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Is our grid ready?

The convergence of renewables, energy storage and electric vehicles

December 6, 2018

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U.S. DEPARTMENT OF ENERGY BATTELLE

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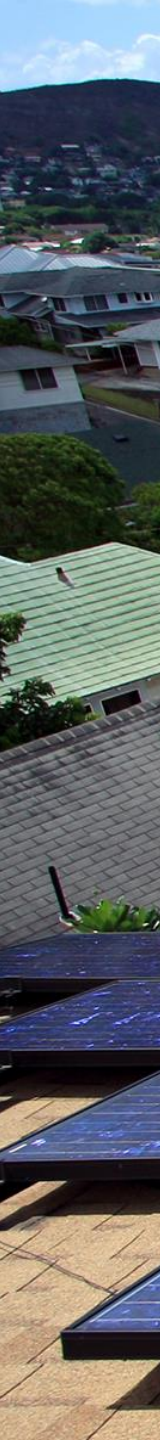

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PNNL supports the breadth of DOE missions

4,500 Staff

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$987M Budget

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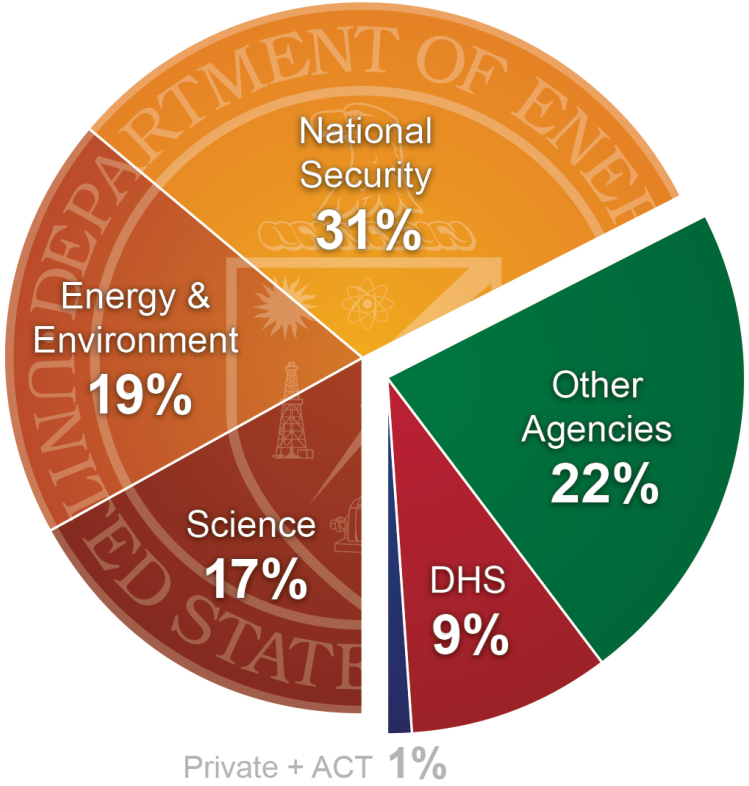
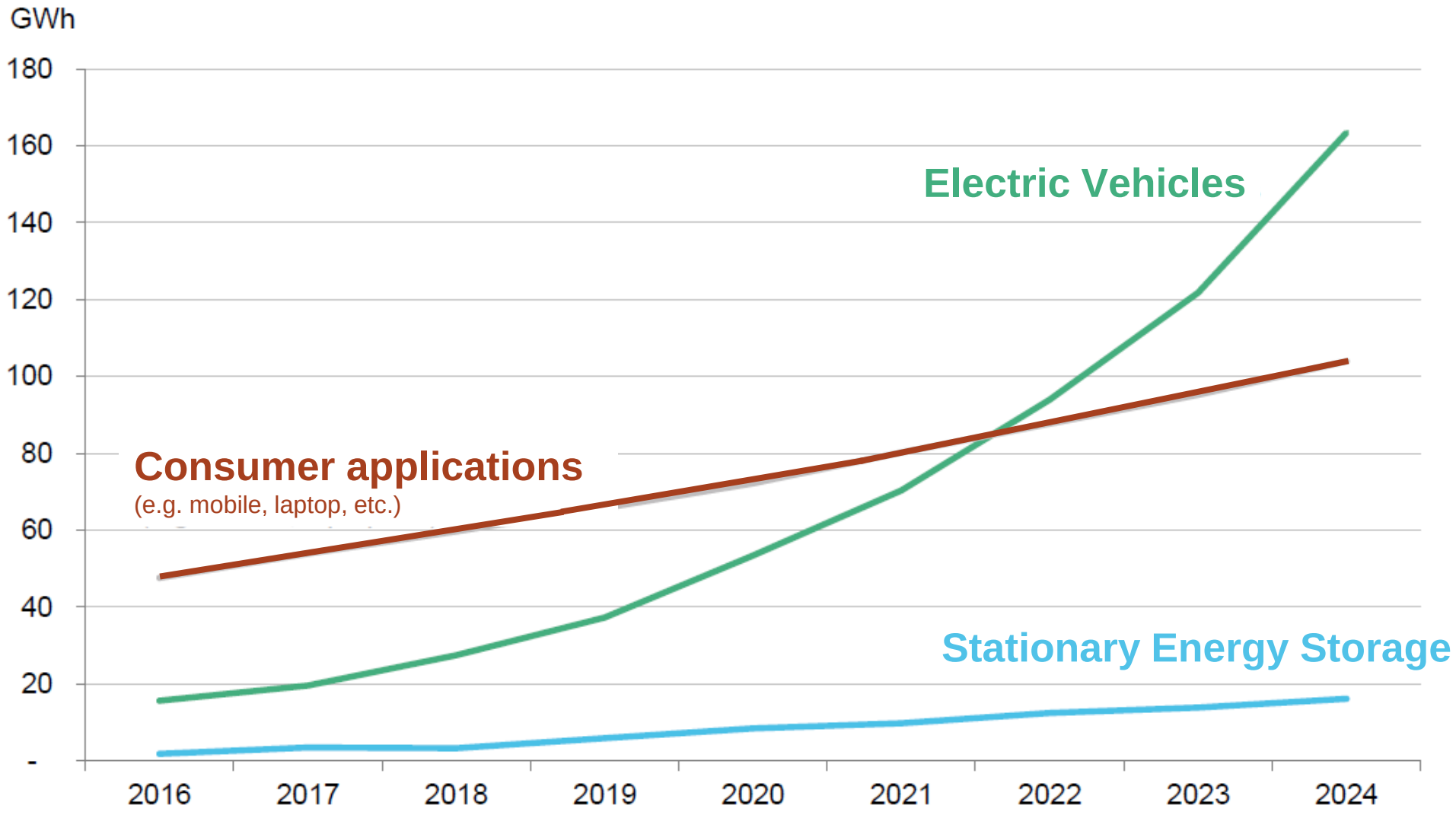


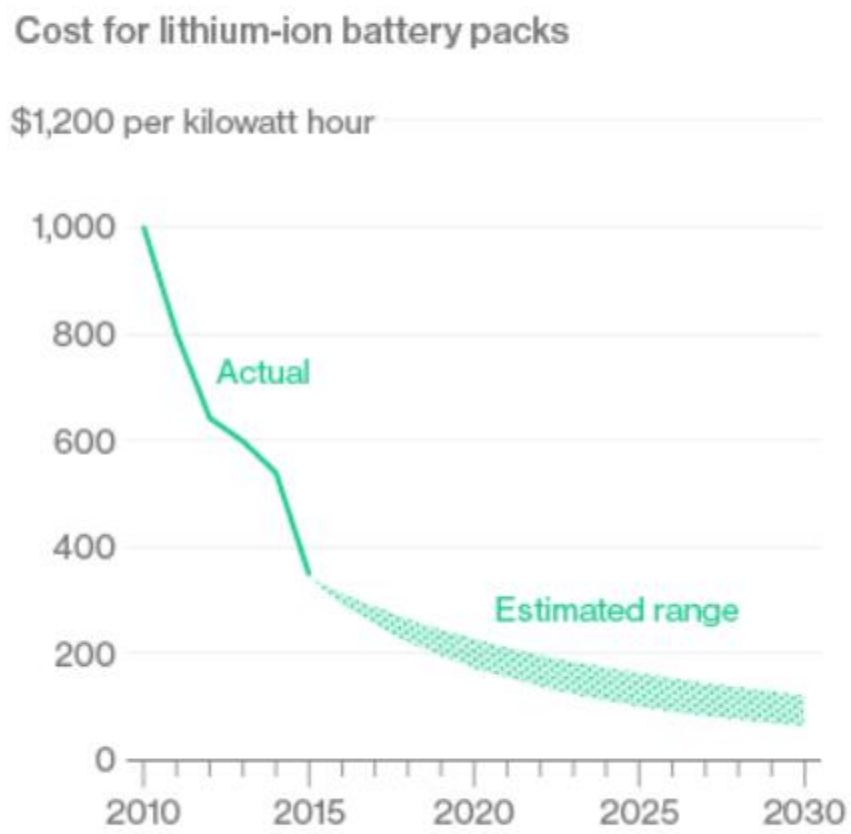
Lithium ion market applications, GWh

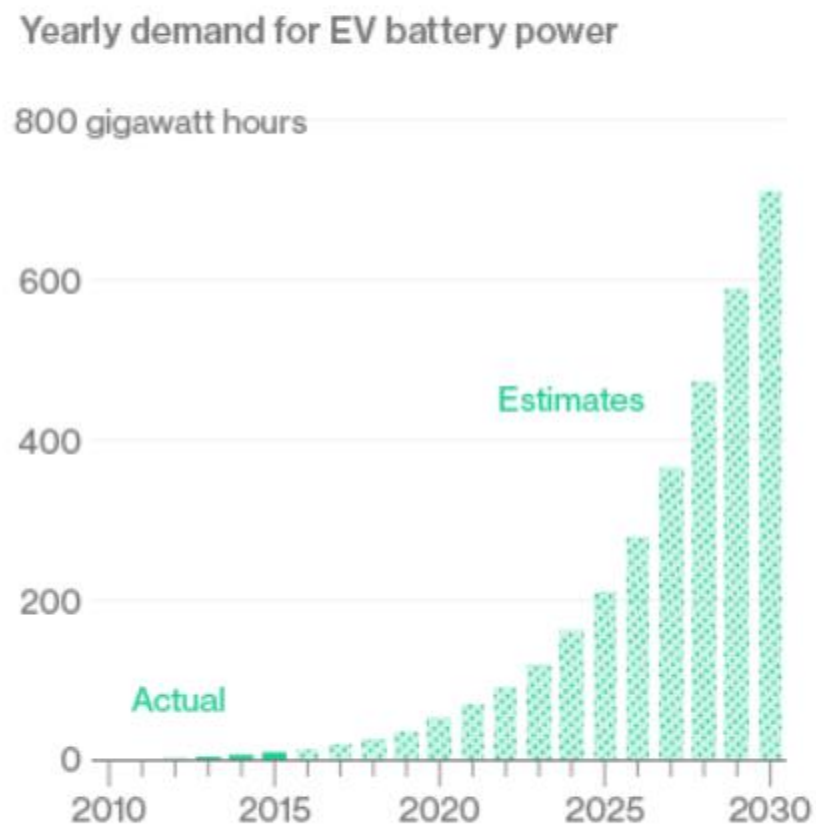


Source: Bloomberg New Energy Finance

It's All About the Batteries

Batteries make up a third of the cost of an electric vehicle.
As battery costs continue to fall, demand for EVs will rise.





