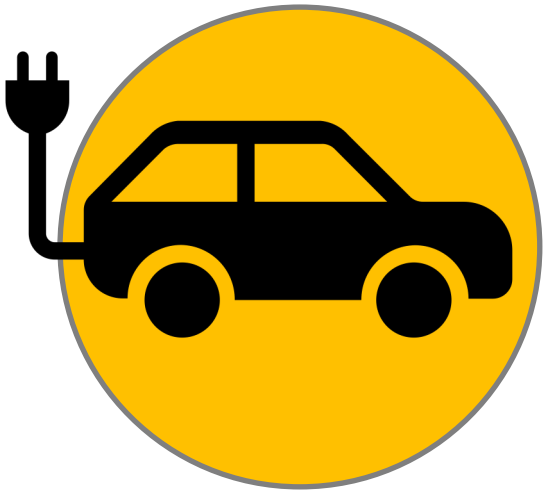


Battery Reuse: A Second-life for Electric Vehicle Batteries

Background Information for the California Lithium Battery Recycling Advisory Group

Dr. Hanjiro Ambrose – May 27th, 2020

Union of Concerned Scientists

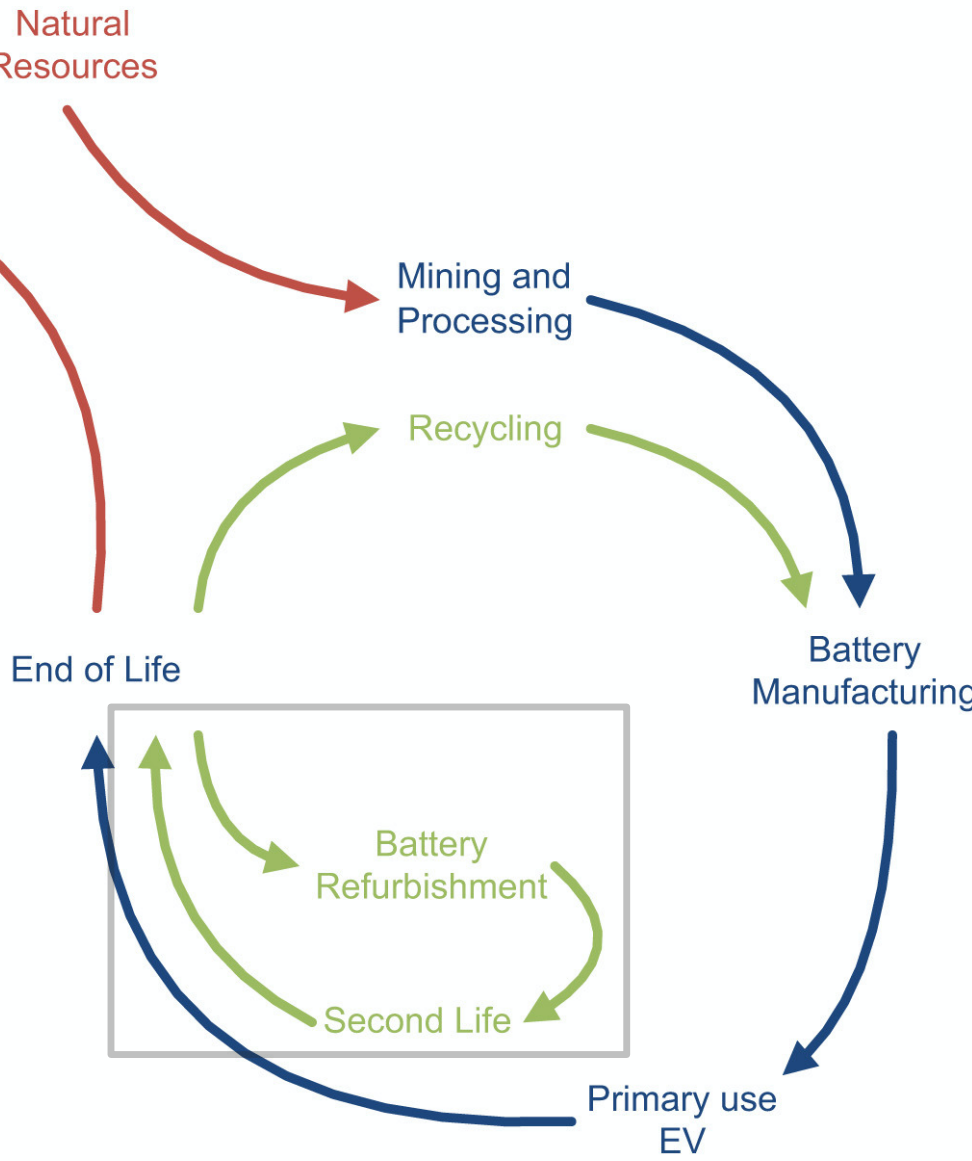
Outline

1. Market potential
2. Technical potential
3. Second-life applications
    a) RePurpose Energy
4. Barriers and policy

Battery Second-life

Potential benefits of second-life:

- Mitiga
  impact
  manuf
- Reduc
  batteri
- Enable increased use of renewables

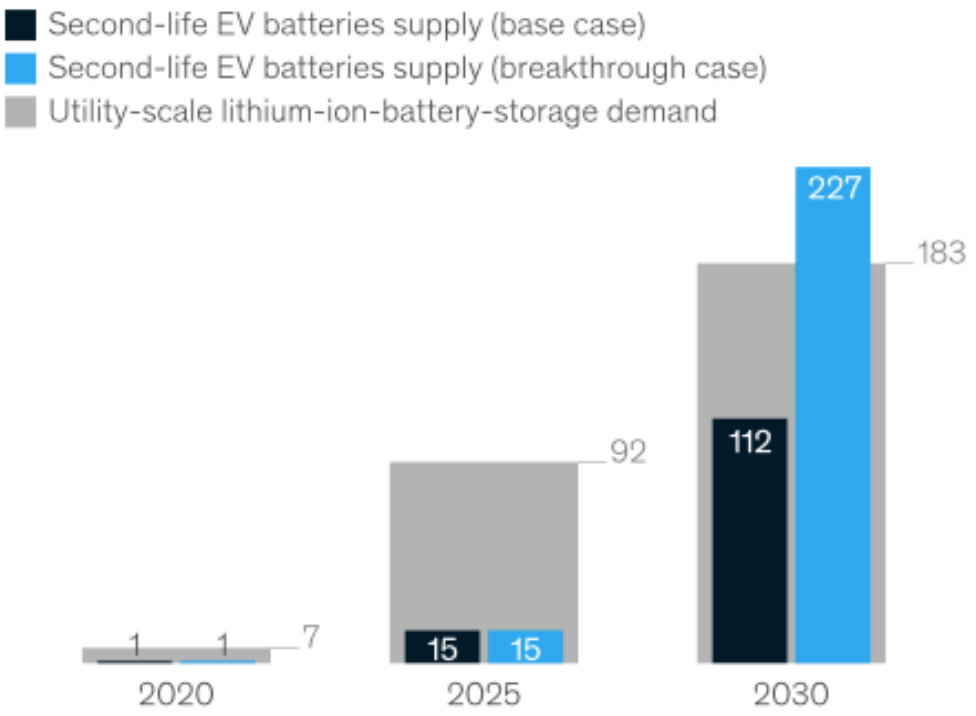


Martinez-Laserna, Egoitz, et al. "Battery second life: Hype, hope or reality? A critical review of the state of the art." *Renewable and Sustainable Energy Reviews* 93 (2018): 701-718.

