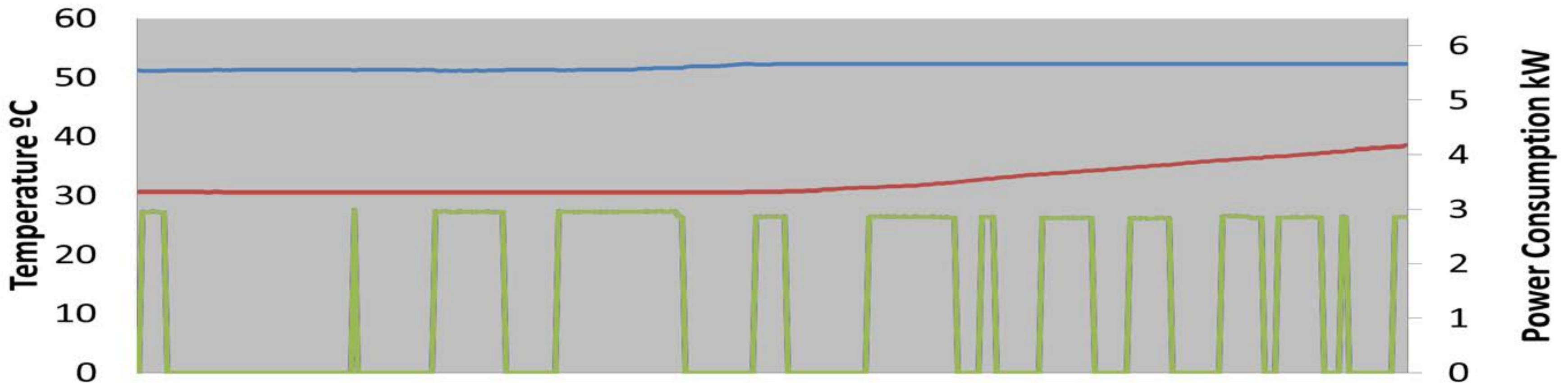
Aquanta. Cool Technology for Hot Water. by Sunnovations — Kickstarter. at <https://www.kickstarter.com/projects/651800236/aquanta-cool-technology-for-hot-water>
Eric Rehberg. Grid Interactive Water Heating. (2013). at <http://aceee.org/files/pdf/conferences/hwf/2013/3C-rehberg.pdf>
Widder, S. H., Parker, G. B., Petersen, J. M. & Baechler, M. C. *Demand Response Performance of GE Hybrid Heat Pump Water Heater*. (Pacific Northwest National Laboratory, 2013). at <http://www.pdf177.com/pdf/demand-response-performance-of-ge-hybrid-heat-pump-water-4612.pdf>

Water heating has remarkable thermal storage value

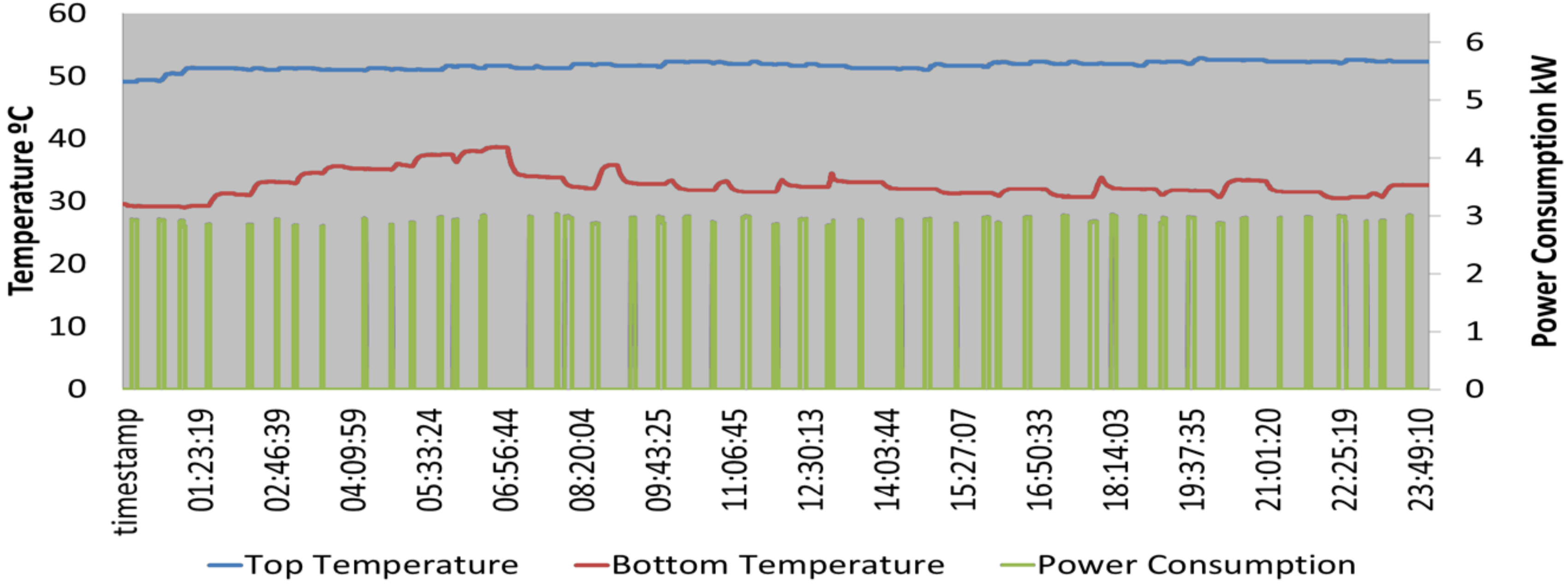


Jim Lazar. Teaching The Duck To Fly. (2014). at <http://www.raponline.org/document/download/id/6999>

GIWH can load-shift in concentrated dispatch (VPP, DR)



