Emerging Technologies
Opportunities & Challenges for Washington

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Washington Energy Strategy Advisory Committee

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Mission-driven locations empower collaboration
The primary energy used to generate electricity in WA State differs dramatically from the nation, and is among the cleanest.

\[
\text{CO}_2 \text{ from generating electricity}
\]

- WA state 25.36 g CO$_2$/MJ
- U.S. 124.83 g CO$_2$/MJ
From 1118 PJ of primary energy WA State generates 420 PJ of low cost electricity which also generates 10.7 Tg of CO₂

- Hydro, 291 PJ (69%)
- Wind, 28 PJ (7%)
- Other, 8 PJ (2%)
- Nuclear, 35 PJ (8%)
- Natural gas, 38 PJ (9%)
- Coal, 19 PJ (5%)
The transportation sector in WA generates an estimated 65 Tg of CO₂

(87-95 g CO₂/MJ of energy)
Building-Grid Integration
Realizing benefits beyond energy savings
Integrating Buildings with the Electric Grid

Fast facts

• The U.S. has 125 million homes and more than 5 million commercial buildings
• Nearly 75 percent of all U.S. electricity is consumed within buildings
• Electricity currently goes to functions such as air conditioning and lighting
• Increasingly, buildings will also use electricity to charge electric vehicles and buildings will generate and store electricity onsite with resources such as solar photovoltaic arrays and batteries
How Could Buildings Support or Enhance Electricity Grid Reliability?

Our goal is to develop the technology that enables utilities to cost-effectively and continuously engage up to 70% of their customers as grid assets and demonstrate the feasibility of this technology to stakeholders within five years.
Challenge: Control & Coordination of Multiple Commercial Buildings and Their Assets

- Coordinate assets with a signal from the utility
- Simultaneously identifying energy efficiency measures
- PNNL campus is a unique experimental platform
Technology Gaps & Key R&D Needs

Informing the future

More advances are required to capitalize on the technology and information revolution around buildings

- Automatic collection of big data for optimizing building operations
- Advanced data analytics and machine learning
- Advanced control theories
- Stakeholder engagement
- Cybersecurity best practices
Grid-Scale Storage

Enhancing System Resilience
Grid Storage Efforts at PNNL

**Cost Competitive Technologies**
- Redox Flow
- Sodium
- Zn-MnO$_2$

**Regulatory Support**
- Washington Utilities and Transportation Commission (UTC)
- Oregon PUC
- PUCN
- State of Hawaii Public Utilities Commission

**Safety and Reliability**

**Industrial Acceptance**
We engage partners across all sectors
PNNL Supporting 26MW of Grid Storage Deployed Across the Nation

26 MW 104 MWh at 14 Sites

Funded by:
Department of Commerce

Glacier, WA
2 MW/4.4 MWh Li-Ion

Richland, WA
1 MW/4 MWh VFB

Decatur Island, WA
0.5 MW/2 MWh Vanadium Flow Battery (VFB)

Pearl Hill, WA
5 MW/30 MWh PSH

NY ISO
5 MW/30 MWh PSH

Salem, OR
5 MW/1.25 MWh Li-Ion

Everett, WA
2 MW/1.2 MWh Li-Ion, 2 MW/8 MWh VFB

Pullman, WA
5 MW/3.2 MWh VFB

Northampton, MA Microgrid
0.5 MW/0.5 MWh Li-Ion

CA ISO
5 MW/30 MWh PSH

Puerto Rico
5 MW/30 MWh PSH

Oahu, Hawaii
5 MW/30 MWh PSH
Grid Energy Storage Launchpad

Mission

• **Validation**: This facility will provide independent testing of next generation grid energy storage materials and systems under realistic grid operating conditions

• **Acceleration**: The facility will reduce risk while speeding the development of new technologies by propagating rigorous grid performance requirements to all stages of storage technology development

• **Collaboration**: By linking the DOE and storage R&D communities in a new collaborative facility, this facility will lower barriers to solving key crosscutting industry challenges
Transportation Electrification

Is the Grid Ready for Loads at Scale?
Globally - It’s all about the batteries!

Battery prices keep falling. As a result, we expect price parity between EVs and internal combustion vehicles (ICE) by the mid-2020s in most segments, though there is wide variation between geographies and vehicle segments.

