Transforming Energy through American Innovation

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Vertical Flight Society Webinar
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An Energy Revolution is Sweeping the Nation

Source: Siemens AG, North Sea, Suffolk Coast, UK
U.S. Energy Supply is Shifting

Renewable energy—not including hydropower—currently produces 10% of the total U.S. electricity generation. Within the next two years, this is expected to grow to 13%.

Costs for Renewables are Falling

Advanced energy technologies are providing real-world solutions by:

• Becoming increasingly cost-competitive
• Boosting the U.S. energy industry
• Providing jobs for American workers

Source: Lazard's 2017 Levelized Cost of Energy Analysis, Version 11, 2 November 2017
Changing Electric Paradigm

**ELECTRIFICATION**
Critical to long-term carbon goals and will be a relevant decentralized energy resource

Key technologies:
- Electric vehicles
- Vehicle to grid/home
- Smart charging, heat pumps

**DIGITALIZATION**
Allows for open, real-time, automated communication and operation of the system

**DECENTRALIZATION**
Makes customers active elements of the system, though requires significant coordination

Key technologies:
- Energy efficiencies
- Decentralized storage
- Microgrids, demand response

Key technologies:
- Network technologies (smart metering, remote control and automation systems, smart sensors, optimization and aggregation platforms)
- Customer technologies (smart appliances and devices, Internet-of-Things)
General Challenges Airports Face

- **Electrification** – Vehicles, GSE, Uber Elevate, Planes
- **Automation** - Greater equipment sensitivity to continuous, high quality energy supply; Cyber vulnerabilities
- **Economic** – Changing cost and revenue structures
- **Environmental** – Many airports in non-attainment areas, with noise concerns and close in development
- **Resiliency** – Number and duration of power outages climbing

### Aviation Industry Challenges

<table>
<thead>
<tr>
<th>Airport</th>
<th>Power Outage Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta Hartsfield (ATL)</td>
<td>December 18, 2017</td>
<td>11 Hours</td>
</tr>
<tr>
<td>Las Vegas (LAS)</td>
<td>June 13, 2018</td>
<td>90 Minutes</td>
</tr>
<tr>
<td>Austin (AUS)</td>
<td>June 24, 2018</td>
<td>45 Minutes</td>
</tr>
<tr>
<td>Washington - Reagan (DCA)</td>
<td>August 16, 2018</td>
<td>60 Minutes</td>
</tr>
<tr>
<td>Hartford, CT (BDL)</td>
<td>November 5, 2018</td>
<td>60 Minutes</td>
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<tr>
<td>Philadelphia (PHL)</td>
<td>November 6, 2018</td>
<td>40 Minutes</td>
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<tr>
<td>New York (LGA)</td>
<td>December 28, 2018</td>
<td>4 Hours</td>
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<tr>
<td>Madison, WI (MSN)</td>
<td>January 21, 2019</td>
<td>3 Hours</td>
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<tr>
<td>Albuquerque (ABQ)</td>
<td>March 23, 2019</td>
<td>5 Hours</td>
</tr>
<tr>
<td>Los Angeles (LAX)</td>
<td>June 6, 2019</td>
<td>3 Hours</td>
</tr>
<tr>
<td>Honolulu (HON)</td>
<td>June 12, 2019</td>
<td>1 Hour</td>
</tr>
<tr>
<td>Oakland (OAK)</td>
<td>June 13, 2019</td>
<td>30 Minutes</td>
</tr>
<tr>
<td>Dallas-Fort Worth (DFW)</td>
<td>June 24, 2019</td>
<td>3 Hours</td>
</tr>
<tr>
<td>Chicago O’Hare (ORD)</td>
<td>June 29, 2019</td>
<td>45 Minutes</td>
</tr>
<tr>
<td>Los Angeles (LAX)</td>
<td>March 3, 2020</td>
<td>20 Minutes</td>
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</tbody>
</table>
Moving people


NASA Photo / Tom Tschida
Examples of MW+ Charging Challenges and Barriers:
On-Board Storage - How to Maximize Charge, Minimize Heat and Maximize Life