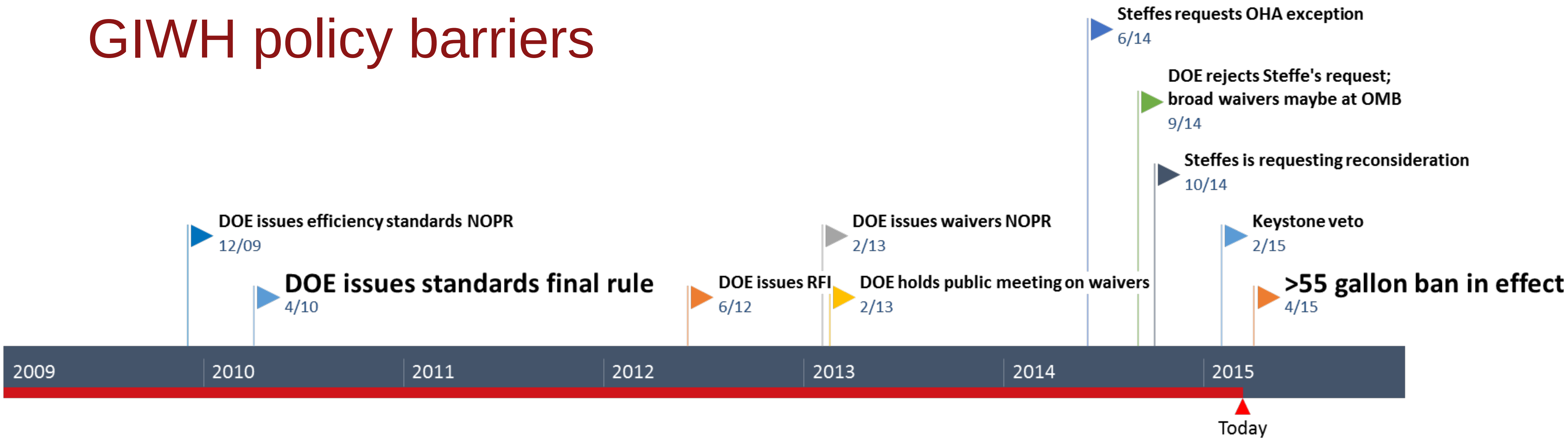
… or they can provide regulation w/ <2s response



Stanford University

Eric Rehberg. Grid Interactive Water Heating. (2013). at <http://aceee.org/files/pdf/conferences/hwf/2013/3C-rehberg.pdf>

GIWH policy barriers



DOE Energy Conservation Standards require energy factor of ≈2 for >55gal WH

- effectively only HPWH can meet these standards

NEEA HPWH tiers limit capability for hybrid electrical/resistive heating

- tiers can determine utility rebate; guide buying patterns
- effectively limiting hybrid HPWH use as GIWH

California CEC Title 24 may limit GIWH as replacements

Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment: Residential Water Heaters. at <http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/water_heater_load_shift_rfi_notice_2012_06_06.pdf>
Northern Climate Qualified Heat Pump Water Heaters Last updated November 13, 2014. (2014). at <http://neea.org/docs/default-source/northern-climate-heat-pump-water-heater-specification/qualified-products-list.pdf>
A Specification for Residential Heat Pump Water Heaters Installed in Northern Climates Version 5.0. (2013). at <http://neea.org/docs/northern-climate-heat-pump-water-heater-specification/northern-climate-specification.pdf>
Keith Dennis. GIWHs Waivers vs. Classification DOE and Congress. at <http://c.ymcdn.com/sites/www.peakload.org/resource/resmgr/2014FallArchive/Dennis.pdf>
RE: Ex Parte Communication, Docket EERE-2012-BT-STD-0022. (2014). at <http://energy.gov/sites/prod/files/2014/09/f18/Ex_Parte_Communication_-_DOE_Water_Heater_Meeting_-_Sept212014_0.pdf>
Lewis PUD County HPWH Incentive Program. at <http://lcpud.org/assets/pdf/FY_2014HP_Water_Heater_rebate.pdf>

What is the opportunity?

Opportunity:

This is a large, cheap energy storage resource

Technically well-studied and known to work as a 1-4s resource

Even more added value as utilities think about high renewable penetration and fuel switching

Challenges:

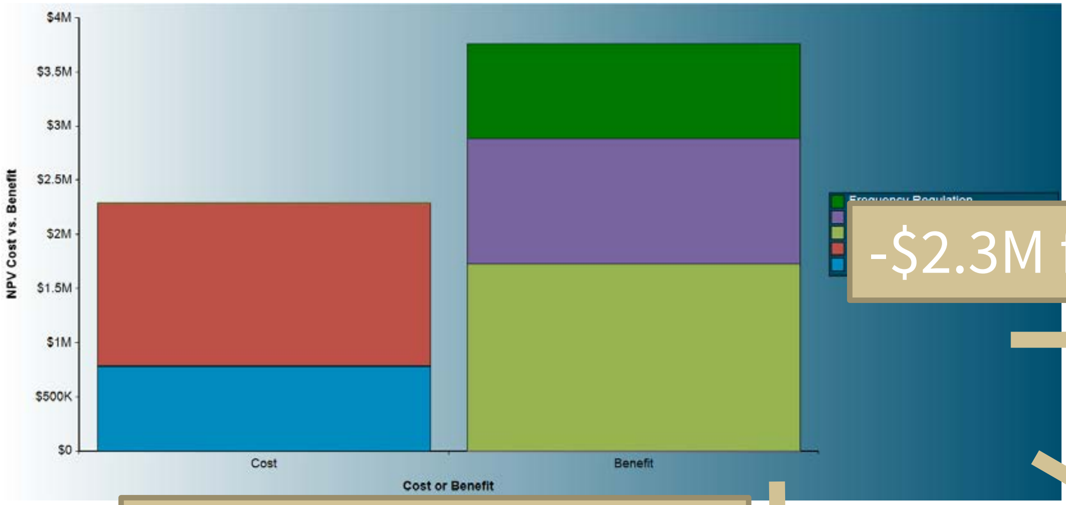
Current policy is led by individual efficiency directives, not overall grid efficiency

Policymakers don't have a good idea of whether grid services can also be provided by high efficiency water heating (either small capacity or heat pumps)

