NREL
Transforming ENERGY

Transforming ENERGY through SUSTAINABLE Transportation

Transportation & Hydrogen Systems Center

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NASEO Energy Policy Outlook Conference
February 5, 2019

NREL's Science Drives Innovation

Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

Grid Modernization

High-Performance Computing

Data and Visualizations

Sustainable Transportation

NREL's sustainable transportation research focuses on new, innovative, and integrated mobility strategies with the potential to:

- *Transform the movement of people and goods*
- *Enhance national energy security*
- *Boost the domestic economy*
- *Save individuals and businesses time and money.*

Vehicle Technology Integration & Evaluation

Light-, medium-, and heavy-duty vehicles

Alternative Fuel Infrastructure

Energy Efficient Mobility Systems and Technologies

NREL's vehicle technology integration work:

- Engages transportation stakeholders to tackle complex problems
- Provides technical assistance for early adopters, and
- Develops tools and information to put cutting-edge mobility technologies into practice.

Clean Cities: Locally-Based Public-Private Partnerships

Clean Cities Coalitions:

- Are comprised of public and private stakeholders who share a common commitment to using alternative fuels
- Provide unique perspective on state-specific efforts
- Facilitate the adoption of new transportation technologies and stimulate local alternative fuel markets
- Leverage public and private funding
- Engage in education and outreach activities

Alternative Fuels Data Center

Interactive tools

Laws & Incentives

Maps and Data

Fuel conservation strategies

Case studies

Information on alternative fuels, vehicles, and fueling

Searchable publications database

afdc.energy.gov

Integrated Resources and Support

Clean Cities Coordinator Request

Original Request

Support to inform FHWA Corridor Request

Compiled summary of relevant regulations from AFDC

Secondary Request

Understand technical aspect of propane fueling stations

Provided staff expertise

Tertiary Request

Gather input from industry stakeholders

Working group informed application

End Result

Submission of the corridor for consideration

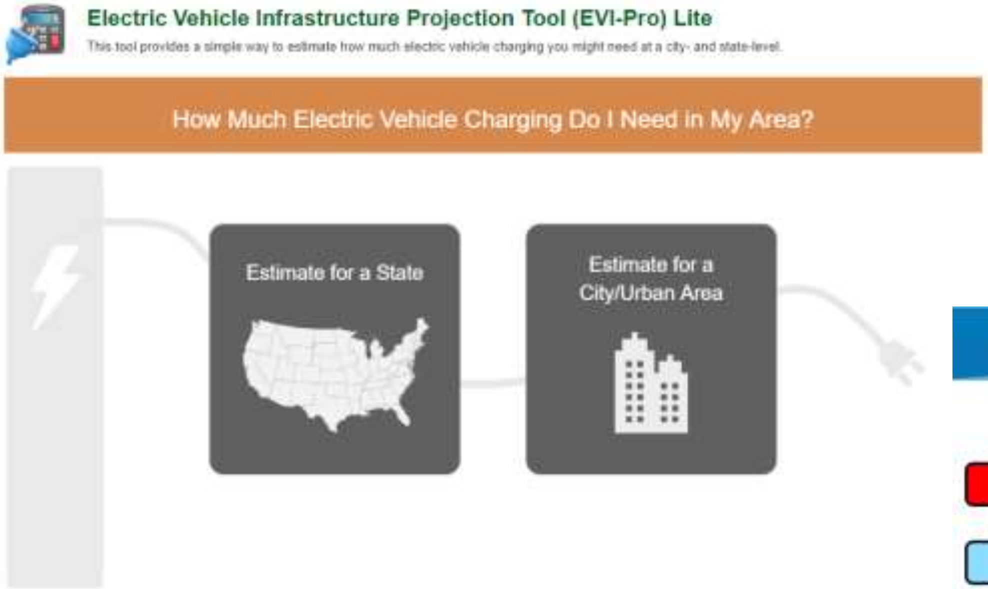
NREL/DOE Support

AFDC Tools: State Information Pages

Information on:

- ***Laws & Incentives***
- ***Fueling Stations***
- ***Coalition(s)***
- ***Fuel Production and Consumption***
- ***Fuel Production Infrastructure***
- ***Electricity Sources and Vehicle Emissions***
- ***Regional Fuel Prices***
- ***Transportation Projects***
- ***Case Studies and Videos.***