- Charging power into the battery is either limited by the port capacity or the battery’s charge acceptance curve (restricts power)
- At 1.5C rate of charging, this 900 kWh battery is limited by the port’s capacity (1.2 MW) and hence charges at constant power of 1.2 MW
- This 660 kWh battery follows the batteries charge acceptance curve to achieve same C-Rate

C-Rate Limits of Cells

- If battery limited cells/batteries, advanced algorithms can speed up charging time
- For fast charging, pulse-based algorithm charges a cell 18% faster compared to CC-CV, and can increase overall station throughput
- Advanced control would be required to minimize the impact of such pulses on the grid/charger system (power quality)

Advanced Charging could impact power quality

- Pulse-based charging can also increase heat generation inside the cell/battery pack
- Novel ways of heat dissipation and waste heat recovery would be required at MW-scale charging
- Heat generation will differ by battery chemistry and rate and will need to be considered for proper thermal control

Heat Generation Concerns
Moving goods

Adv. Combustion & Electrification
Hybridization & Electrification
Biofuels
Hydrogen
Energy storage
Enabling Electrified Vehicles in the U.S: Some of the Challenges and Opportunities in High Power, MW+ Charging Scenarios

- Understanding Use Cases for Optimal Control
- Charge Control of Vehicle Batteries within a MW+ Charging Station
- Power Handling Challenges of Connectors and Cabling
- Opportunities for DER and BTMS
- Site Optimization via Control Approaches
- Grid Impacts
- MV Power Hardware
- Conversion Equipment
- Codes and Standardization
Powering mobility

- Renewables
- Grid Integration / Managed Charging
- Buildings Integration
- Cybersecurity
- Extreme fast charging
• **Challenges:**
  - Current wave: Light duty vehicles/eGSE ongoing
  - 1st Wave: Buses
  - 2nd Wave: Class 8 and heavy-duty trucks
  - 3rd Wave: Aviation
    - Urban Air Mobility
    - Pilot Training/Regional Service (8-12 passenger)
    - Hybrid regional aircraft

• **Opportunities:**
  - Vehicle to Grid (V2G) Storage resources
  - Siting Energy Generation/Storage near load
  - Designing transportation system improvements

• **Recent Extreme Fast-Charging Workshop:**
• A total cost of ownership (TCO) study for Medium Duty Delivery trucks:
  • $0.10/kW-h, payback period for an EV is 3½ years
  • $0.20/kW-h, payback period is 5 years

Because of time-of-use and demand charges, the average cost of electricity can more than double for fast charging compared to slow overnight charging.

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3 Cummins Electric Truck with Range Extending Engine (ETREE)
DOE Cooperative Agreement No. DE-EE0007514
Behind-The-Meter Storage (BTMS) Research Guided by System Level Thinking.

• Focus on specific end user outcomes
• Minimize cost of energy to user
• EVs will be charged at/near buildings.
• Demand charges need to be eliminated.
• Grid impacts minimized.
• Integration of PV is/will be common.

• Both electrons and heat need to be stored.
• New batteries are needed
• New thermal storage is needed

A partnership with the DOE Buildings, Solar, and Vehicles Offices
Techno-economic modeling can identify the trade-off between capital costs and optimal cost savings under complex utility tariff.

Example:
- Results show 12.4MW PV + 2.4 MW:3.7 MWh storage can provide $19.3 million NPV.
- Battery is only economical when paired with PV at this site due to wide peaks.
Biofuels (SAF)/Hydrogen

- **Challenges:**
  - Electrification of long-haul aviation not near term
  - Hybrid electric systems require fuel source

- **Opportunities:**
  - Utilization of SAF to improve resiliency position for longer term outages
  - Onsite Generation
  - Logistics of material movement
  - Hydrogen generation could be utilized to store cyclical energy generation (wind/solar)
Sources of Energy System Disruption

Natural Disasters
Space Weather
Physical Threats
Electromagnetic Pulse
Cyber Threats

Natural Threats
Human Threats
We live in an increasingly connected world.