Volume weighted average lithium-ion pack price

Real 2018 USD

Source: BloombergNEF

Global long-term passenger vehicle sales by drivetrain

Source: BloombergNEF
Battery500 Consortium

**Goal:** Double the specific energy (to 500 WH/kg) relative to today’s battery technology while achieving 1,000 electric vehicles cycles

**Materials**
- Stanford University
- Pacific Northwest National Laboratory

**Architectures**
- INL
- Brookhaven National Laboratory

**Integration**
- University of Washington
- SLAC National Accelerator Laboratory

**Advisory Committee**
- Tesla
- IBM
- USABC
- NAATBatt
- FMC
Washington State uses 714 PJ of transportation fuels generating 65 Tg of CO$_2$ and 420 PJ of electricity generating 10.6 Tg of CO$_2$

Data from Energy Information Agency, additional analysis from GREET
The fuel economy at which a gasoline vehicle produces CO₂ emissions equivalent to a battery electric vehicle changes by region.

source: Figure 19 from ADLittle analysis, https://www.adlittle.com/sites/default/files/viewpoints/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf
A cleaner grid can help reduce the CO$_2$ footprint of transportation upon electrification

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1. [https://www.bts.gov/archive/publications/national_transportation_statistics/table_01_35_m](https://www.bts.gov/archive/publications/national_transportation_statistics/table_01_35_m)
2. MPG from [https://afdc.energy.gov/data/10310](https://afdc.energy.gov/data/10310), 121.1 MJ gal$^{-1}$
EV-Grid Impact Study

**OBJECTIVE:** As adoption of EVs is accelerating, provide insights into the ability of the U.S. bulk power grid to serve the new EV load

**Question 1:** Are there sufficient resources in the U.S. bulk power grid to provide electricity to the projected EV fleet?

**Question 2:** How will the generation mix dispatch be impacted by the additional EV load?
- what are the expected production cost impacts?
- what are the challenges and benefits to grid operations?

**Question 3:** What are the net impacts and benefits to emissions?
EV Penetration for LDVs in 2028: National

Preliminary Results: Reliability Perspective

• Resource Adequacy addresses *generation and transmission* resources necessary to meet additional EV loads.

Even at high LDV Penetration Scenario (24 Mill.), no expected resource adequacy issues with any of the charging strategies *under normal system conditions and all lines in service*

• At what penetration beyond 24 million could we expect potential reliability issues?

![Graph showing unserved energy in % relative to load]

- Onset of unserved energy indicating outages
- Between 30-37 Mill. LDVs
Electric vehicles will compete for electrons needed for other uses, so important to understand the implications

- Considering mode (LD, MD, HD), time of charging, location on U.S. 1.1 TW capacity

**WECC-US**
- Installed Capacity: ~214GW
- Peak Load: ~137GW

**EI-US**
- Installed Capacity: ~761GW
- Peak Load: ~544GW

**ERCOT**
- Installed Capacity: ~104GW
- Peak Load: ~73GW

**24 Million new electric vehicles**
- Resiliency (capacity) manageable
- Evening loads stress system the most
- At 30 million LDVs, encounter operational issues—with transmission as foremost limiting factor
- Natural gas combined cycle to carry bulk of the load
- Changes in hydro dispatch in WA
- Emissions benefits vary by location and season
- Average production cost increase of 13 percent in the WECC
- Reduce renewable curtailment by 70%
Power to Liquids?
SeaTac uses 63% of the jet fuel in the state, replacing it would use 36% of the electricity generated in WA or require 5,000 new turbines

SEA (Seattle Tacoma)

Electricity required

640 mil gallons (2018)

Power-to-Liquids (ideal)

Would require 36% of total generation from WA State

Potential CO₂ saving is less than 50% (based on grid)

Capital for turbines adds $530,000 BOE⁻¹ day⁻¹ (to capital for conversion)

Wind farm

• Shepherds Flat Wind Farm (Columbia Gorge) is rated at 0.85 GW and could produce 6-10 PJ
• It cost $2 billion to build (the turbines cost $1.6 billion with service contract)
• Fifteen equivalent-sized wind farms would be needed
Jet Fuel From Industrial Waste

• First commercial flight on recycled waste gas
• LanzaTech developed process to convert waste gas to ethanol
• PNNL developed catalytic process to upgrade ethanol to jet fuel

The October 2018 Virgin Atlantic flight took off from Orlando and landed in London.
Maritime Trends - Emissions

Heavy fuel oil (HFO), or bunkers, and to a lesser extent marine gas oil (MGO), are the traditional sources of energy to power ships. Shipping is consuming around 3.2 million barrels per day of HFO and 800,000 bpd of MGO – totaling more than $100 billion a year, or about 5% of global demand.