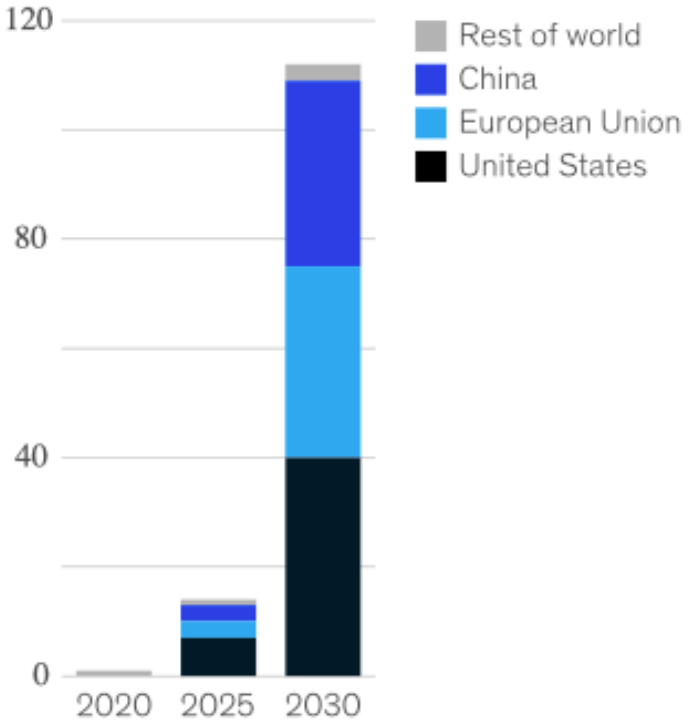
Second-life Market: Supply

Second-life lithium-ion battery supply could surpass 200 gigawatt-hours per year by 2030.

Utility-scale lithium-ion battery demand and second-life EV[1] battery supply,[2] gigawatt-hours/year (GWh/y)



Second-life EV battery supply by geography (base case[2]), GWh/y

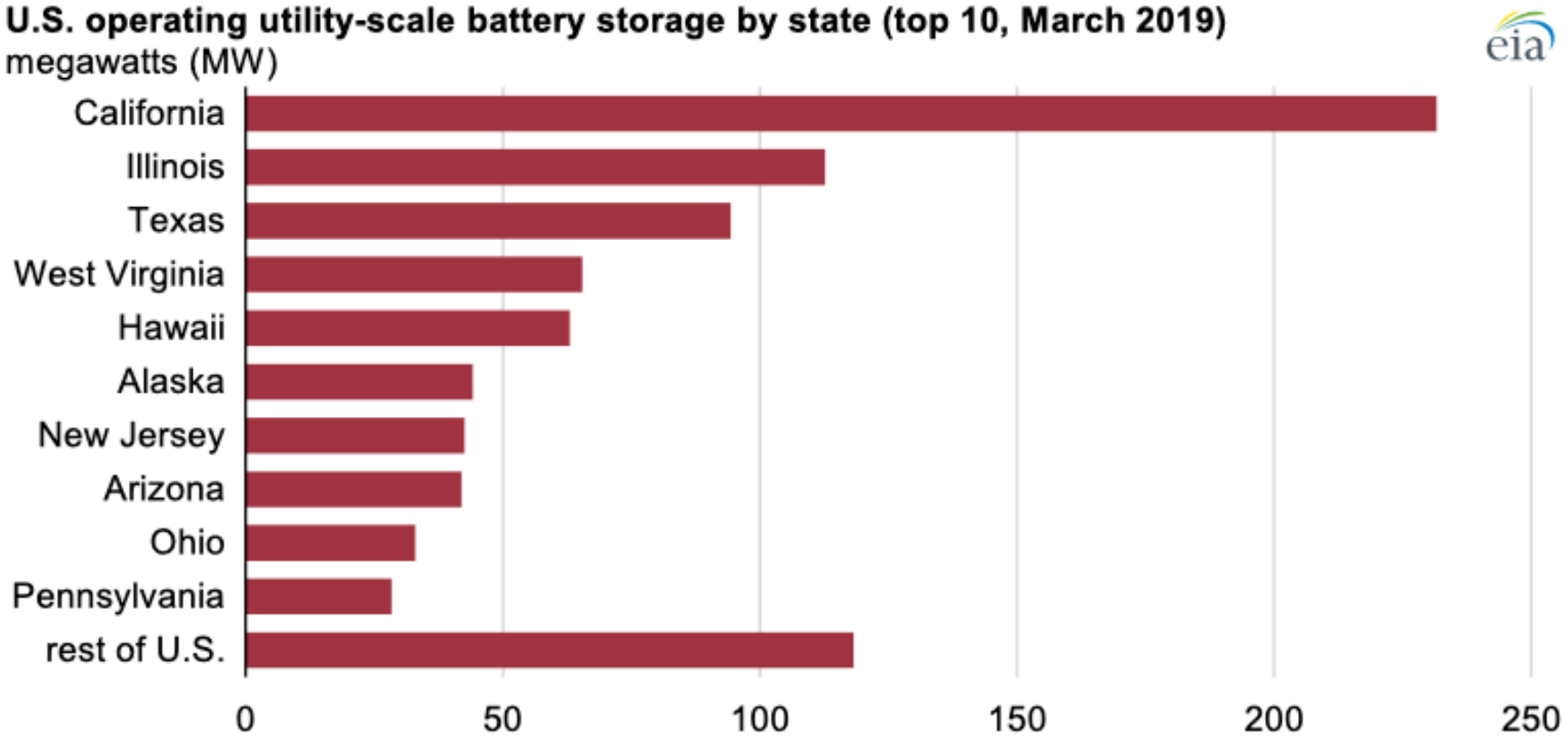


[1]Electric vehicle.
[2]Only for batteries from passenger cars.

https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage

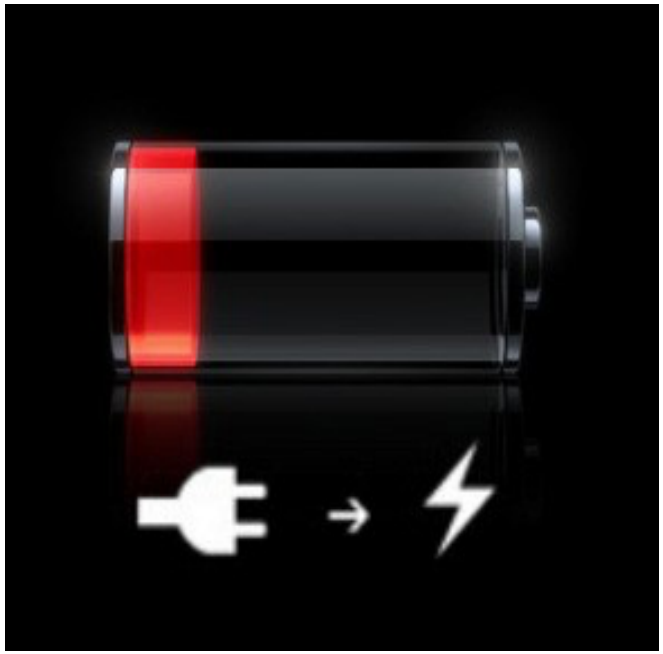
Second-life Market: Demand

The US added 522.7 megawatts/1,113 megawatt-hours of energy storage in 2019.



