



**National Laboratory
of the Rockies**

Ports & Energy

Jason Lustbader and Brett Oakleaf

Team: Bharat Solanki, Emily Newes, Eric Miller, Anelia Milbrandt, Monte Lunacek, Michael Lammert, Kyungsoo Jeong, Yi He, Setayesh Fakhimi, Kelcie Kraft, and Philip Voss

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Association of Pacific Ports 112th Annual Conference

NLR at a Glance

The National Laboratory of the Rockies is the nation's primary energy systems integration laboratory.

Quick look:

3,400 NLR researchers and staff

1,100+ partnerships spanning:

- Commercial & Industrial
- Public Agency & Nonprofits
- National Security & Defense

Focus:

- Developing and scaling energy technologies that lower costs, drive economic growth, and deliver abundant and reliable energy.



Photo by Josh Bauer, National Laboratory of the Rockies



R&D for Ports, Islands, and Maritime Communities

Over the past 15 years, NLR has supported more than 20 island nations and jurisdictions, 12 U.S. seaports, and 15+ major airports.

Integrated Systems Approach:

- Modernize ports for faster, more efficient operations
- Improve grid infrastructure, security, and stability
- Enable on-site energy generation, inverter-based resources, and greater load flexibility



NLR support and capability includes:

- **Security** (cyber, supply chain, grid) – analysis, microgrid modeling/design
- **Planning, modeling, grid readiness** – power/grid reliability, load growth, affordability
- **Interconnection and technical standards** – modeling, technology integration, grid/generation controls
- **Energy storage** – strategy, controls, configuration
- **Alternative fuels** – supply chain and integration analysis
- **Institutional capacity and procurement advising** – Local capacity building, RFP development/bid evaluation, program design
- **Cross-agency coordination and shared tools** – Align federal support and guidance with shared priorities and metrics
- **Stakeholder education** – Cost-effective solutions
Local expertise – leveraging on-site NLR staff

Case Study:

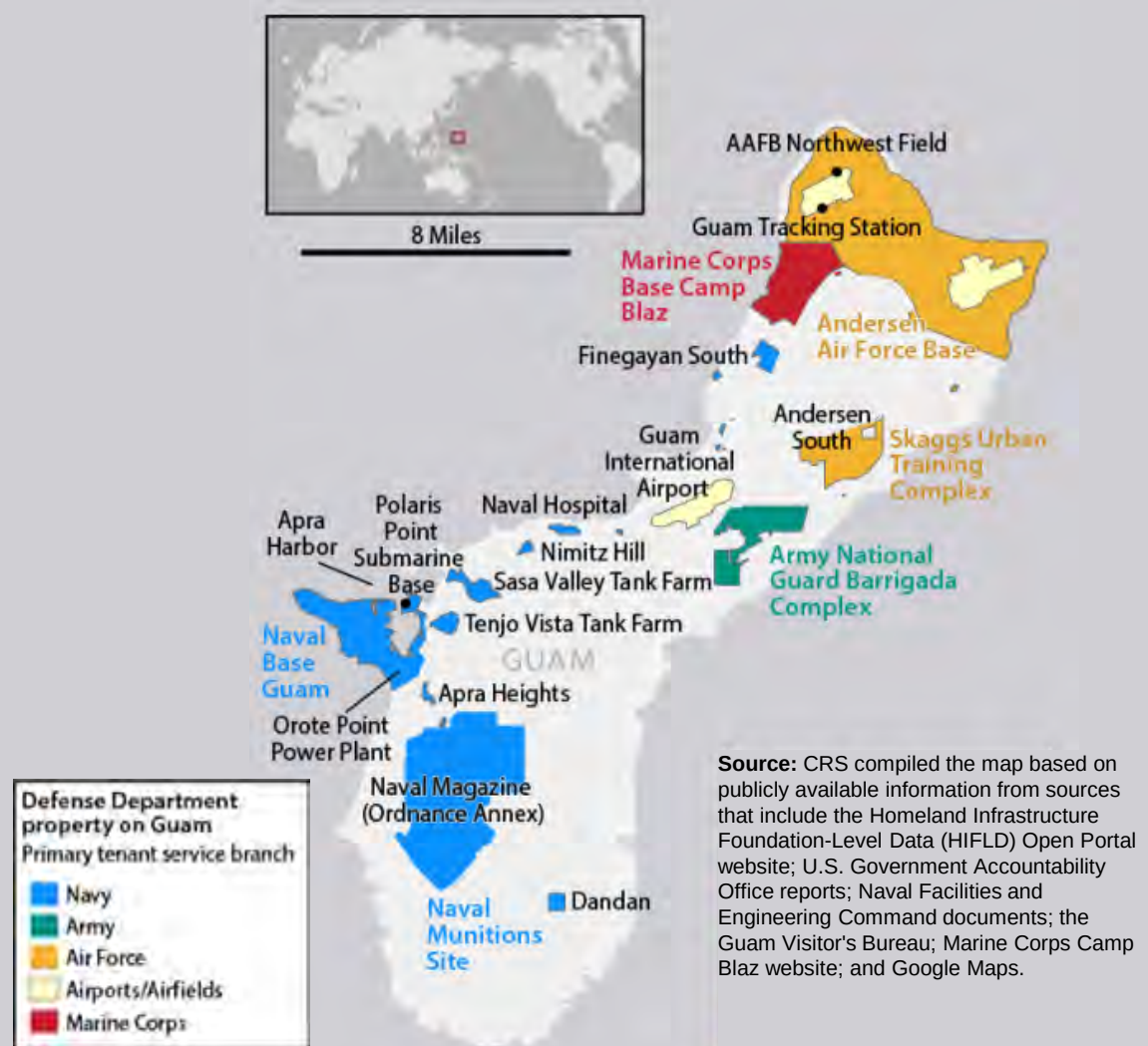
NLR Support for DOW on Guam

Navy-funded post-typhoon assessment of utility-scale, distributed PV systems

- Focus: Survivability and resilience

Primary support areas:

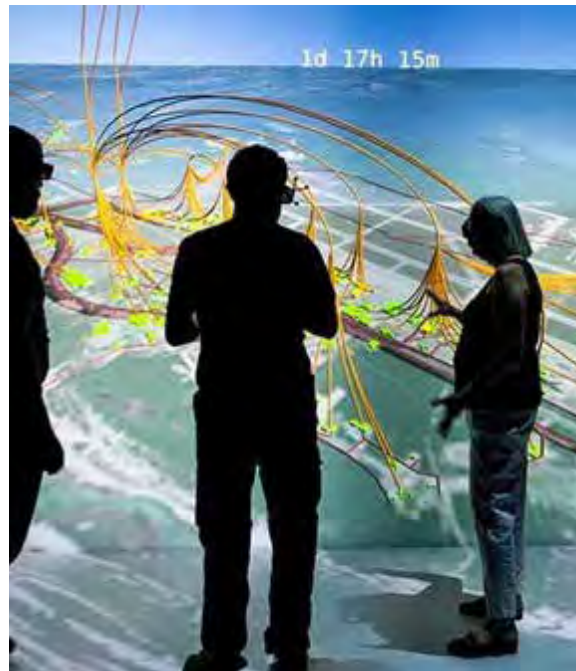
- Distributed power systems analysis
- Building energy efficiency and project implementation support
- Emerging technology testing and demonstration



Source: CRS compiled the map based on publicly available information from sources that include the Homeland Infrastructure Foundation-Level Data (HIFLD) Open Portal website; U.S. Government Accountability Office reports; Naval Facilities and Engineering Command documents; the Guam Visitor's Bureau; Marine Corps Camp Blaz website; and Google Maps.

Mitigation Strategies for PAC Islands

- Strengthen and diversify installation and community infrastructure such as on-base generation, storage and on-island liquid fuel storage and supply sources
- Improve overall grid infrastructure and stability to handle integration of Inverter Based Resources and manage load flexibility
- Utilize shared investment structures for both military and civilian infrastructure, including financing pathways
- Understand the energy-water-food nexus for each local installation and community



Ports Are At An Inflection Point

Efficient, modernized ports not only add to the resilience of the U.S. freight system—they allow us to maintain our global economic competitiveness and leading edge in manufacturing and distribution.

At the same time:

- **Increasing demands** for freight, passenger, energy, and security are pushing ports to move goods faster while protecting global supply chains
- **Aging infrastructure and limited redundancy** are increasing exposure to disruption
- **New technologies** are changing how ports plan, operate, and invest, offering potential efficiencies, but also uncertainty.

The bottom line: Ports must prepare for both growth and disruptive events.





Image from iStock 1419799291

A Systems Approach To Modernization Is Critical

- Investments in resilient, efficient ports strengthen supply chains, economic competitiveness, and national security
- Increasingly, ports and airports are becoming integrated logistics and energy hubs, requiring coordinated planning across transportation modes.
- Modern ports are no longer just logistics hubs, they are critical infrastructure that underpins economic growth, resilient supply chains, and global competitiveness
- The next generation of ports will not only be shaped by increasing supply chain demands but advances in energy and fuel systems, digital technologies, automation, and integrated freight operations.