At present, shipping contributes 2.5% of global greenhouse gas emissions, twice that of Canada.

International Maritime Organization Regulations

Enforce a new 0.5% global Sulphur cap on fuel content from 1 January 2020 onwards, lowering from the present 3.5% limit.

By 2025, all new ships will be a massive 30% more energy efficient than those built in 2014.

Reduce GHG emissions by at least 50% by 2050 compared to 2008, while pursuing efforts to phase them out.
Vessel operators are investigating alternative fuels and methods of propulsion, largely in response to industry trends.

Alternative Fuels and Propulsion

• Fully Electric or Hybrids
• Hydrogen Fuel Cells
• Wind Turbines
• Biofuels
• Solar PV
Wildcards

Understanding Implications of Wildfire & Hydro Variability
**Sustainable Biomass, Grid & Wildfire Resilience**

**Challenge:** Fire suppression, land management and climate variables have resulted in greatly increased forest density which increases mega-fire frequency, and alters multiple hydrologic processes including streamflow patterns, and reduced water availability.

**USFS/DOI/States response:** implement strategic thinning and prescribed burning across the U.S.

- Air quality standards, forest economic sustainability and budgets limit amount of annual restoration

**Goal:** Develop and demonstrate an analysis framework to prioritize how and where to target forest restoration (timber harvest and thinning) and fuels reduction to have the greatest benefit for bioenergy, reduce severe wildfire risk, increase water yield, and improve ecosystem services.

- Multi-agency collaboration between DOE-BETO (PNNL, ORNL) and USFS R&D
Hydro Dynamics: Impacts of Intensifying Dispatch Variability

Potential Questions We Can Answer:

- How can operational variability/cycling be classified?
- Is operational variability changing? If so how/where?
- Is there a measurable maintenance/cost impact of operational variability?
- How can plants be run to minimize maintenance requirements?

**Drivers of Variability**

![Graph showing BPA Balancing Authority load and total wind, hydro, and thermal generation from Nov 26 to Dec 3, 2014.](source)

**Francis Turbine Relative Damage Drivers**

![Bar chart showing relative damage drivers for Francis turbines.](source)

Climate Events Create Compound Challenges for Electricity Planning

“The paper explores how climate-driven variations in both energy demand and water availability affect the power system, showing that combined climate change impacts on loads and hydropower generation may have a transformative effect on the nature and seasonality of power shortfall risk in the Pacific Northwest.”

Key Takeaways

- **Efficiency** remains the resource of first resort in the PNW

- **Buildings can become responsive grid assets**, bolstering system resilience

- **Grid-scale storage** can improve system resilience and operational flexibility, in response to emerging trends

- **LDV electrification & integration** manageable for bulk power system

- **Maritime & aviation** pose technical challenges at scale, require continued innovation

- **Wildfire & hydro system dynamics** require additional, ongoing consideration
Thank you!

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BACKUP SLIDES
Energy in universal units

Energy (J)
• Energy is the ability to do work
• $1 \text{ J} = \text{kg m}^2 \text{s}^{-2}$

Power (W)
• Energy over time
• $1 \text{ W} = \text{kg m}^2 \text{s}^{-3}$

Energy units

$1 \text{ kJ} = 0.95 \text{ Btu}$
$1 \text{ kJ} = 0.278 \text{ Wh}$
$1 \text{kJ} = 0.239 \text{ kcal}$

$1 \text{ Quad} = 1.055 \text{ EJ}$

$1 \text{ gal of jet} = 134 \text{ MJ}$

Kilo (k) = $10^3$ (thousand)
Mega (M) = $10^6$ (million)
Giga (G) = $10^9$ (billion)
Tera (T) = $10^{12}$ (trillion)
Peta (P) = $10^{15}$ (quadrillion)
Exa (E) = $10^{18}$ (quintillion)
Washington at a glance

- The Grand Coulee Dam on Washington’s Columbia River is the largest hydroelectric power plant in the United States by generation capacity, and can provide electricity to 2.3 million households a year.