Source: Data compiled by Bloomberg New Energy Finance

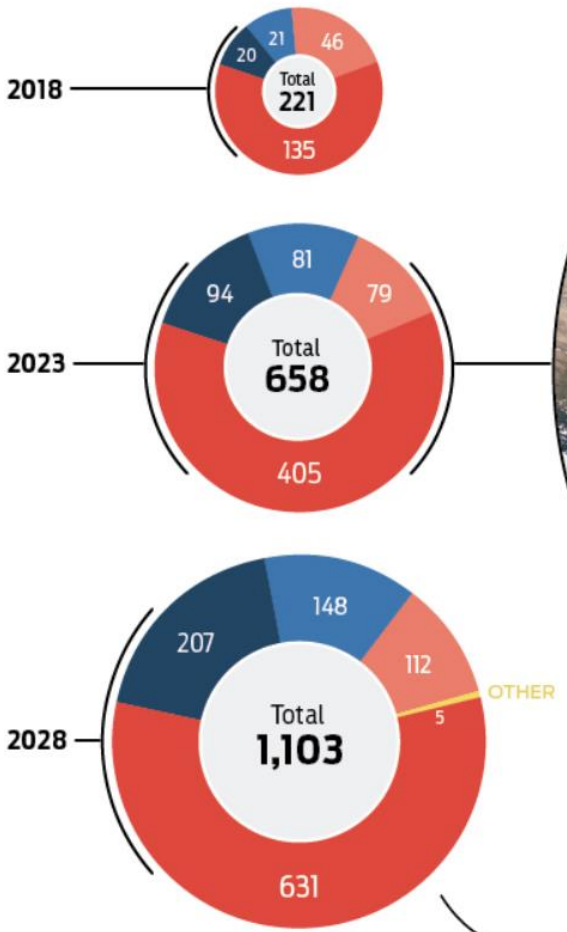
Bloomberg

LITHIUM-ION REVOLUTION

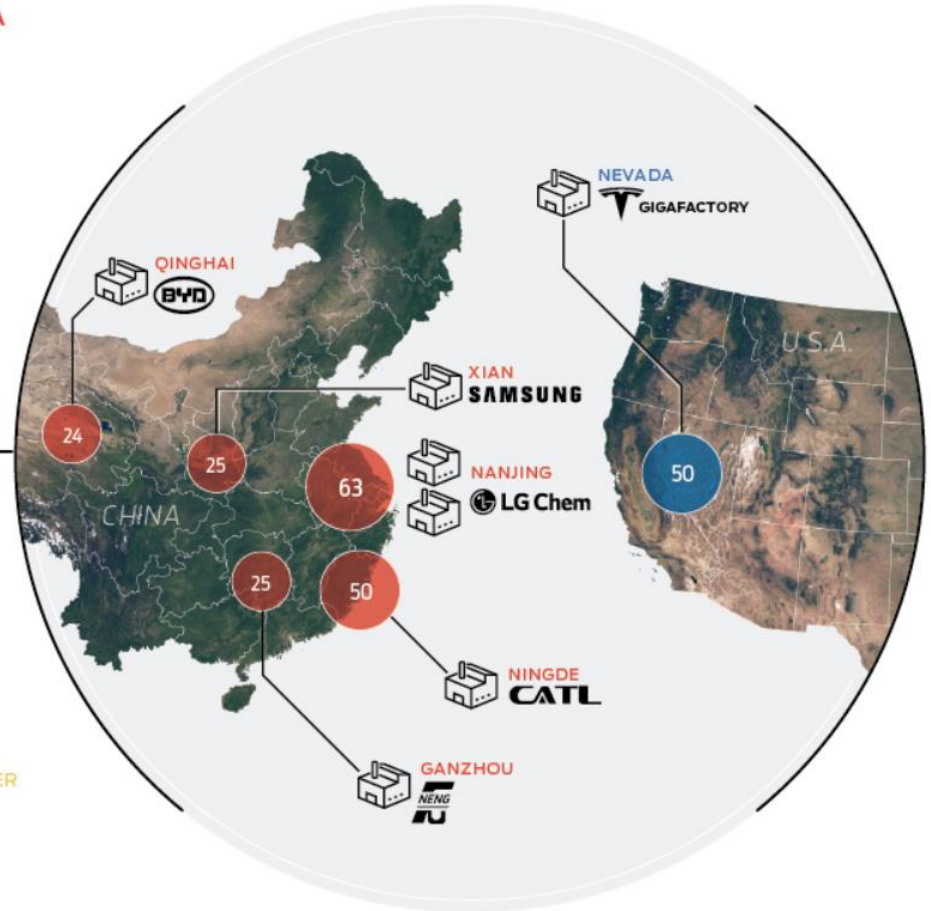
Battery production to ramp up dramatically, with the equivalent of 22 Gigafactories online by 2028

CAPACITY BY REGION
GIGAWATT HOURS

EUROPE U.S.A. ASIA (Excluding China) CHINA



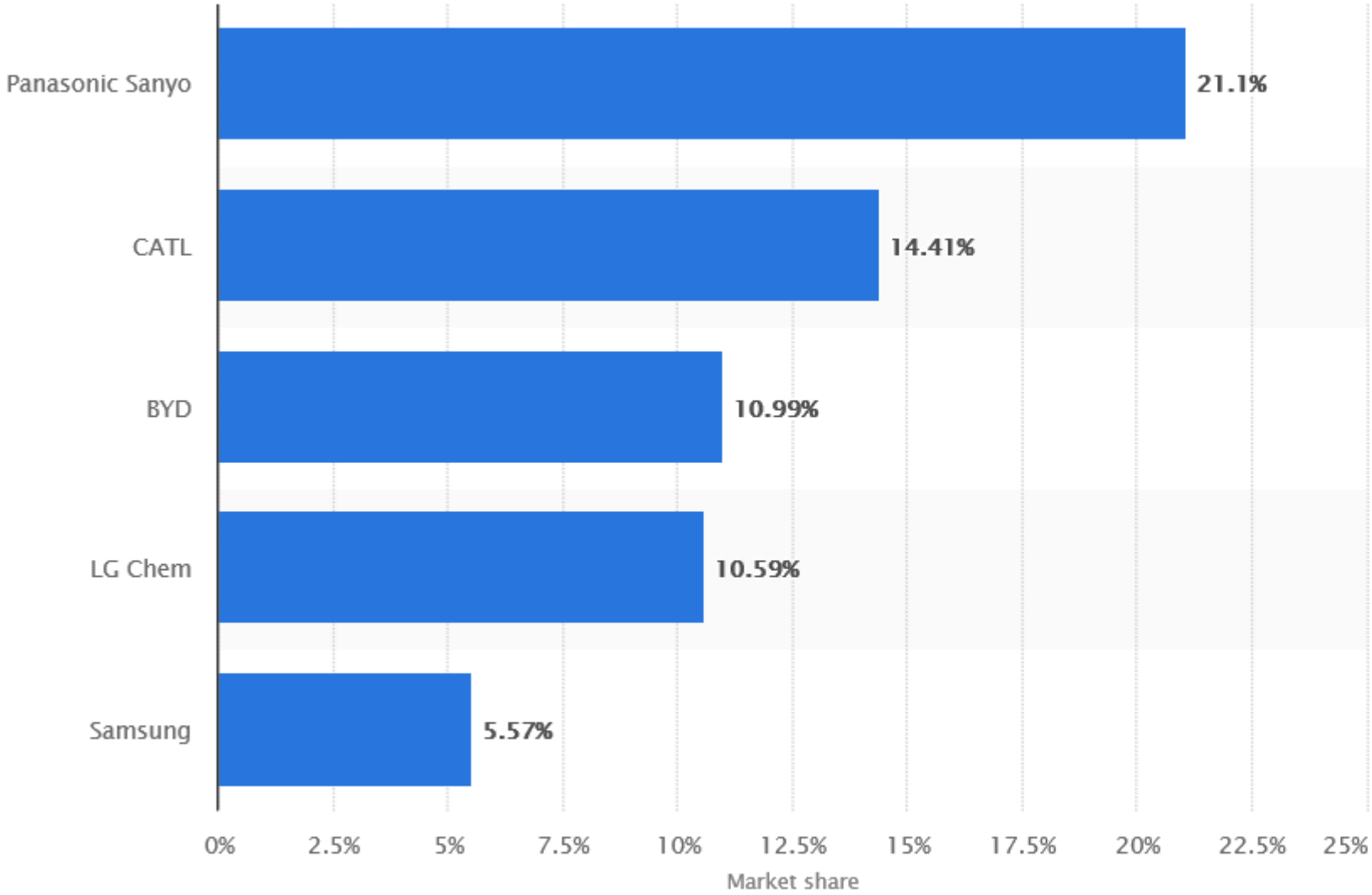
TOP 7 PLANTS
GIGAWATT HOURS (2023)



In just a decade, global lithium-ion battery production capacity will increase **399%** to surpass the **1 TWh** mark.

Data by: BENCHMARK MINERAL INTELLIGENCE

Global market share of lithium ion battery makers in the 1st quarter of 2018



Data visualized by tableau

VW wants to be the most profitable electric car company in the world

- Volkswagen said it will spend 44 billion euros on electric cars, digitalization, autonomous driving and new mobility services by 2023.
- The auto maker also plans to increase productivity of its factories by 30 percent by 2025.

Electric vehicles will grow from 3 million to 125 million by 2030, International Energy Agency forecasts

- The number of electric vehicles on the road around the world will hit 125 million by 2030, the International Energy Agency forecasts.
- The world's fleet of electric vehicles grew 54 percent to about 3.1 million in 2017.
- The IEA says government policy will continue to be the linchpin for electric vehicle adoption.

