DESIGN OF ENERGY STORAGE UNIT FOR THE SPARTAN SUPERWAY TRANSPORTATION NETWORK

ME295A
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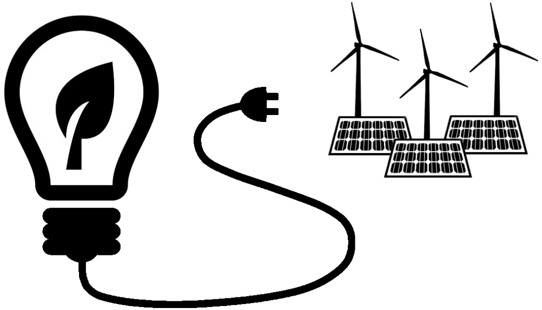
Personal Background

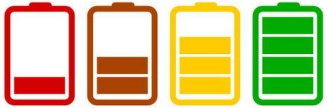
SJSU SAN JOSÉ STATE UNIVERSITY



Source: https://www.sjsu.edu/communications/identity/powersource/marks/

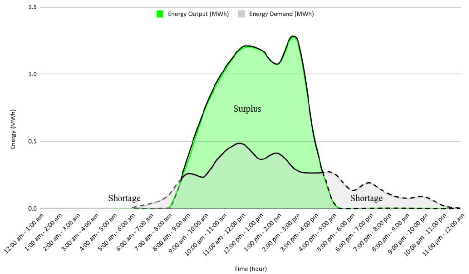
This presentation focuses on current research and analysis for storage unit design options

Introduction / Background



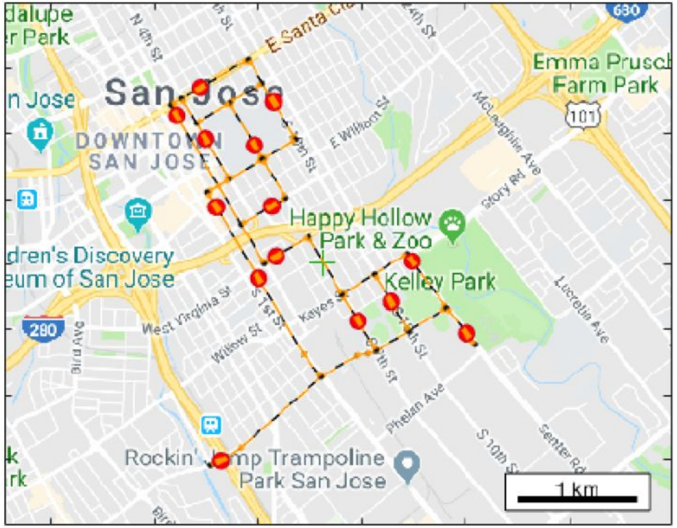
Objectives

Methodology



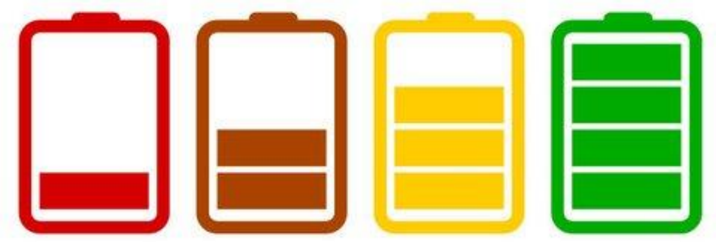
Results / Summary

The Spartan Superway is an opportunity reduce inimical impacts of modern transportation methods

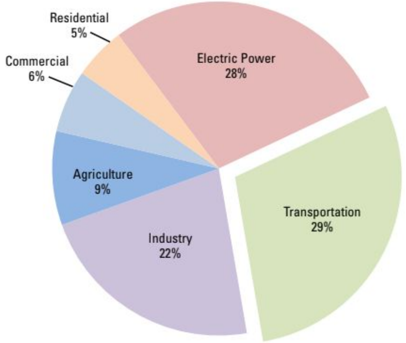


Source: / Furman, B., & Swenson, R. (2019). Solar Powered Automated Rapid Transit Ascendant Network. Retrieved from https://www.inist.org/library/2019-10-14.FurmanSwenson.SPARTAN.SJSU_WhitePaper.pdf / Fogelquist, J. B. (2019). Computational Aid for Designing PV Canopy for Solar-Powered Transit. San Jose, CA: San Jose State University.

Propose design for energy storage unit that can be deployed for Superway network

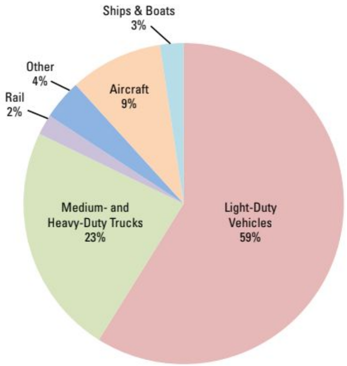


Transportation sector has critical implications on the environment and public safety



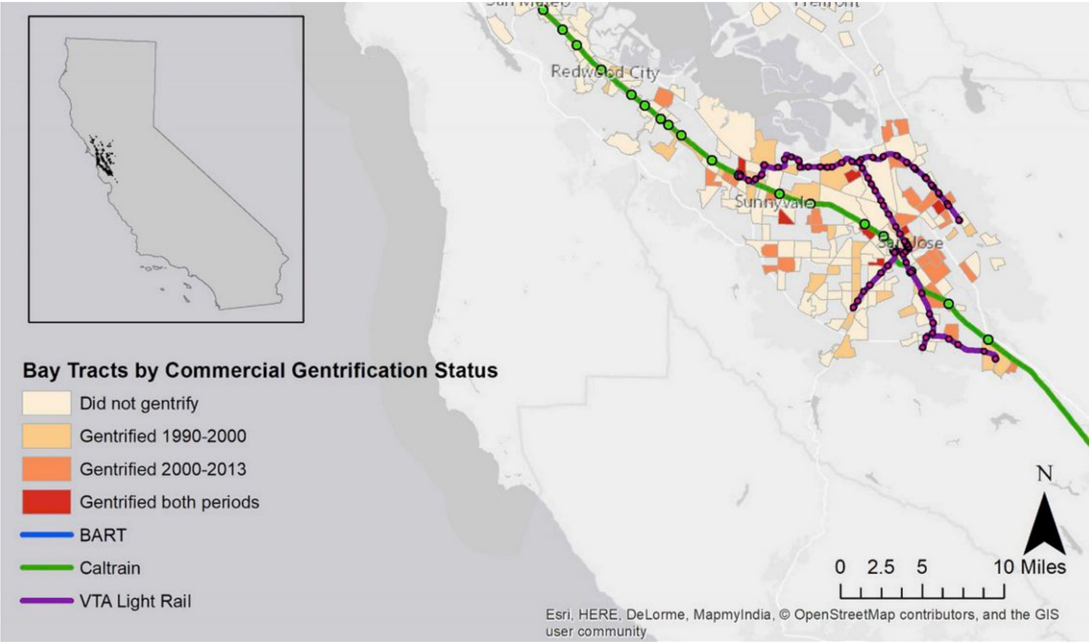
Share of U.S. GHG Emissions by Sector, 2017[3,4]

Note: Totals may not add to 100% due to rounding.