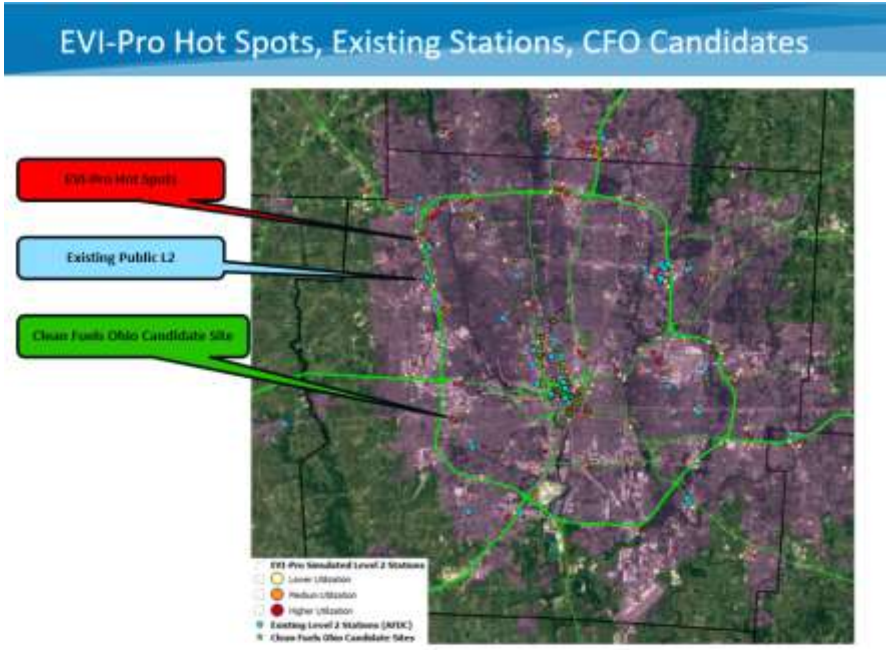
EVI-Pro (and Lite)



- EVI Pro projects consumer demand for EV Charging Infrastructure
- NREL has supported statewide assessments in Massachusetts, Maryland, California, and Colorado

Can provide guidance to stakeholders to:

- Reduce range anxiety as a barrier to increased PEV sales
- Ensure effective use of private/public infrastructure investments



Transportation Analysis with State Decision Makers

- Supported Regional Air Quality Council and the State of Colorado with RFP development, application review, and station and vehicle specific technical knowledge
- Provided technical expertise to Clean Cities Coalitions regarding eligible mitigation actions for the VW Settlement
- Developed economic analysis for assessing Battery Electric Bus feasibility in Bozeman, MT.

Battery Electric Bus Economic Analysis

Sensitivity and Variability of Project Parameters

	Parameter	Baseline Input	Low Input (-50%)	High Input (+50%)	Low NPV ('000)	High NPV ('000)	NPV Swing ('000)	Variability	
General	Number of electric buses covered by grant	2	1	3	-$273	$1,501	$1,775	High	★
Diesel Bus	Cost of new 40-ft diesel bus	$460,094	$230,047	$690,141	-$219	$1,447	$1,666	Medium	★
General	Average vehicle miles traveled	45,160	22,580	67,740	-$118	$1,346	$1,464	High	★
Electric Bus	Purchase price of electric bus	$887,308	$443,654	$1,330,962	$1,334	-$105	$1,439	Medium	★
Diesel Bus	Diesel vehicle maintenance ($ per mile)	$0.83	$0.41	$1.24	-$102	$1,331	$1,433	Medium	★
Diesel Bus	Fuel economy diesel buses (mpg)	4.7	9.5	3.2	-$15	$1,244	$1,259	Medium	★
Diesel Bus	Diesel fuel price ($/gal)	$2.93	$1.47	$4.40	-$15	$1,244	$1,259	Low	
Electric Bus	EB vehicle maintenance costs ($/mile)	$0.64	$0.32	$0.96	$1,085	$143	$942	Low	
General	Average Life of bus (years)	12	6	18	$376	$933	$557	Low	
EVSE	Charger price (each, after any grant funding is subtracted)	$495,636	$247,818	$743,454	$862	$366	$496	High	★
Electric Bus	Demand charge of electricity (per kW)	$9.93	$4.965	$14.895	$800	$428	$372	Low	
General	Required rate of return or discount rate	4%	2%	6%	$777	$482	$296	High	★
Electric Bus	Electric bus efficiency (kWh/100miles)	175.0	87.5	262.5	$733	$496	$237	Medium	
Electric Bus	Price of electricity (per kWh)	$0.08	$0.04	$0.11	$733	$496	$237	Low	
EVSE	Installation cost (each EVSE)	$202,811	$101,406	$304,217	$716	$513	$203	High	