Key Infrastructure Elements of Port Modernization

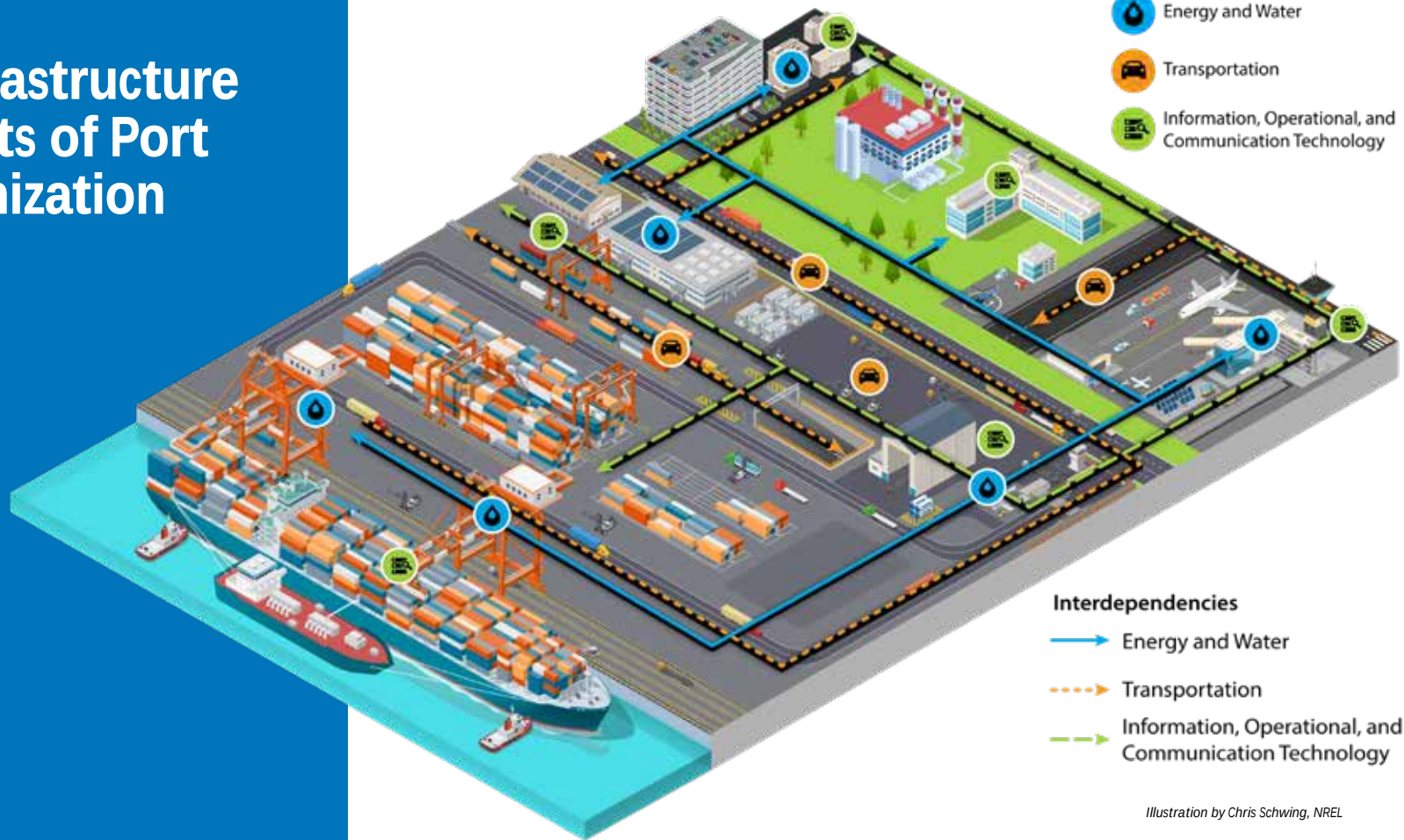
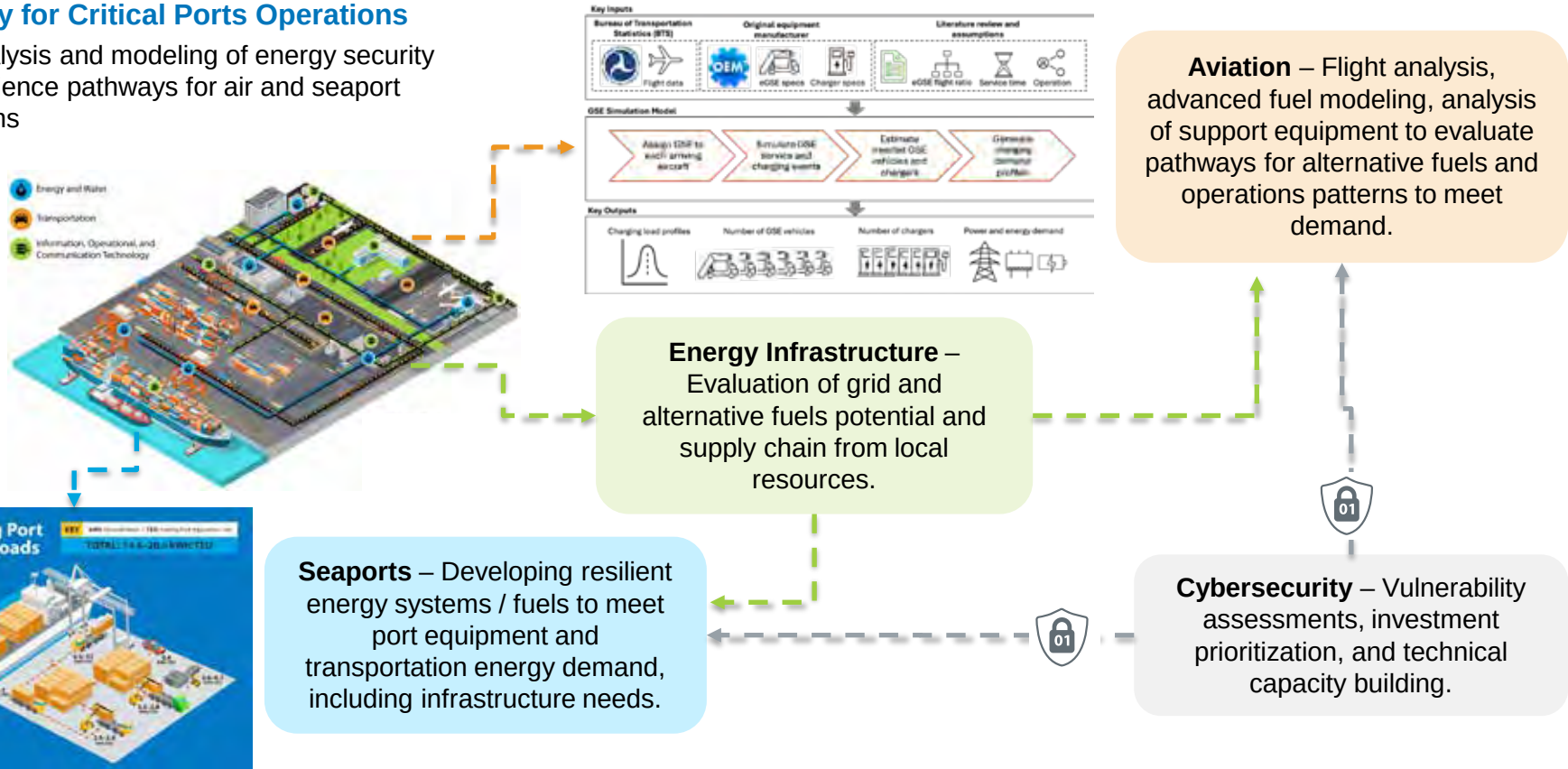


Illustration by Chris Schwing, NREL

NLR analysis and modeling of energy security and resilience pathways for air and seaport operations



NLR's Port Modernization Experience



Port of Long Beach*

Port of Honolulu*

Port of Hueneme

Port of Los Angeles*

Port of Bellingham

Port of Tacoma

Port of Seattle*

Port Houston*

Port of Corpus Christi*

Port Authority of New
York and New Jersey*

Port of Baltimore
Port of Hamilton
(Canada)

Port of Detroit

Illinois International
Port District

Port of Ogdensburg

Port of Duluth-Superior

& 15+ airports spanning the U.S.

**A top 50 U.S. water port by tonnage of trade*

Modernizing Port Operations



Planning the Next Generation of Port Infrastructure

Effective infrastructure investments require understanding both today's operations and tomorrow's energy needs.