Share of U.S. Transportation Sector GHG Emissions by Source, 2017[4,5]

Note: Totals may not add to 100% due to rounding.



Source: U.S. Environmental Protection Agency, Office of Transportation and Air Quality. (2019, June). Fast facts: U.S. Transportation Sector Greenhouse Gas Emissions 1990-2017. Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100WUHR.pdf / González, S., Loukaitou-Sideris, A., & Chapple, K. (2019). Transit neighborhoods, commercial gentrification, and traffic crashes: Exploring the linkages in Los Angeles and the Bay Area. Journal of Transport Geography, 77, 79-89.

The Spartan Superway is considered an automatic transit network

PRT Morgantown, West Virginia

ParkShuttle, Netherlands

PRT, Madagascar

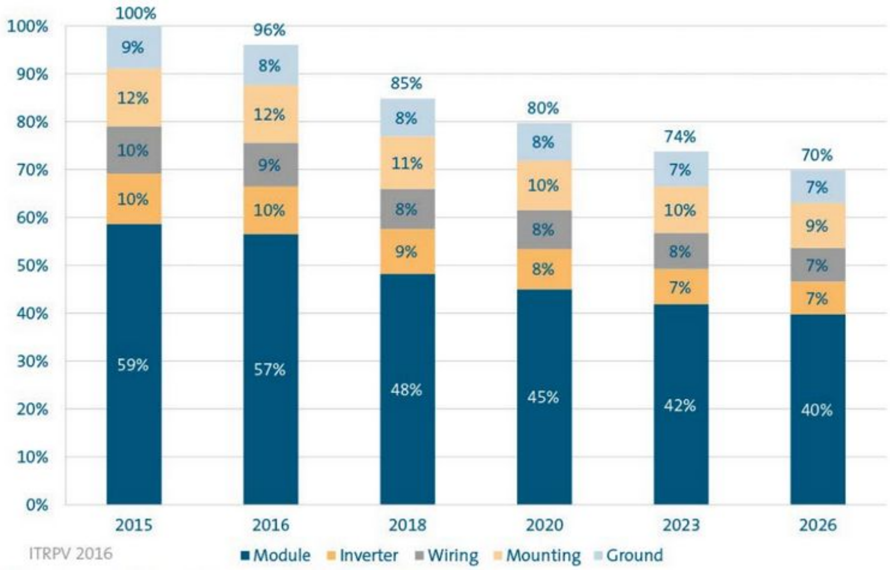
Shuttle, London

PRT, South Korea

Source: Furman, B., Fabian, L., Ellis, S., Muller, P., & Swenson, R. (2014). Automated Transit Networks (ATN): A Review of the State of the Industry and Prospects for the Future. Mineta Transportation Institue, 19-25.

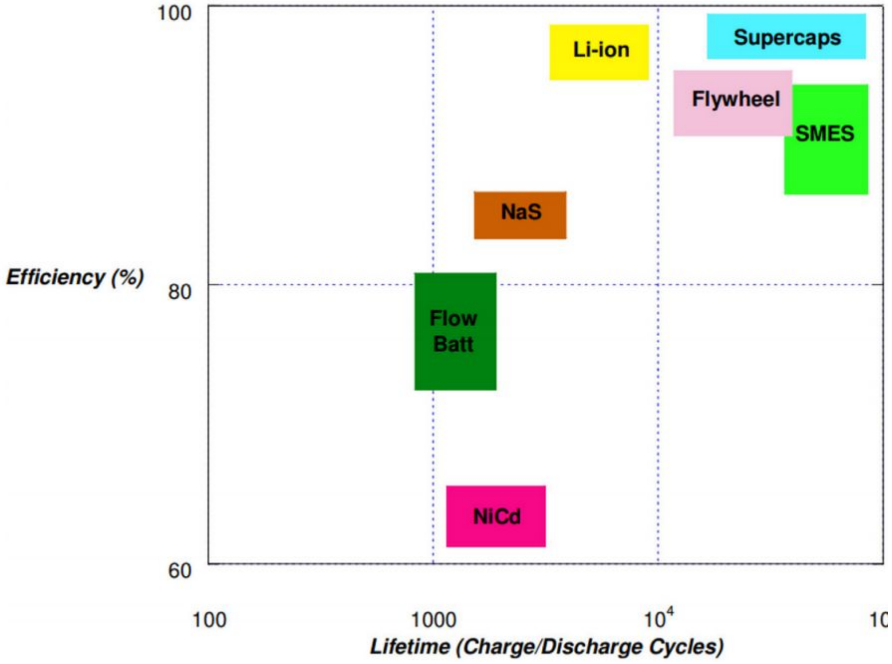
Megawatt and gigawatt arrays are becoming more common while systems show decreasing costs

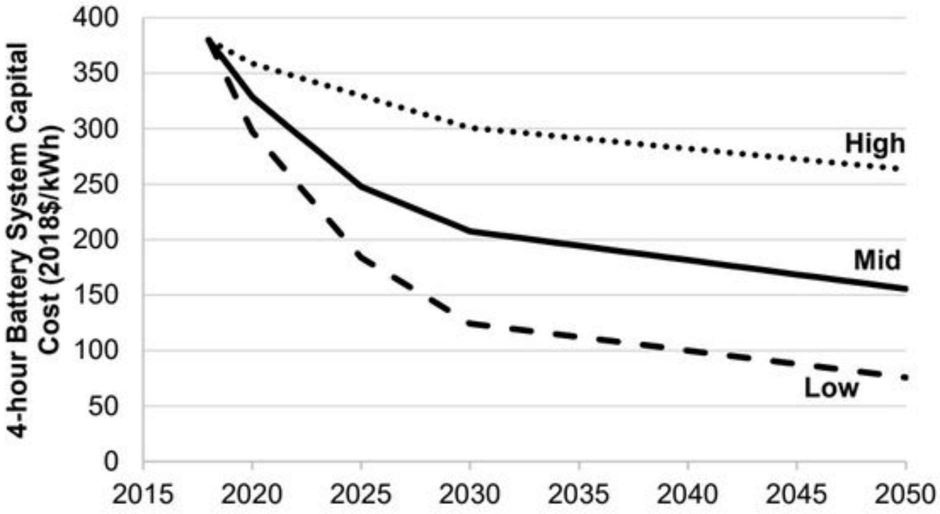
PV Cell Technology	Band-gap [eV]	Manufacturing Processes	Efficiency Record [%]
Crystalline Silicon			
Mono-crystalline	1.11	Cz-Si, float-zone, BST	27.6 (26.1)[a]
Poly-crystalline	1.11	BCG, block-casting	22.3
HIT	1.11	Deposition	26.6
Micro	1.11	PECVD, HWCVD	21.2
Thin-film			
CIGS	1.7	scr.-print, coat, MOCVD	23.3 (22.9)[a]
CdTe	1.5	sputter., HVE, MOCVD	22.1
Amorphous Si:H	1.5–1.8	PECVD	14
GaAs	1.42	VGF, BST, LEC, MOCVD	30.5 (29.1)[a]
Multi-junction	multiple	MOCVD, mech.-stacking	46
Emerging			
Organic	1–4	Roll-to-roll mfg.	15.6
Dye-sensitized	≈ 3.2	Roll-printing	11.9
Perovskite	≈ 1.5	spin-coat, scr.-print, VD	28 (24.2)[a]