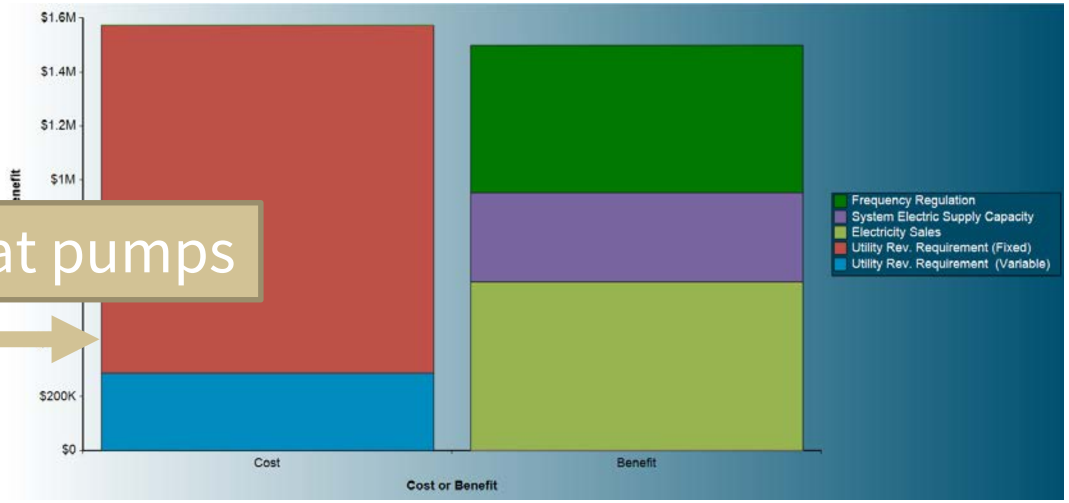
Technology is billed as a useful service to be sold by the utility—not as a competing technology as storage