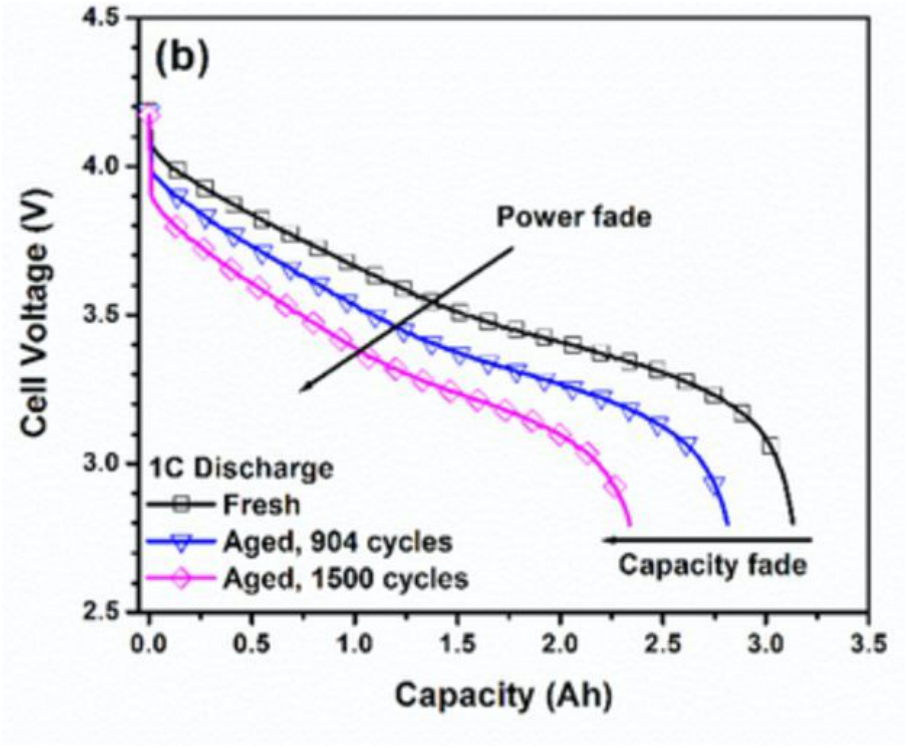
EV Battery Lifetime

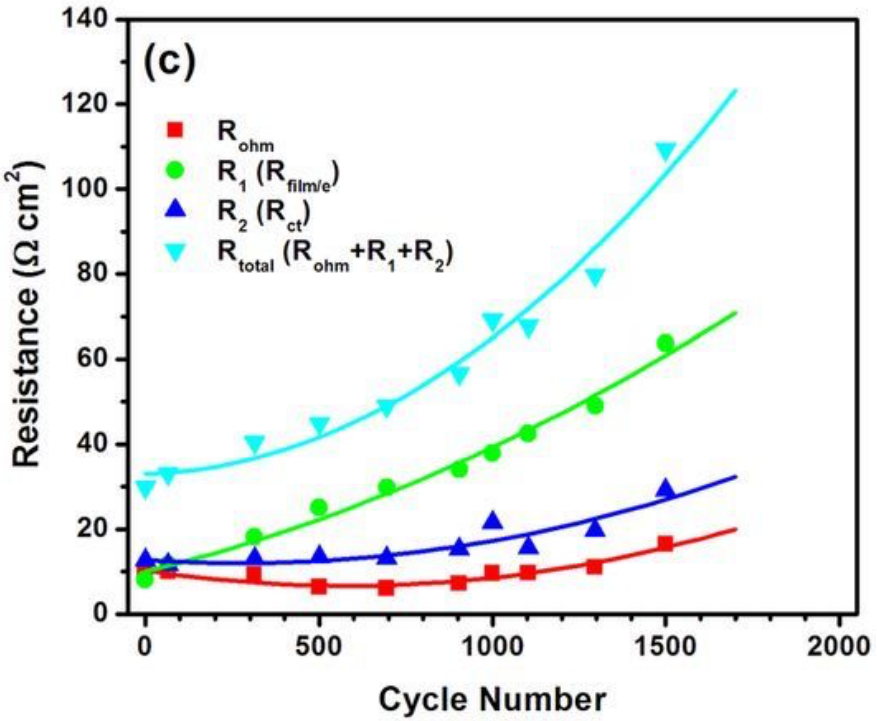
- How many times a battery can deliver its stored energy at a specific rate is a function of degradation
- Current lithium-ion batteries used in EVs can generally deliver 80% of their initial capacity >> 1000 times in average conditions



EV Battery Lifetime

As batteries degrade, stored energy becomes inaccessible at higher loads





Yongjun Leng *et al* 2017 *J. Electrochem. Soc.* **164** A1037

EV Battery Lifetime

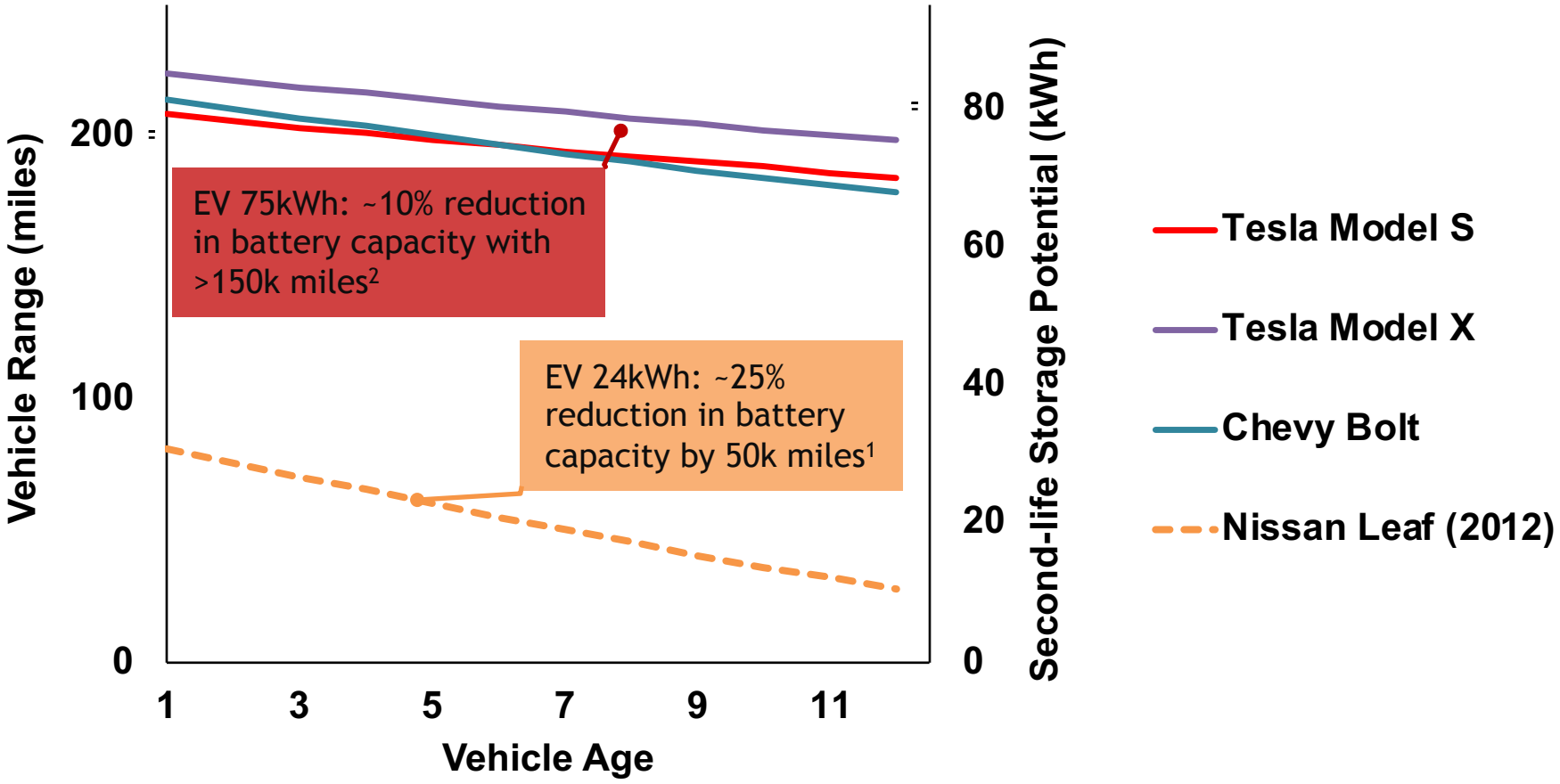
Three main pathways for degradation in a lithium ion battery:

- temperature,
- cycles, and
- time.

