Vehicle Electrification Technological Change

Electric Vehicle (EV) advances, power demand and risk

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Topics

- Historical background
- Electric Vehicle (EV) technological advances
- Electric power terminology
- EV auto manufacturers expanded production
- Data/Studies
  - National Renewable Energy Lab
  - ISO New England
- Risks
  - Grid shortfall
  - EV technology supply chain - Rare earth magnets/lithium batteries

Vermont circa 1900

- Most cities have electricity
- Rural electrification is years in the future
- Personal transport is horse drawn
- Very few cars- 80% are steam or electric

Newport Vermont Circa 1920-1940

Newport, Vt 1920's

Almost all cars are powered by gasoline internal combustion engines

Newport, Vt 1940's

US Motor Vehicle Ownership 1900 to 1940/EV 2011 to 2030

1900 – 8,000 motor vehicles

1910 – 468,500 including 10,123 trucks

1920 – 9,239,161 including 1,107,639 trucks

1930 – 26,749,853 including 3,674,593 trucks

1940 – 32,453,233 including 4,886,262 trucks and 101,145 buses

2011 – 17,731 EV's in the US

2015 – 113,773 EV's in the US

2019 – 1,180,000 EV's in the US

2021 – 2,200,000 estimated EV's in the US

2025 – 6,000,000 estimated EV's in the US

2030 – 18,700,000 estimated EV's in the US – 7% of market

Will require 9.6 million chargers

https://www.eei.org/resourcesandmedia/newsroom/Pages/Press%20Releases/EEI%20Celebrates%201%20Million%20Electric%20Vehicles%20on%20U-S-%20Roads.aspx

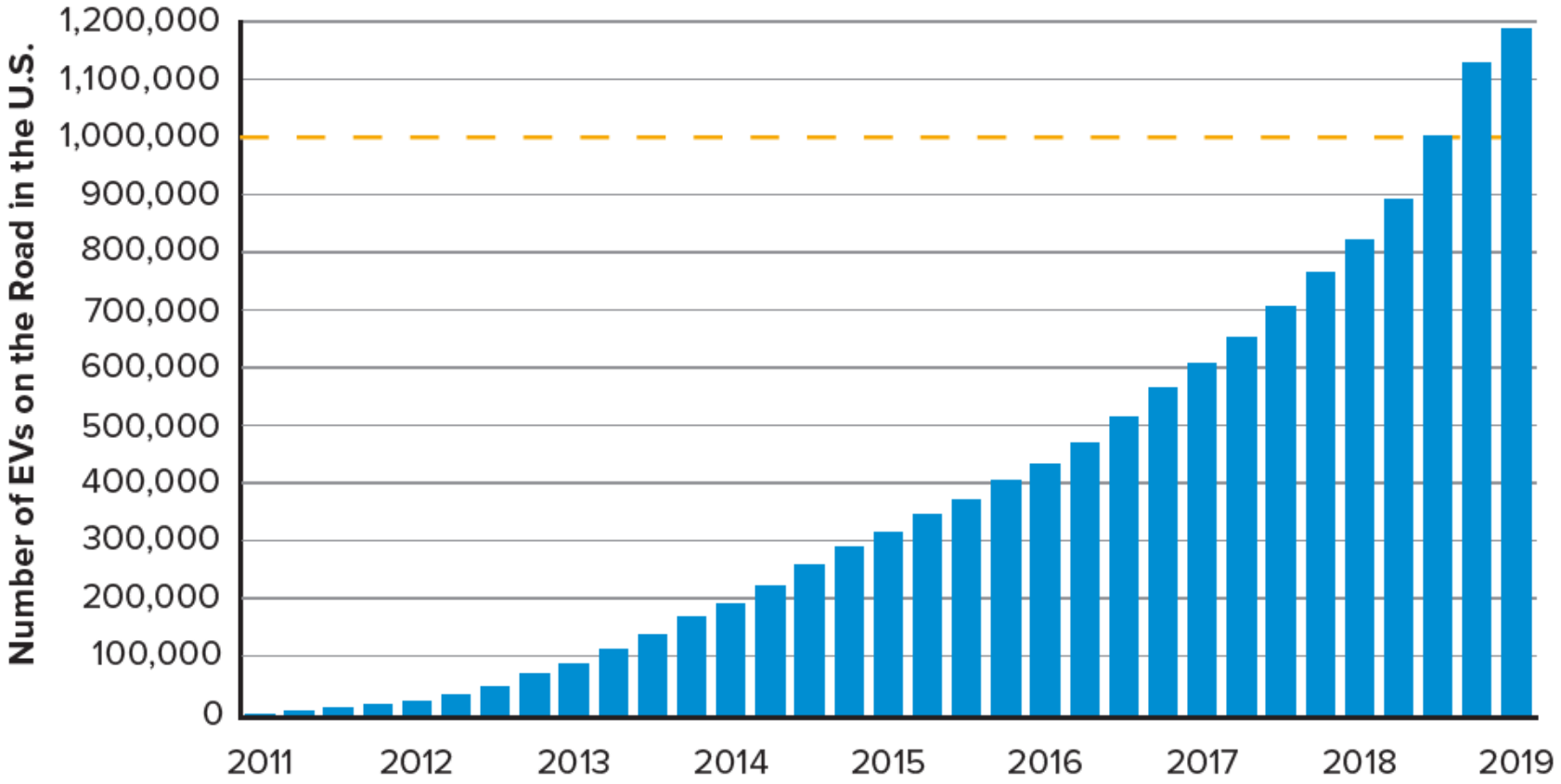
https://www.edisonfoundation.net/iei/publications/Documents/IEI_EEI%20EV%20Forecast%20Report_Nov2018.pdf