Project summary: CAISO, 10,000 water heaters

80gal ER, 120°F ± 5°F: $2.35M NPV



80gal **HP**, 120°F ± 5°F: -$74K NPV

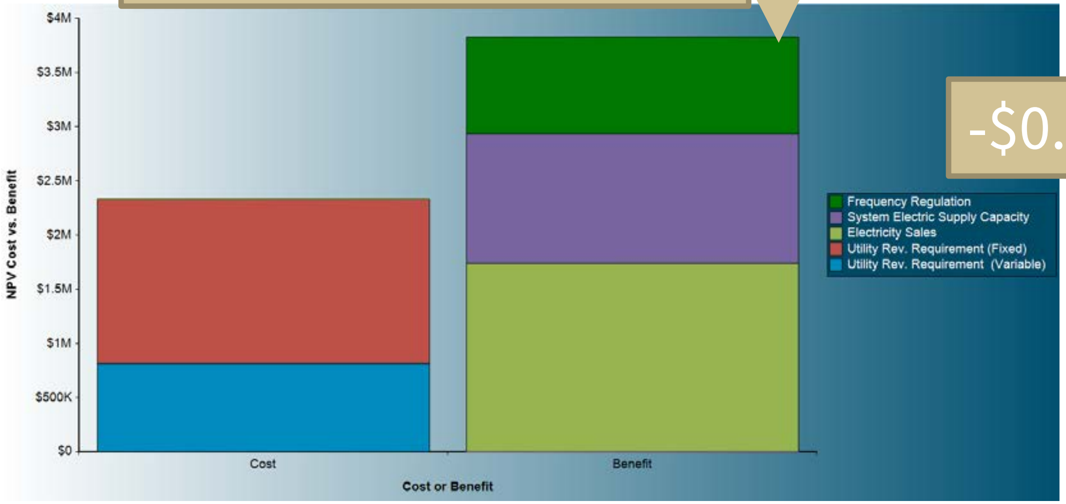


-$2.3M for heat pumps

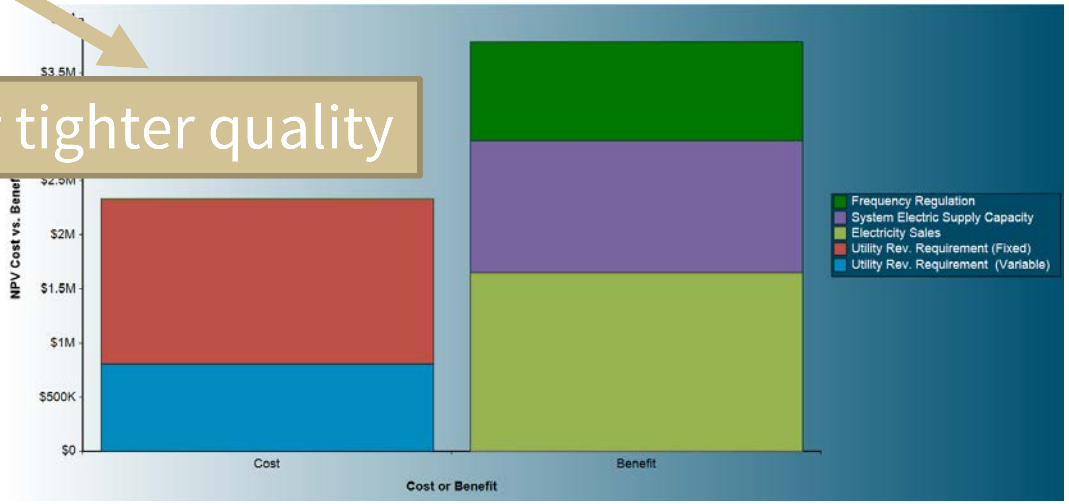
-$0.8M for smaller WH

-$0.9M for tighter quality

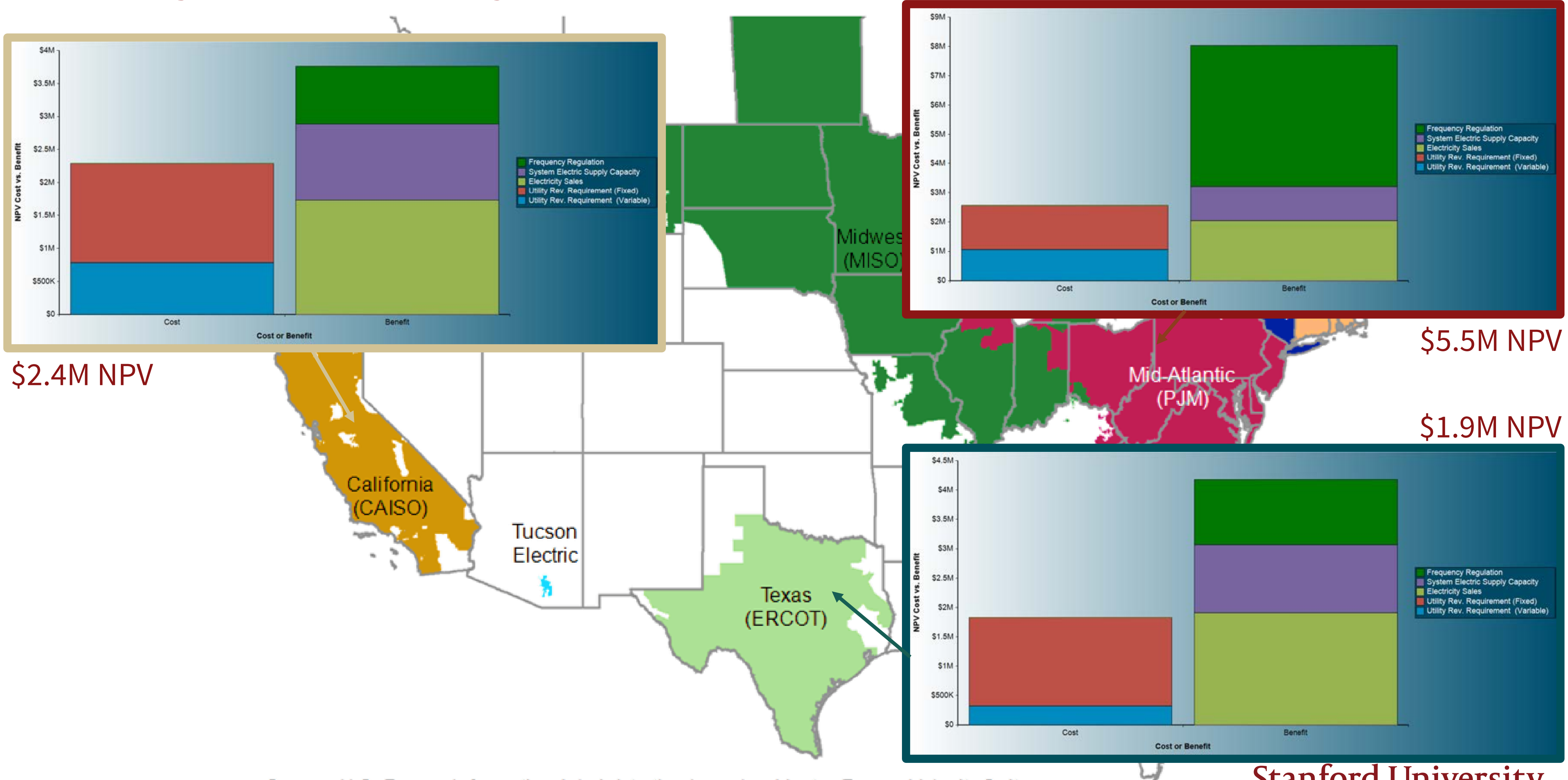
60ga



80gal ER, 120°F ± **2.5°F**: $1.45M NPV



Project summary: CAISO vs PJM vs ERCOT



Source: U.S. Energy Information Administration based on Ventyx Energy Velocity Suite.

Objective 1: stochastic model of 100, 1000, 10000 WH

Value?

- Produce the first validation-ready model which focuses on modeling the capacity and ramping ability of a large fleet of water heaters, over different geographic zones

Inputs

- GridLAB-D code (up to date with both ER and HP WH, as provided by PNNL)
- Fleet location
- Validation: working with EPRI and DirectEnergy on obtaining time-series data

Task (code):

- Stochastically generate houses with random demands within a known climate (TMY climate data for PJM, MISO, ERCOT)
- Extend water heater code in GLD
- Implement DR signal code into GLD

Outputs

- Sensitivity study: given *a temperature deadband, water heater capacity, and an ISO*, amount of possible storage capacity over time
- Above for both resistance and heat pump WH

Objective 1: stochastic model of 100, 1000, 10000 WH

Input parameters

Stochastically-generated water demand of a typical US home (200L/day) and TMY (typical meteorological year) climate data of cities in CAISO, PJM, ERCOT

100 generated homes:

Case 1: 80gal **HP and ER** water heaters, DR deadband of +/- 5°F

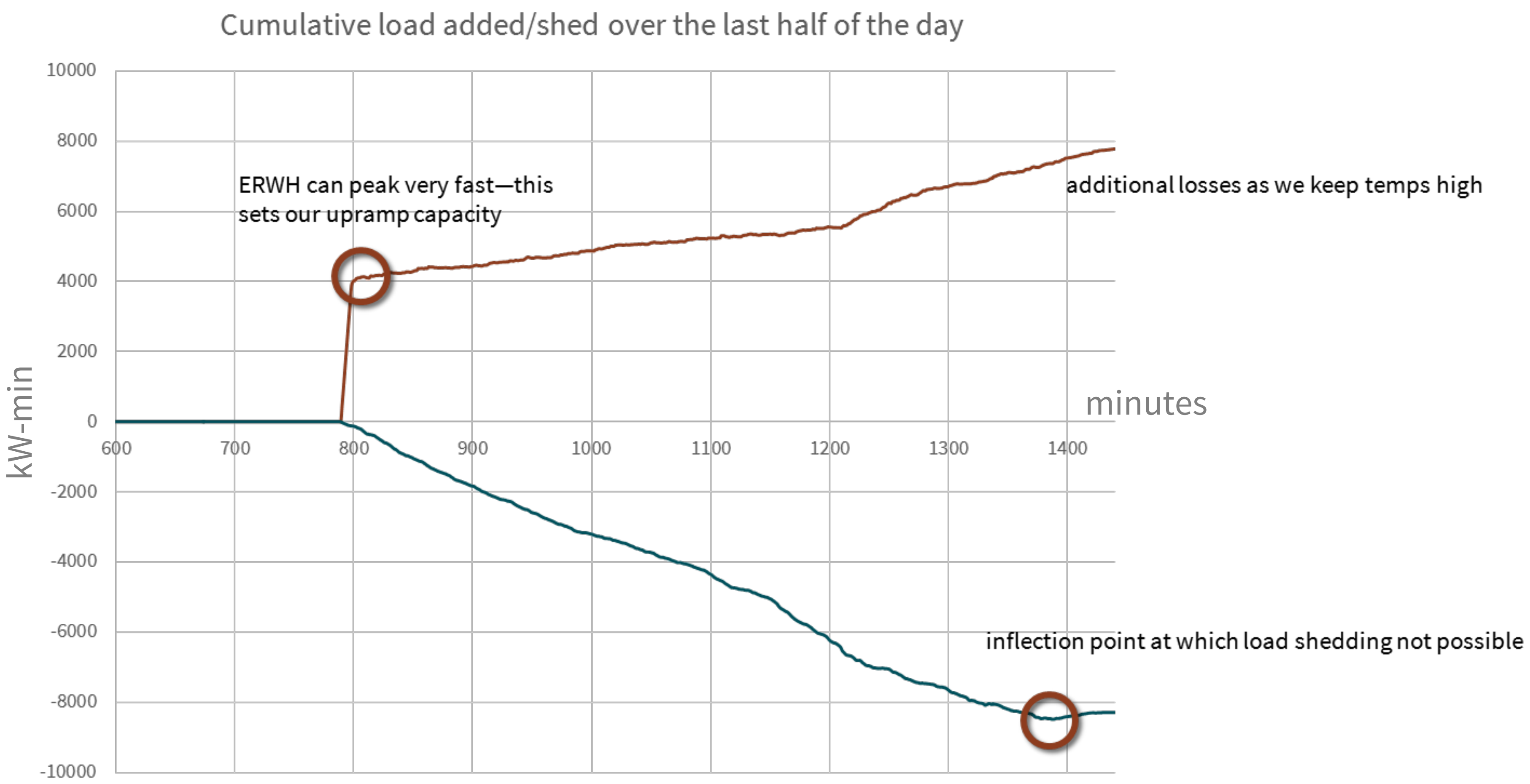
Case 2: 60gal **HP and ER** water heaters, DR deadband of +/- 5°F