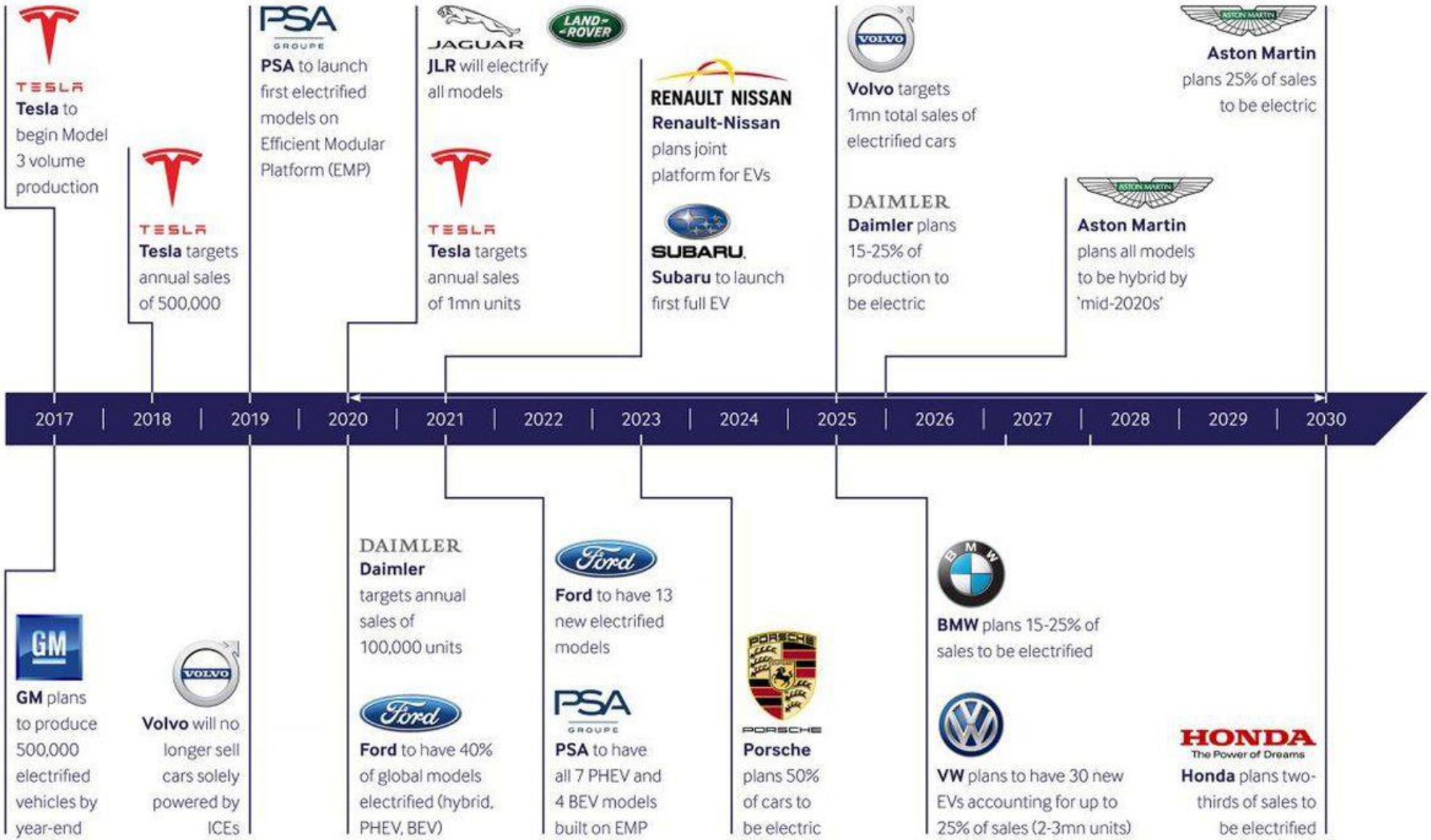
Tom DiChristopher | @tdichristopher

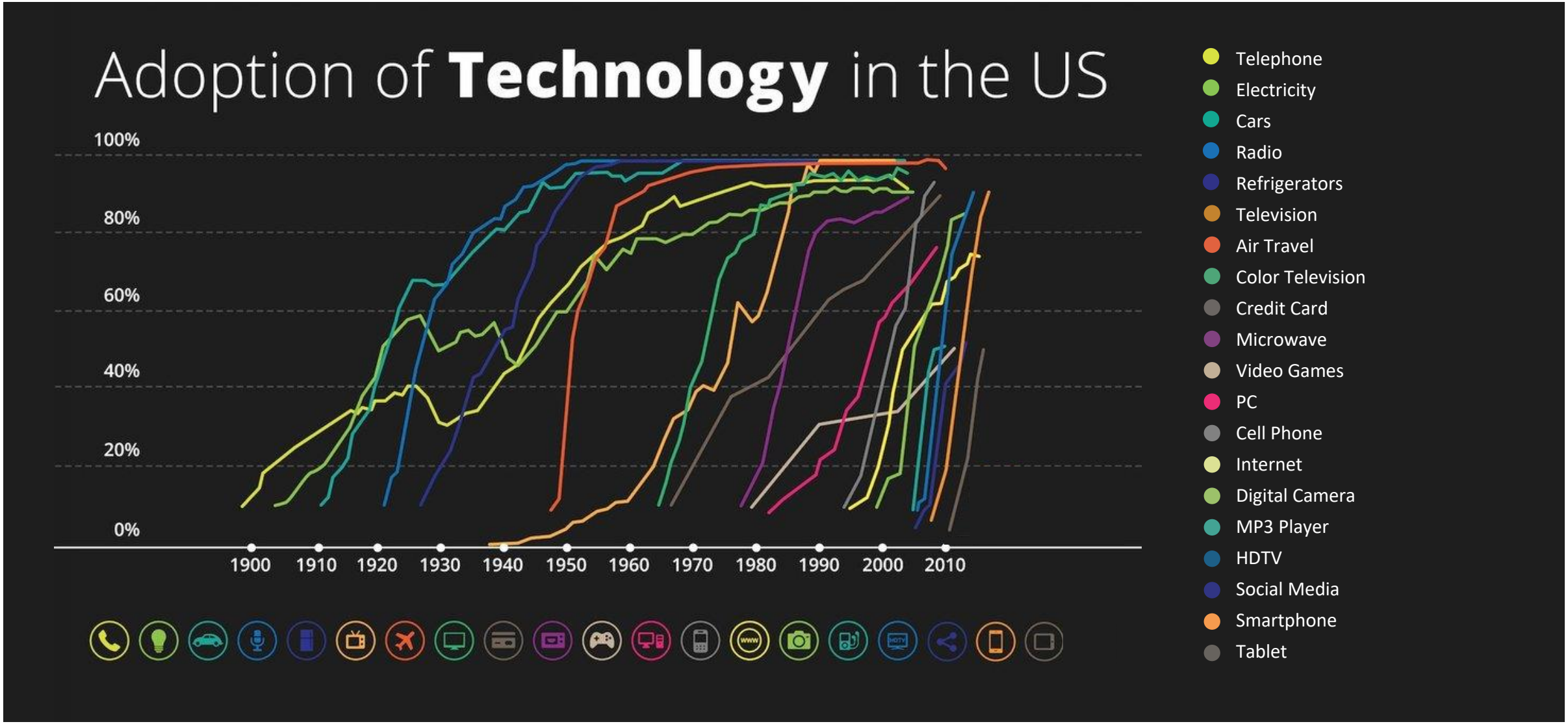
Published 6:57 AM ET Wed, 30 May 2018 | Updated 2:55 PM ET Wed, 30 May 2018

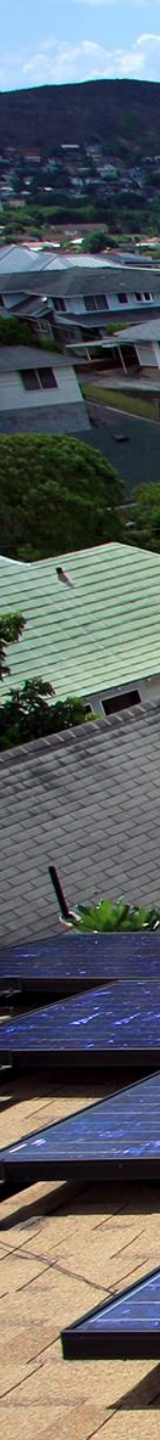
CNBC

Electric Vehicle Timeline

BMI Research
A FitchGroup Company




Adoption of Technology in the US
100%
80%
60%
40%
20%
0%
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Telephone
Electricity
Cars
Radio
Refrigerators
Television
Air Travel
Color Television
Credit Card
Microwave
Video Games
PC
Cell Phone
Internet
Digital Camera
MP3 Player
HDTV
Social Media
Smartphone
Tablet



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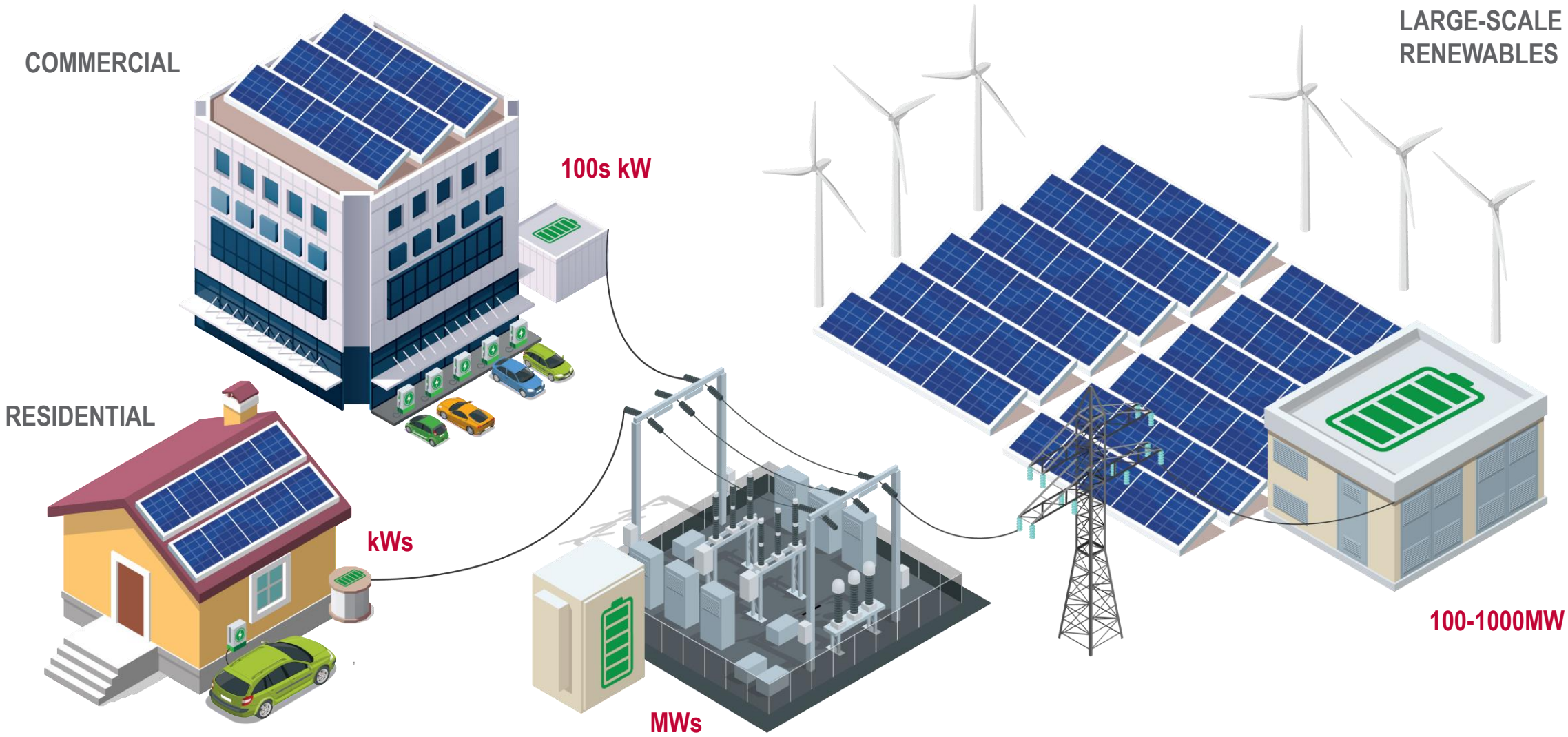
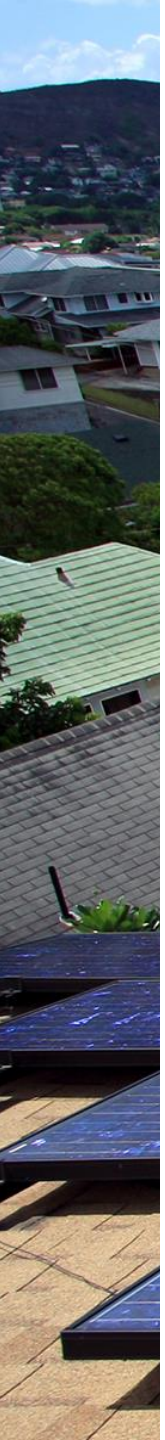
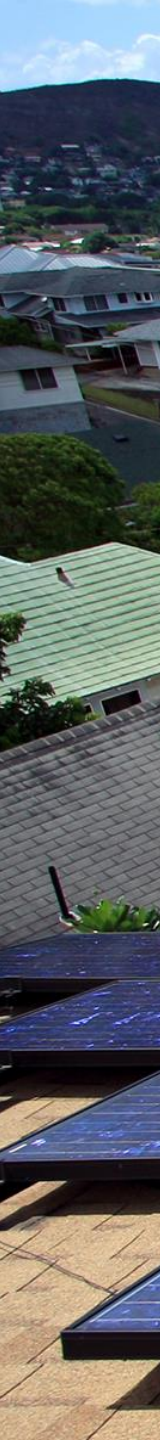
Is our grid ready?