https://www.iea.org/reports/global-ev-outlook-2019

Electric Vehicle Sales: Facts & Figures

April 2019

ELECTRIC VEHICLES ON THE ROAD IN THE U.S.



Source: InsideEVs.com and HybridCars.com

Technology Advancement

- Technology moves in fits and starts
- Sudden technological breakthroughs can lead to significant disruptive economic shifts
- Electric vehicle batteries are breaking previous chemistry constraints
- Manufacturers are investing billions in EV manufacturing infrastructure and supply chains
- EV technological adoption may come faster than the grid is prepared to support
- We need to ask different questions and look at vehicle electrification from a new perspective

Battery and Power Terminology

- Ampere-hours battery capacity is the discharge current a battery can release over time –typical starting batteries are rated at 12 volts and 48 amp hours; The Tesla Model 3 extended range battery is rated at 350 volts and 230 amp hours.
- Watt-hours (Wh) Measure of specific power a battery can deliver over time
- Kilowatt hour (KWh)- eg.100 kilowatt/hr used in defining EV battery specific power
- Kilowatt hours/mile KWh/mile is the term that determines how much battery power is required to move a EV vehicle one mile replacing miles per gallon metric used with Internal Combustion Engine (ICE) vehicles.
- Megawatt (MW)- 1 million watts is the standard power industry term to describe power generating facility rating
- Megawatt hour (MWh) A unit for measuring electric power or the rate at which energy is produced or consumed; equal to 1,000 kilowatts of electricity used for one hour, or 1,000 kilowatt-hours.
- Gigawatt hours (GWh)- 1 billion watt/hours a less common term used by ISO New England to describe monthly supply of electricity to the grid
- Terawatt hours (TWh)- 1 trillion watts/hr used by National Renewable Energy Lab (NREL) and International Energy Agency to describe annual power required to electrify various economic sectors

Automaker Electric Vehicle Investments and production

- Automakers plan $*300 billion* investments in EV's over ten years– $135B in China, $82B Europe, $34B in US
- Nearly half of the current EV vehicles are in China
- A complete range of all vehicle classes have been announced - cars, SUV's, pickups, buses, delivery trucks and class 8 semi trucks
- This highly competitive market is already driving to ever larger battery capacity vehicles in all vehicle classes
- The International Energy Agency's high end global EV production estimate is 100 million EV's by the year 2025 and 250 million by 2030 while other forecasts are half as much or lower
  - https://www.iea.org/reports/global-ev-outlook-2019
  - https://graphics.reuters.com/AUTOS-INVESTMENT-ELECTRIC/010081ZB3HD/index.html