- **Understanding Operations:** Data collection, vessel movements, terminal operations, and vehicle activity.
- **Forecasting Future Energy Demand:** Cargo scenarios, electrification, alternative fuels, and charging operations
- **Evaluating Technology Options:** Shore power, charging, grid upgrades, storage, fuels
- **Reducing Risk:** Digital twins, simulations, scenario analysis, resilience planning

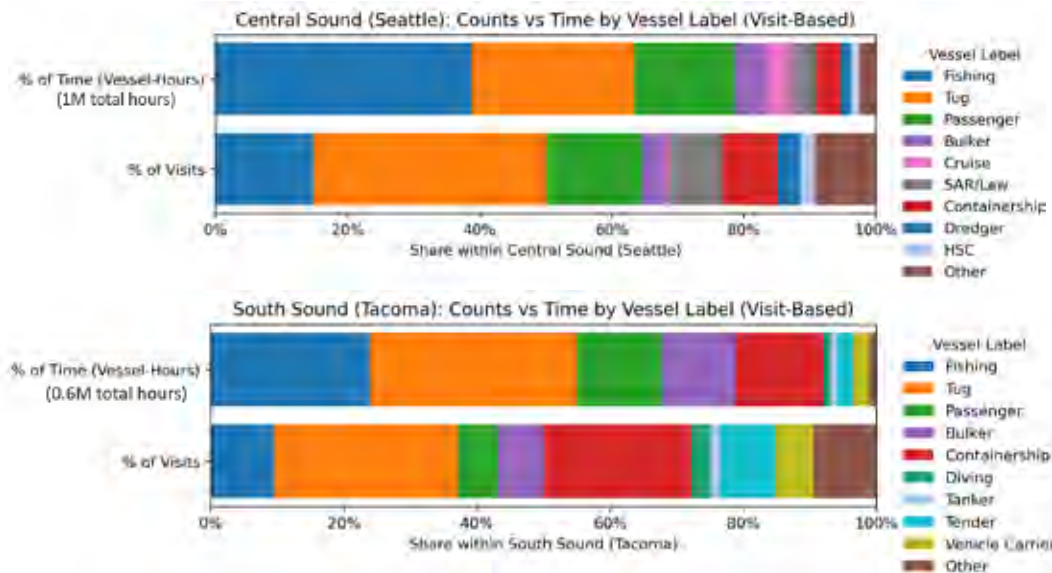
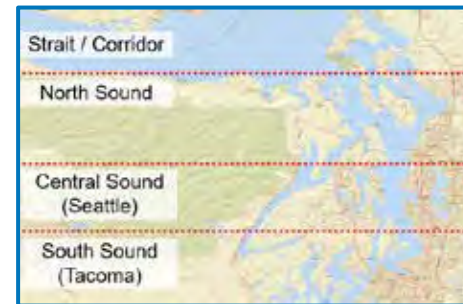




Understanding Regional Activity Through Vessel Data in the Puget Sound

Maritime Safety and Security Information System (MSSIS) data from U.S. DOT Volpe Center for calendar year 2022

- 51 million entries – automatic identification system (AIS) pings; approximately 11,000 unique Maritime Mobile Service Identity (MMSI) numbers
- Combined vessel movements with modeled fuel consumption to characterize regional activity and fuel burn
- Geospatial analysis identified vessel activity by type, frequency, and duration within geographically distinct regions of Puget Sound





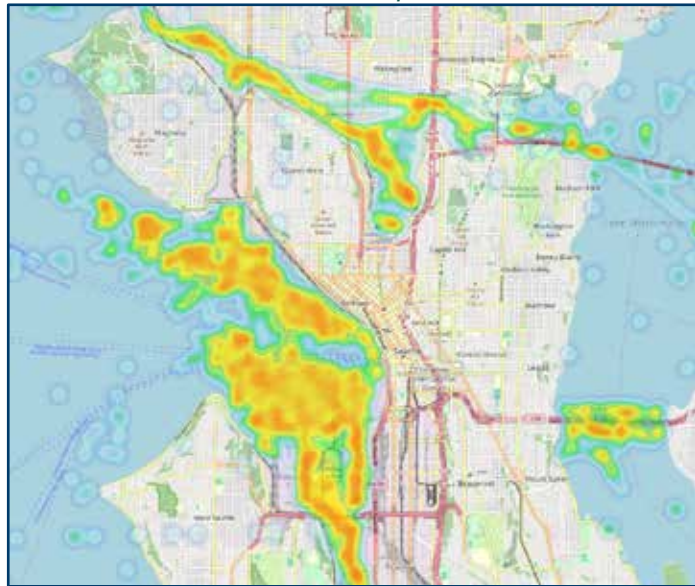
Tug Boat Operational Data Supports Planning

GPS Density



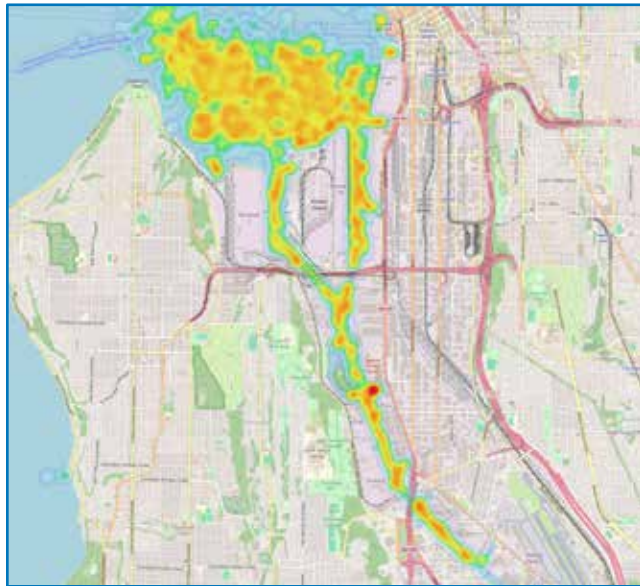
Identify vessel traffic patterns to understand where port activity is concentrated

Dwell Hot Spots



Locate high-idling dwell areas to support infrastructure planning while minimizing disruptions to operations

Fuel-weighted Dwell Hot Spots



Highlights where energy demand and emissions are greatest in high-idle dwell areas



Operational Analysis Driver Infrastructure Planning

In collaboration with Port of Honolulu

Scope:

- On-site operational data collection
- Characterize Equipment Duty cycle
- Forecast Future Energy Demand
- Evaluate Infrastructure Alternatives
- Support planning and investment decisions

<https://docs.nlr.gov/docs/fy25osti/92141.pdf>

Estimating Port Terminal Loads



Drayage Vehicles | Port Yard Tractors | Harbor Cranes | Forklifts
Cargo Handling Equipment | Tugboats | Marine Vessels

Port Energy Modeling



Studied energy demands at the top 25 container ports by tonnage in the US leveraging past project data collection on the CHE

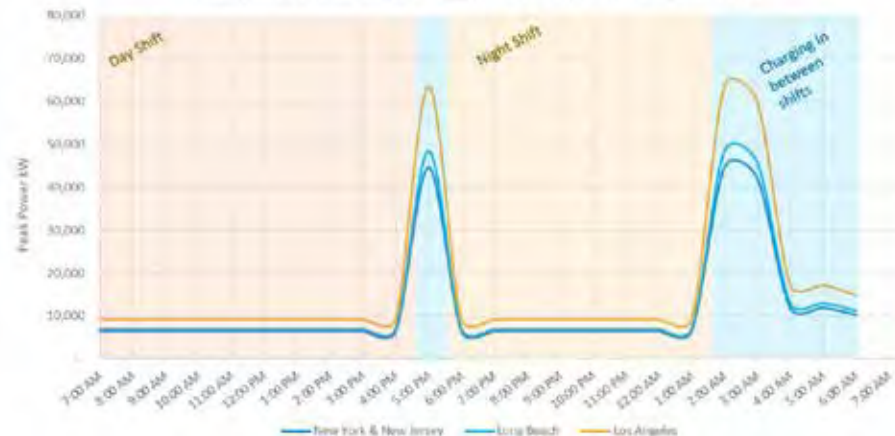
- Detailed energy use by CHE type
- Consider CHE inventory by port, operational profiles (single shift, 2 shift, 3 shift) and baseline port electricity usage
- Models impact of adoption scenarios for energy carriers
- Supports resiliency planning

Container Movements (Equipment Used)	Energy Consumed Per Container
Vessel to Dockside (Ship-to-Shore Crane)	6.5–12 kWh/TEU
Dockside to Container Stack (Yard Tractor)	2.1 kWh/TEU
Yard Tractor to Container Stack (Reach Stacker)	2.5–2.8 kWh/TEU
Container Stack to Drayage Truck (Reach Stacker)	2.5–2.8 kWh/TEU
Forklifts: Light, Medium, and Heavy Duty	0.6–0.7 kWh/TEU
Personnel Vehicles: Light Duty	0.4 kWh/TEU

CHE Inventories for Top 3 U.S. Container Ports

Port	Annual TEU Throughput	Pickup Trucks	Tour Vans	Personnel Vehicles	Yard Tractors	5-ton Forklifts	15-ton Forklifts	Top Handlers	STS Cranes
New York & New Jersey	6.2 million	92	11	104	173	11	11	57	57
Long Beach	6.8 million	100	12	112	188	12	12	62	62
Los Angeles	8.9 million	131	16	147	246	16	16	82	82