Is our Grid Ready - Questions?

1. Is there enough generation capacity to switch cars from oil to electrons?
2. Can the grid T&D infrastructure handle the increase in electricity
3. What is the optimized role and value of centralized & decentralized stational energy storage?
4. What is the optimal EV charging strategy (location and time)
5. Can we reduce cost of electricity and increase reliability and resiliency
6. Can we deliver electricity equitable for all?



Transitioning the transportation to the grid

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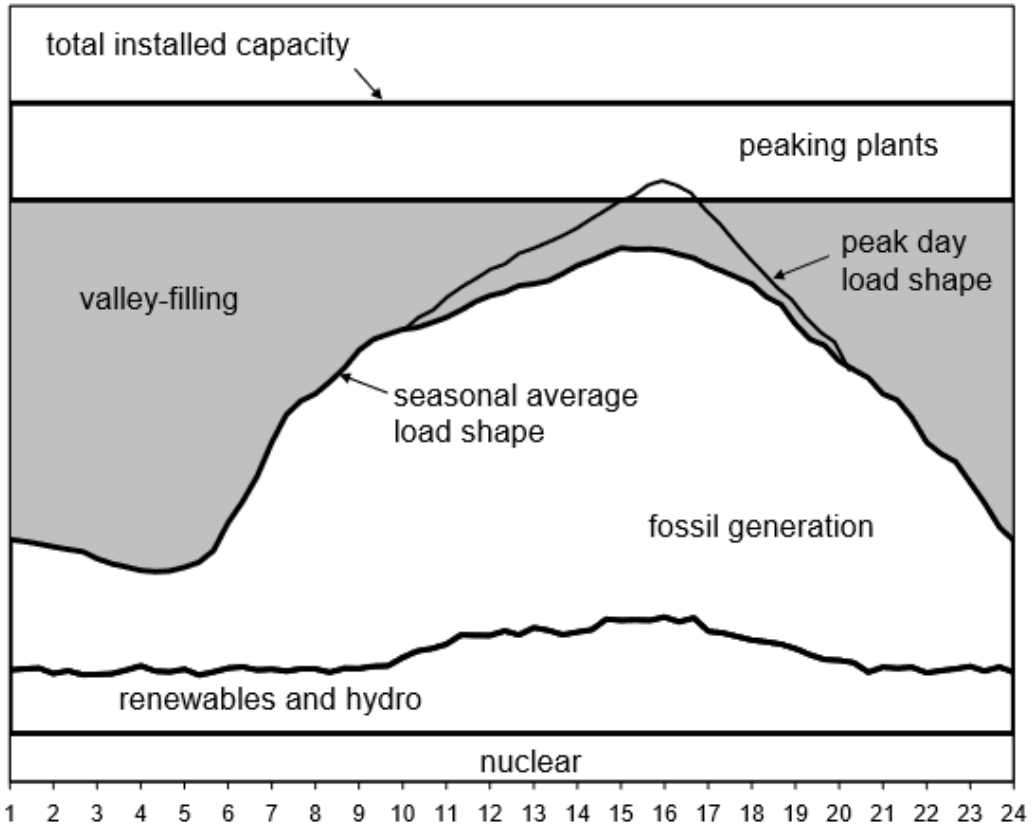

Figure 2: Stylized Load Shape for 1 Day During Peak Season, Generation Dispatch, and Installed Capacity

Generation Capacity & Valley Filling !

- ✓ How many cars can you put on the grid with current generation, T&D infrastructure?
- ✓ How will this change in the future with RPS?
- ✓ How do we optimize valley-filling (off peak)?
- ✓ What impact does this have on grid reliability & resiliency
- ✓ What is the optimized role of stationary storage (vs energy efficiency, demand response, distributed generation) ?

IMPACTS ASSESSMENT OF PLUG-IN HYBRID VEHICLES ON ELECTRIC UTILITIES AND REGIONAL U.S. POWER GRIDS PART 1: TECHNICAL ANALYSIS
Michael Kintner-Meyer, Kevin Schneider, Robert Pratt (Pacific Northwest National Laboratory)

How many cars can we put on the grid via valley filling?

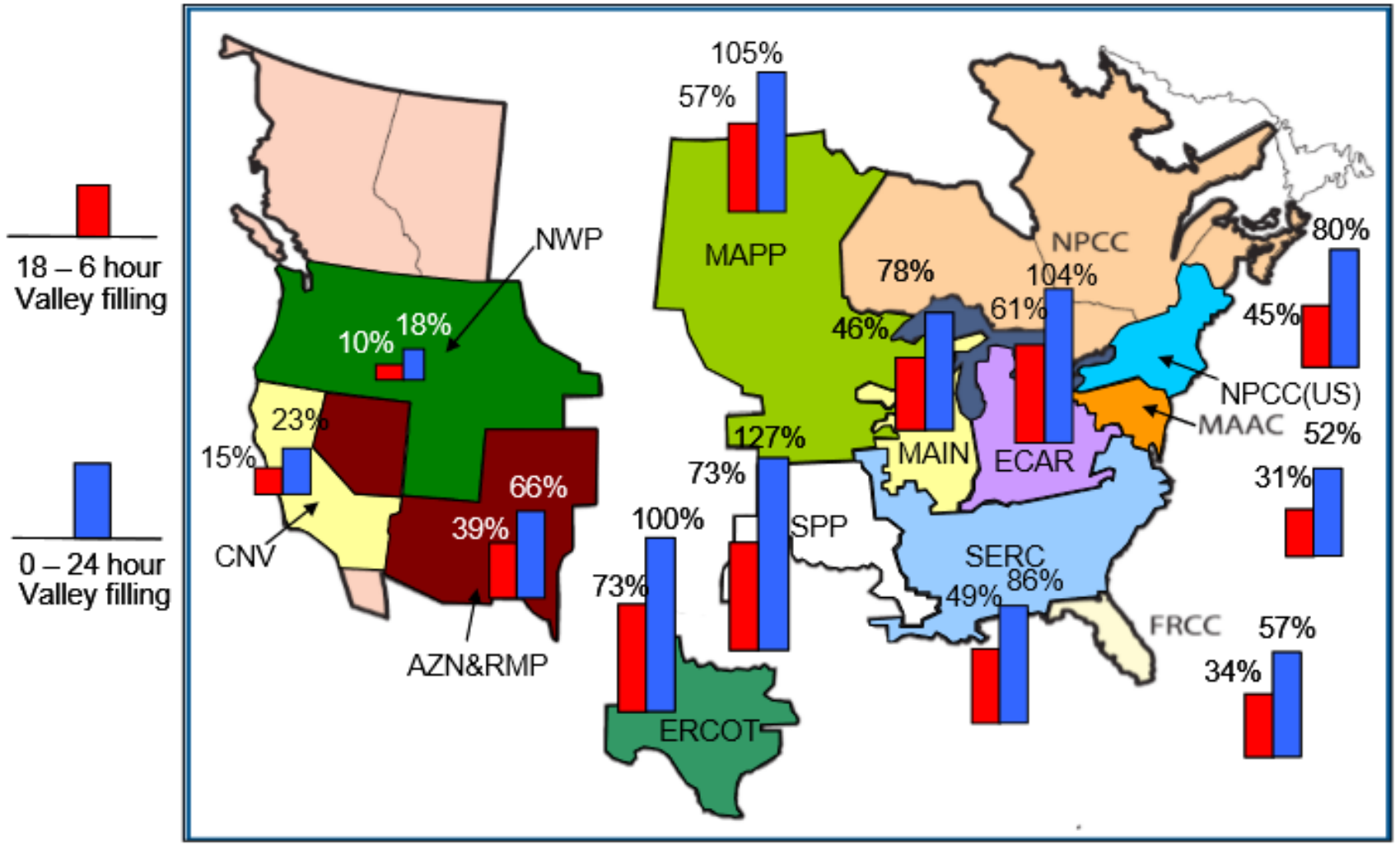

Figure 3: Technical Potential for Fueling the Regional Light Duty Vehicle Fleet with Available Electric Capacity

IMPACTS ASSESSMENT OF PLUG-IN HYBRID VEHICLES ON ELECTRIC UTILITIES AND REGIONAL U.S. POWER GRIDS PART 1: TECHNICAL ANALYSIS
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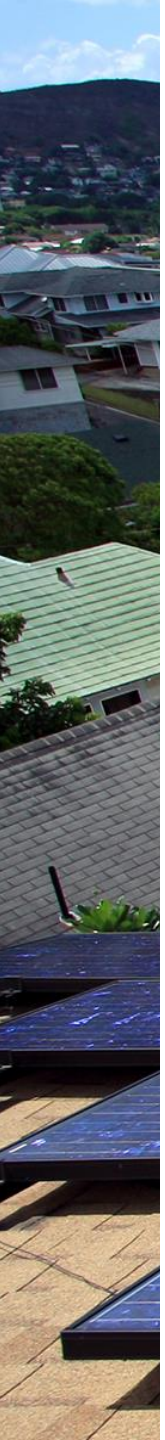

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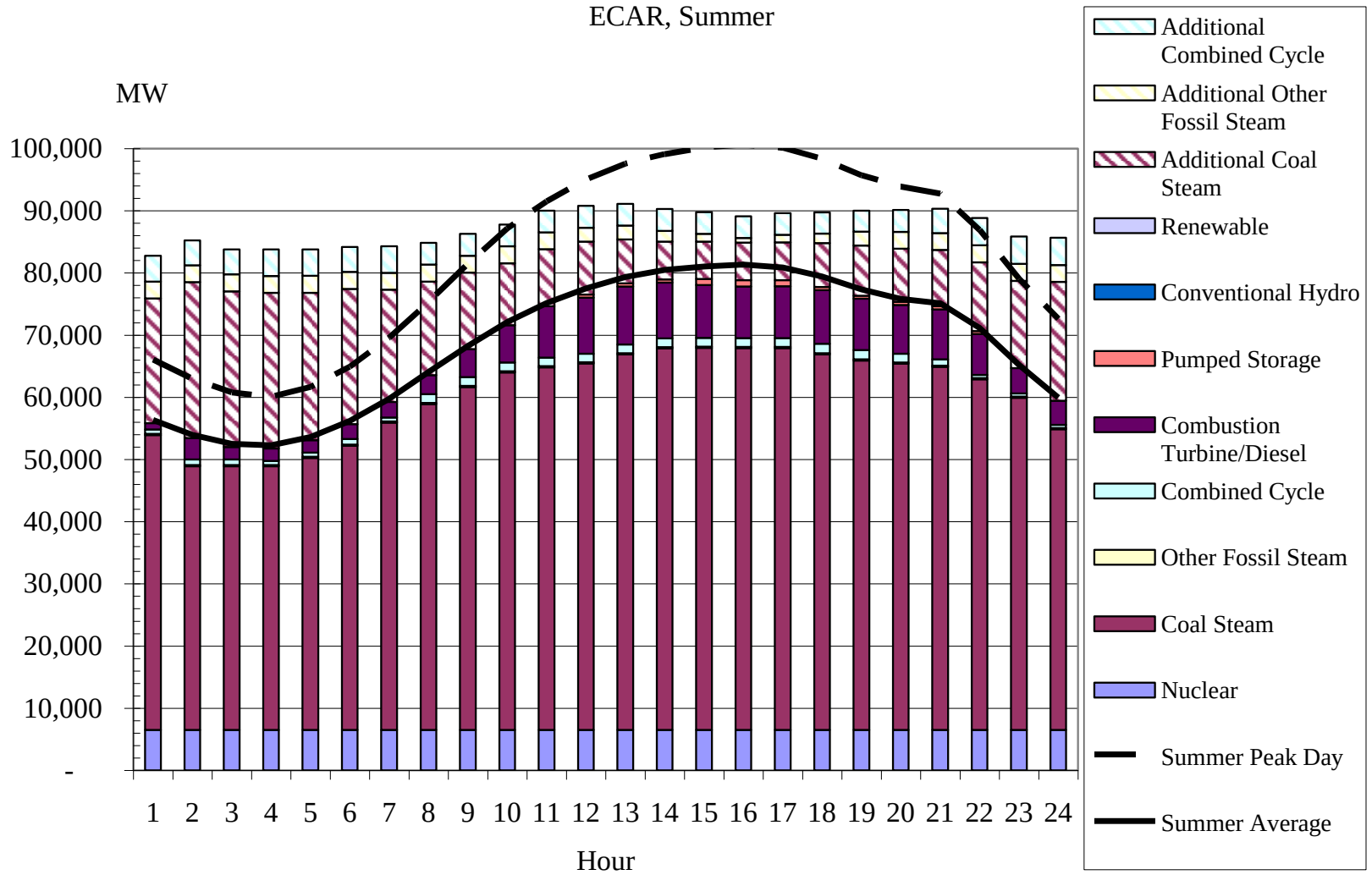
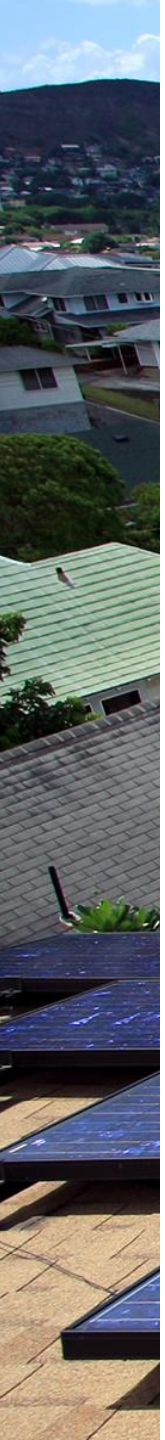
Current Generation and "Valley-Filling" ECAR, Summer