- Half the world’s population uses the Internet.
- By 2030, 125 billion IoT devices are expected to be in use.
- Over the past 10 years, malware attacks have totaled 780 million.

*Source: Assessing the DNS Cyber Attack Security Risk
2018 Ponemon Report on DNS Security and Cyber Attack Risks*
Energy Security & Resilience

ENERGY SECURITY
- A strategic objective to maintain energy services
- Protecting systems against disruption from natural, human or technological causes

ENERGY RESILIENCE
- An energy system property
- The ability to adapt to changing conditions and recover from disruptions
- Contributes to energy security
Cost-competitive renewables are making up a larger share of the energy mix. The grid edge is transforming into a dynamic space where networked, distributed energy generated, stored, managed, and traded.
Strategic research to mitigate fast-charge infrastructure consequences

- NREL is conducting a full threat assessment of extreme fast charging and wireless power transfer charging infrastructure, assessing plug-in electric vehicles, charging infrastructure, electric grid R&D, and national cybersecurity expertise.

- **Lab Partners**: Idaho National Laboratory and Oak Ridge National Laboratory

- **Industry Partners**: Electrify America, ABB, Tritium
Transformative technologies

- Automation
- Connectivity
- Wireless charging
- Big data/analytics
- Deep learning
Athena Project Overview

Caleb Phillips and Monte Lunacek
Data Science, Analysis and Visualization
Computational Sciences Center
National Renewable Energy Laboratory

Kenneth (Ken) Kelly
Team Leader – Commercial Vehicle Technologies
Transportation and Hydrogen Systems Center
National Renewable Energy Laboratory
Athena Stakeholders

Technical Advisors (Ports) and Industry Advisors ensure generalizability and broad success.
Athena Focus Areas

OPERATIONS
- Shuttle optimization & EV analysis
- Curbside congestion & policies
- Freight modeling & analysis

PLANNING
- Mode choice modeling
- Long term planning & CTA decision

Early wins
18 months
Ongoing
36 months
Digital Twin

Demand Forecast → Network + Policy → Digital Twin Output

- Demand Forecast
- Traffic Management System
- SUMO Microsimulator
- Traffic on each Road Segment
  - Speed
  - Volume
  - Energy
The above graphs represent sample prediction across 3 different forecast horizons – using Recurrent Neural Network.

30 Minute (showing consecutively)

1 day

1 week (showing a single day)
# Airport-NREL Collaboration Areas

<table>
<thead>
<tr>
<th>Technical Needs</th>
<th>Metrics</th>
<th>NREL’s Strategic Capabilities</th>
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</thead>
<tbody>
<tr>
<td>On-site Resilience Planning / Microgrids</td>
<td>Cost savings, energy savings, emissions reductions, outage extension</td>
<td>REopt™ (Renewable Energy Optimization); URBANopt; RADE; CORE™ (Continuously Optimized Reliable Energy) Microgrid</td>
</tr>
<tr>
<td>Cyber / Physical Security</td>
<td>Physical to grid edge analysis, testing &amp; validation</td>
<td>Energy Security and Resilience Center</td>
</tr>
<tr>
<td>Sustainable Transportation</td>
<td>Operational and financial implications of fossil fuel to electric conversion</td>
<td>Bus, vehicle, GSE electrification; infrastructure charging requirements; Fleet DNA clearinghouse</td>
</tr>
<tr>
<td>Building Efficiency, Net Zero Design, Grid Interactivity</td>
<td>Cost savings, energy savings, emissions reductions, resilience</td>
<td>OpenStudio, EnergyPlus, URBANopt</td>
</tr>
<tr>
<td>Aviation Biofuels</td>
<td>Energy density, emission reduction</td>
<td>Biofuel feed stock chemistries</td>
</tr>
<tr>
<td>Master Planning</td>
<td>Development scenario analysis</td>
<td>High Performance Computing (HPC) / Visualization Center</td>
</tr>
<tr>
<td>Systems Integration</td>
<td>Modeling and validating solutions, integration of transportation and broader energy infrastructure</td>
<td>HPC, system design, digital twins</td>
</tr>
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➢ **Drivers:** Electrification, Automation, Economic, Resilience, Environmental