Case 3: 80gal **HP and ER** water heaters, DR deadband of +/- 2.5°F

Apply a DR signal at a common time (first-order estimates of DR capability)

Case 1: total “storage” (kW-min) over 100 units

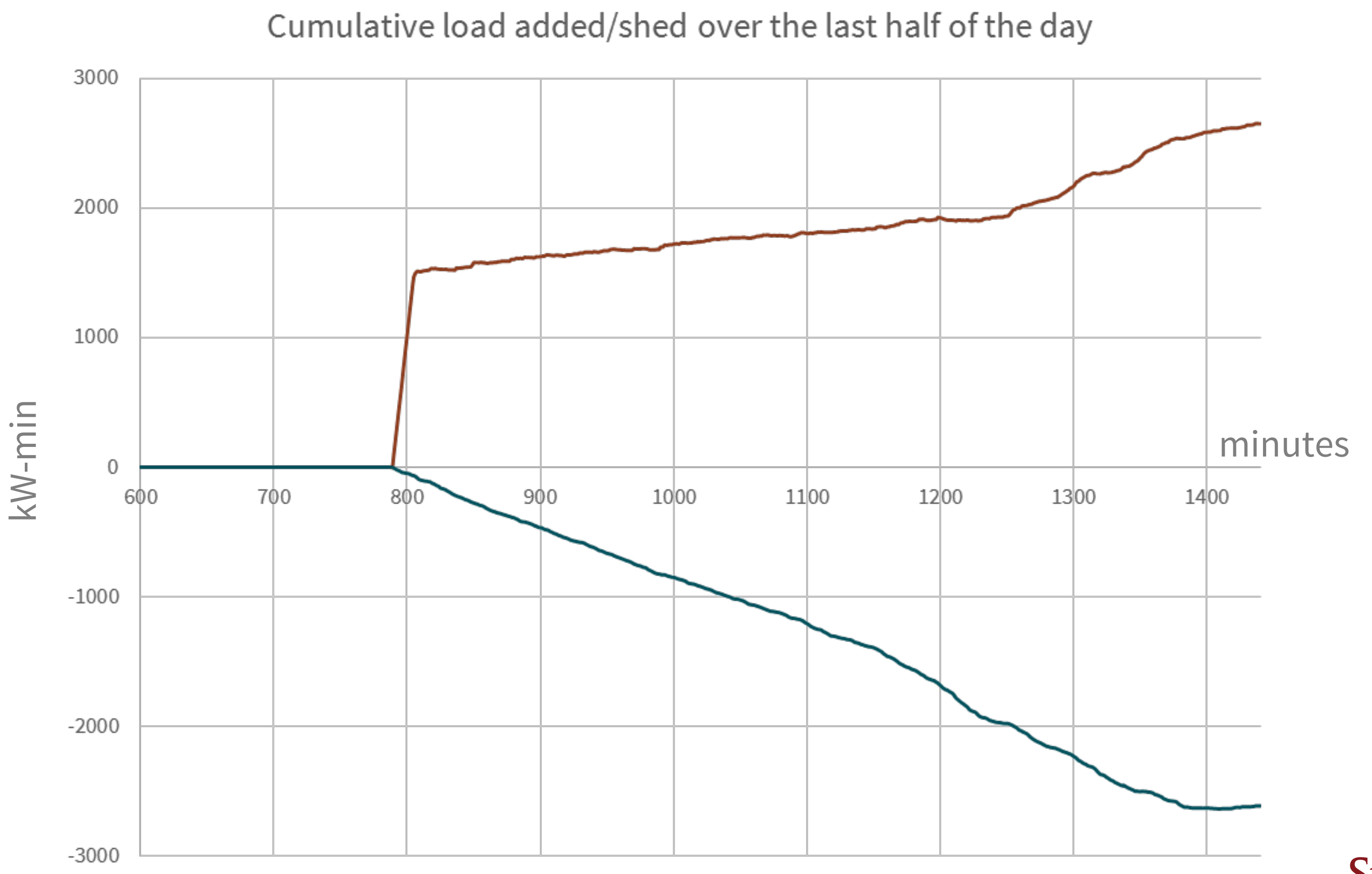
Case 1: 80gal **ER** water heaters, DR deadband of +/- 5°F, cumulative power profiles



Case 1: total “storage” (kW-min) over 100 units

Case 1: 80gal **HP** water heaters, DR deadband of +/- 5°F, cumulative power profiles

Result is surprisingly similar, but scaled; HP takes into account ambient T for COP



Performance: electric resistance vs heat pump

Parameter	80gal, +/- 5F	HP 80gal, +/- 5F	60gal, +/- 5F	HP 60gal, +/- 5F	80gal, +/- 2.5F	HP 80gal, +/- 2.5F
Storage capacity based on discharge (kWh)	154	44	145	28	118	40
Discharge rate (kW)	14	4	14.5	4	14.7	4
Discharge time (h)	11	11	10	7	8	10
Charge rate (kW)	430	91	425	90	430	90
Charge time (min)	9-10	16	7	12	2	3

Overall, between 3 to 5x less storage capacity for HPWH—similar to PNNL hardware study results

New knowledge: 80gal vs 60gal vs deadband

Objective 2: valuation of water heaters on the grid

Value?