Repeated utilization of the maximum storage potential of the battery, rapid charge and discharge cycles, and exposure to high temperatures are all likely to reduce battery performance.

EV Battery Lifetime

Increasing battery sizes + improved lifetimes = more 2nd life potential

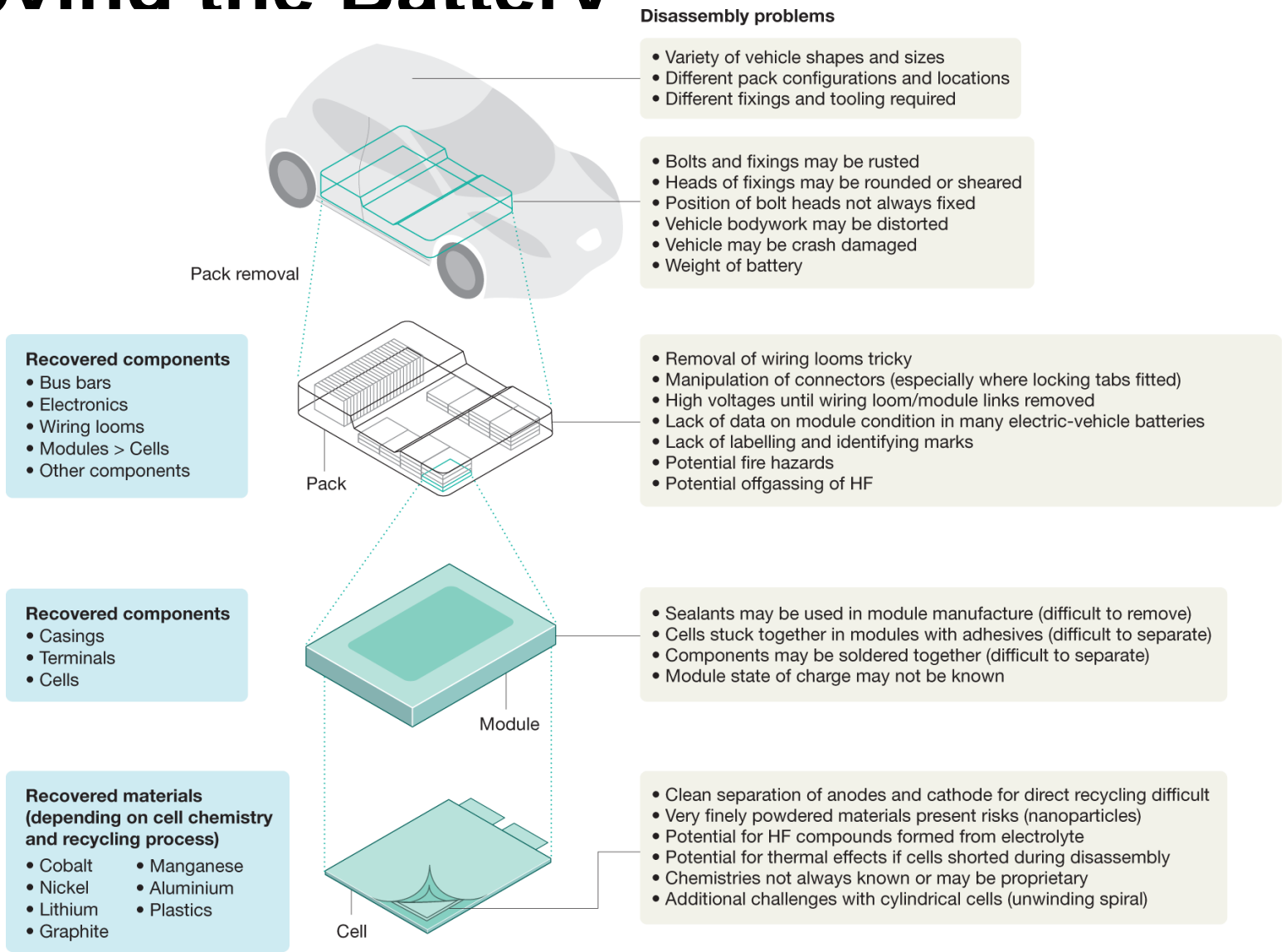


Repurposing EV Batteries

Three main steps:

1. Testing the battery
2. Removing the battery from the vehicle
3. Reconfiguring the battery for the second-life application

Removing the Battery

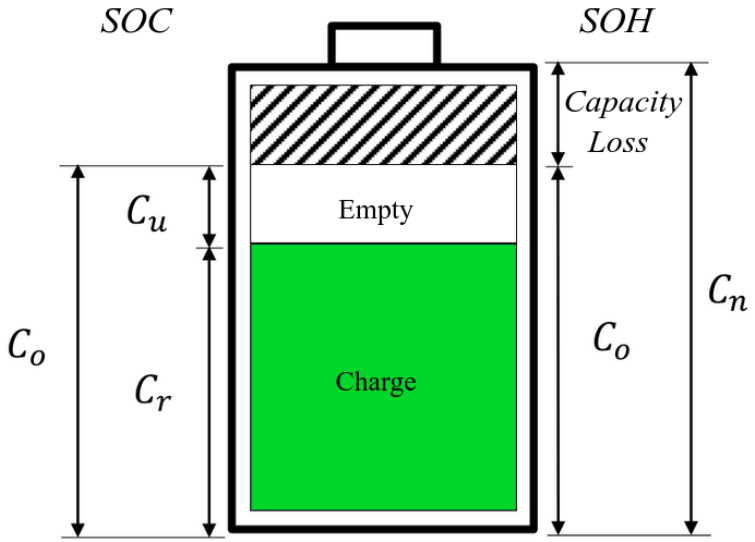


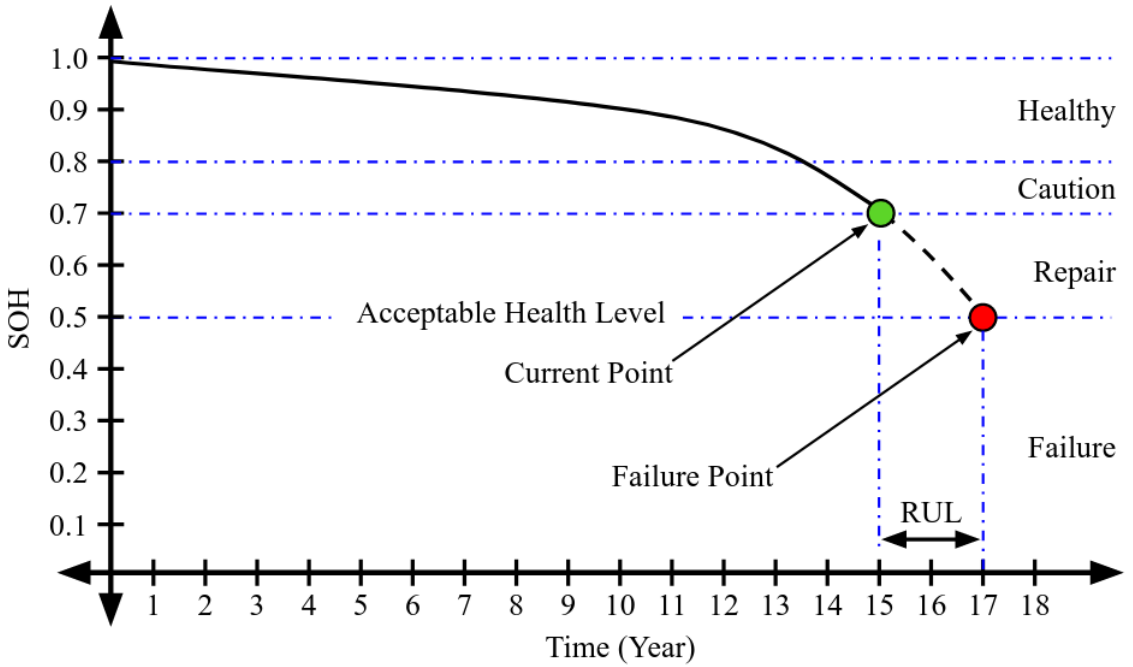
Casals, L. C., García, B. A., & Canal, C. (2019). Second life batteries lifespan: Rest of useful life and environmental analysis. *Journal of environmental management*, *232*, 354-363.