61 % to 104%

Existing Light Duty Vehicle (gasoline) to Electric Vehicles.





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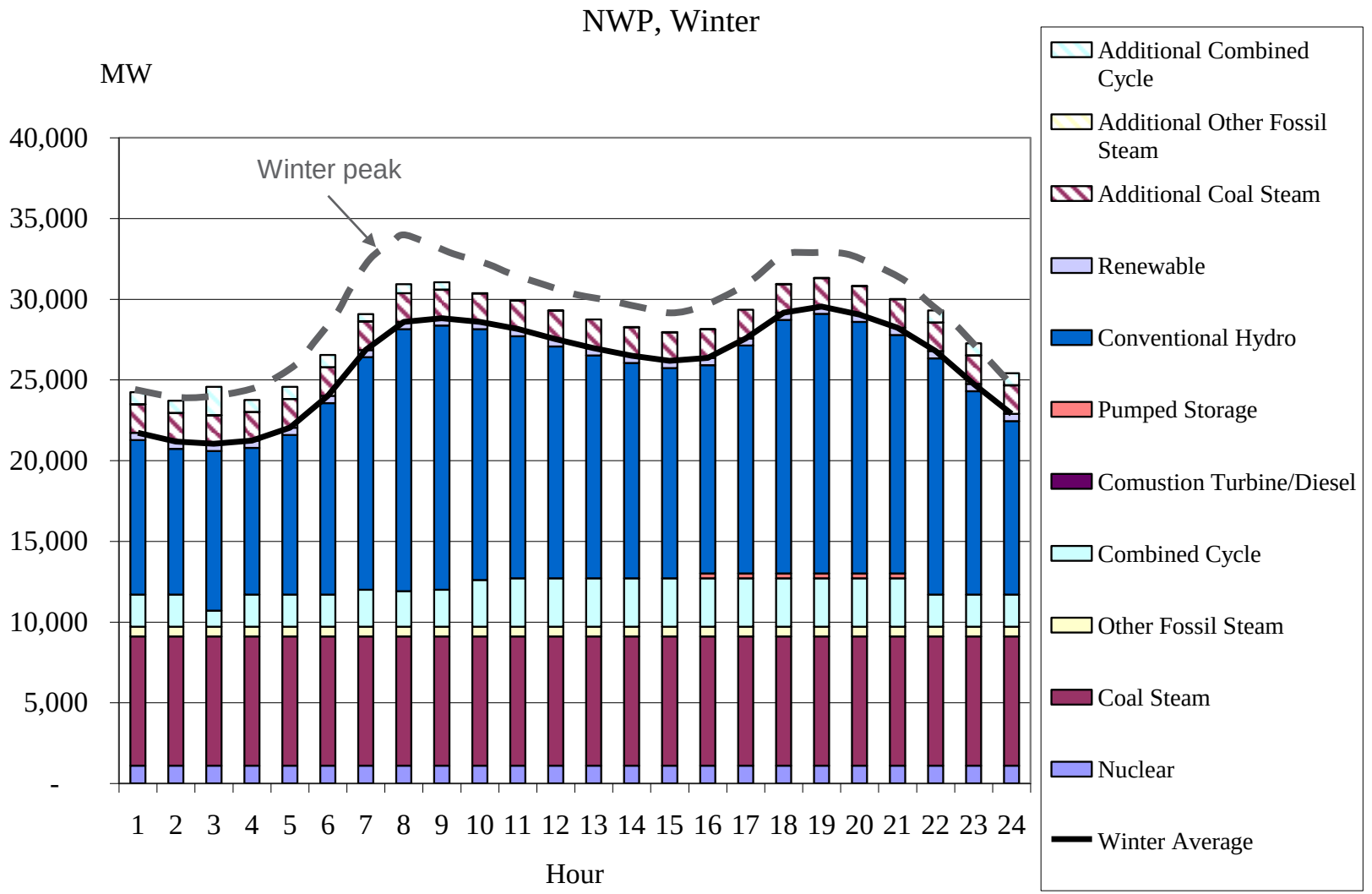
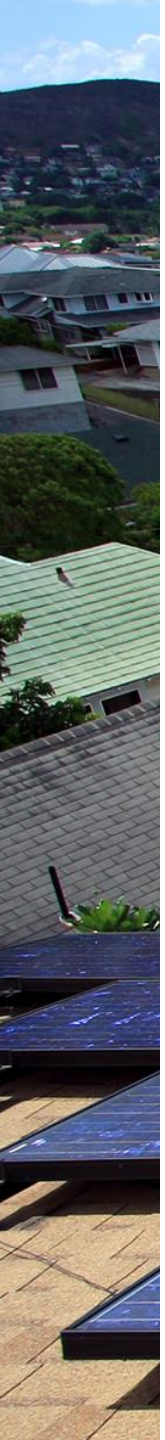
Current Generation and "Valley-Filling" NWP, Winter

10% to 18%

Existing Light Duty Vehicle (gasoline) to Electric Vehicles.

Stationary Energy Storage could play Key role !





Renewable Portfolio Standards and Grid Energy Storage – inter-hour balancing

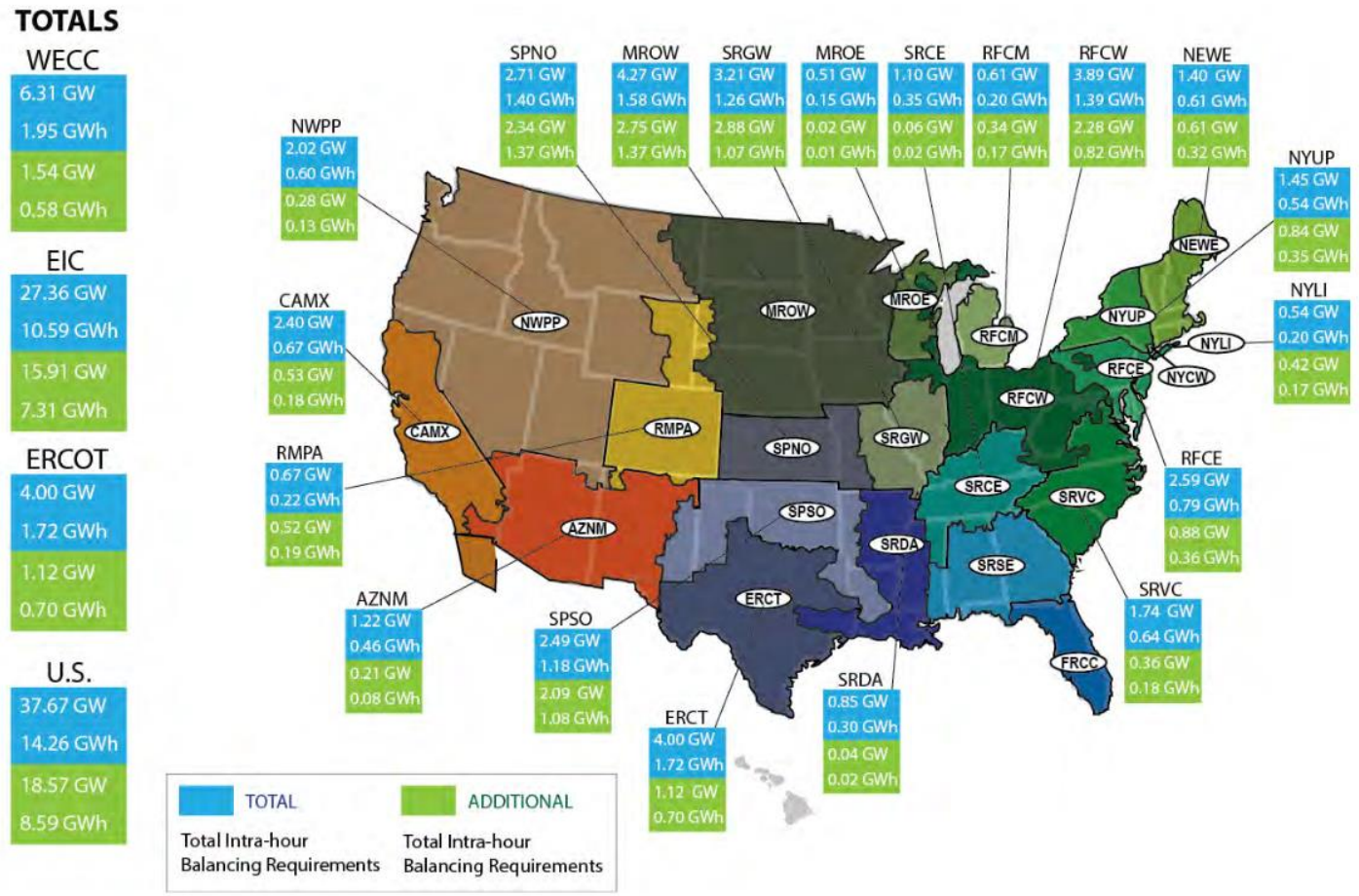


Figure ES.2. Market Size Estimates for Storage Technologies necessary to Meet Additional and Total Intra-Hour Balancing Requirements for a 2020 Grid with 20 percent RPS.