Source: Shubbak, M. H. (2019). Advances in solar photovoltaics: Technology review and patent trends. Science Direct, 1-5. / Trube, J. (2016). International Technology Roadmap for Photovoltaic. Retrieved from Trube, J. (2016). International Technology Roadmap for Photovoltaic. Retreived from https://solarcluster-bw.de/fileadmin/user_upload/PDF/Solarbranchentag/1515_3_Trube_VDMA.pdf

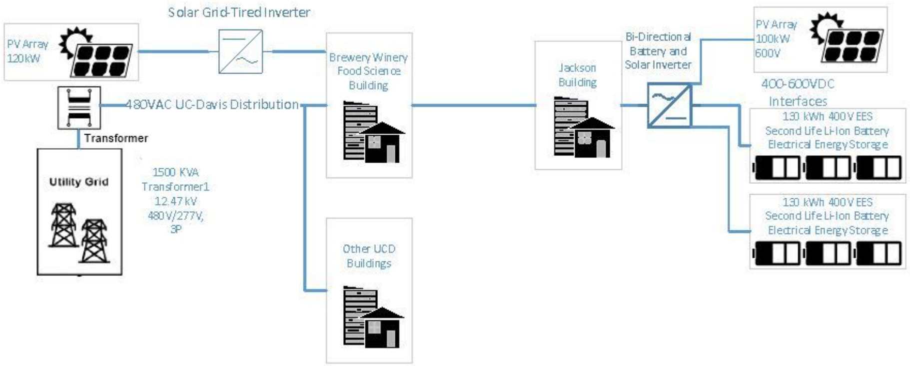
Lithium technologies show potential for storage systems while systems show decreasing costs





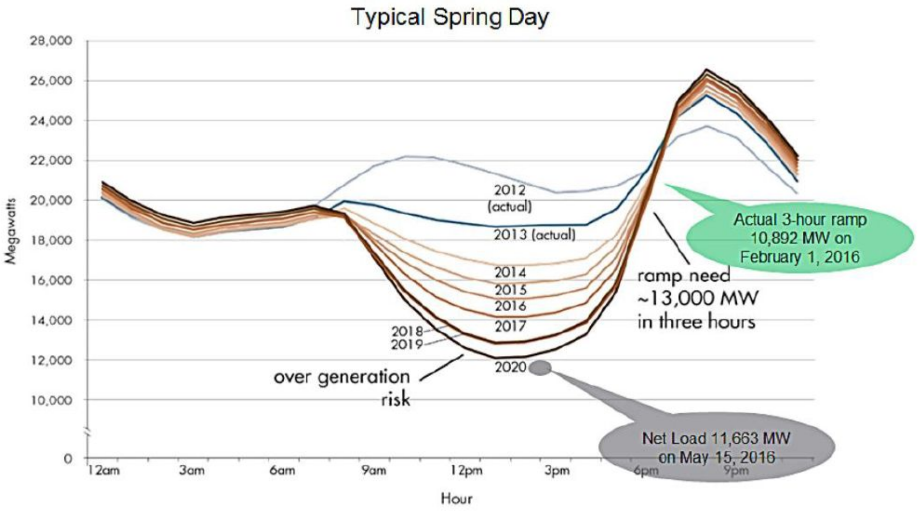
Source: Koohi-Fayegh, S., & Rosen, M. (2020). A review of energy storage types, applications and recent developments. Science Direct, 27, 1-23. / Cole, W., & Frazier, A. W. (2019). Cost Projections for Utility-Scale Battery Storage. Golden, CO: National Renewable Energy Laboratory.

Utility-scale systems are using lithium batteries



Source: Park, J. W. (n.d.). UC Davis RMI Winery Microgrid Project. Davis, CA: UC Davis. / http://www.montereycountyweekly.com/blogs/news_blog/pg-e-s-massive-battery-storage-project-at-moss-landing/article_d024179c-5d77-11ea-a4b8-334d45b7f474.html

The grid and storage systems can work together by following standards



Standard No.	Title of Standard	Publication
IEC 61727-2004	PV systems—characteristics of the utility interface	International Electrotechnical Commission
IEEE Std 1547TM-2003 (R2008) (including amendment IEEE 1547a-2014)	IEEE Standard for interconnecting DRs with electric power systems	The Institute of Electrical and Electronics Engineers
IEEE Std 929-2000	Recommended practice for utility interface of PV systems	The Institute of Electrical and Electronics Engineers
Rule 21-2014	Generating facility interconnections	California of America

Source: CAISO. (2016). California ISO fast facts. Folsom, CA. / Wu, Y.-K., Lin, J.-H., & Lin, H.-J. (2017). Standards and Guidelines for Grid-Connected Photovoltaic Generation Systems: A Review and Comparison. IEEE Transactions on Industry Applications, 53(4), 3205-3215.

Transit energy equation and computer model to determine energy demand of system

$$t_s = t_D + \frac{D_s}{V_L} + \frac{V_L}{a_m} + 1$$

$$E(t_s) = \frac{1}{\bar{\eta}_m}\left\{(1-\eta_{regen})N_T\frac{m_v V_L^2}{2} + \frac{1}{2}\rho_{air}C_D A_v\left[(V_L^2 + \langle V_w^2\rangle)D_s - \frac{V_L^4}{2a_m}\right] + N_T m_v\left[k_{srr}\frac{C_{srr} g D_s}{R_w} + C_{drr}V_L\left(D_s - \frac{V_L^2}{3a_m}\right) + \Delta h_{avg} g\right]\right\} + N_T P_{aux} t_s$$

Vehicle Hourly Demand

$$E_{vhd} = \frac{E_{ahd}}{N_v}$$

→

Vehicle Number

$$N_{vn} = \frac{N_{sp}}{N_p}$$

→

Hourly System Demand

$$E_{hsd} = N_{vn} E_{vhd}$$

Source: Anderson, J. E. (1978). Transit Systems Theory. Lexington, MA: Lexington Books. / Furman, B. (2016). 2016-07-02.BFJ.EnergyCalculation. San Jose, CA: San Jose State University. / Fogelquist, J. B. (2019). Computational Aid for Designing PV Canopy for Solar-Powered Transit. San Jose, CA: San Jose State University.