Testing the Battery

A primary goal of second-life testing is to determine the remaining useful life of the battery:

- The state of health (SOH) is the ratio of maximum capacity to the nominal capacity





https://medium.com/it-paragon/remaining-useful-life-predictive-maintenance-5b78a17f7d10

Testing the Battery

Key types of standard safety and abuse testing for batteries:

- Mechanical – Drop, penetration, immersion, and crushing
- Electrical – external and internal shorts, overcharge/discharge
- Environmental – Thermal shocks, fire, extreme temperatures
- Chemical – Emissions, flammability

Refurbishing the Battery

In addition to testing, repurposing can entail:

- Reconfiguration of packs and modules
- Installation of new battery charge and/or thermal management

Cummins partners with the University of California San Diego on second-life battery development

Aug 27, 2019 Columbus, IN

https://www.cummins.com/news/releases/2019/08/27/cummins-partners-university-california-san-diego-second-life-battery

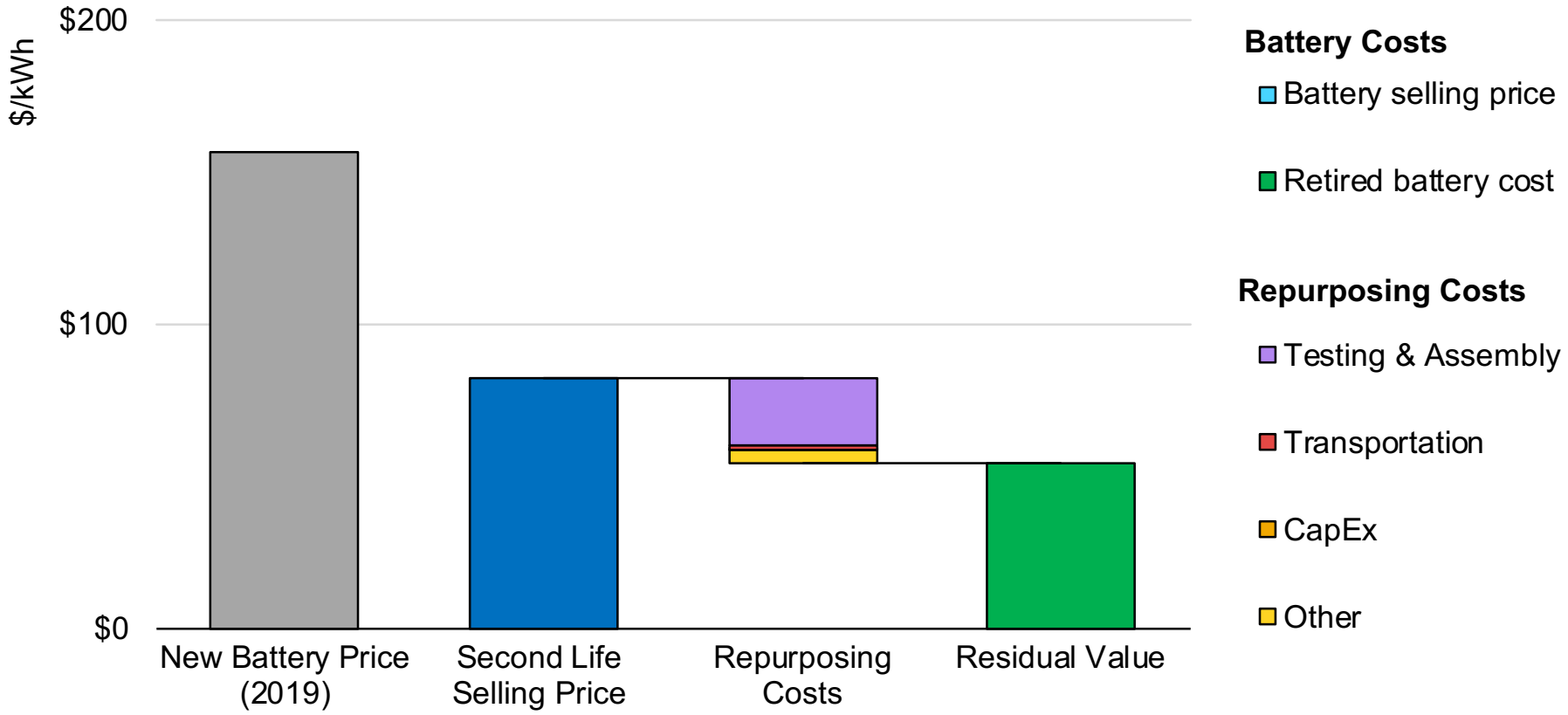
Second-life Battery Costs

New Battery Price	Second Life DoD	Vehicle	Second Life Health	Refurbished Battery Market Price ($/kWh)	Used Battery Salvage Value ($kWh)	Cost to Refurbish ($/kWh)
250 $/kWh	60%	BEV75	0.33	83	51	32
		PHEV20	0.29	73	43	30
	50%	BEV75	0.72	180	131	49
		PHEV20	0.65	163	117	46
150 $/kWh	60%	BEV75	0.33	50	24	26
		PHEV20	0.29	44	19	25
	50%	BEV75	0.72	108	72	36
		PHEV20	0.65	98	64	34

Martinez-Laserna, Egoitz, et al. "Battery second life: Hype, hope or reality? A critical review of the state of the art." *Renewable and Sustainable Energy Reviews* 93 (2018): 701-718.

Second-life Battery Costs

Second-life could help to lower the costs of EVs



Generated using the NREL Battery Second-Use Repirposing Cost Calculator (https://www.nrel.gov/transportation/b2u-calculator.html), assumes 1 GWh/year volume, 60kWh pack.

RePurpose Energy

Mission:

Reuse Electric Vehicle Batteries To Store Solar Energy

2010

1st Used EV Battery Project

2018

Commercial-Scale Demonstration

2019

BIG IDEAS

BIG BANG!