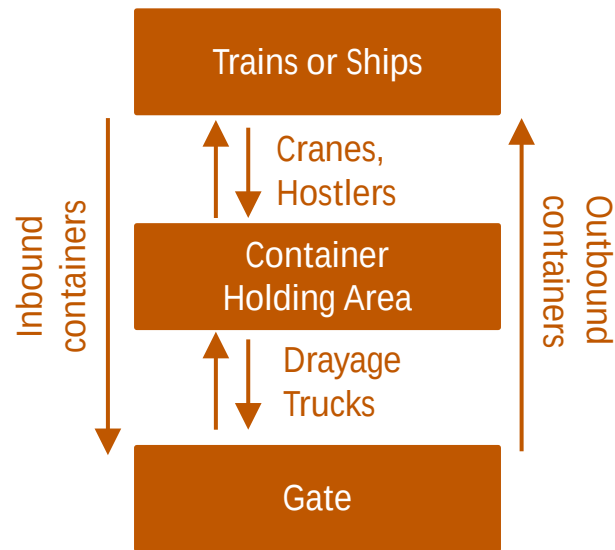
Hourly Load Profile 100% EV Adoption for Top 3 US Container Ports





Terminal Operations Modeling

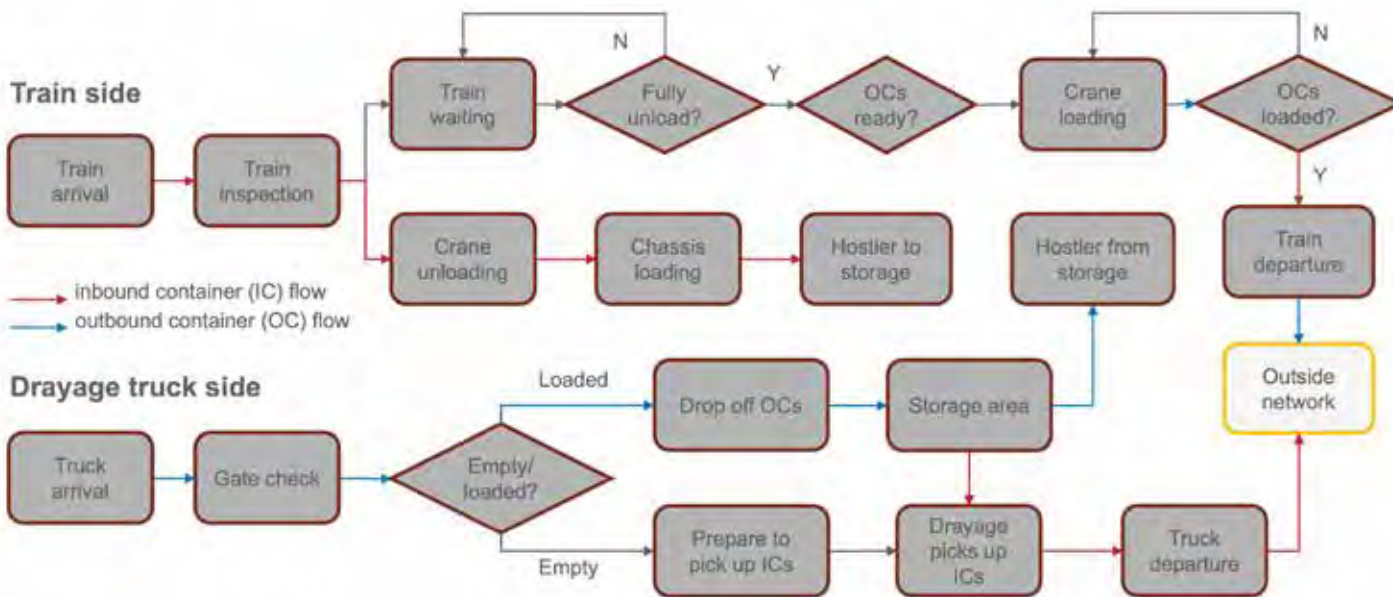
NLR's **ALTRIOS-LIFTS** can simulate operations, movements, and queuing within the gates of a freight terminal to enable understanding and optimization of real-world logistics.



arpa-e



ALTRIOS-LIFTS can simulate highly detailed, user-customized process flows within a freight terminal

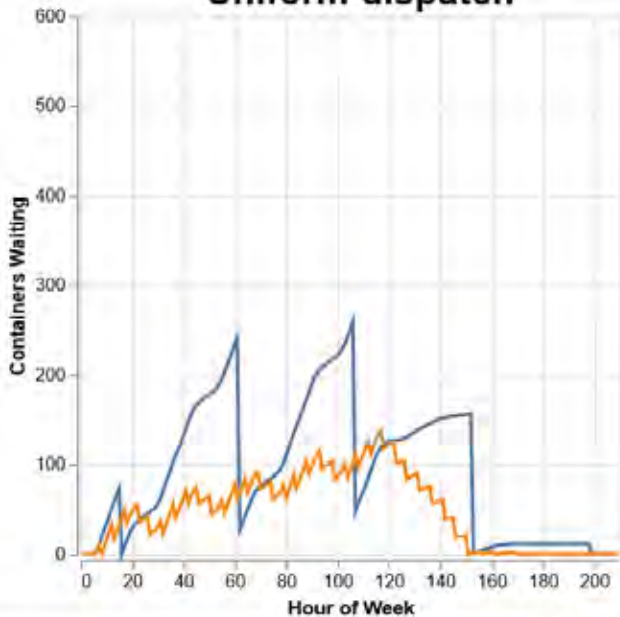


Case Study:

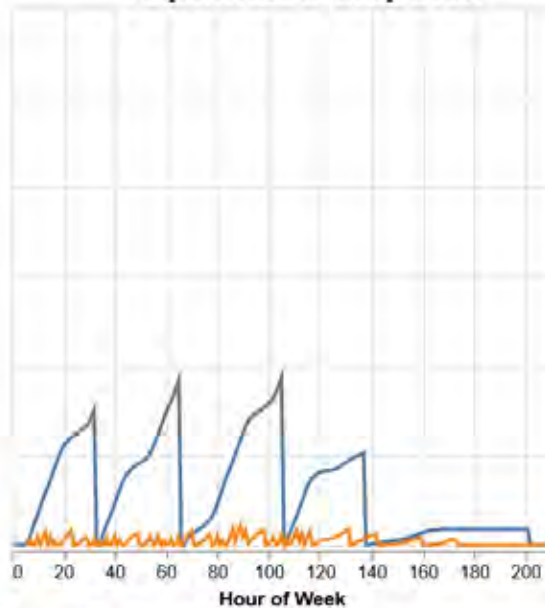
ALTRIOS-LIFTS Supports Parallel Systems

Self-Propelled Autonomous Rail Cars (SPARCs) Pilot on Heart of Georgia Railroad

Uniform dispatch



Optimized dispatch



— Diesel
— PS_locomotive



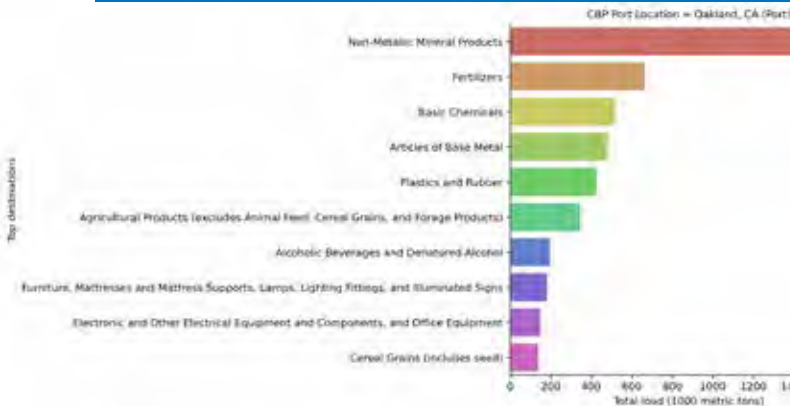
Photo and visualization from Parallel Systems

Optimized SPARC dispatching strategy can slash delivery times by nearly 70%, reduce storage requirements, and uses 30% of the energy.