- With our (unique computational) knowledge of how WH models work, we can vary capacity, deadband temperatures, and climate zones to value a fleet of ER vs HP WH.
- First (known) use of EPRI ESVT to value water heater thermal storage

Inputs

- Battery output and input parameters as from objective 1
- EPRI ESVT
- Parameters within ESVT (CAISO-, PJM-, ERCOT-relevant)

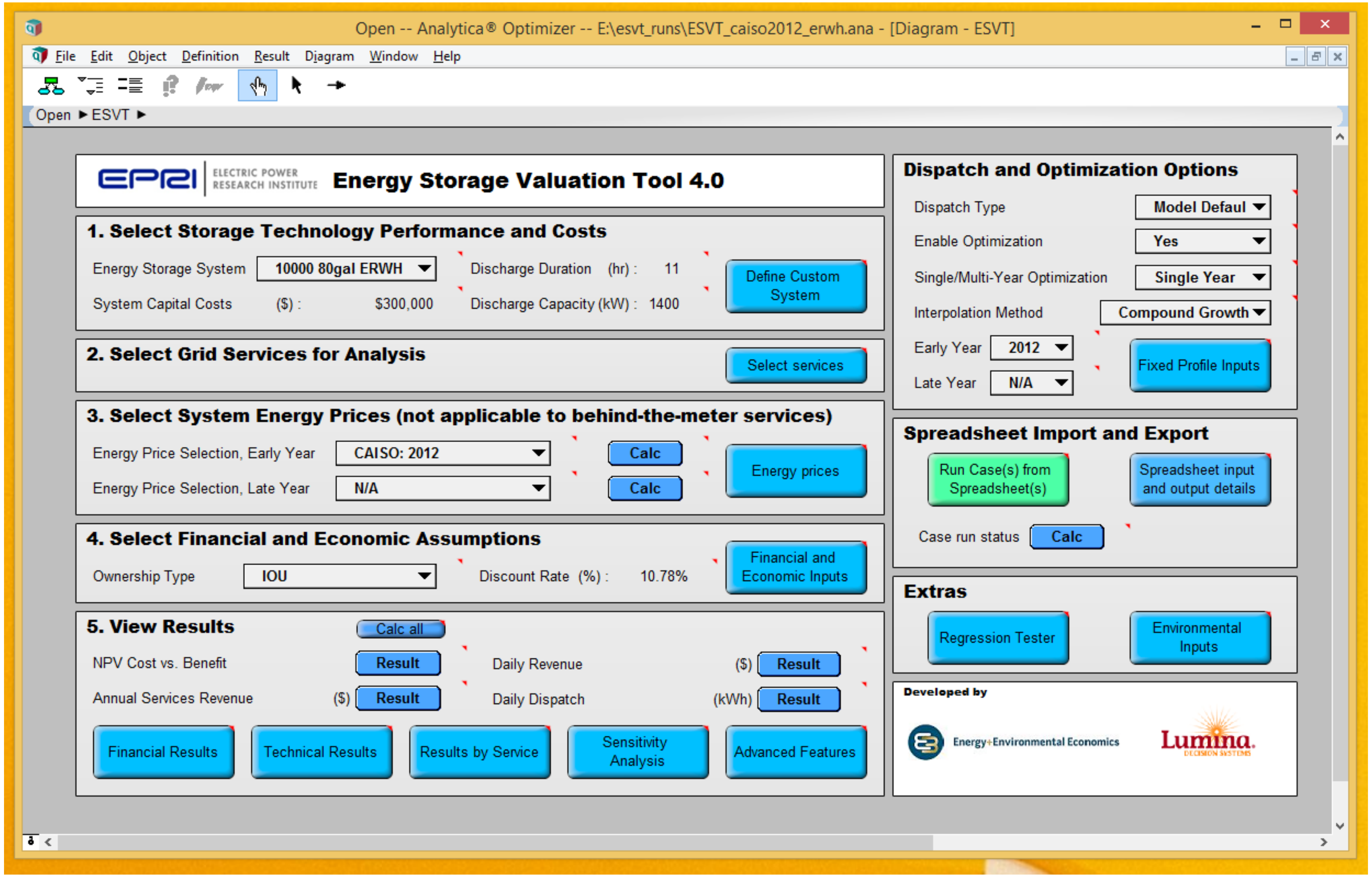
Task

- Work with VoStorage team to run ESVT with best-known inputs
- Use appropriate storage parameters to run ESVT models
- Future: calculate environmental/integration benefits within ESVT

Outputs

- Economic comparison of resistance and heat pump water heaters across ISOs

Objective 2: valuation of water heaters on the grid



Objective 2: valuation of water heaters on the grid

From ESVT manual:

Category	Input	2020					2015	
		Battery*	Flow Battery	PHS	AG CAES	CT**	Battery	Flow Battery
Technology Cost / Performance	Nameplate Capacity (MW)	50	50	300	100	50	50	50
	Nameplate Duration (hr)	2	4	8	8	-	2	4
	Capital Cost ($/kWh) -Start Yr Nominal	528	443	166	211	-	603	775
	Capital Cost ($/kW) - Start Yr Nominal	1056	1772	1325	1684	1619	1206	3100
	Project Life (yr)	20	20	100	35	20	20	17
	Roundtrip Efficiency	83%	75%	82.50%	-	-	83%	70%
	Variable O&M ($/kWh)	0.00025	0.00025	0.001	0.003	0.004	0.00025	0.00025
	Fixed O&M ($/kW-yr)	15	15	7.5	5	17.4	15	15
	Major Replacement Frequency	1	0	-	-	-	1	0
	Major Replacement Cost ($/kWh)	250	-	-	-	-	250	-
	MACRS Depreciation Term (yr)	7	7	7	7	7	7	7
	Energy Charge Ratio (CAES)	-	-	-	0.7	-	-	-
	Full Capacity Heat Rate (CAES/CT)	-			3810	9387	-	-
	Heat Rate Curve (CAES/CT)	-	-	-	see wkst	see wkst	-	-
	Turbine Efficiency Curve (PHS)	-	-	see wkst	-	-	-	-
	Pump Efficiency (PHS)	-	-	see wkst	-	-	-	-

Technology Type	Charging Ability (Electric Power)	Non-electric Fuel Use	Constrained Charging*	Constrained Discharging*
Battery/Flywheel	Yes	No	No	No
Pumped Storage	Yes	No	Yes	No
CAES	Yes	Yes	No	Yes
CT	No	Yes	N/A	Yes

*Constraints include non-trivial start-up costs, start-up times, and minimum operating levels

This Guide generally presents one DA and one RT optimization formulation across all technologies. The next subsection defines the optimization problems for each technology separately in order to call attention to the key differences.