CLEAN TECH OPEN

2019 NATIONAL FINALIST

CalSEED

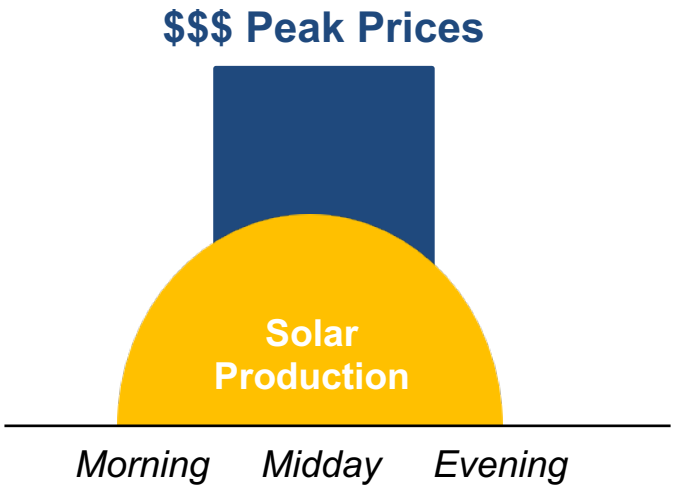
2020

X5

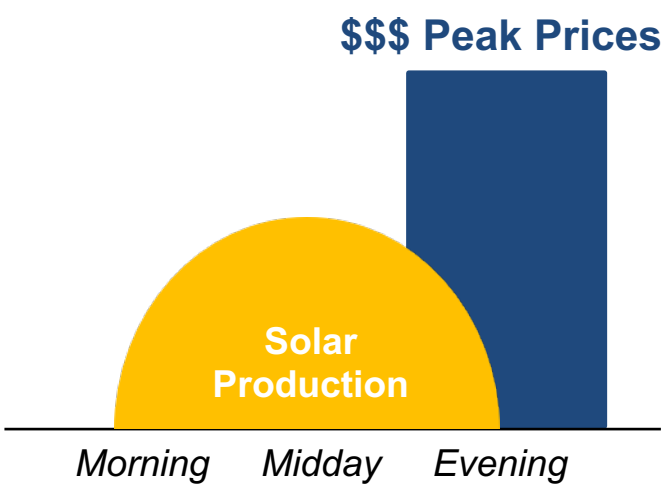
Next Project In Development

Need for "Solar After Sunset"

Old Electricity Rates



New Electricity Rates



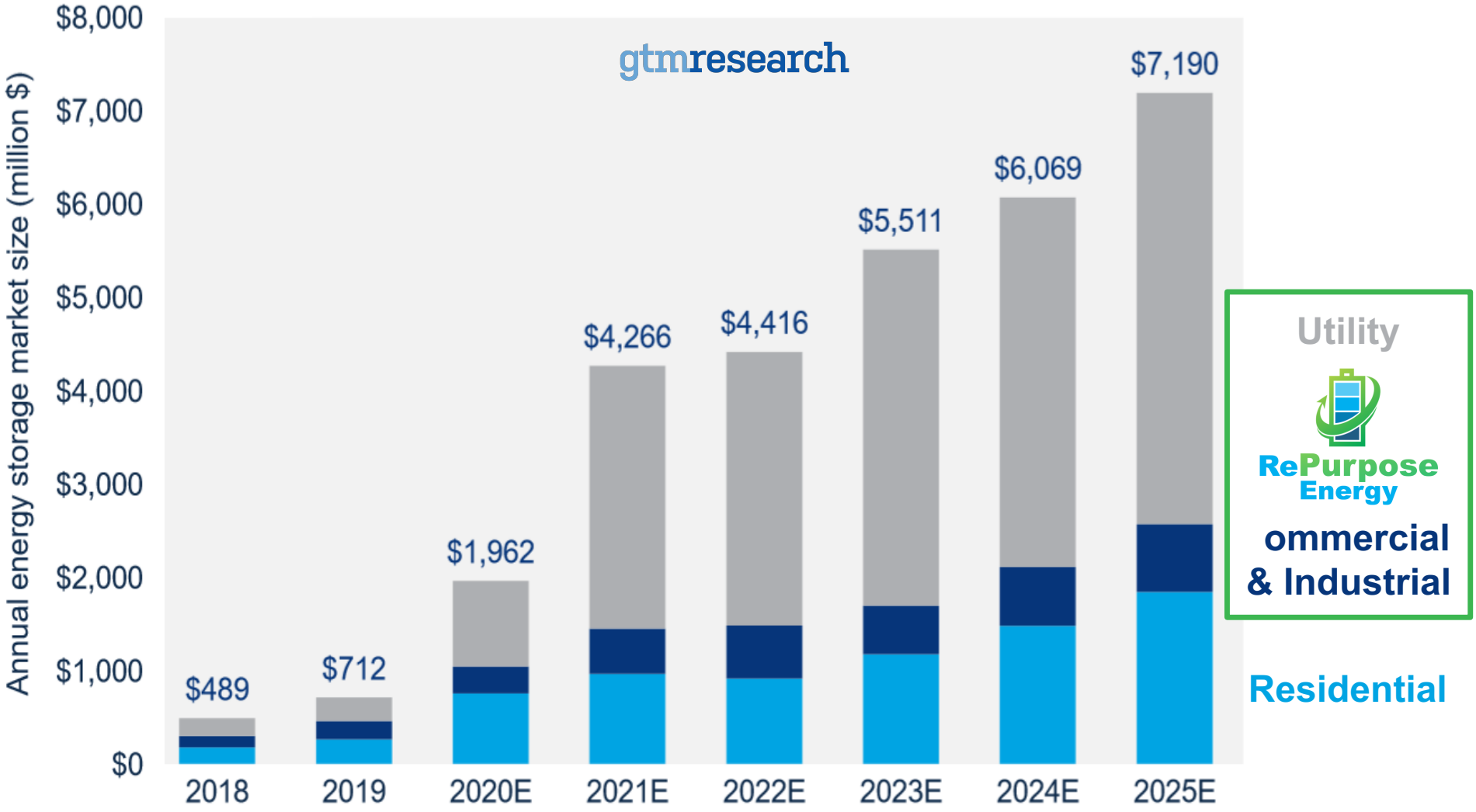
Representative Economics (IRR):