Hourly array power output equation and computer model to determine PV energy supply

$$P_{A,h} = \eta_{elec} \sum_{N_{sub}} (P_{mod,un,h} N_{un,h} + P_{mod,sh,h} N_{sh,h})$$

$$\eta_{elec} = \eta_{inv} \eta_{wire} \eta_{con} \eta_{mis}$$

System Hourly Power Output → $P_{sys,h} = \sum_{N_A} P_{A,h}$

Source: Fogelquist, J. B. (2019). Computational Aid for Designing PV Canopy for Solar-Powered Transit. San Jose, CA: San Jose State University.

Battery sizing calculations accounting for inefficiencies and safety factor

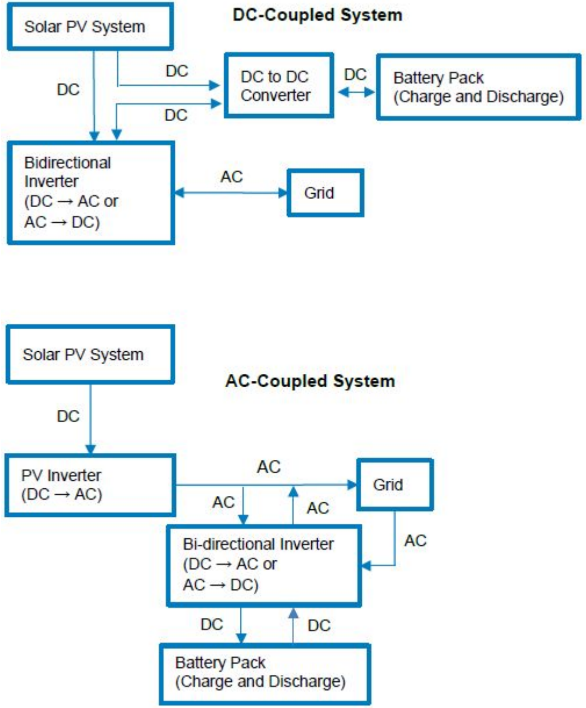
$$E_{td} = \Sigma E_{hsd}$$

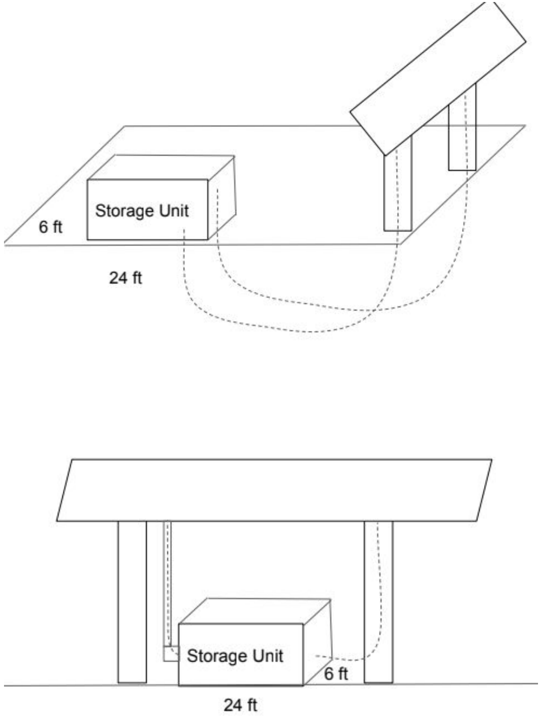
$$E_{ts} = \Sigma P_{sys,h}$$

$$E_{tea} = E_{ts} - E_{td}$$

$$L_B = \frac{E_{tea}}{\eta_{inv} n_{wir}}$$ → X 1.25 Factor

Searching for design and layout options

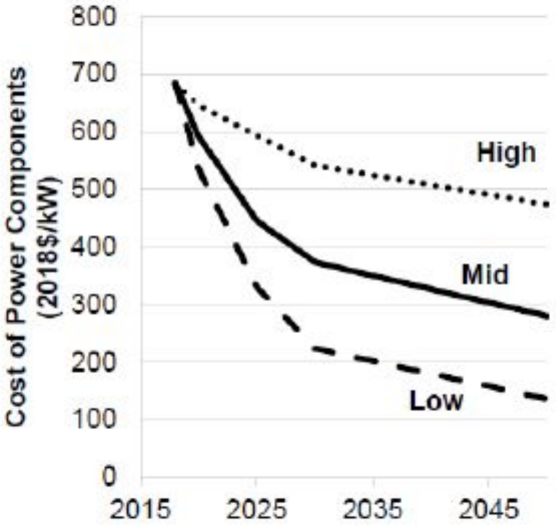


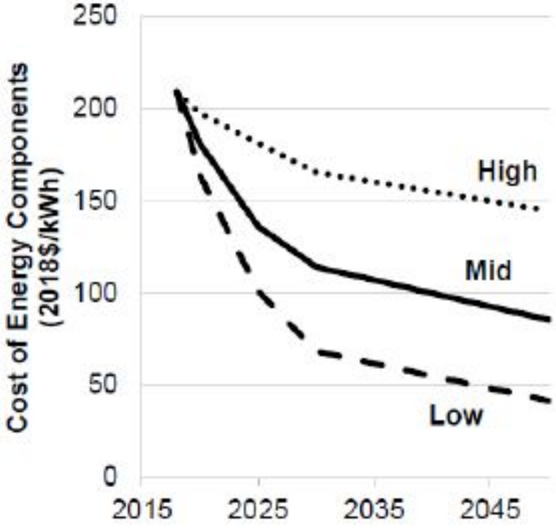


Source: Fu, R., Remo, T., & Margolis, R. (2018). 2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark. Golden, CO: National Renewable Energy Laboratory.

Approximating projected cost trends for the storage capacity needed

$$Total\ Cost\ \left(\frac{\$}{kWh}\right) = Energy\ Cost\ \left(\frac{\$}{kWh}\right) + Power\ Cost\ \left(\frac{\$}{kW}\right) /\ Duration\ (hr)$$





Source: Cole, W., & Frazier, A. W. (2019). Cost Projections for Utility-Scale Battery Storage. Golden, CO: National Renewable Energy Laboratory.