EV Grid Integration Efforts @ NREL

- Facility Smart Charge Management: NREL employee workplace charging integration with building load for demand charge mitigation.
- DCFC Systems Integration: DC fast charging system integration with onsite storage, generation, L2 charging, and building load.
- Distribution System Vehicle-Grid Impacts and Charge Management: PHIL capability to emulate multiple nodes on a feeder at medium voltage to residential (L1/L2) and/or commercial (XFC) up to 2 MW real load
- Wireless Charging and Transportation Systems: Energy use and design analysis for adding frequent intra-day charging to a shuttle services
- EVSE Cyber Security: Virtualized environment representing power and operational networks of a small distribution utility enables protect, detect, and isolate strategies for grid integrated infrastructure


Facility Smart Charge Management – Demand Charge Mitigation


DC Fast Charge Systems Integration


Distribution System: Vehicle to Grid Impacts


Energy Security and Resilience

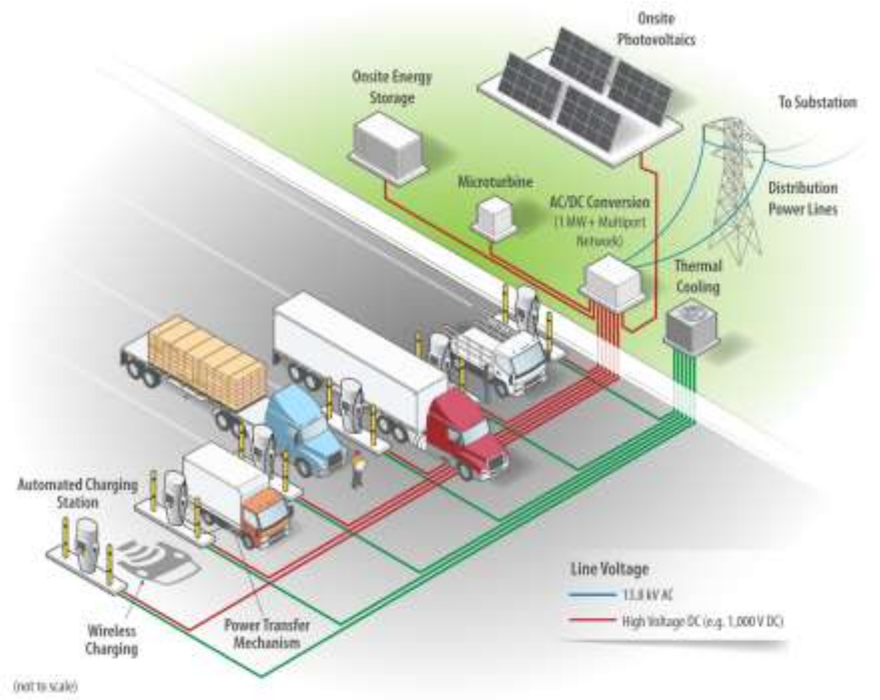
Wireless Charging and Transportation Systems