24%  12%

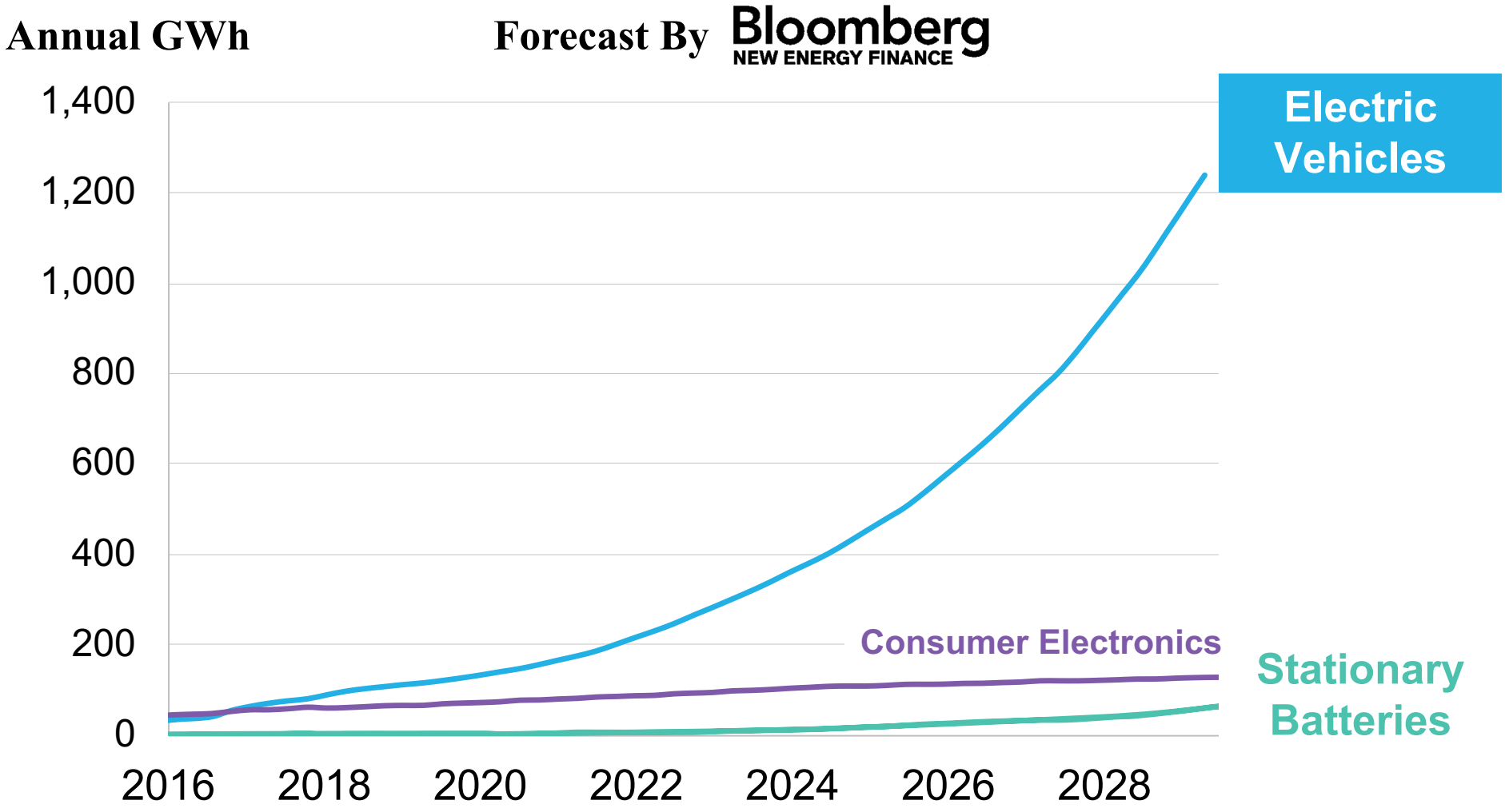
\+

8%  18% 2-4 Year Payback

Energy Storage
Annual Market Projections

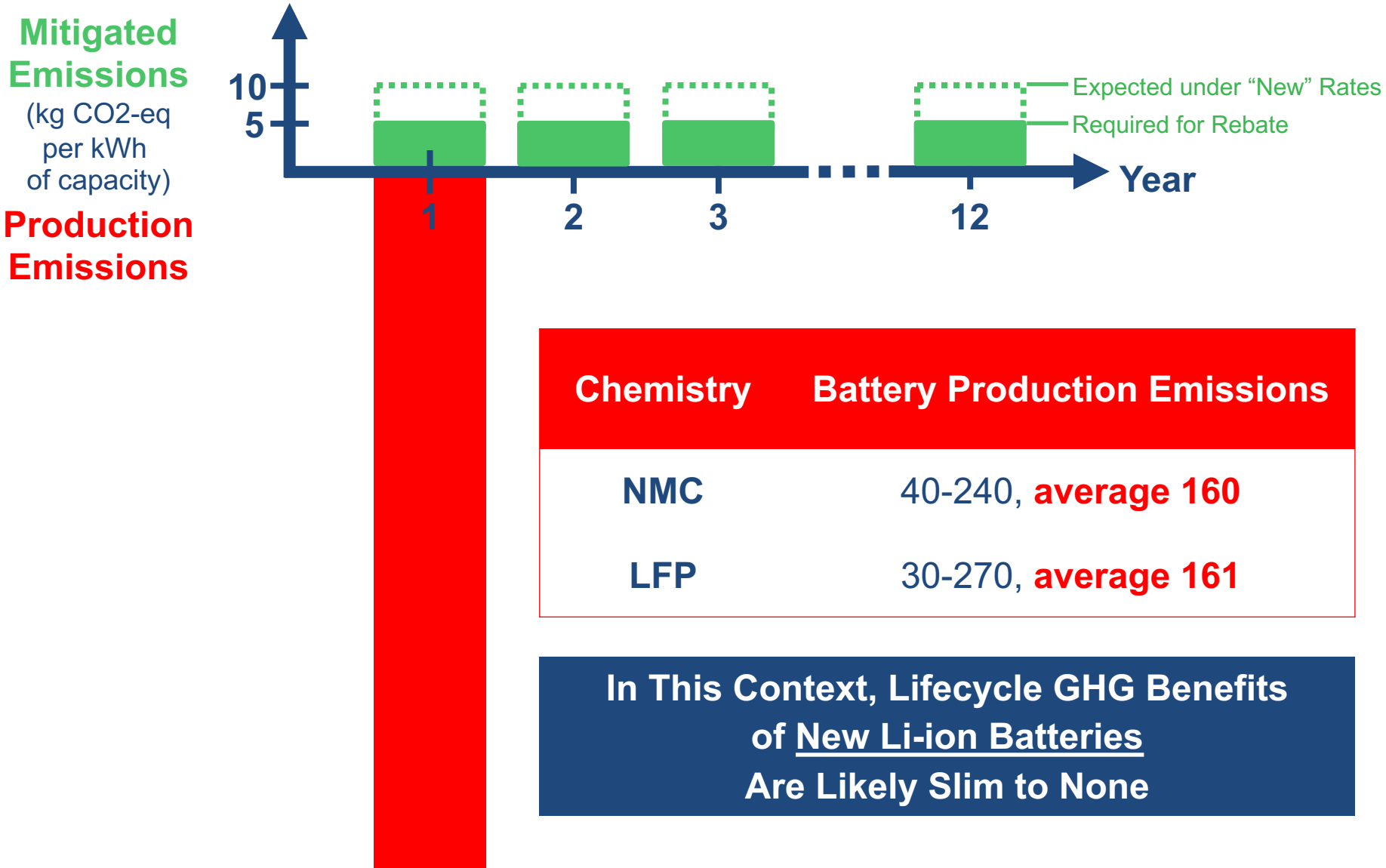


Global Battery Demand



More Affordable Energy Storage

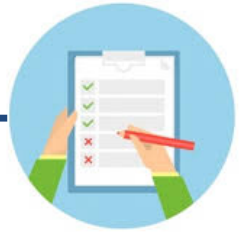
GHG Benefits of New Batteries Installed with Solar PV at Commercial & Industrial Facilities in CA



Chemistry	Battery Production Emissions
NMC	40-240, **average 160**
LFP	30-270, **average 161**

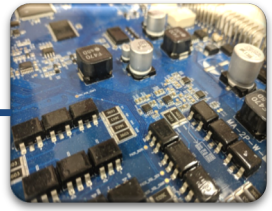
In This Context, Lifecycle GHG Benefits of New Li-ion Batteries Are Likely Slim to None