National Assessment of Energy Storage for Grid Balancing and Arbitrage , Phase: II: WECC, ERCOT, EIC, Volume 1: Technical Analysis

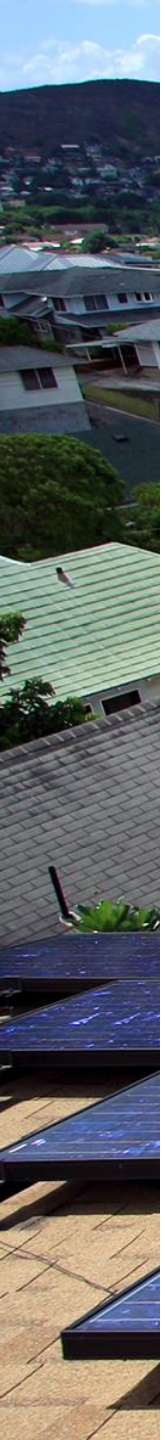
M Kintner-Meyer, P Balducci, W Colella, M Elizondo, C Jin, T Nguyen, V Viswanathan, Y Zhang (September 2013)

Stationary energy storage – value stacking

Puget Sound Energy Utility "Use Case"

- **The Challenge**
  - Substations are capacity constrained
  - Reliability issues with radial transmission and distribution
- **The Solution**
  - Optimal energy storage is 3 MW and 9-12 MWh
  - Total Cost $3,690 per kW installed
  - Battery Cost $2300/kw
  - Net benefits of $6.5M
  - Total cost ~ $11.8M

Assessment of Energy Storage Alternatives in the Puget Sound Energy System , Volume 1: Financial Feasibility Analysis, PNNL - 23040



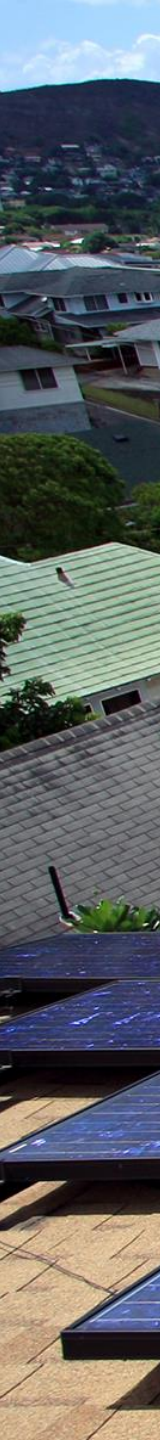
Energy storage applications – which one provide greatest benefit?

- Evaluate arbitrage, balancing services, outage mitigation, distribution upgrade deferral and capacity value

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Total Revenue Requirements
Revenue Requirements					$20,340,000
Arbitrage and Energy Costs	$53,299	$40,833	$53,299	$40,833	
Balancing Services	$2,899,171	$2,898,352	$2,899,171	$2,898,352	
Outage Mitigation	$10,656,246	$10,889,467	$10,656,246	$10,889,467	
Distribution Upgrade Deferral	$6,252,000	$6,252,000	$6,252,000	$6,252,000	
Capacity Value	$1,373,000	$1,373,000	$6,787,000	$6,787,000	

RESULTS - $26M potential Benefit

- Outage Mitigation – 41%
- Capacity Value – 25%
- Deferral upgrade – 23%
- Balancing – 11%
- Arbitrage – 0.15%



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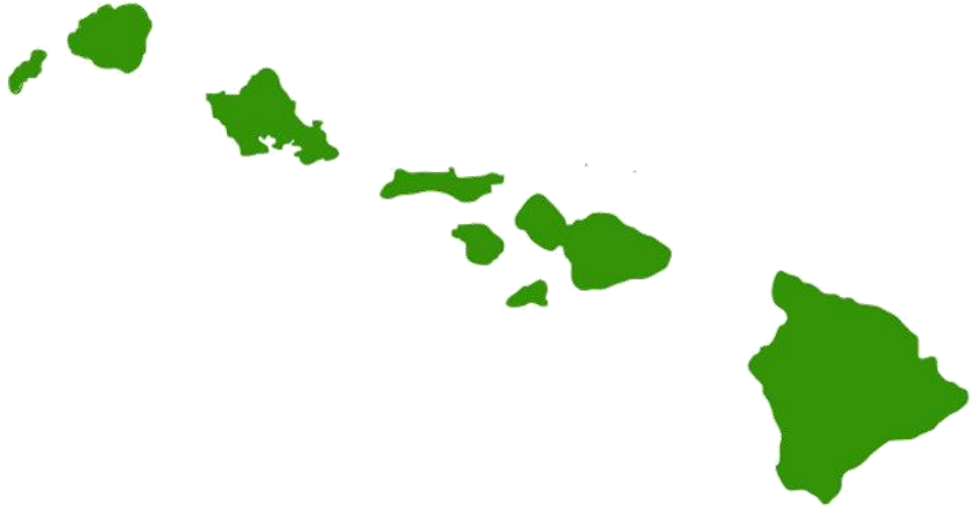
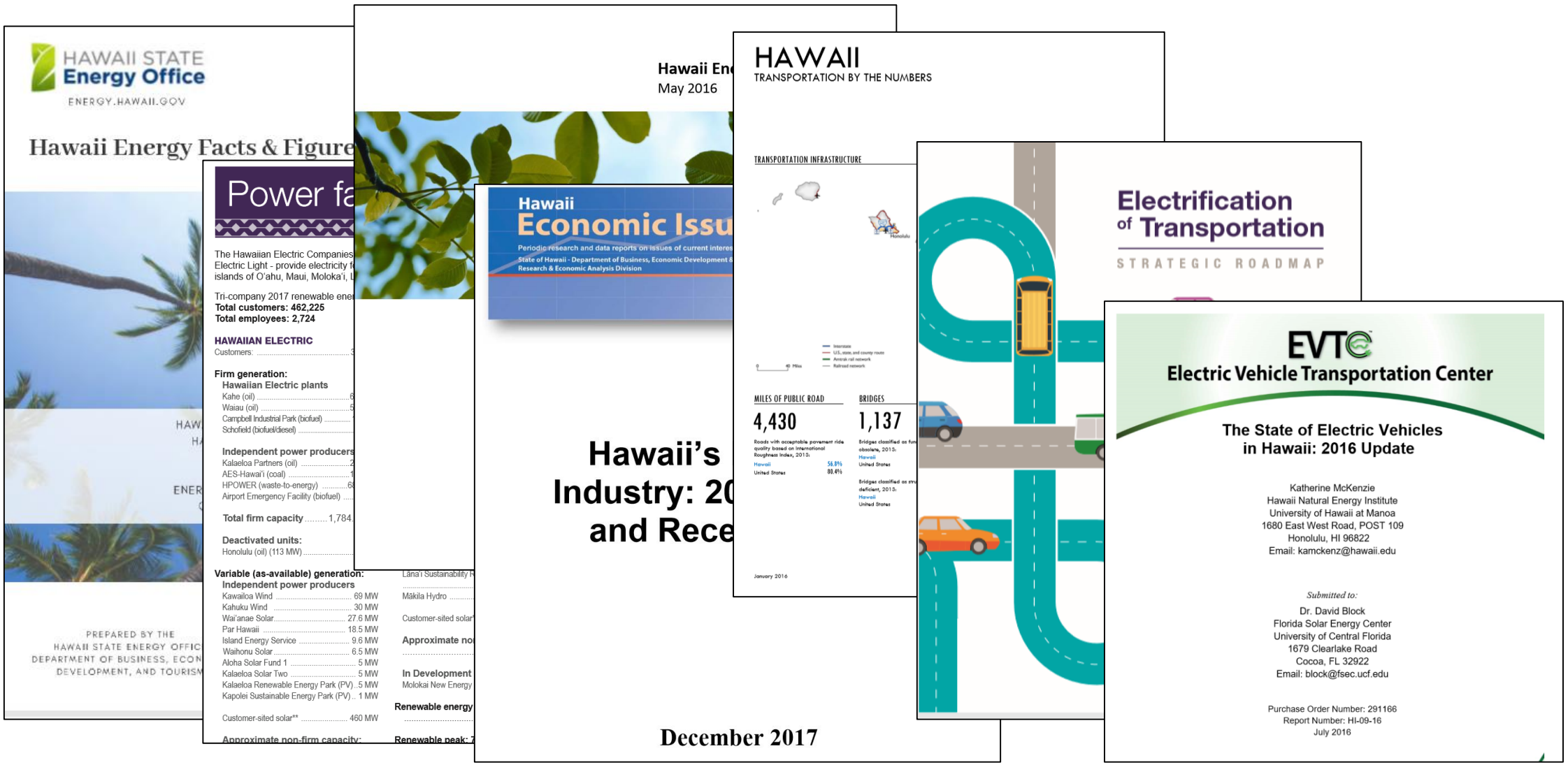
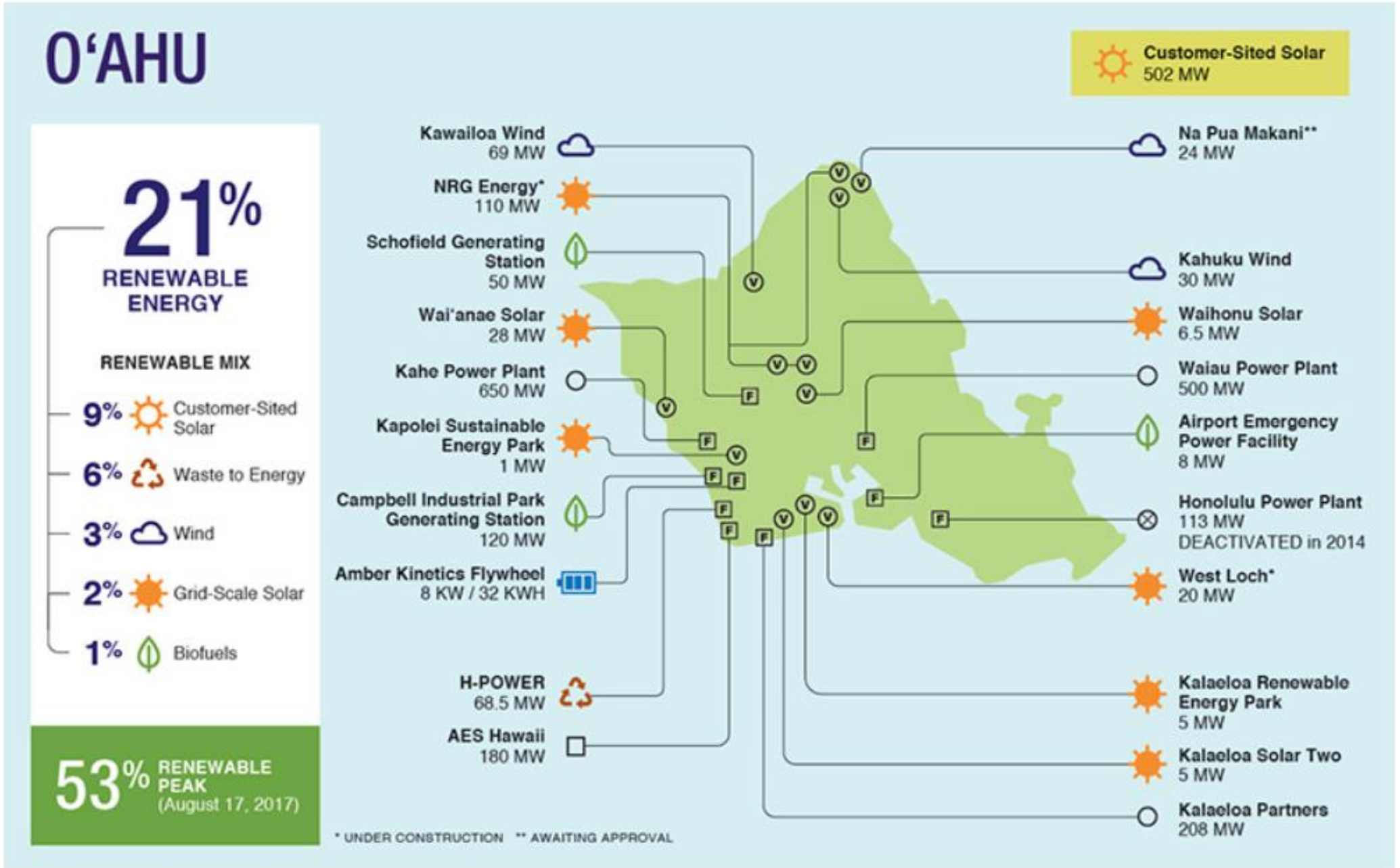
Thinking about what this means for Hawaii….