Electric Vehicle Technology Advances

1996-99 GM EV-1 – NiMH 26.4 KWh battery range 105 miles

2011 Chevy Volt - 16 KWh battery range 35 miles plus 1.4L gasoline engine

2016 Chevy Volt - 18.4 KWh battery range 53 miles plus 1.4L gasoline engine

2018 Nissan Leaf - 40 KWh battery range 151 miles

2020 Chevy Bolt - 66 KWh battery range 259 miles

2020 Tesla Model 3 - 75 KWh battery range 325 miles

2020 Tesla Model S Extended Range (+) 100 KWh battery – 390 miles

2021 Rivian Automotive RT1 pickup/RS1 SUV–180 KWh battery range 400 miles

2021 Ford EV F150 – 200+ KWh battery/range?

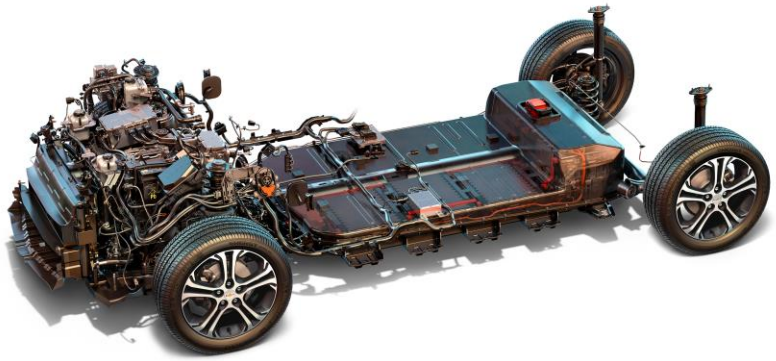
Battery costs declined 87% between 2010 and 2019 allowing EV automakers to build bigger battery packs with more range at lower cost

The Electric Vehicle Skateboard Design

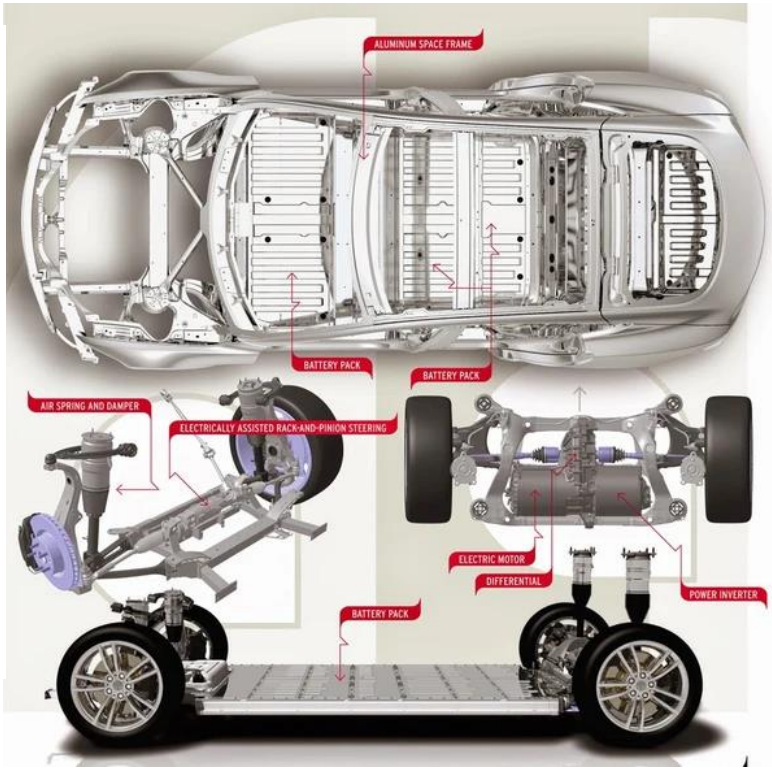
Permanent Magnet Synchronous Reluctance Motor

https://chargedevs.com/features/teslas-top-motor-engineer-talks-about-designing-a-permanent-magnet-machine-for-model-3/