Vehicle hourly demand was calculated to 10.4 kWh

System and Route Characteristics	
Vehicle Mass (kg)	1900
Vehicle Frontal Area (m^2)	4
Wheel Radius (m)	0.1524
Static Rolling Resistance Coefficient (m)	0.057
Drag Coefficient	0.51
Average Electric Motor Efficiency	0.85
Regenerative Braking Efficiency	0.3
Auxiliary Power Demand (W)	3500
Line Speed (m/s)	13.4
Headway (s)	5
Dwell Time (s)	20
Average Elevation Change (m)	0
Number of Vehicles	155
Number of Stations	14
Route Length (km)	14.9
Average Station Distance	1.49
Average Trip Duration	2.29

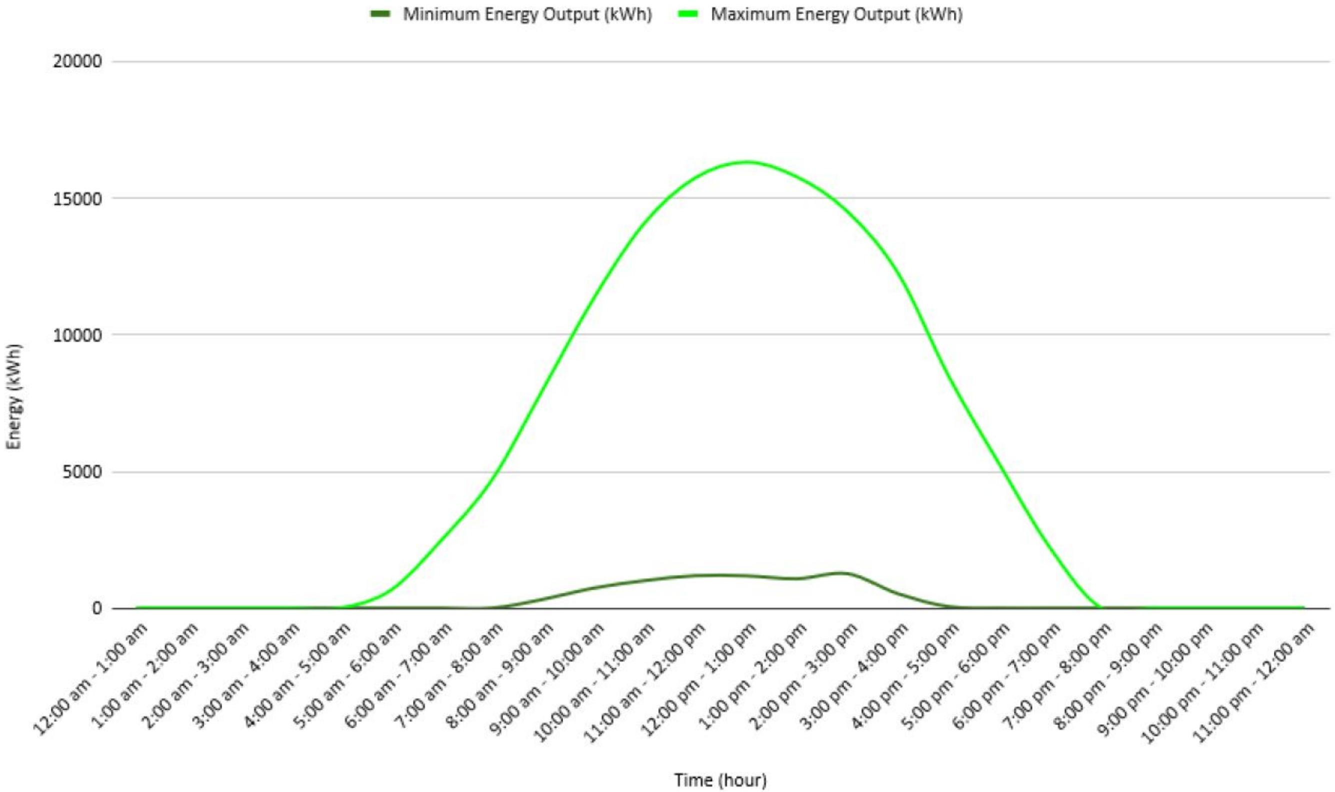
Yearly Demand

14.1 GWh

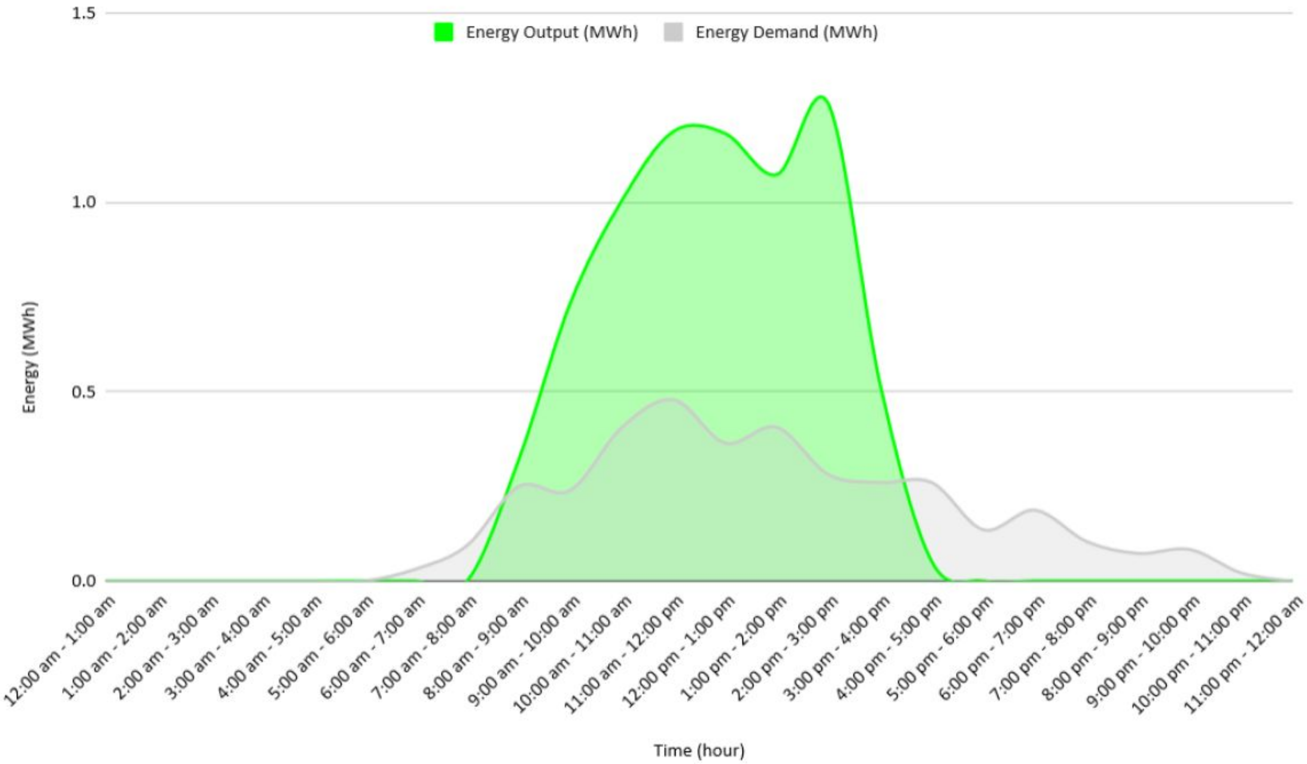
Average Vehicle Efficiency

.27 kWh / km

System power supply was 7.3 MW for lowest generating day of the year

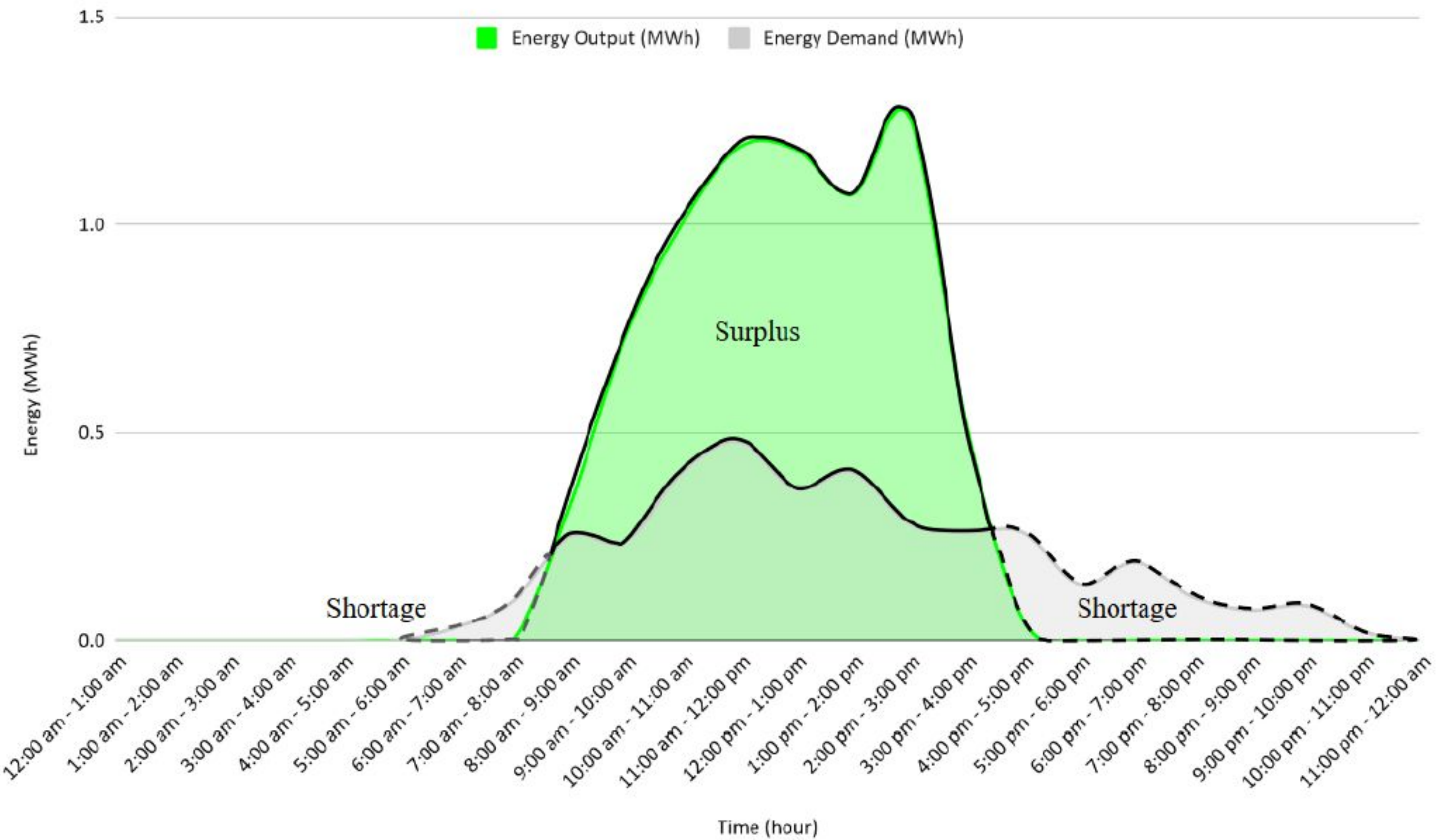


Storage size needed to operate system on stored energy calculated to 4.97 MWh (one day) / 9.95 MWh (two days)