We have modeled the WH as a normal battery/flywheel, as heat inputs and constraints on charging are not required

Objective 2: valuation of water heaters on the grid

Example parameters of 10000 ERWH, 80gal, 10 degree DR deadband

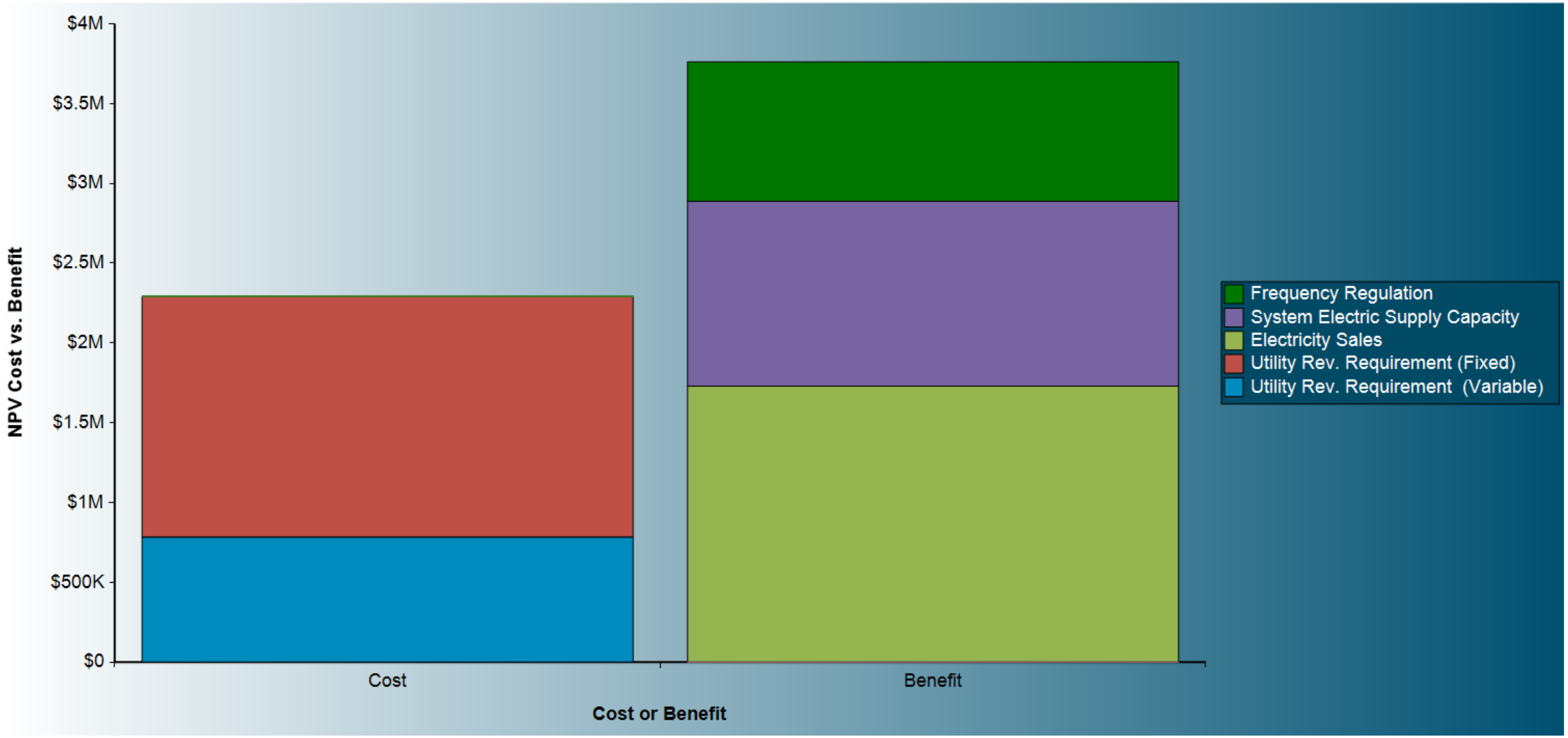
Parameter	
Maximum plant life (years)	15
Discharge Capacity (kW)	1400
Discharge Capacity (kVA)	1400
Discharge Duration (hours)	11
Depth of Discharge	1
Charge Capacity (kW)	43000
Annual degradation	0
AC-AC RT Eff	1.00
Capital cost ($)	**10000 * $30 = $300K ($214/kW)** **10000 * $100 = $1000K ($714/kW)** **(all presented results are at $100/unit for comms)**
Housekeeping power	0
Capital cost ($/kW)	0 as input; can vary as sensitivity
Capital cost ($/kWh)	0 as input; can vary as sensitivity
Variable O&M ($/MWh)	Assume 2.5 (similar to resource adequacy cost)
Fixed O&M ($/kW-year)	Assume 28 (similar to resource adequacy cost)
Technology replacement years	15
Battery replacement costs ($/kWh)	15 (not necessarily, assuming no battery degradation)
Replacement costs (reduction %/yr)	0