Chevy Bolt electric motor/battery layout



Tesla single electric motor/battery layout



Medium and heavy trucks

- Daimler eCascadia Freightliner tractor trailer and box truck tests use 300 KWh to 550 KWh batteries with a range of 250 miles
- Tesla describes its class 8 semi truck as having 300-500 mile range requiring a 600-1,100 KWh battery
- Innolith battery technology claims 1000 KWh for its pre-production battery giving a 600 mile car range

Daimler-Freightliner Electric Trucks

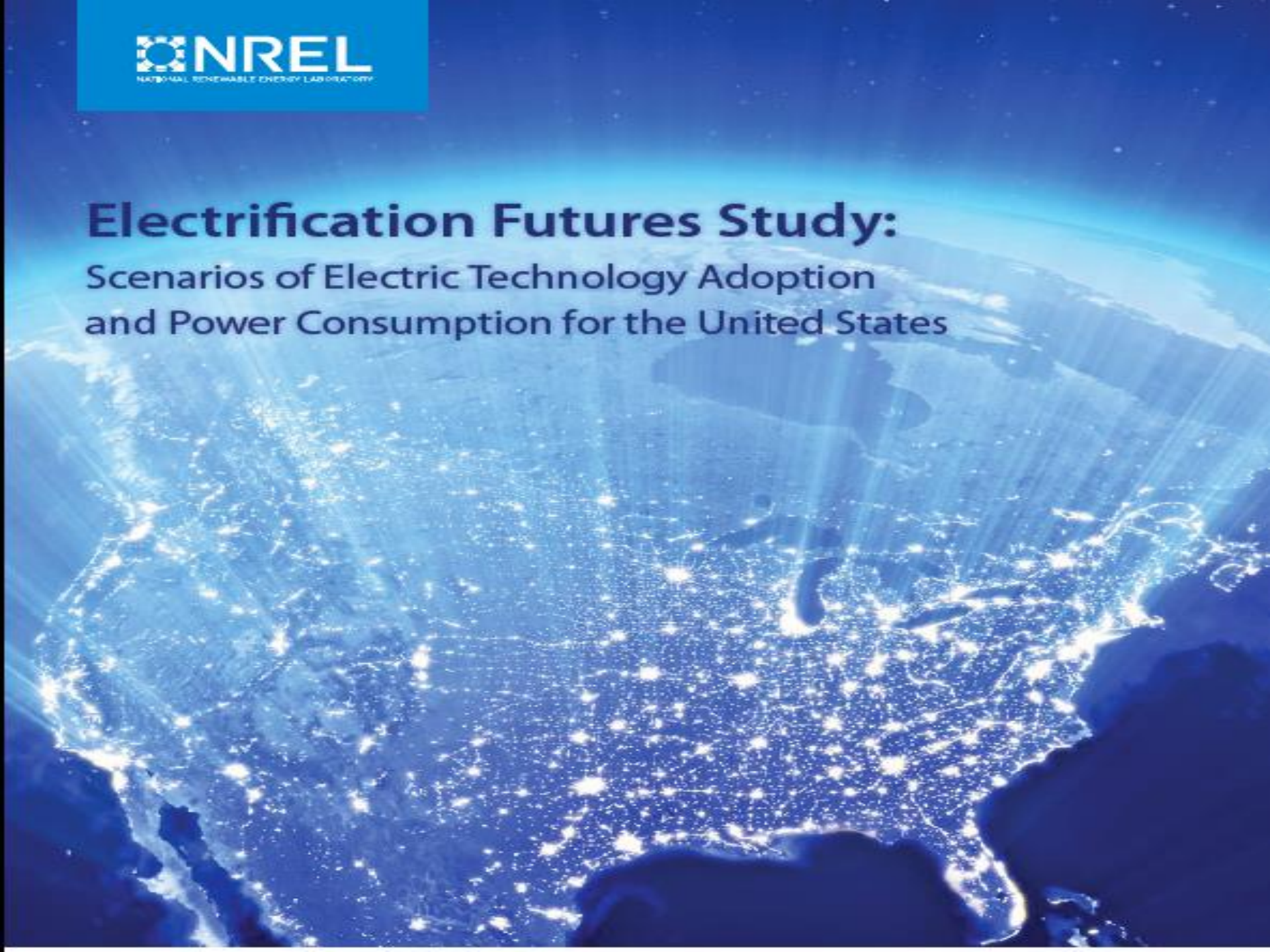
Next Generation Electric Vehicle Technology is Here