Multiport 1+ MW Charging System Challenges for MD and HD

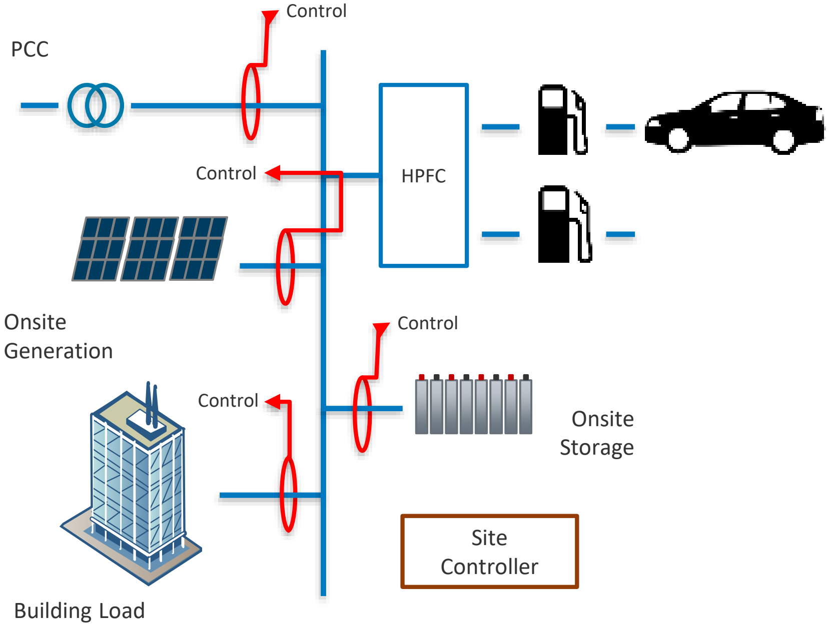
Can megawatt (MW)-scale charging systems that can quickly charge large capacity (~800 kWh) battery packs in less than ~30 minutes be built at an attractive charging cost ($/kWh)?

Many challenges must be met to realize such an integrated system, including:

- Understanding and **optimizing power demand and management** requirements to integrate with local infrastructure requirements,
- Developing **distribution voltage-level hardware (13.2 kVa)** for the point of grid connection, designing grid interface converters
- Understanding and overcoming **power electronics semiconductor** and architecture limitations at high voltage and power levels
- Developing safe and **robust hardware connections** – especially where human interaction is required
- Designing **real-time battery charge control** algorithms to account for chemistry dynamics and thermal constraints while minimizing peak power demands
- Developing **robust thermal management systems for all parts of the system**
- Assessing and developing **vehicle-side power** delivery architectures



<u>1+MW Challenges and Gaps:</u>
Site Optimization and Resilience via Control Opportunities



<u>Need to Predict:</u> Load and generation estimation is required for optimal energy storage integration

- **High Power EV charging <u>loads</u>** will vary depending on charging infrastructure and travel patterns
- **Building <u>load</u>** will be dependent on occupancy, building design, and is subject to seasonal weather variation
- Onsite **renewable <u>generation</u>** will be dependent on regional conditions

<u>Need to Control:</u> Control integration of all loads and generation is required for optimal energy system and microgrid management

- **Interoperability** of communication and control across multiple sectors
- Resolving **multi-objective optimization** across the building, transportation, and grid interface that is open yet cybersecure

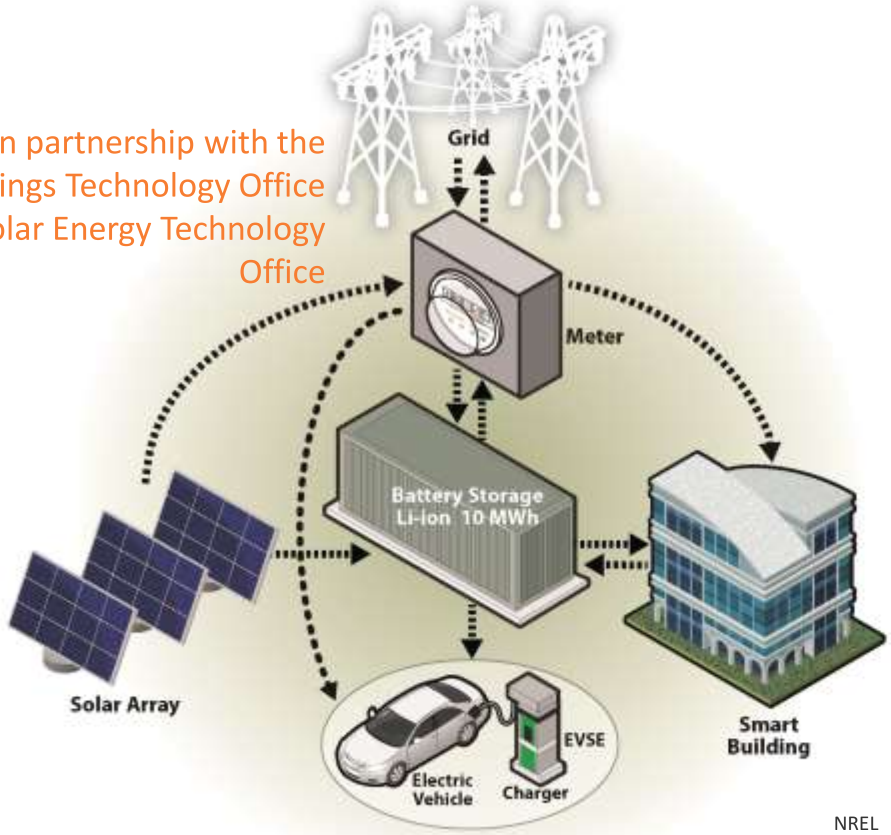
NREL’s Behind-The-Meter Storage (BTMS) Effort