Logistics Strategies



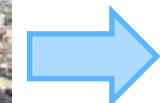
FAMOS Application for SF County Transportation Authority



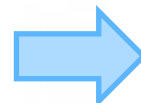
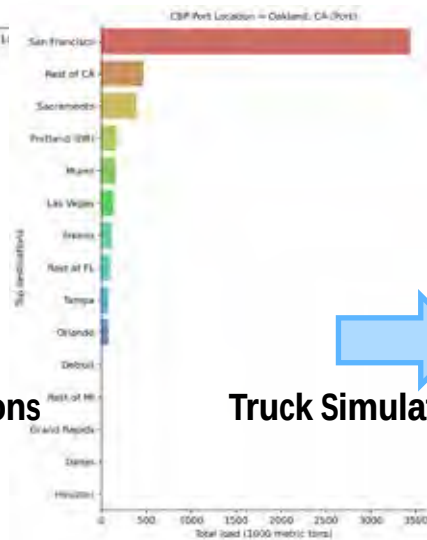
Commodity for Import



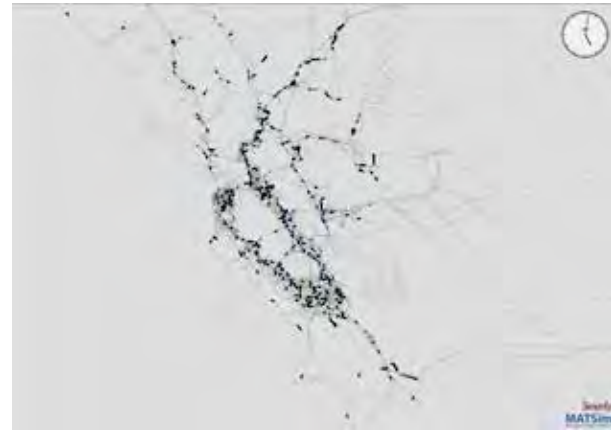
Port of Oakland



Destinations



Truck Simulation



Understanding the impact of port-related freight activity on local networks and population in San Francisco Bay Area:

- Distribution of freight contribution to VMT and congestion on roads surrounding ports
- Distribution of freight-generated emissions and health impacts in local population

Modeled and generated port-related shipments and working on truck simulation and analysis

INFORMES: Intermodal Freight Optimization for a Resilient Mobility Energy System



Answer questions about **technology changes** and **operational strategies** over multi-modal transportation network and infrastructure

Origin



Port

TRUCK

RAIL

DOMESTIC
MARITIME



Destination

Factory



Farm



Other

KEY



Trucking

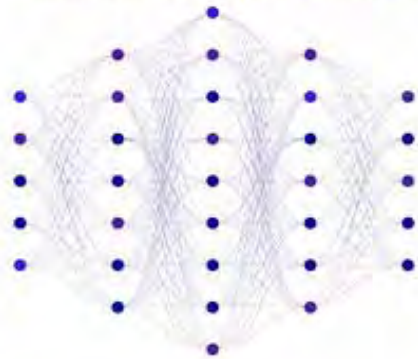


Rail



Domestic Maritime

AI + High Performance Computing for National Freight Optimization



AI

- RouteE physics-informed AI surrogates
- Rapid energy prediction
- Route optimization
- Technology screening



HPC

- National-scale scenarios
- Large-scale design exploration
- Uncertainty analysis



National Freight Decision Support

- Cost
- Energy
- Travel time
- Infrastructure planning



National-Scale Optimized Container Flows



Resilient Energy & Infrastructure

Planning for Diverse Infrastructure Types



KEY INSIGHT

Each load contributes to site demand in different ways. It is important to strategize how port operations would leverage each option, and how their respective loads may or may not coincide to impact peak demand and grid capacity needs.

Example NLR Analyses:

- Drayage electrification at Port of New York & New Jersey (NY/NJ)
- Port yard tractor electrification at Port of Long Beach and Port of NY/NJ
- Hydrogen integration for drayage, cargo handling, and shore power at Port of NY/NJ
- Biofuel/alternative marine fuel availability at Washington ports, Port of Corpus Christi, and globally

Plug-In



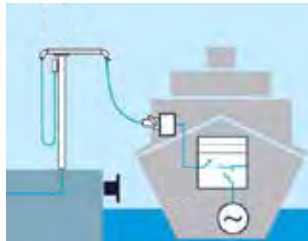
- Charges vehicles only when parked
- Prolonged vehicle occupancy limits sharing
- Loads would not coincide with shift operations

Direct Connected



- Draws electricity only when in use
- Requires direct electrical connection to device
- Loads would not coincide with overnight charging

Shore Power



- Draws electricity as needed by each ship
- Requires dedicated connection to each ship
- Loads could vary throughout the day/night

Wireless



- Supports opportunity charging throughout shifts
- Short opportunity charging supports sharing
- Loads could vary throughout the day/night

Enabling Technologies – Microgrids

Distributed energy resources alone do not guarantee resilience, but when integrated through a well-designed microgrid, they become capable of sustaining critical operations during grid outages. A microgrid is essential to unlocking the full resilience potential of on-site energy assets.

Benefits

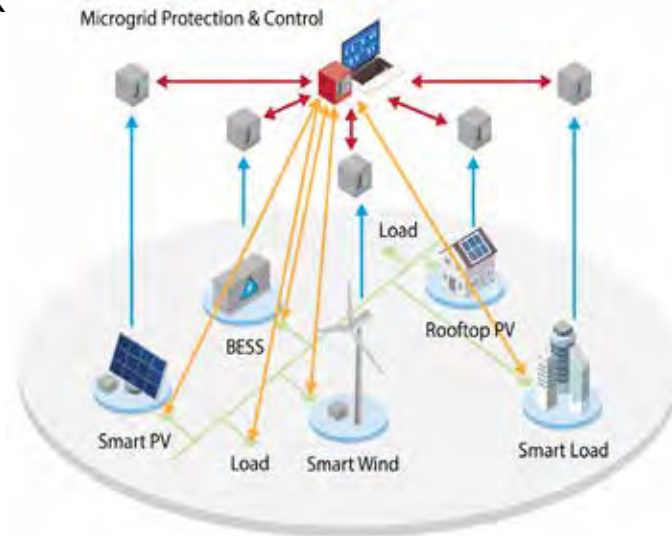
- Resilience
- Efficient use of energy
- Critical load prioritization
- Cyber/physical security
- Utility savings

Negatives

- High initial CAPEX
- Complexity.

Required Investments

- Energy management system (EMS)
- Switchgear and controls
- Power conversion equipment
- Advanced metering infrastructure (AMI)



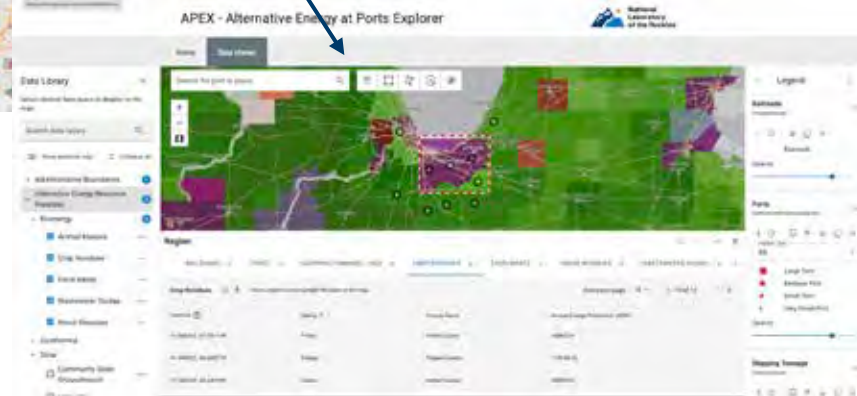
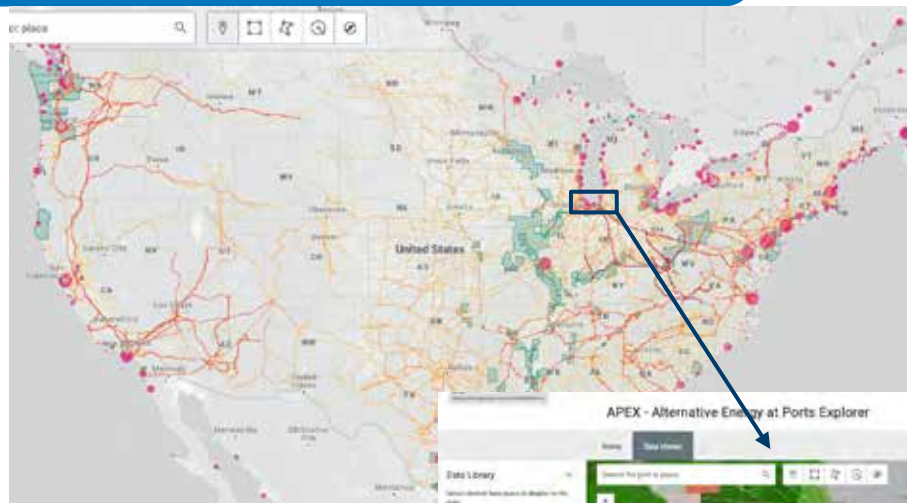
Graphic by Anthony Castellano, NLR

Resource Assessment Data Aggregation

Public access available at:
<https://maps.nlr.gov/apex>

Initial Information Layers

- Alternative energy resources:
 - Land-based wind
 - Offshore wind
 - PV
 - Geothermal
 - Biomass
 - Hydrogen
 - Pumped storage hydroelectric
- Levelized cost of electricity (LCOE) for select resources
- Infrastructure (e.g., roads, transmission lines, pipelines, etc.)
- Other relevant data from the Energy Information Administration (EIA), the Environmental Protection Agency (EPA), the Bureau of Transportation Statistics (BTS), etc.