- Current EV technology will become obsolete quickly
- The next generation leap-ahead EV technology is going into production
- This is a potentially disruptive technology
- The power requirements for these vehicles may require up to 50% more power than currently produced nationally.
- We need to start planning for significant EV power demand and infrastructure implementation.
- Emissions will drop as a result of this technology if the infrastructure is there to support it.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electrification Futures Study:

Scenarios of Electric Technology Adoption and Power Consumption for the United States



National Renewable Energy Lab Transportation Electrification Studies

- The NREL Electrifications Futures Study released June 2018 analyzed residential, commercial, industrial and transportation sector electrification
- Estimated annual power demand for three scenarios for the years 2020-2050
- Transportation electrification created the largest power demand – building/industrial electrification required only 360 TWh/yr increase
- Baseline scenario demand 4,722 TWh/yr assuming a gradual introduction of electric vehicles and other sector electrification
- Mid-range 5,520 - 5,871 TWh/yr – in between baseline and high scenarios
- High – 6,280 - 6,846 TWh/yr based on significant transportation electrification most LDV's, med/hvy trucks - only 10,000 of 983,232 buses
- The EIA estimates that national annual power supply available in 2020 as 4,126 TWhr and that the power supply in 2050 will be 5,429 TWhr
    - https://www.nrel.gov/docs/fy18osti/71500.pdf
    - EIA Annual Energy Outlook (AEO 2020) estimates https://www.nrel.gov/docs/fy18osti/71500.pdf

DECEMBER 20, 2019

Draft 2020 Transportation Electrification Forecast

Load Forecast Committee

Jon Black

MANAGER, LOAD FORECASTING

ISO New England Draft Transportation Electrification Study Dec 2019

- ISO New England draft vehicle electrification study released 20 December 2019 analyzed northeast states transportation electrification
- Covered 2019-2029 time frame and light duty vehicles (LDV) only
- Estimated an increase from 41,349 BEV/PHEV out of 12,452,628 LDV's in 2018 to 515,683 EV's in 2029
- Estimates Vermont EV share to grow from 2,926 to 36,492
- Estimates the annual power demand for EV's by 2029 as only .4 GWhr out of 160 GWhr monthly supply
- This estimate is good through the early study period though it would be too low at 2030 and beyond because it excludes large truck fleet conversion to EV's
- https://iso-ne.com/static-assets/documents/2019/09/p3_transp_electrification_update.pdf

Vermont's Energy profile

- Nationally Vermont produces 40% of its electricity but only 20% of its total energy needs
- Vermont produces 2.18TWh electricity but consumes 5.53 TWh annually
- The estimated Vermont additional annual power supply required for complete transportation sector electrification is 2.66 TWh
- Including 13 million tourists and through traffic an estimated 3 TWh (+/-) total additional annual power will be required

- https://legislature.vermont.gov/assets/Legislative-Reports/Weight-Based-Registration-Legislative-Report-12-13-2019-Final.pdf
- https://accd.vermont.gov/tourism

Key Electric Vehicle Raw Materials

- Massive EV manufacturing increases and demand for large battery packs may outstrip short-term lithium supplies slowing near-term EV production
- Significant near-term supply constraint for EV mass production is the supply of rare earth element (REE) permanent magnets used in 93% EV vehicle motors
- China dominates the REE market supplying 80% of the US's refined rare earth materials
- China is electrifying it’s transportation sector much more quickly than the rest of the globe and its demand for permanent magnets will consume much of Chinese REE production
- The REE’s are critical for all military forces, and the Defense Department has announced plans to stockpile the same REE's used in commercial electronics and EV permanent magnets.
- The third effect is to impose an increasingly large environmental damage burden on areas of the world previously untouched by extractive mining and toxic minerals refining.