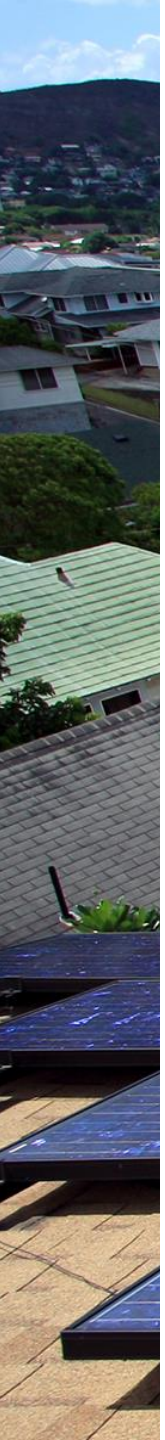


Hawaii energy data





https://www.hawaiianelectric.com/clean-energy-hawaii/clean-energy-facts/about-our-fuel-mix



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Oahu electricity and transportation data

Electricity Generation

2.4 GW installed generation

15,367 GWh – annual energy capacity (firm plus variable)

- ✓ 12,078 GWh – oil and coal (79%)
- ✓ 460MW customer-sited solar

6,976 GWh HECO total annual energy use

- ✓ 25% residential
- ✓ 75% commercial

Transportation Data

906,237 registered vehicles

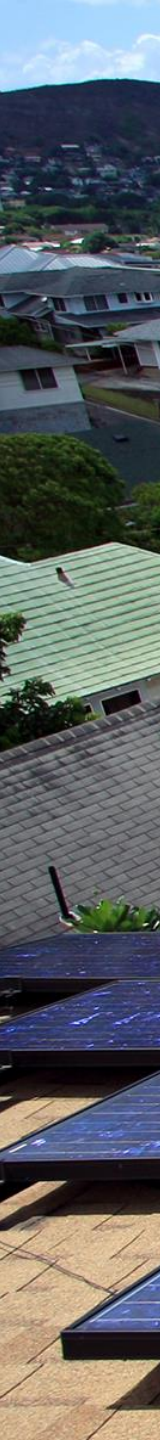
9,400 annual average miles travelled

20.1 average miles/person/day

Assume 0.25 KWh/mile for an Electric Vehicle

2,129 GWh energy needed if all vehicles were electric vehicle!

- ✓ 31% of current HECO energy consumption
- ✓ 5KW/hr/day per vehicle



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Does Oahu have enough generation capacity to put all vehicles on the grid?

YES! Current Generation Profile

15,367 GWh total Capacity

✓ 79% oil & coal

6,976 GWh current load

2,129 GWh Electric Vehicle

9,105 GWh current load + EV

15,367 GWh > 9,105 GWh

NO! 100% Renewables

3,288 GWh Total Renewables

9,105 GWh current load + EV

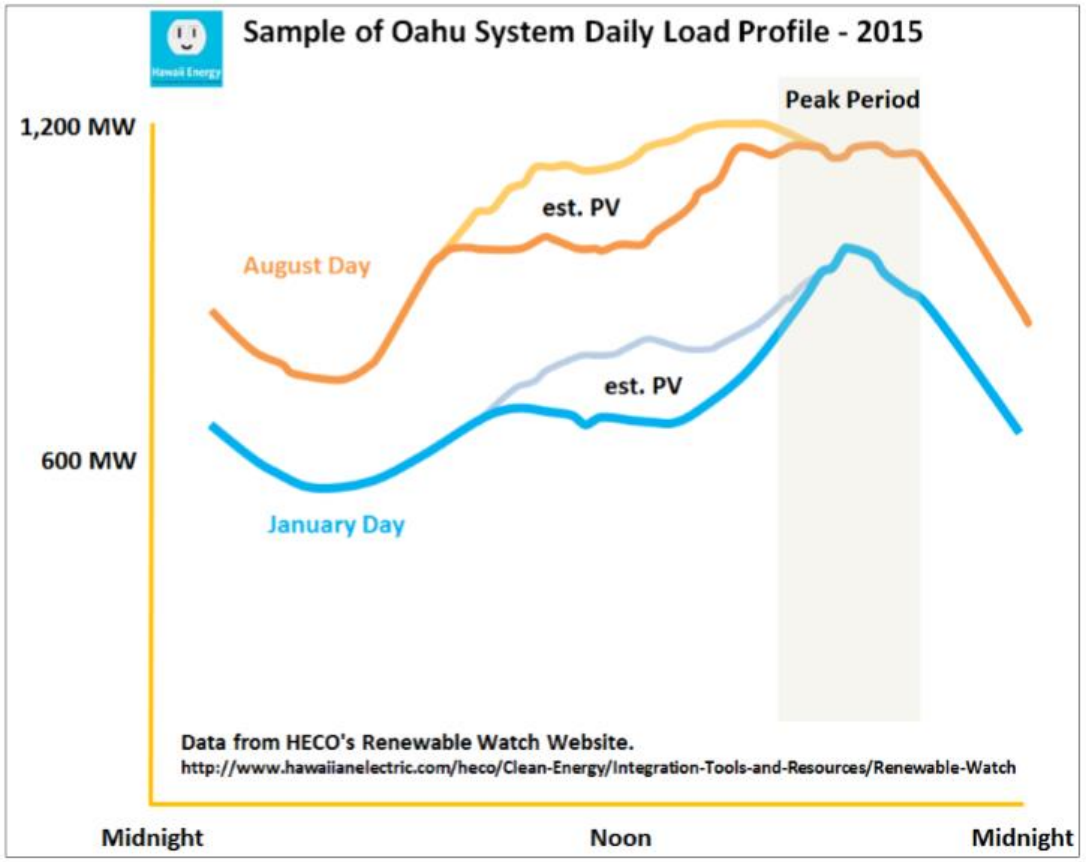
3,288 GWh < 9,105 GWh

5,816 GWh Renewable Generation needed

(~2.2GW solar or wind)

Big Bucket thinking is fun, need to really understand the specifics of T&D infrastructure?

Figure 2
Average Daily Seasonal Demand (Load) Profile + Rooftop PV Generation



ANNUAL REPORT Program Year 2016 July 1, 2016 – June 30, 2017 Submitted to the Hawai'i Public Utilities Commission

- Impact of distributed PV on distribution infrastructure
- Location of EV chargers & smart charging
- Location of and size of stationary energy storage
- Demand response and optimized real-time operational control
- Performance and cost trade offs.

Optimizing stationary storage with distributed renewable generation!

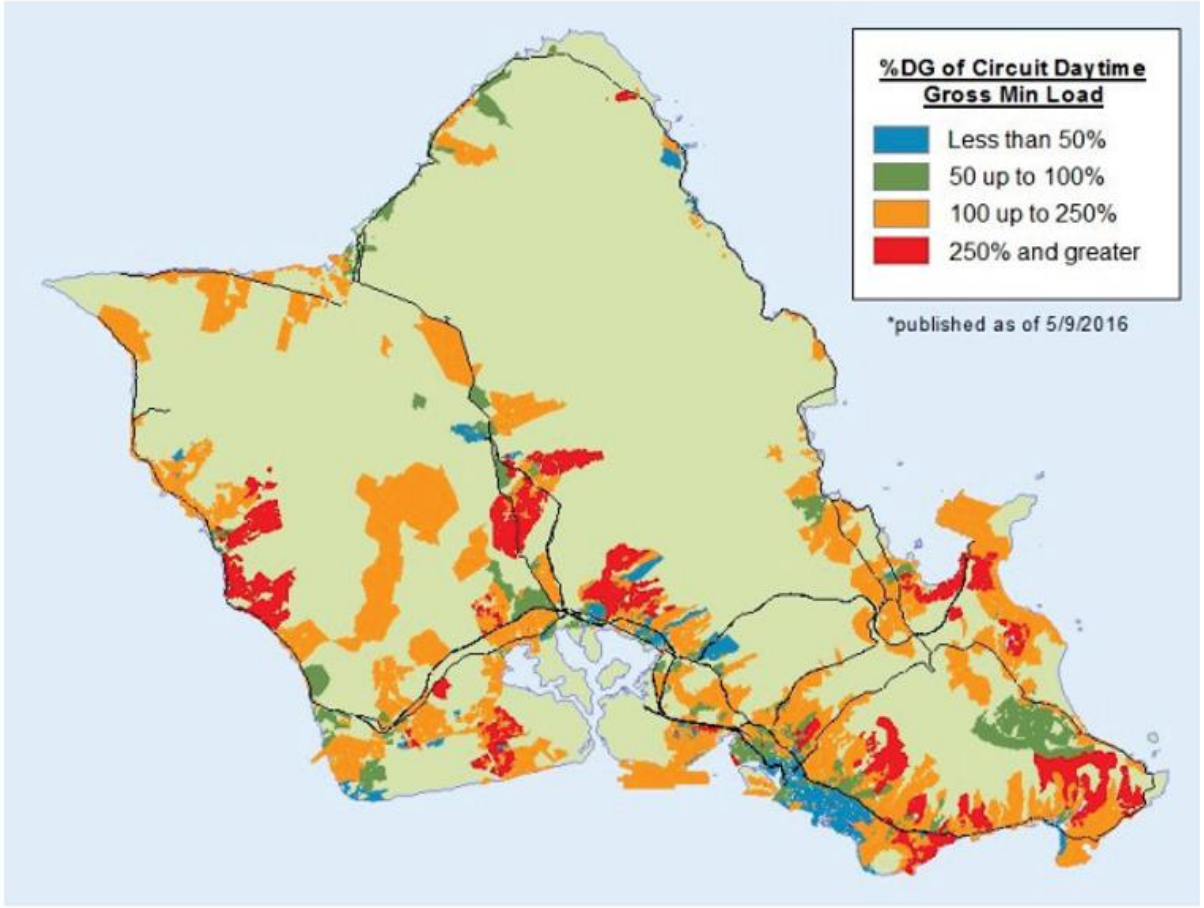


Figure 16. HECO's map for Oahu, with distributed generation (mostly PV) as a percent of minimum daytime load on distribution circuits.

