Emerging Technologies
Opportunities & Challenges

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Energy Leadership Summit

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Mission-driven locations empower collaboration

- Sequim
- Seattle
- Richland
- Portland, OR
The primary energy used to generate electricity in WA State differs dramatically from the nation, and is among the cleanest.

CO₂ from generating electricity
- WA state: 25.36 g CO₂/MJ
- U.S.: 124.83 g CO₂/MJ
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
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-MnO₂

Regulatory Support
- WASHINGTON
- UTC
- PUCN
- STATE OF HAWAI'I

Safety and Reliability

Industrial Acceptance
PNNL Supporting 26MW of Grid Storage Deployed Across the Nation

Funded by:

Department of Commerce

26 MW 104 MWh at 14 Sites
We engage partners across all sectors
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?
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

Global long-term passenger vehicle sales by drivetrain

Source: BloombergNEF
Electric Vehicle Timeline

- **Tesla**
  - 2017: Begins Model 3 volume production
  - 2018: Targets annual sales of 500,000 units

- **PSA**
  - Planning to launch first electrified models on Efficient Modular Platform (EMP)

- **JAGUAR**
  - Land Rover to electrify all models

- **RENAULT NISSAN**
  - Renault-Nissan plans joint platform for EVs

- **Subaru**
  - Targets annual sales of 1mn units

- **Volvo**
  - Targets 1mn total sales of electrified cars

- **DAIMLER**
  - Daimler plans 15-25% of production to be electric

- **Aston Martin**
  - Plans all models to be hybrid by 'mid-2020s'

- **GM**
  - Plans to produce 500,000 electrified vehicles by year-end

- **Volvo**
  - Plans to no longer sell cars solely powered by ICEs

- **Ford**
  - Plans to have 13 new electrified models

- **PSA**
  - Plans to have all 7 PHEV and 4 BEV models built on EMP

- **Porsche**
  - Plans 50% of cars to be electric

- **BMW**
  - Plans 15-25% of sales to be electrified

- **VW**
  - Plans to have 30 new EVs accounting for up to 25% of sales (2-3mn units)

- **Honda**
  - Plans to have two-thirds of sales to be electrified
Battery500 Consortium

**PPNLL Leads 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**

**Architectures**

**Integration**

Advisory Committee

- Tesla
- IBM
- USABC
- NAATBatt
- FMC
Washington State uses 702 PJ of fuel for transportation (including 225 PJ for ships and planes) but generates 420 PJ of electricity.

Data gleaned from Energy Information Agency.
The fuel economy at which a gasoline vehicle produces fewer CO$_2$ emissions than a battery electric vehicle changes by region.

source: Figure 19 from ADLitle analysis, [https://www.adlittle.com/sites/default/files/viewpoints/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf](https://www.adlittle.com/sites/default/files/viewpoints/ADL_BEVs_vs_ICEVs_FINAL_November_292016.pdf)
EV-Grid Impact Study

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

**Question 1:** Are there sufficient resources in the US 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?

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%
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

<table>
<thead>
<tr>
<th>SeaTac</th>
<th>Electricity required</th>
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<tbody>
<tr>
<td>SEA (Seattle Tacoma)</td>
<td>150 PJ</td>
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<tr>
<td>Power-to-Liquids (ideal)</td>
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Would require 36% of total generation from WA State

Potential CO$_2$ 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.

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.

At present, shipping contributes 2.5% of global greenhouse gas emissions, twice that of Canada.
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
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 integration** manageable for bulk power system

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