Core Capabilities



Rapid Battery Testing

Optimized Reassembly



Proprietary Battery Management System

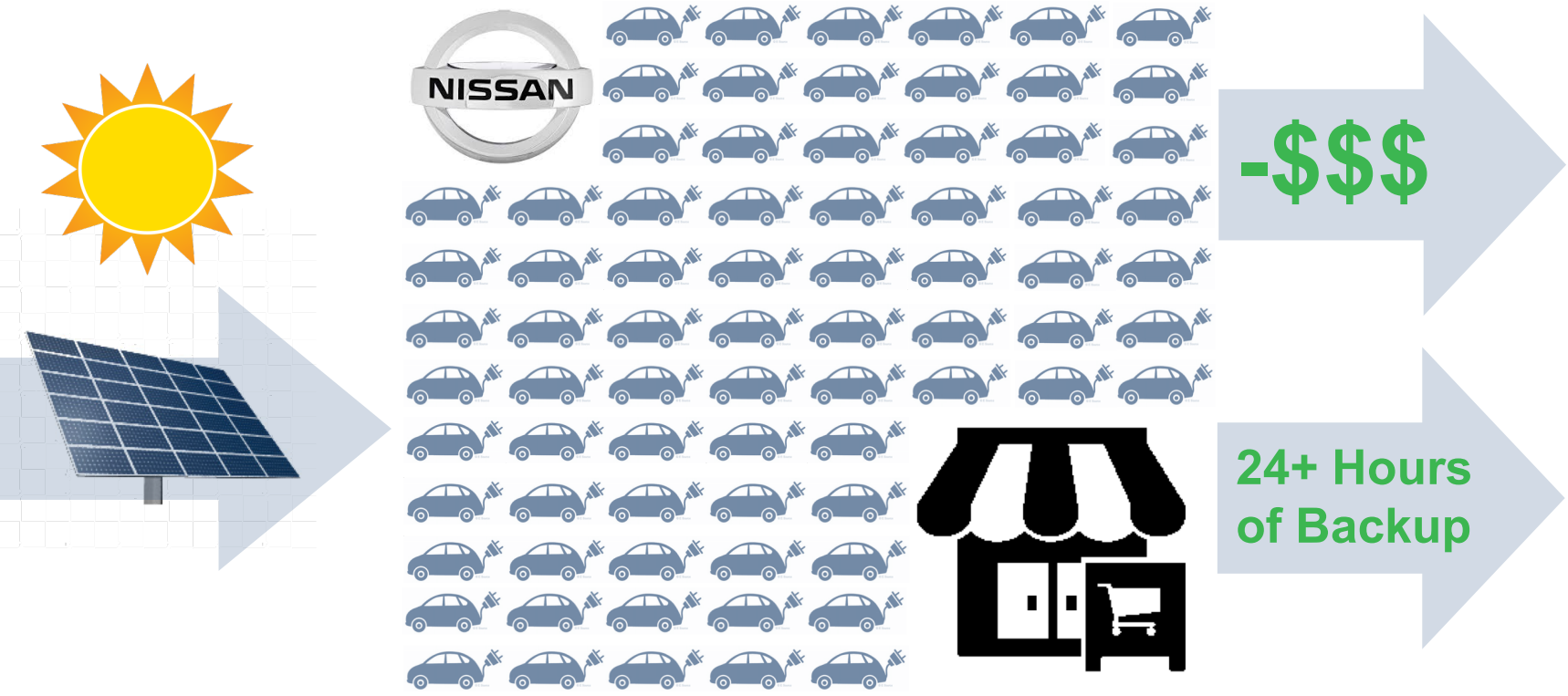
CalSEED **Non-Destructive Battery Fire Suppression**

Commercial-Scale Demonstration

- 40%

Mondavi Institute
Davis, CA

Project in Development



Other Goals

- Measure & Mitigate Battery Degradation Rates
- Demonstrate 30%+ Cost Advantage over New Batteries

To Enable EV Battery Reuse:

1. Ensure Eligibility for Key Incentives (e.g. SGIP)
2. Encourage Solutions with Low Production Emissions
3. Centralize or Increase Oversight of Battery Collection & Disposal

RePurpose Energy

Ryan@RePurpose.Energy

Pilots/Demos

Growing number of pilot and demonstration projects create opportunities for continued learning

Joint Ventures	Description	Location
Daimler GETEC/ the mobility house remondis / EnBW	Battery storage unit with a total capacity of 13 MWh using degraded EV batteries from Daimler EV models	Luenen, Germany
BMW/PG&E	18-month pilot project to demonstrate EV smart charging and optimization grid efficiency with participation of 100 BMW i3 owners	San Francisco, USA
Nissan Sumitoto (4R Energy)/Green charge network	System (600 kWh/400 kWh): 16 Nissan Leaf LIBs regulate energy from a solar plant	Osaka, Japan
BMW/Vattenfall/Bosch	2,600 battery modules from 100 electric cars, and provides 2MW of output and 2.8 MWh of capacity	Hamburg, Germany
Renault/Connected Energy Ltd	"E-STOR": on-grid providing energy storage that prevents power grid overload and balances supply and demand	United Kingdom, Europe
Mitsubishi/PSA EDF/ Forsee Power/ MMC	Bi-directional battery energy consumption optimization from retired batteries	Paris, France
General Motors/ ABB	5 Chevrolet Volt LIBs, 74 kW solar array & two 2 kW wind turbines to power a General Motors office building site	USA

Hossain, Eklas, et al. "A Comprehensive Review on Second-Life Batteries: Current State, Manufacturing Considerations, Applications, Impacts, Barriers & Potential Solutions, Business Strategies, and Policies." *IEEE Access* 7 (2019): 73215-73252.

Key Issues for Battery Reuse

- Data, testing, and repurposing costs
- Logistics
- Reliability and performance
- Competition

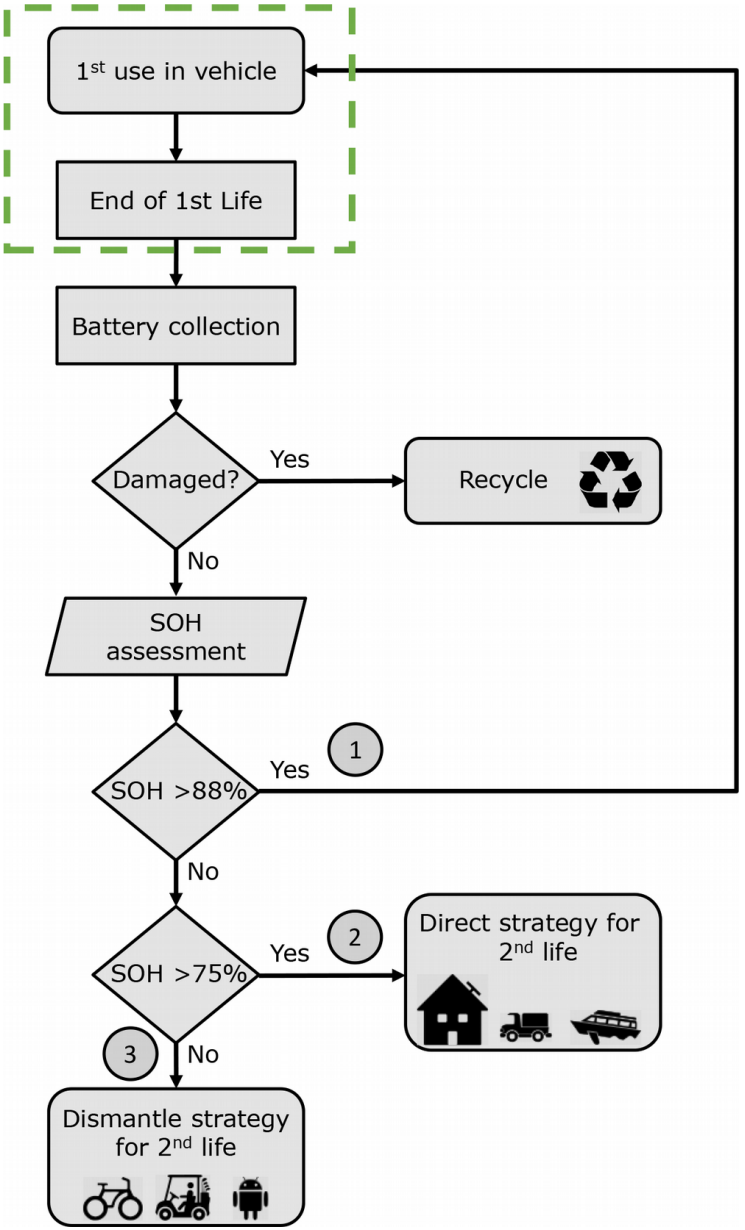


Figure 2. Decision making flow diagram for batteries at the end of its 1st life on EVs

Casals, L. C., García, B. A., & Cremades, L. V. (2017). Electric vehicle battery reuse: Preparing for a second life. *Journal of Industrial Engineering and Management*, *10*(2), 266-285.

Thank you

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UC DAVIS
UNIVERSITY OF CALIFORNIA

Union of Concerned Scientists