Extreme fast-charging is a new FY18 initiative in DOE’s Vehicle Technologies Office to enable commercial charging stations similar to today’s gas stations.

Substantial power levels are required for extreme fast-charging at levels of >350 kW per vehicle. Novel solutions are needed to avoid significant negative impacts to the grid.

The goal is to produce behind-the-meter battery solutions deployed at scale to implement renewable generation, minimize cost, and meet the functional requirement of high-power electric-vehicle charging.

In partnership with the Buildings Technology Office and Solar Energy Technology Office



Electro-Chemical

Technology Solutions Needed to Mitigate Electricity Cost for Electric Vehicle DC Fast Charging

- BTMS explores the use of technology solutions to mitigate electricity cost for DCFC (7,000 commercial electricity rates currently available in the U.S.)

- The technology focus is on deploying a DCFC station in conjunction with PV panels, energy storage (battery), and co-located on the same meter as a commercial building to minimize DCFC cost.

Different rates and situations require specialized solutions

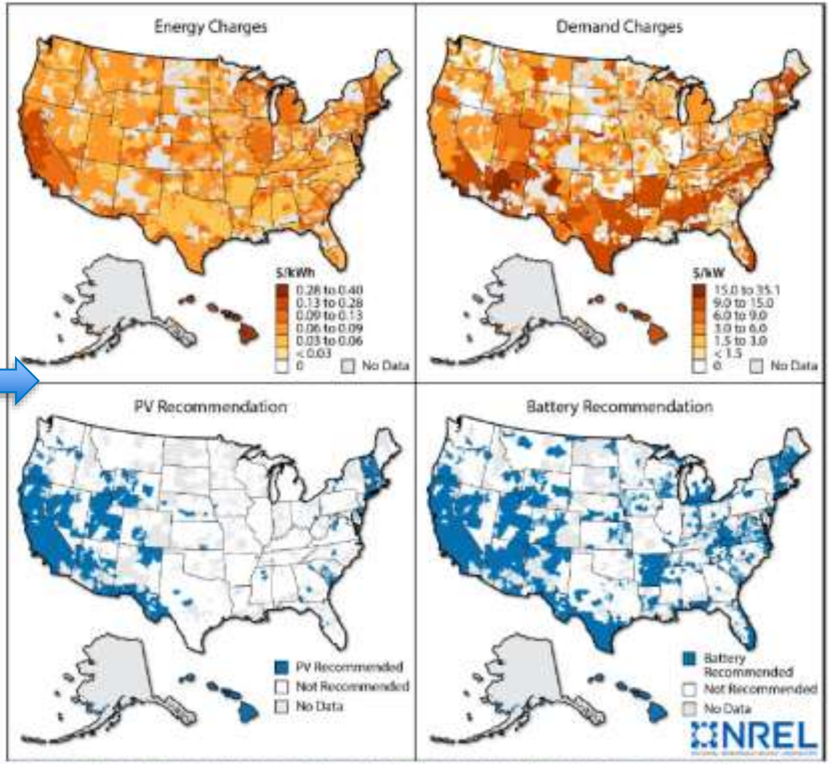


Figure 6. Geographic distribution of energy and demand charges as well as the technology recommendation for scenario B.