Technology/model knowns

Sensitive guesses

Objective 2: valuation of water heaters on the grid

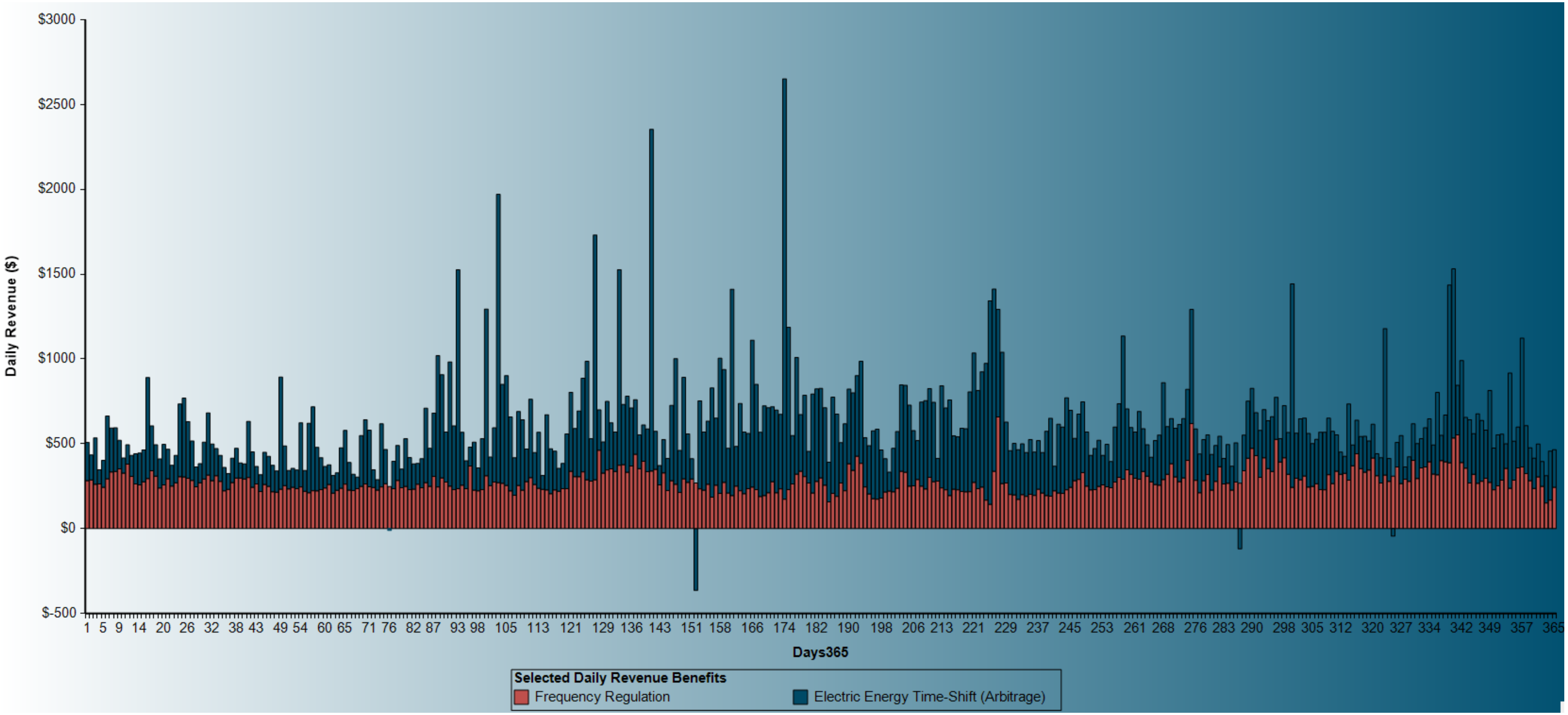
10000 80gal ERWH, CAISO



Small tanks can easily do regulation, and large tanks end up having quite some value as load-shifting. Also, this is CAISO…

Objective 2: valuation of water heaters on the grid

10000 80gal ERWH, CAISO: daily revenue

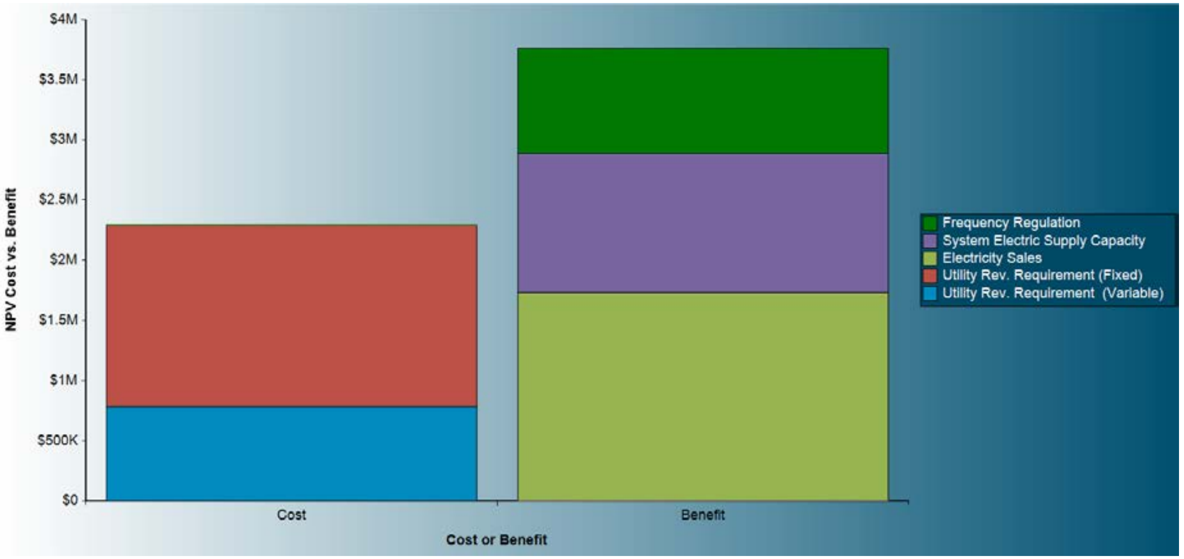


Objective 2: valuation of water heaters on the grid

Next steps:

- Better support chosen input parameters (though cost and discharge parameters seem within published experimental data)
  - Validation with time-series data from technology partners
- Regressions/sensitivity tests on all input parameters
- Close the loop: use output dispatch model and feed this back into WH model to ensure water heaters can match regulation signal without compromising quality

Conclusion



- There is substantial value, especially *now* (technology is much cheaper than current lithium)
- We wish to confirm our data with real time-series data
- Extend value of storage to environmental results for a highly-renewable grid
- Additional research on retrofits vs new installs
- Continuing research on behalf of CPAU/PJM

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