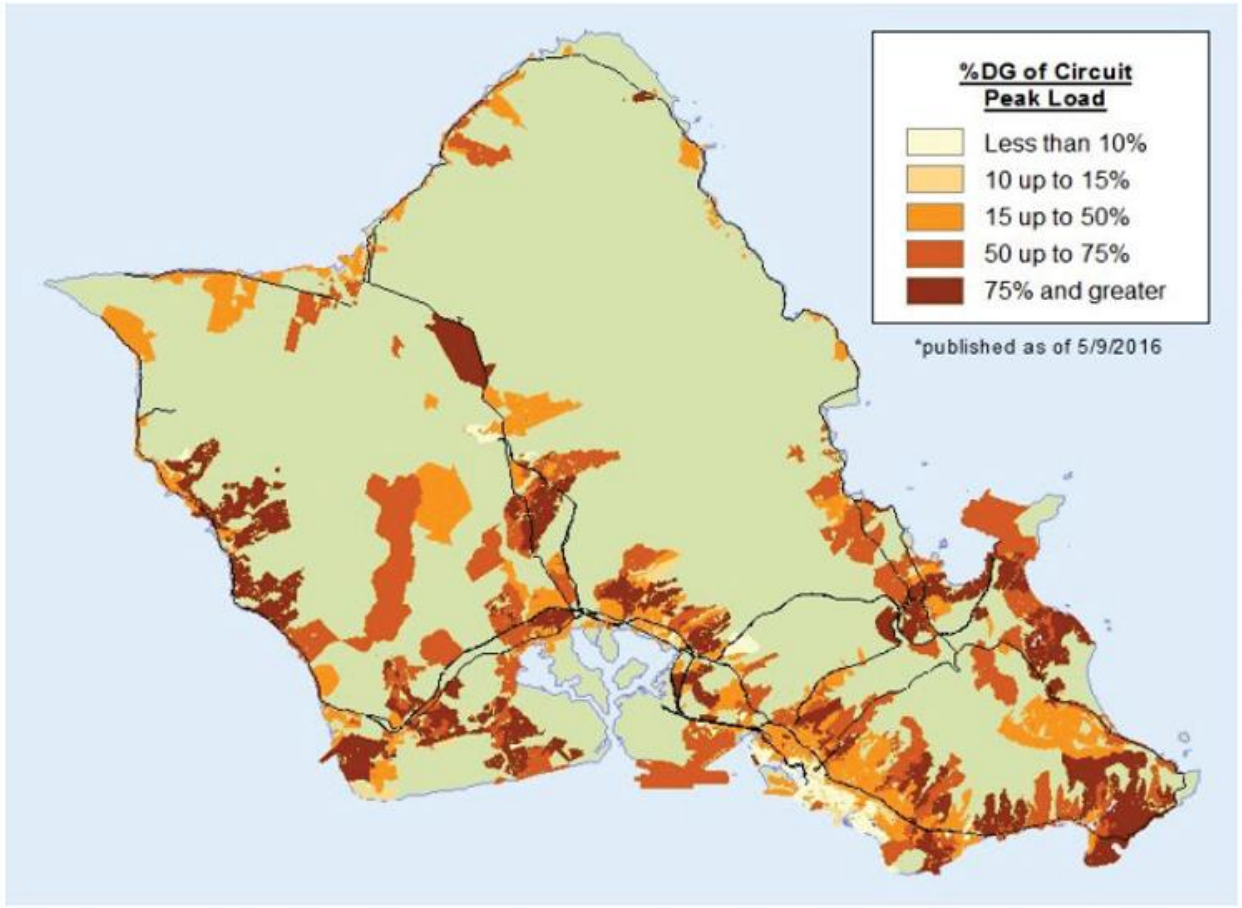
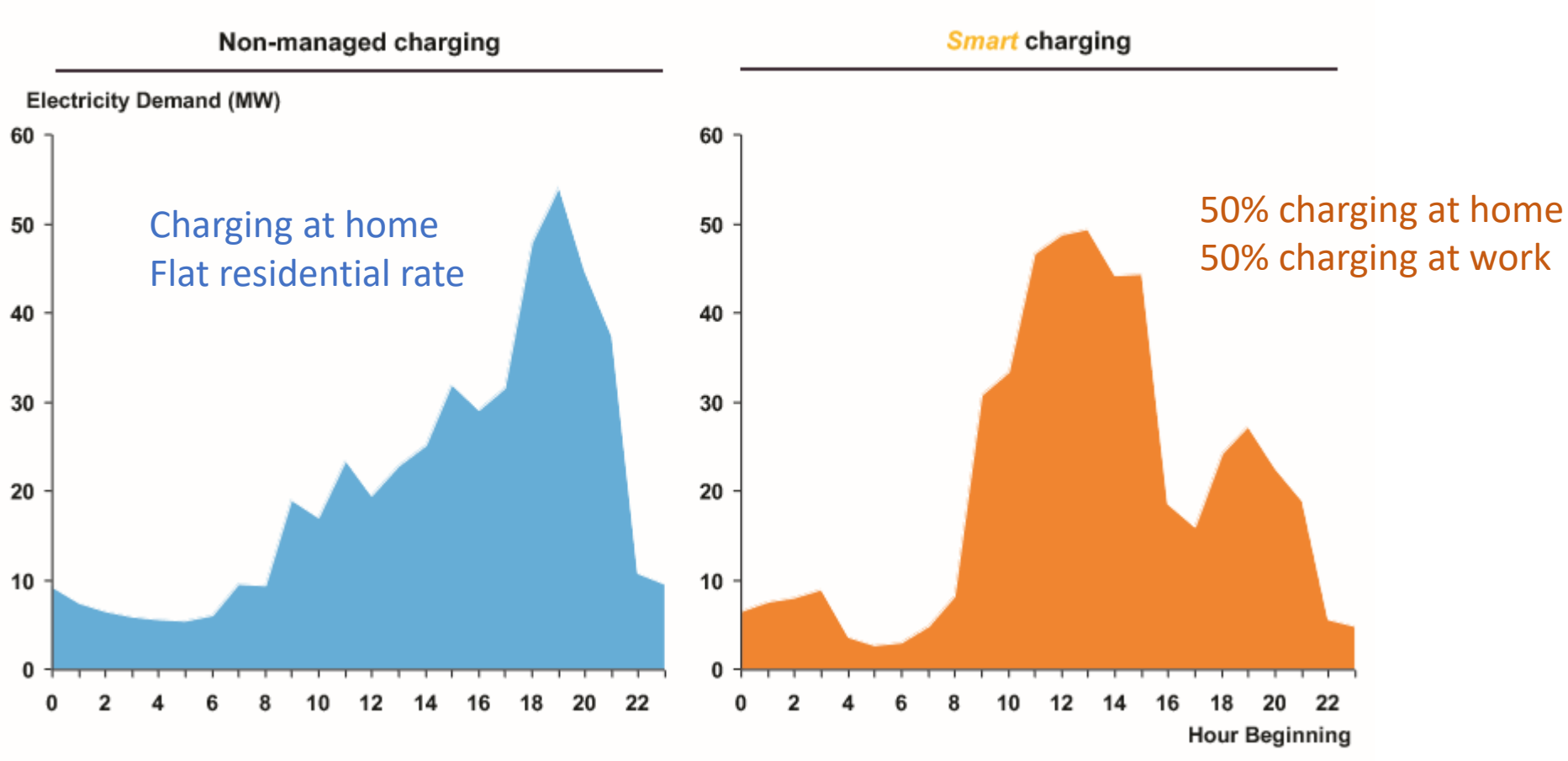


Figure 17. Connected and accepted distributed generation (mainly PV) on distribution circuits as a percent of peak circuit load on Oahu.

EVTC Electric Vehicle Transportation Center. "The State of Electric Vehicles in Hawaii: 2016 Update." Katherine McKenzie, Hawaii Nature Energy Institute

Smart Charging + stationary energy storage is key (5KWh/vehicle/day)

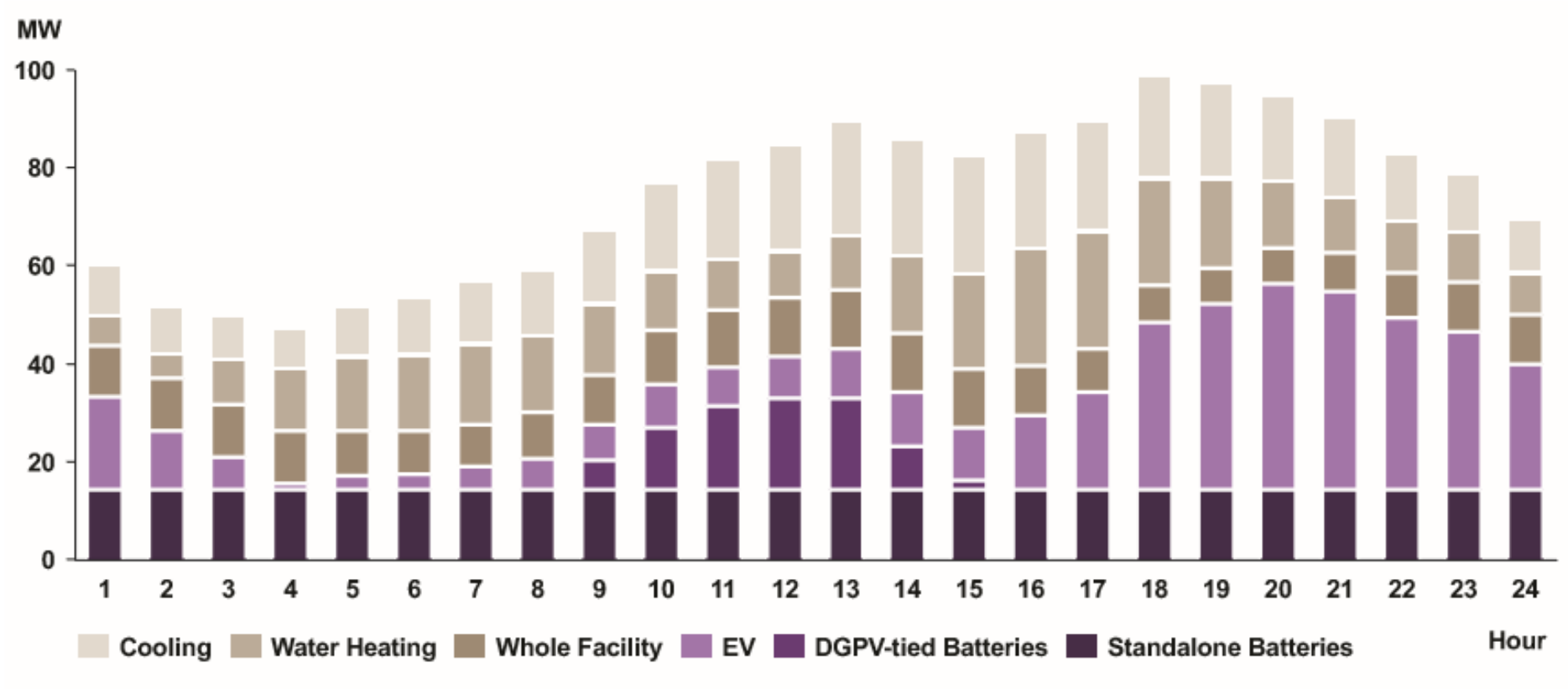
Figure 33. Average weekday charging load for personal, light-duty EVs, Non-Managed Charging case and Smart Charging case, 2030



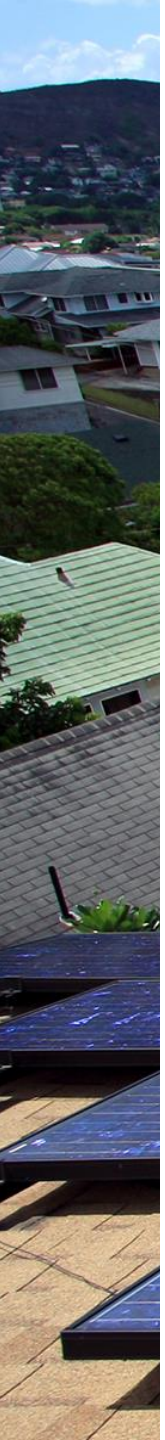
Source: E3 Analysis

Potential of fast frequency response services

Figure 31. O'ahu Fast Frequency Response Load Reduction Potential from DR Filing



Source: Docket 2015-0412, "Revised DR Portfolio Filing" filed on February 10, 2017, Attachment A "Potential Study" at 26.



Take away thoughts…….

Reliable, Resilient, Equitable, Electricity Delivery System

- ✓ Are we at a tipping point with energy storage?
- ✓ Will change occur faster than we expect?
- ✓ **The role of stationary energy storage will need to be optimized for the system.**
- ✓ Great opportunity to work with local utilities to develop an optimize future system view
- ✓ Hawaii will lead the world!

Electricity Delivery System of the Future

Stationary and vehicle energy storage - centralized and decentralized renewable generation - energy efficiency - transmission and distribution capacity - demand response – real-time operational and decision tools…..

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Thank You!