Matteo Muratori et. al. National Renewable Energy Laboratory (NREL)

BTMS: Need for Targets for Fast Charging Systems

Example: Battery Storage **1–10 MWh** systems at **$100/kWh** able to cycle **2x/day** with a **4-h discharge** and lifetime of **20 yrs** and **8.000 cycles**

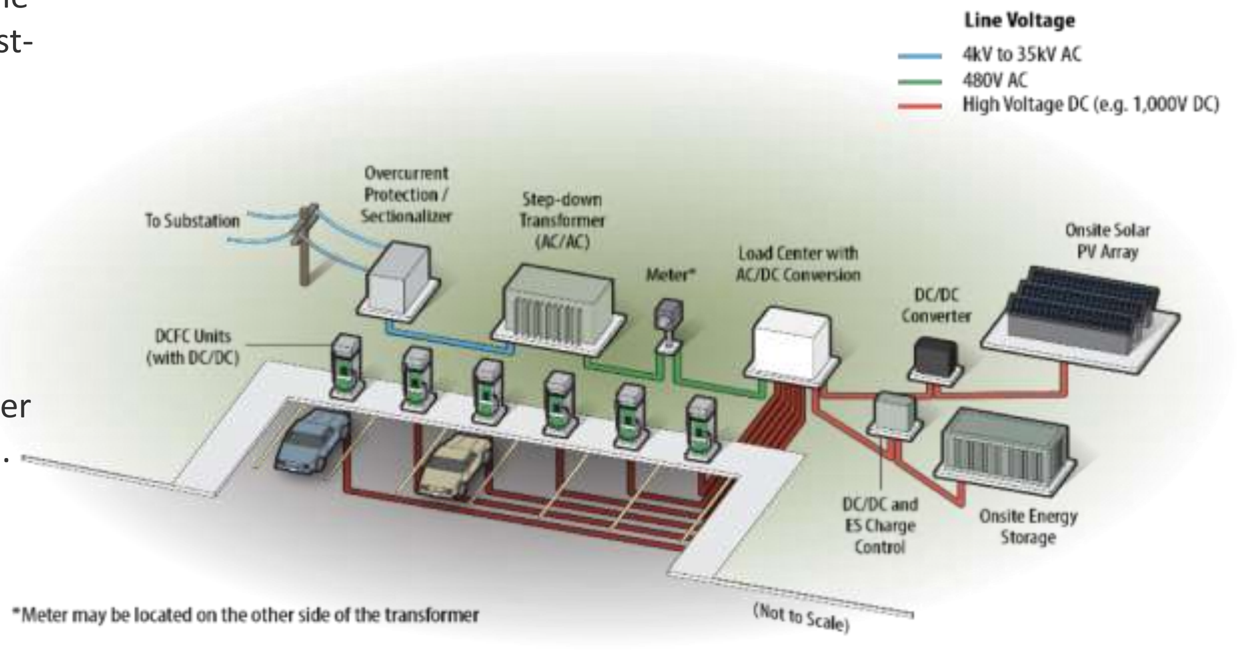
Major effort in FY19 will be to define the specific targets for BTMS for fast-charging and GEB applications.

Chemistry will dominate lifetime, power, and energy.

Balance-of-plant issues may dominate cost.