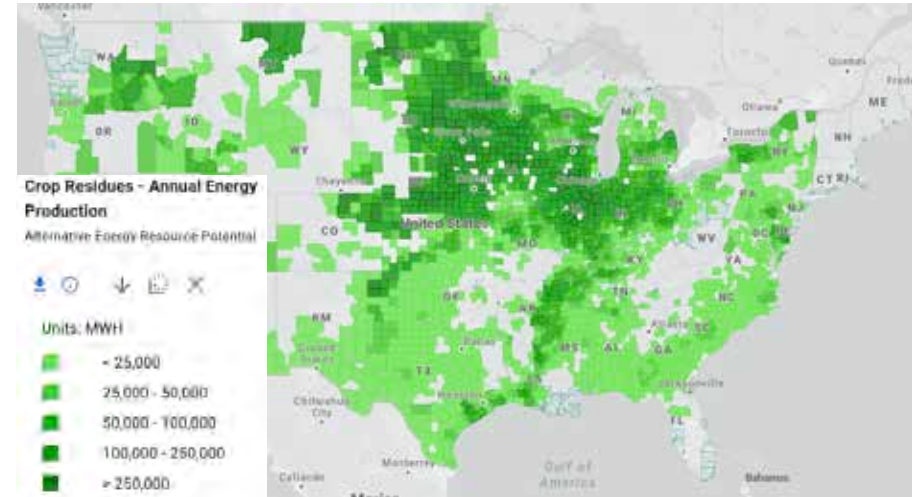
APEX Additions: Biofuels Module

Expected Release:
September 2026

- **Purpose:** Enable evaluation of biomass-derived fuel pathways for the maritime sector
- **New data integration:**
 - Biomass availability and cost (from Billion Ton Study¹ supply scenarios)
 - Port bunkering volumes
 - Existing infrastructure: pipelines, biorefineries
- **Decision support capabilities:**
 - Conduct location-specific scenario analyses to estimate biomass availability and corresponding marine biofuel production potential

- **Practical Context:**

- Assess project feasibility
- Examples to illustrate real-world deployment pathways



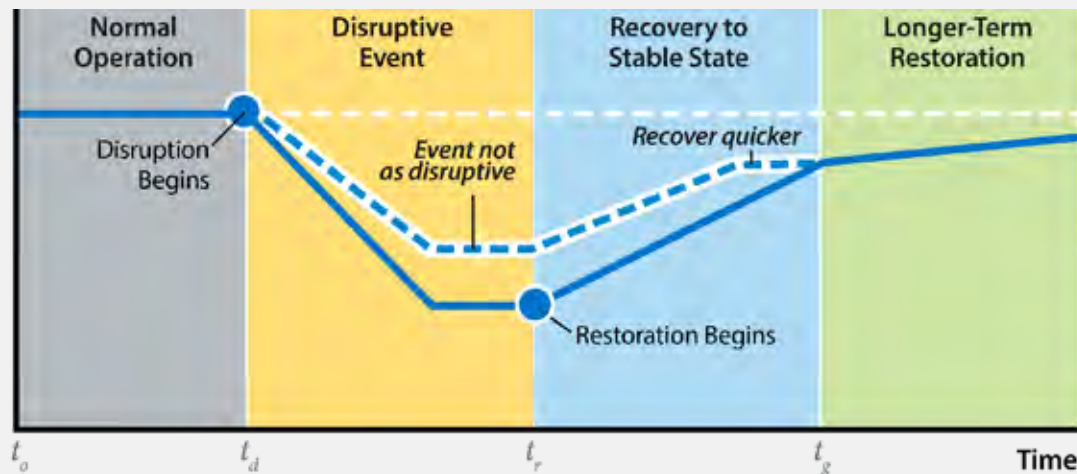
Map generated in Alternative Energy at Ports Explorer (APEX) Data Viewer tool. NLR. <https://maps.nlr.gov/apex/data-viewer/>.

What Is Resilience?

The ability to **anticipate**, **prepare** for, and **adapt** to changing conditions and **withstand**, **respond** to, and **recover** rapidly from disruptions.*



A resilient port can cope with shocks, absorb disruptions, and quickly restore operations to a level similar to—or above—baseline.



* Hotchkiss, Eliza; Dane, Alex. 2019. [Resilience Roadmap: A Collaborative Approach to Multi-Jurisdictional Resilience Planning](#). Golden, CO. National Renewable Energy Laboratory. Graphic by NLR.



Evaluating resilience is cyclical, requiring a recurring review of:

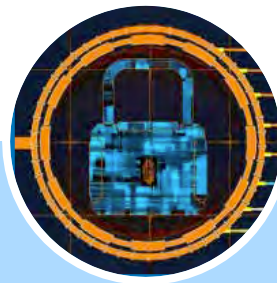
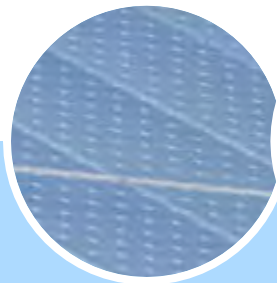
- How are things now?
- How can hazards and threats expose existing vulnerabilities?
- What can be done to prepare for, reduce the impacts of, and recover quickly from acute shocks and chronic stressors?
- How did improvements from the last assessment improve resilience?



Graphic by NLR, source: [Anderson et al. \(2019\)](#).

NLR's Resilience Assessment Approach

Case Study: Saipan Airport Energy Resilience & Security Support



Energy Optimization & Energy Audit

- Identified energy efficiency and power options to reduce utility costs
- Presented findings to Commonwealth Port Authority – used to apply for EIC grant

Cybersecurity

- Full presentation with CPA and discussion of findings

Glint/Glare Analysis

- Siting analysis to avoid glare affecting pilot and tower visibility

Application of Findings

- System sizing of Saipan Airport PV + storage for CPA-RFP-014-25
- Technical and security review of vendor solar/storage proposals

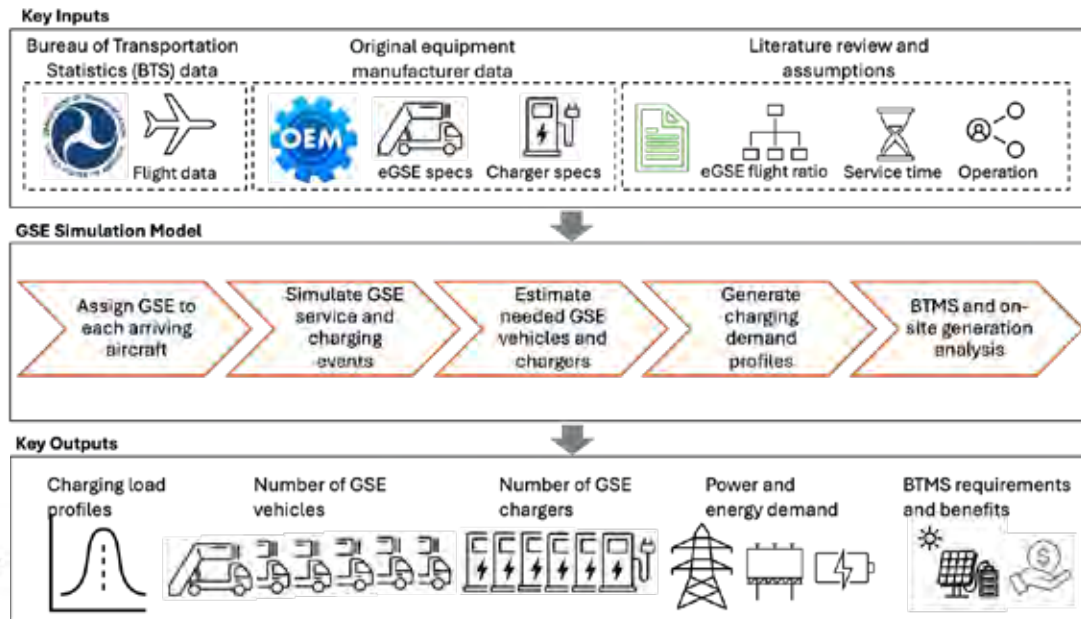
Analysis conducted by NLR for Saipan International Airport (CNMI) from June–October 2025 with funding from FEMA through DOE Grid Deployment Office

Emerging Technologies—and the Future of Aviation

eGSE Modeling Method

GSE operation and charging modeling:

- GSE operations are inherently dependent on flight activity at airports, as each arriving aircraft requires a specific number of GSE vehicles for servicing.
- We model eGSE operation and charging activities based on flight arrival data and the operation pattern of GSE.



Distribution of annual flight arrivals across the airports

Peak Power Demand

Peak demand closely aligns with flight arrival volume.

- Large hub airports, with the highest arrivals, show the highest peak demand, while medium hub, small hub, and non-hub airports have progressively lower demand levels.

Charging strategy strongly affects peak demand.

- The delayed charging strategy results in the lowest peak demand, immediate charging increases demand, and overnight charging produces the highest peak demand across most airport groups.