		Time (hour)	Passengers	Vehicles Needed	Energy Demand (kWh)
February 11, 2019 (Least Busy)	1	12:00 am - 1:00 am	0	0	0
	2	1:00 am - 2:00 am	0	0	0
	3	2:00 am - 3:00 am	0	0	0
	4	3:00 am - 4:00 am	0	0	0
	5	4:00 am - 5:00 am	0	0	0
	6	5:00 am - 6:00 am	0	0	0
	7	6:00 am - 7:00 am	4	1	10.40
	8	7:00 am - 8:00 am	16	3	31.20
	9	8:00 am - 9:00 am	169	29	301.64
	10	9:00 am - 10:00 am	56	10	104.01
	11	10:00 am - 11:00 am	147	25	260.04
	12	11:00 am - 12:00 pm	144	24	249.63
	13	12:00 pm - 1:00 pm	89	15	156.02
	14	1:00 pm - 2:00 pm	132	22	228.83
	15	2:00 pm - 3:00 pm	132	22	228.83
	16	3:00 pm - 4:00 pm	47	8	83.21
	17	4:00 pm - 5:00 pm	101	17	176.82
	18	5:00 pm - 6:00 pm	92	16	166.42
	19	6:00 pm - 7:00 pm	55	10	104.01
	20	7:00 pm - 8:00 pm	49	9	93.61
	21	8:00 pm - 9:00 pm	28	5	52.01
	22	9:00 pm - 10:00 pm	25	5	52.01
	23	10:00 pm - 11:00 pm	8	2	20.80
	24	11:00 pm - 12:00 am	0	0	0