Transportation Electrification Risks

- Transforming the transportation sector from its current multi-modal portable and storable energy supply. Nationally there typically exists 2-3 weeks on-hand hydrocarbon fuel supplies.
- Interruptions and shortages occur but supplies are routinely moved as needed.
- Transportation electrification depends on a single, non-portable/storable supply modality (grid transmission lines) subject to interruption over a wide area.
- Battery electric storage is decades in the future. The entire future national battery electric storage projects planned for 2023 would provide enough power for 1/6th of ISO New England's hourly generation for one hour.
- https://www.eia.gov/todayinenergy/detail.php?id=40072

ISO New England Grid Evolution

Gordon van Welie, president and CEO of ISO New England,

“This era that we're entering into I think is going to be one of the most challenging eras of our history,”

But increasingly, our energy supplies are insecure. Says van Welie, “We have rapidly moved to what we're now defining as an energy limited system.”

https://www.wbur.org/earthwhile/2019/06/04/region-energy-future-climate-change

Transportation Electrification Risks

- 1998 Northeast Ice Storms destroyed a large swath of the grid including 1,000 transmission towers and 13,000 utility poles. Over 4 million customers were left in the dark for days to weeks across parts of New York, Vermont, Maine, and southern Canada and 44 people died mostly from hypothermia.
- 2003 Northeast Blackout caused by a software bug left 50 million people without power for hours to days.
- 2011 Southwest Blackout caused by a technician switching error left 2.7 million customers without power for hours.
- 2012 Midwest derecho blackout across the Midwest and mid-Atlantic left 4.2 million people without power for hours or days
- 2012 Hurricane Sandy affected primarily New York and New Jersey with damage to both generating facilities and the grid. Outages affected 8.35 million customers for days to weeks.

January 2018 Northeast Cold Snap

- New England was gripped by cold weather between December 25, 2017 and January 8, 2018
  - Monthly HDD is 20.6% higher than January 2017
  - Peak load of 20,599 MW was 5.1% higher than January 2017
  - Frigid cold drove up demand for natural gas which was consumed faster than it could be delivered
  - Gas pressure dropped in the lines feeding the natural gas power plants
  - Natural gas and fuel oil price inversion led to fuel oil being in economic merit and subsequently base loaded. As natural gas prices rose, the entire season's oil supply rapidly depleted. Coal use also increased over normal use
- Sea/river ice affected ship and barge deliveries to fuel oil terminals located in NH, ME and on the Hudson River
- Trucking transport of fuel oil was the primary refueling constraint
- Massachusetts Governor Baker signed hours-of-service waivers to provide fuel deliveries for residential and commercial customers, and power plants
- To increase situational awareness, the ISO initiated semi-weekly then daily fuel surveys of oil-fired generation
- 37 natural gas issues were reported for the period, primarily Operational Flow Orders (OFOs) on Algonquin, Iroquois, and Tennessee Gas Pipelines; 2 in-region force majeure declared ISO-NE requested two conference calls with the Northeast Gas Association's - Gas Supply Task Force
- ISO-NE was in daily communications with interstate pipeline operators

Mitigate Risk

- JFO, Vermont AOT, DPS, VELCO, and utilities calculate the total power required for transportation electrification in each power utility's area
- Establish a deliberate 10 year plan to electrify Vermont's transportation consistent with grid/utility power supply
- Identify and resolve utility and grid constraints
- Identify risks and accept that electrification will not happen overnight
- Identify and plan additional power generation
- Review long-term power supply contracts
- Increased DCFC power output
- Recycling/reuse plan for batteries and permanent magnet motors

Questions

Vermont Transportation Emissions Reduction Factors 2025-2030

H.688 required 2025 Greenhouse Gas reductions = 110 million fewer E10 equivalent gallons/yr

EV mass production begins 2022

2030 global EV sales estimates 21 – 44 million w/50% China

EV medium truck/bus battery packs w/300 KWh batteries=4X power density of a Tesla Model 3's

Pickup/SUV EV battery packs w/200 KWh batteries= 3X the power density of Tesla Model 3's

EV semi truck battery packs w/500-1,000 KWh batteries=7-14X of Tesla Model 3's

One Class 8 semi will use the electricity equivalent to that required for 12.8 average American homes – there are 2.752 million registered US semi-trailers

The EIA and ISO New England's EV power demand forecast based on 2030 low end estimate

The NREL estimated annual power required for transportation sector electrification as 6,786 TWh vs 4,126 TWh today; ISO New England supplies 123.3 TWh annually