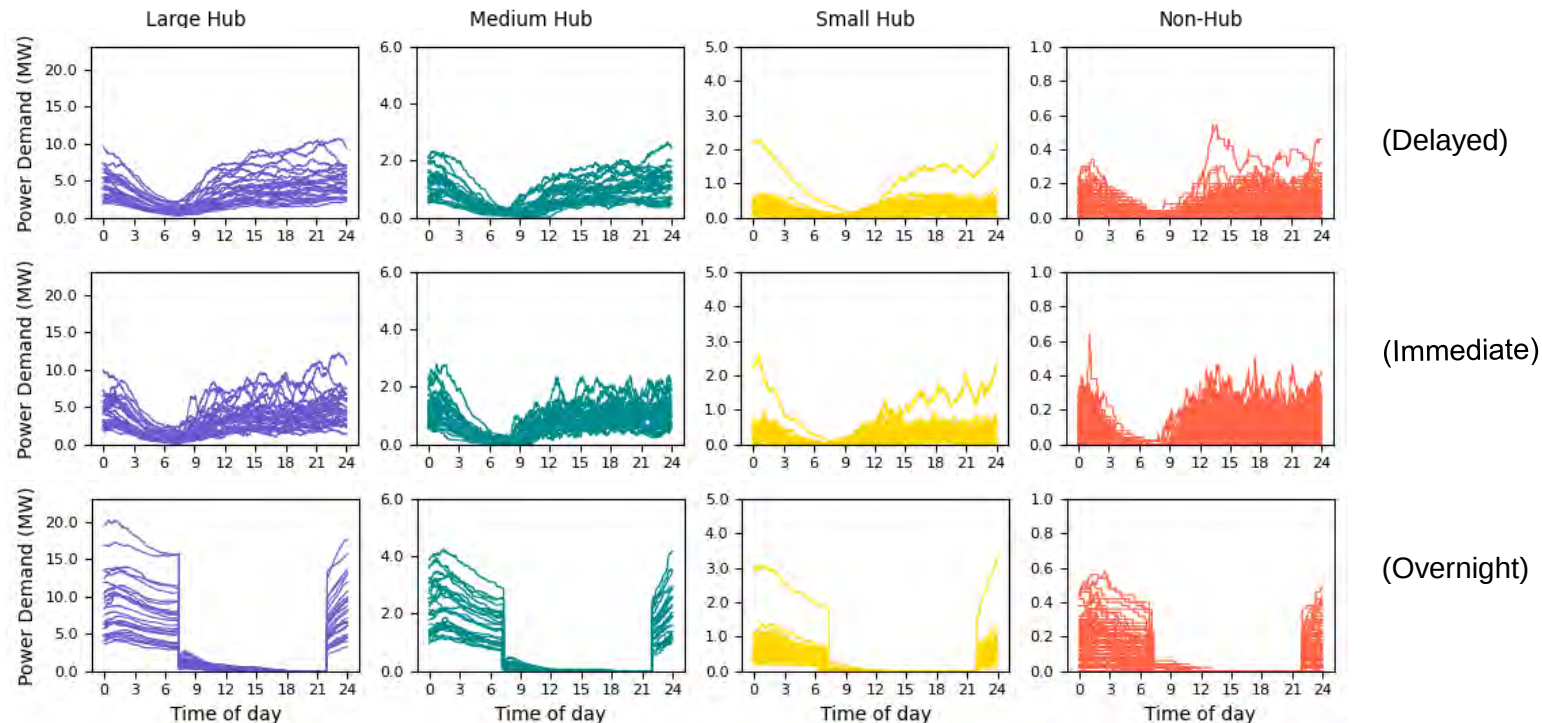
Note: Delayed (charge when SOC is insufficient) is considered as the base scenario, hollow points in the other two scenarios (Immediate and Overnight) represent the decrease in peak demand and solid points represent the increase in peak demand compared to the base scenario.





eGSE Load Profiles

20 kW chargers



Annual energy (MWh)	Min	10,819	2,941	577	8
	Max	50,878	12,102	9,239	1,204



Supporting Energy Infrastructure Behind Advanced Air Mobility (AAM)

- Modern aircraft need modern infrastructure.
- AAM can expand mobility, access, and economic opportunity.
- Energy, grid, and resilience planning are **essential** to deployment.

Photo from Joby Aviation

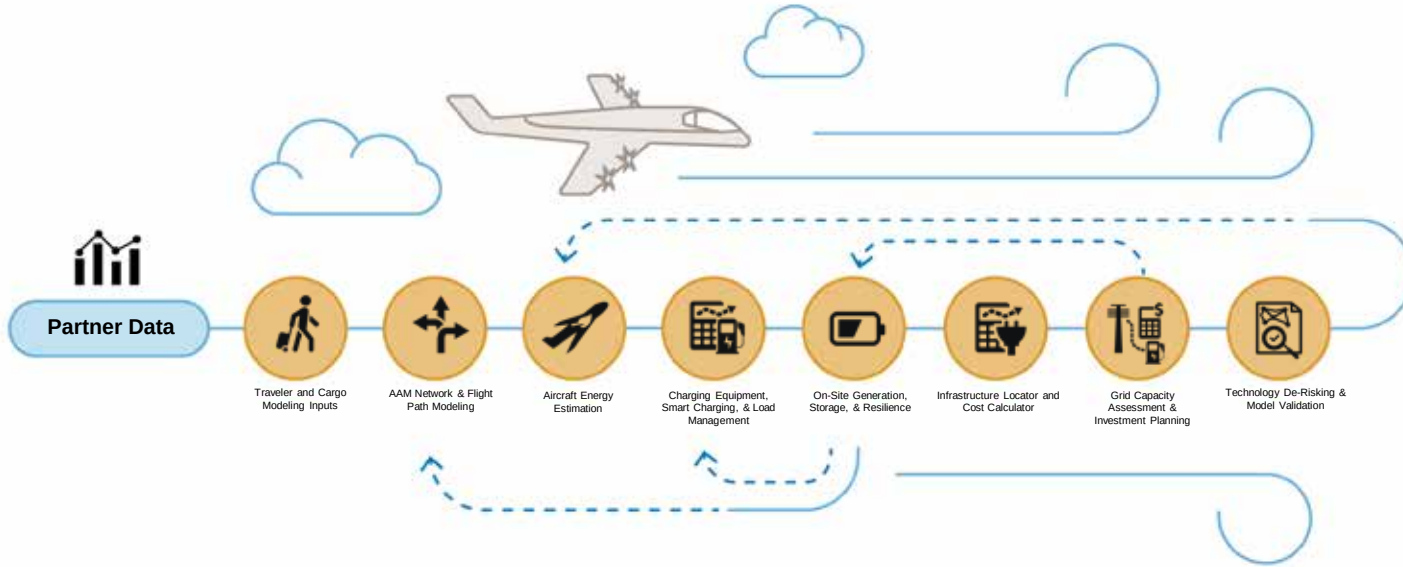
Future Aviation-Energy Supply Chains



AAM Electrification is an Infrastructure Challenge, Not Just an Aircraft challenge

- Electric aircraft introduce high power charging loads.
- Airports and vertiports must integrate:
 - Charging
 - Building loads
 - On-site generation assets
- Utilities, airports, FAA, operators, and other stakeholders need planning guidance
- Energy infrastructure resilience is critical





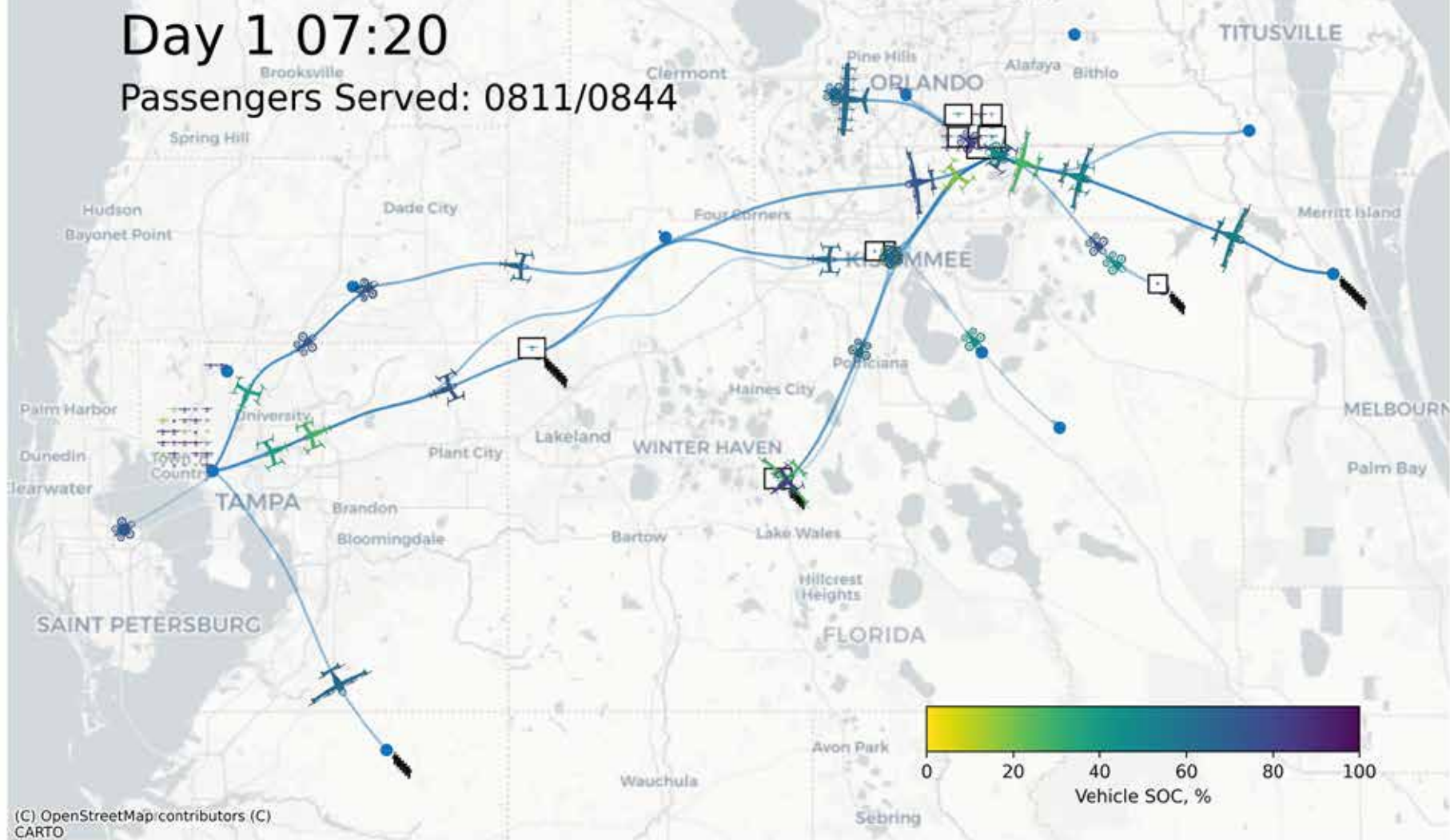
Highly Connected Infrastructure Analysis