		Time (hour)	Passengers	Vehicles Needed	Energy Demand (kWh)
February 8, 2019 (Most Busy)	1	12:00 am - 1:00 am	0	0	0
	2	1:00 am - 2:00 am	0	0	0
	3	2:00 am - 3:00 am	0	0	0
	4	3:00 am - 4:00 am	0	0	0
	5	4:00 am - 5:00 am	0	0	0
	6	5:00 am - 6:00 am	0	0	0
	7	6:00 am - 7:00 am	15	3	31.20
	8	7:00 am - 8:00 am	50	9	93.61
	9	8:00 am - 9:00 am	142	24	249.63
	10	9:00 am - 10:00 am	134	23	239.23
	11	10:00 am - 11:00 am	232	39	405.66
	12	11:00 am - 12:00 pm	272	46	478.47
	13	12:00 pm - 1:00 pm	208	35	364.05
	14	1:00 pm - 2:00 pm	229	39	405.66
	15	2:00 pm - 3:00 pm	160	27	280.84
	16	3:00 pm - 4:00 pm	147	25	260.04
	17	4:00 pm - 5:00 pm	146	25	260.04
	18	5:00 pm - 6:00 pm	76	13	135.22
	19	6:00 pm - 7:00 pm	104	18	187.23
	20	7:00 pm - 8:00 pm	55	10	104.01
	21	8:00 pm - 9:00 pm	37	7	72.81
	22	9:00 pm - 10:00 pm	43	8	83.21
	23	10:00 pm - 11:00 pm	7	2	20.80
	24	11:00 pm - 12:00 am	0	0	0

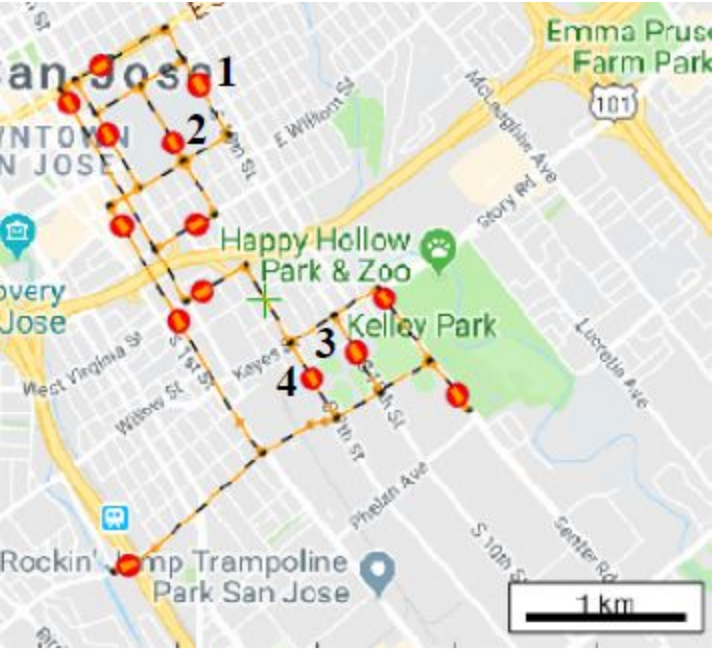


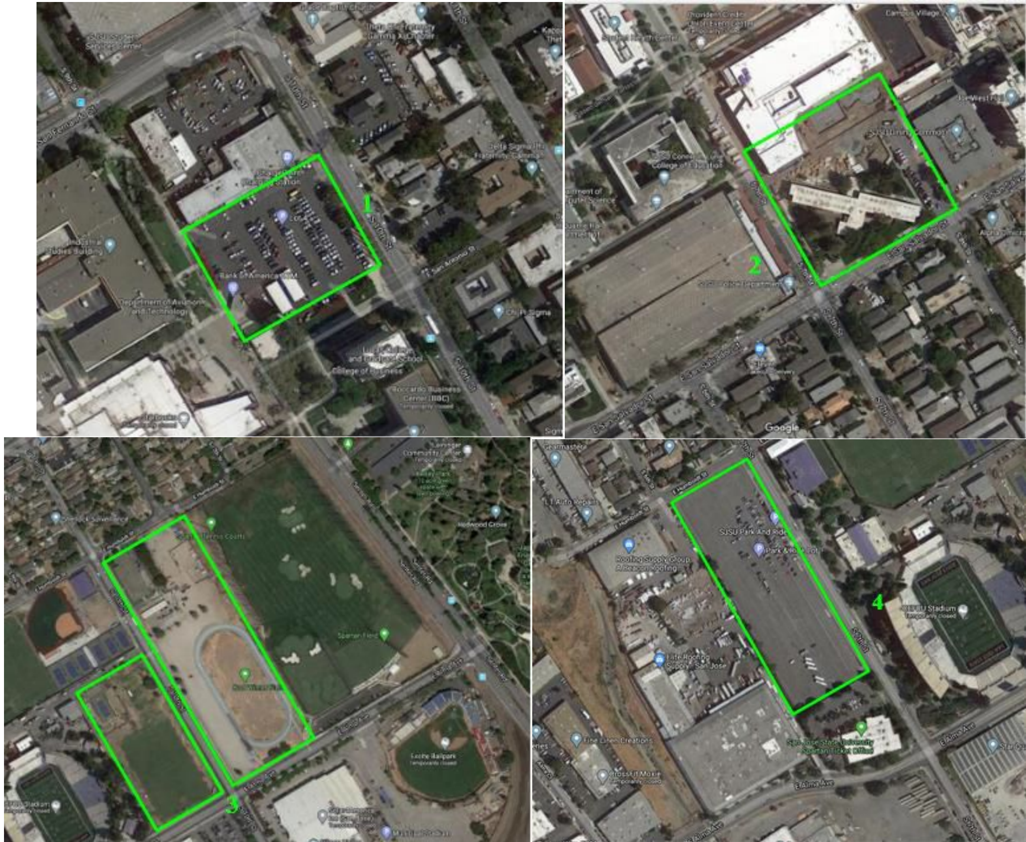
Energy Output (MWh)
Energy Demand (MWh)
1.5
1.0
0.5
0.0
Energy (MWh)
Surplus
Shortage
Shortage
12:00 am - 1:00 am
1:00 am - 2:00 am
2:00 am - 3:00 am
3:00 am - 4:00 am
4:00 am - 5:00 am
5:00 am - 6:00 am
6:00 am - 7:00 am
7:00 am - 8:00 am
8:00 am - 9:00 am
9:00 am - 10:00 am
10:00 am - 11:00 am
11:00 am - 12:00 pm
12:00 pm - 1:00 pm
1:00 pm - 2:00 pm
2:00 pm - 3:00 pm
3:00 pm - 4:00 pm
4:00 pm - 5:00 pm
5:00 pm - 6:00 pm
6:00 pm - 7:00 pm
7:00 pm - 8:00 pm
8:00 pm - 9:00 pm
9:00 pm - 10:00 pm
10:00 pm - 11:00 pm
11:00 pm - 12:00 am
Time (hour)