Current partnerships: Metropolitan Washington Airports Authority (DCA, IAD), Dallas-Fort Worth (DFW), Los Angeles World Airports (LAX)
Developing partnerships: New York-New Jersey (JFK, LGA, and EWR)
Identified Gaps in Research or Technical Solutions
Increasing Electric Dependency

- **Gap/Barrier:** Future electrified load growth for stationary and mobile energy loads are not well understood on a micro- or macro-scale.

- **Potential Opportunities:**
  - Tools to estimate, model, and validate load growth
    - Including existing electrical infrastructure constraints (feeder limitations)
    - Increases in loads for increased passengers, passenger amenities, plug loads
  - Research, analysis, and innovation at the energy-mobility nexus
    - Implications on energy use and demand
    - Charging infrastructure implications
    - Behavior and choice modeling coupled with economic analysis

*Consolidated Utility Base Energy, or CUBE, was developed for the U.S. Army by NREL to use in forward operating bases. Photo by Dennis Schroeder*
Microgrids for Survivability

• **Gap/Barrier:** As stationary and mobile energy loads increasingly become electrified, robust and resilient electricity infrastructure becomes more vital.

• **Potential Opportunities:**
  – Advanced strategies and analysis for microgrid planning and resilience
    • Renewable energy opportunities in the often-limited airport footprint
      – Re-evaluate FAA policies surrounding glint/glare with current technologies
      – Update best practices for siting photovoltaics and storage at airports
      – Macro-scale analysis of potential for renewable natural gas to support airports operations
    • Grid-interactive buildings
    • Analyze cyber-related vulnerabilities in the aviation sector (related to energy systems)
      – Develop best practices for cyber-secure airport microgrids
Planning for Resilience

• **Gap/Barrier:** A changing climate and associated extreme weather-related events have the potential to impact aviation operations and infrastructure; these impacts and potential mitigation measures are not well understood across the aviation industry.

• **Potential Opportunities:**
  – Develop best practices in resilience planning for the aviation industry, including resources risk assessments and financing mitigation solutions.
  – Identify broader community and stakeholder partnership opportunities for operational resilience.
  – Research cascading failures or impacts associated with climate impacts on airline operations and air traffic patterns
  – Assisting remote sites with improved efficiency and resilience
Financing of Innovative Projects

- **Gap/Barrier:** Limited appetite for third-party financing of innovative or emerging technologies and projects, including those for resilience; this risk is perceived too high or valuation methodologies are unclear.

- **Potential Opportunities:**
  - Identify best practices for third-party financing of innovative or emerging technologies and projects.
  - Aviation industry-focused technology demonstration programs which test innovative or emerging technologies in real-world applications with a wide dissemination of results.
  - Research in the valuation of resilience and in mechanisms to finance resilient technical solutions, for both buildings and transportation applications.
Robust Datasets

- **Gap/Barrier:** Lack of data and data transparency throughout aviation sector operations inhibits intermodal research and innovative solution development and identification.

- **Potential Opportunities:**
  - Data sharing agreements and widespread collaboration across all aviation operations and stakeholders
    - Airlines/Airport/FAA/TSA
    - Ground service providers
    - Taxi management and gate control
  - Independent/open data gathering with common interfaces/formats
  - Standardized performance metrics and reporting conventions
  - Better optimize facility and ground transportation systems

Source: [https://www.fly.faa.gov/Products/Information/information.html](https://www.fly.faa.gov/Products/Information/information.html)
Partnering with Business for Competitive Advantage

In 2019 NREL had:

- 299 new partnership agreements
- $74.0M value of new partnership agreements
- 255 unique new partners
- 587 unique active partners

Nearly 900 active partnerships with industry, academia, and government
Thank you

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