- Site Selection and Network Impacts Analysis
- Fleet and Charging Infrastructure Impacts
- Utility and Site Planning
- Technology de-risking for site infrastructure

Data Collection Driven
by Future Outcomes

Day 1 07:20

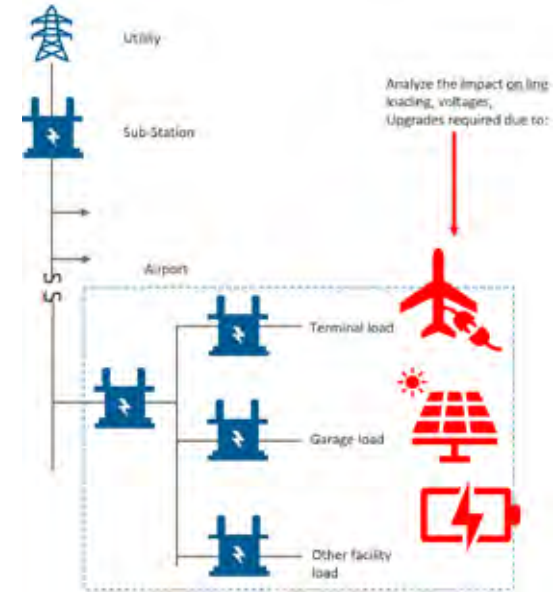
Passengers Served: 0811/0844



High Power Charging Can Exceed Grid Capacity

eVTOL charging is likely to increase site load demand 6–7x

- Current feeders could accommodate a 2–3x increase
- Simulation showed potential heavy overloading:
 - Transformers up to 670%
 - Lines up to 360% were heavily overloaded
- Overloading leads to potential power quality and cause equipment malfunction and power interruptions
- Potential utility level solutions:
 - Line and transformer upgrades
 - Voltage mitigation measures (capacitor and regulator settings)
- Site specific mitigation:
 - On-site energy storage and generation

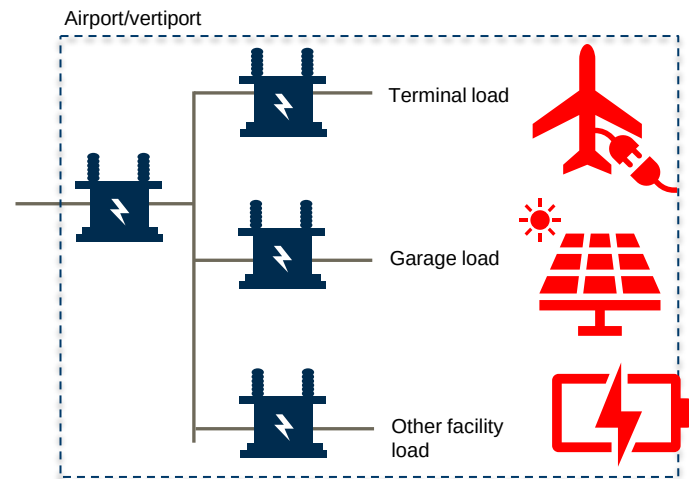


- In the absence of actual utility feeder models, realistic test feeders were selected
- SMART-DS datasets were utilized

Site Energy Design Can Help Manage Cost, Peak Demand, and Resilience

CAPEX/OPEX with eVTOL: REopt Analysis

- Total yearly consumption increases by ~6-20%
- Peak demand increased from 200% to 1,100%
- Electric utility bills increased 17% to +305%
- Utility requests may require alternate rate tariffs and/or adjust how peak demand is quantified



For all the sites in study area, PV + BESS integration leads to NPV savings considering capital, lifecycle (25 years) costs and certain discounting rates (5.64%).

Note: This is utility specific and varies by region.

Athena



National Laboratory
of the Rockies

Sign In



The Athena project helps airports adapt to uncertainty and new technologies by applying AI, optimization, high-performance computing (HPC), and other modern tools.



About



Aeroportal

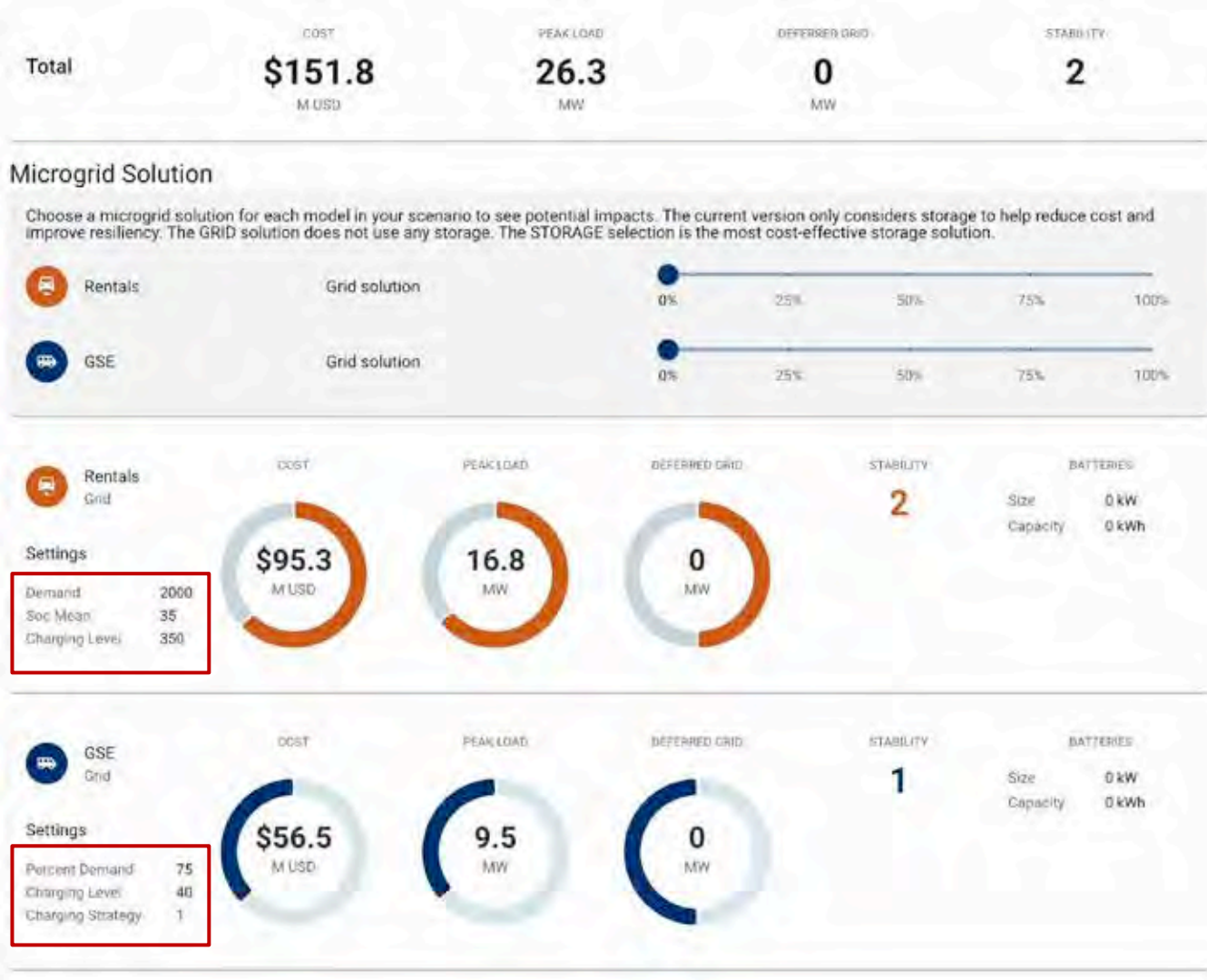


Seaportal

Example Planning Interface

Explore microgrid solution options for each operational area

Configure simple inputs that determine load



Thank you

Jason Lustbader

Jason.Lustbader@nlr.gov



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