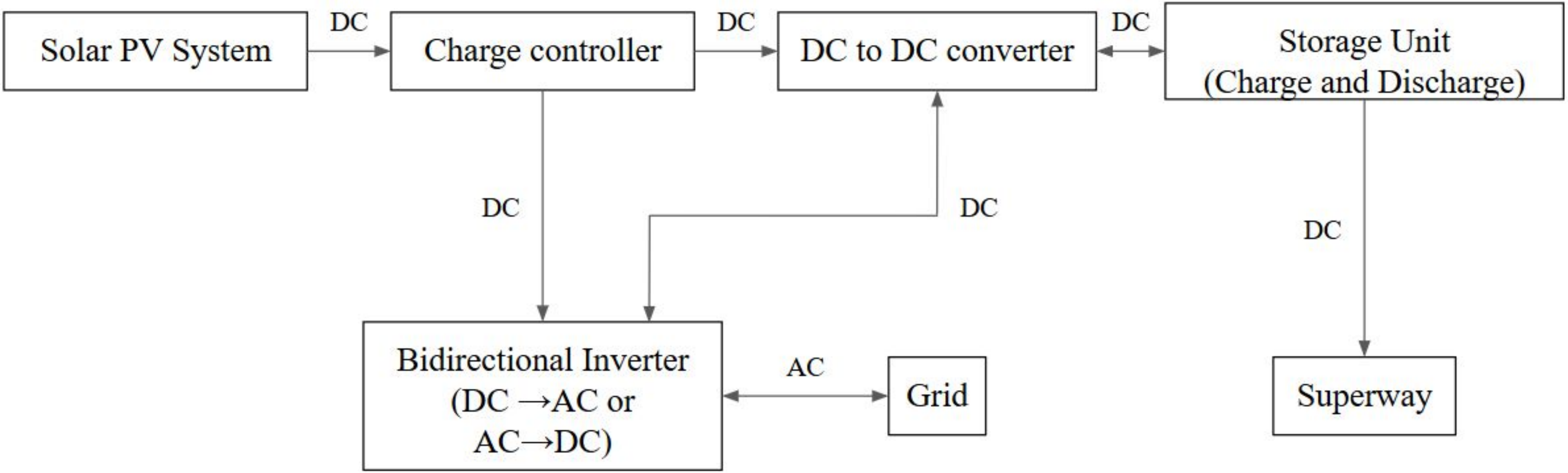
Diverse design options available commercially for the system

Specifications	Tesla Megapack	Oilfield Instrumentation Model 20-2
		
Storage Capacity	3 MWh	N/A
Dimensions	23 ft 5 in x 5 ft 3 in x ~ 8 ft	20 ft x 8 ft x ~ 8 ft
Components / Features	Battery modules, bi-directional inverters, thermal management system, AC main breaker, Controls	Combustion resistant materials, thermostat, HVAC controls, humdity indicator, audible and visual strobe warnings, and electric panels
Assembly Required	No	Yes
Applications	Renewable smoothing, T&D investment deferral, voltage support, capacity support, microgrid, market participacttion, and frequency regulation	Lithium battery storage and related
Support	Team helps to identify custom site requirements and design a solution for application	Can contact for custom project options
Weight	N/A	13,800 lbs
Full Distribution	0.24	N/A
Partial Distribution	1	N/A
	Tesla Powerpack	Tesla Powerwall
		
Storage Capacity	232 kWh	13.5 kWh
Dimensions	41.1 in x 54.9 in x 86.2 in (inverter - 41.1 in x 54.9 in. x 86.2 in)	45.3 in x 29.6 in x 5.75 in
Components / Features	16 battery pods, DC-DC converter, cell monitoring sensors, thermal control system (liquid cooling)	Connection point, liquid cooling, inverter, battery pack
Assembly Required	No	No
Applications	Outdoor rated, peak shaving, emergency backup, load shifting, demand response, microgrid, power production, grid reliability	Weatherproof, solar self-consumption, back-up power, time-based control, off-grid capabilities
Support	Company support, certifications	Company support, 10 year warranty, certifications
Weight	4,847 lbs (inverter - 2,470 lbs)	251.3 lbs
Full Distribution	4	53
Partial Distribution	11	185

Four possible locations available for units next to stations






Solar PV System
DC
Charge controller
DC
DC to DC converter
DC
Storage Unit
(Charge and Discharge)
DC
DC
DC
Bidirectional Inverter
(DC →AC or
AC→DC)
AC
Grid
Superway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Mechanical Engineering
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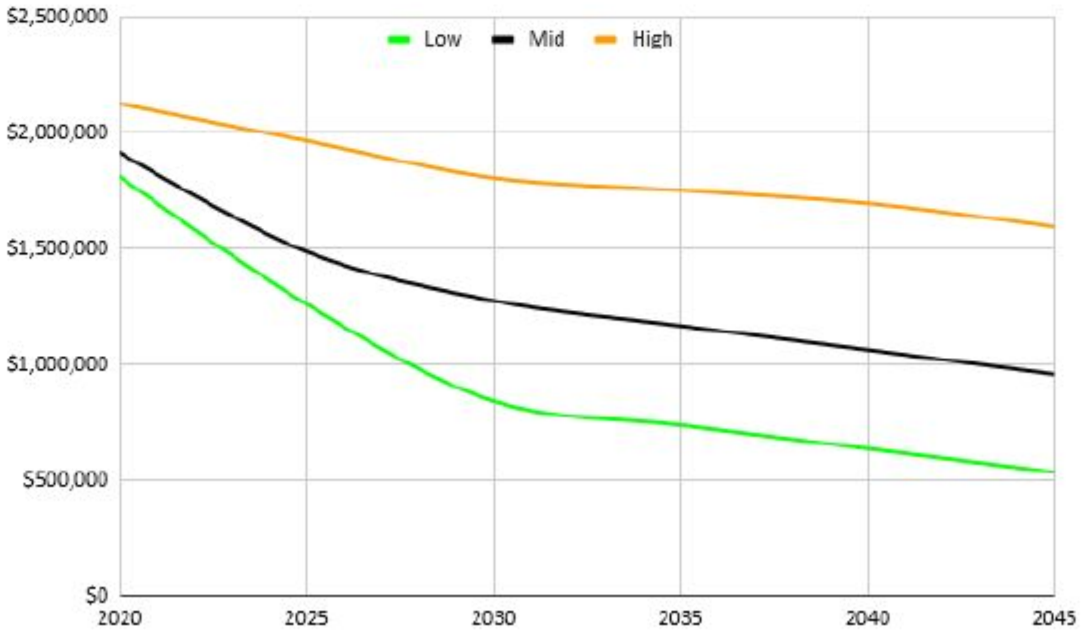
Department of Aviation
and Technology

Projected cost of energy storage system is expected to decrease in the upcoming years



There are solutions out there