- Washington is the top U.S. producer of electricity from hydroelectric sources and routinely accounts for 25% of the nation’s annual utility-scale net hydroelectricity generation.

- Although not a crude oil producing state, Washington has the fifth largest U.S. oil refining capacity for making petroleum products with the ability to process 638,000 barrels of oil a day at the state’s five refineries.

- Just over one-half of Washington households rely on electricity as their primary heating fuel and one-third of households depend on natural gas.

- Because of the relatively low operating costs of hydroelectric power generation, Washington had the nation’s second lowest average retail electricity price, after Louisiana, in 2017.

[https://www.eia.gov/beta/states/states/wa/overview](https://www.eia.gov/beta/states/states/wa/overview)
WA State uses 2.3 EJ of primary energy (2017), dominated by renewables and petroleum

- Renewables, 992 PJ
- Petroleum, 862 PJ
- Natural gas, 293 PJ
- Nuclear, 89 PJ
- Coal, 65 PJ
Both the light duty fleet and the heavy duty fleet have room to improve fuel economy

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<td>2. Improve fuel economy to 11 mpg</td>
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Petroleum refining is highly efficient compared to electricity production.

Primary energy used to produce electricity and transportation fuels (WA State, 2017 estimates)

Primary energy, power sector:
- 1118 PJ
- 873 PJ
- Electricity generated:
  - 420 PJ
- 90 PJ
- 92 PJ
- 64 PJ
- 327 PJ
- 35 PJ
- 38 PJ
- 19 PJ

Primary energy, Transportation:
- 794 EJ
- 780 PJ (est.)

Transport fuels:
- 702 PJ
- Ship (91 PJ)
- Gasoline (343 PJ)
- Diesel (130 PJ)
- Jet (134 PJ)

Sources Within Sectors:
- Renewable Energy
- Nuclear Electric Power
- Petroleum
- Natural Gas
- Coal
A 737 on a 4 hour flight uses around 430 GJ (10 t); battery technology will need to improve >60 fold to match jet fuel.

Energy density
Jet fuel density = 43 MJ/kg
Battery density = 0.72 MJ/kg (200 Wh/kg)

Today (Tesla Model 3 battery)
- battery weight = 600 t
- Volume = 154 m³

737-900 (passenger)
- MTOW = 85 t, 51.3 m³ of cargo

737-400 BCF cargo plane
- 21 t of cargo, 141 m³

Batteries will need to improve 25 fold to even fly the plane (if no other cargo or passengers were on board)

Energy calculated by Holladay and compared to GA Tech models

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2. [http://www.b737.org.uk/737ng.htm#737-900](http://www.b737.org.uk/737ng.htm#737-900)
A 777 on a 10 hour flight uses 3 TJ of fuel having a mass of 70t; today’s battery would have a mass of 4,200 t

Jet fuel density = 430 MJ/kg
Battery density = 0.72 MJ/kg (today)

Today (200 Wh/kg):
• battery weight = 4,200 t
• Volume = 2,100 m³

777-300 (passenger)
• MTOW = 340 t, 214 m³ of cargo

777F cargo plane
• 104 t of cargo, 636 m³

Batteries will need to improve 40 fold to simply fly the plane with no passengers or cargo

2 http://www.aerospaceweb.org/aircraft/jetliner/b777/
Aircraft use 100s and even 1000s of GJ of energy for single flights

While even takeoff takes more energy than a typical car uses in a year, a lot more people are on the jet (737-900 seats 177 passengers, a 777 seats 396 people)

G = giga = billion; T = tera = trillion
There are several disconnects that must be solved

1. Size
   - Energy used in transportation is nearly 2x generation

2. Logistics (co-location)
   - Sourcing of clean, concentrated CO₂ and clean electrons

3. Land use questions
   - Lack an understanding of implications on land use

S&T needs to support highly distributed collection and processing.
Even the relatively small scale of an ethanol plant would require massive wind or solar farms.