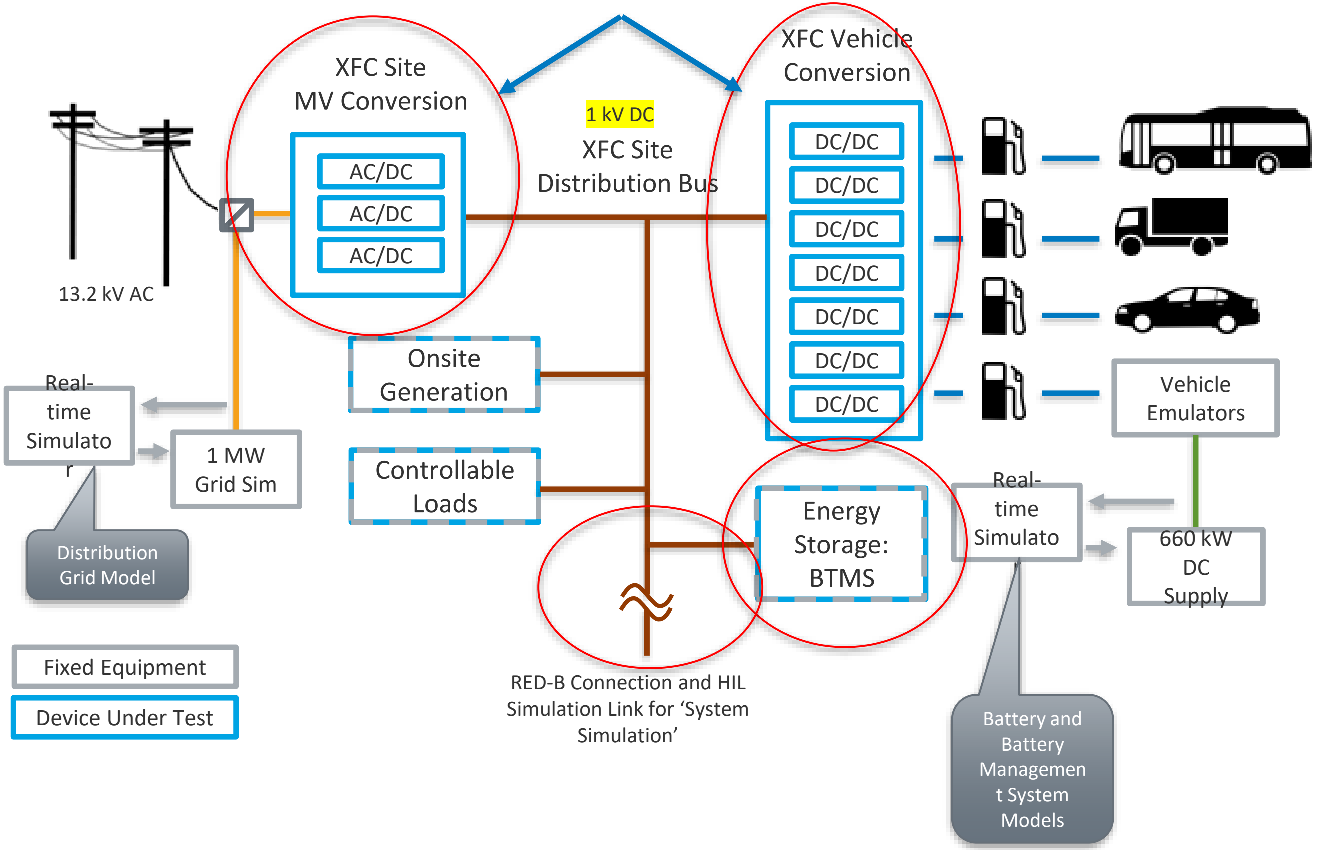
Thermal management of high-power systems will need to be considered.

No use of critical materials!

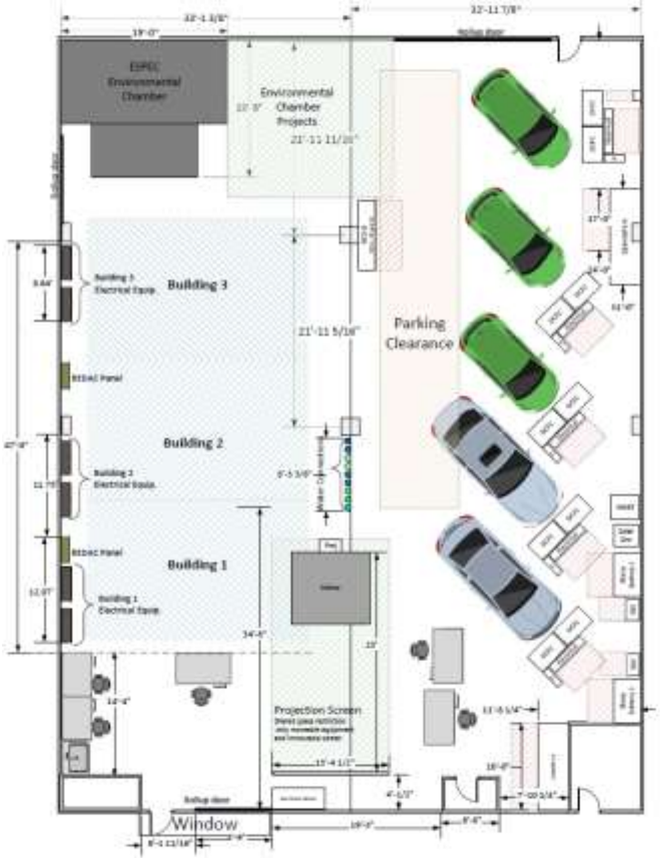


Buildout of NREL Capabilities:

Bringing Together Necessary Elements to Assess and Develop Optimal MW+ Charging Systems



Buildings + Storage + Fast Charging Lab Buildout: Commercial Building & Vehicle XFC Integration Opportunities



Using ESIF and Connected XFC Station Hardware: Outdoor & Accessible 1+MW Charging

Existing Lab Infrastructure

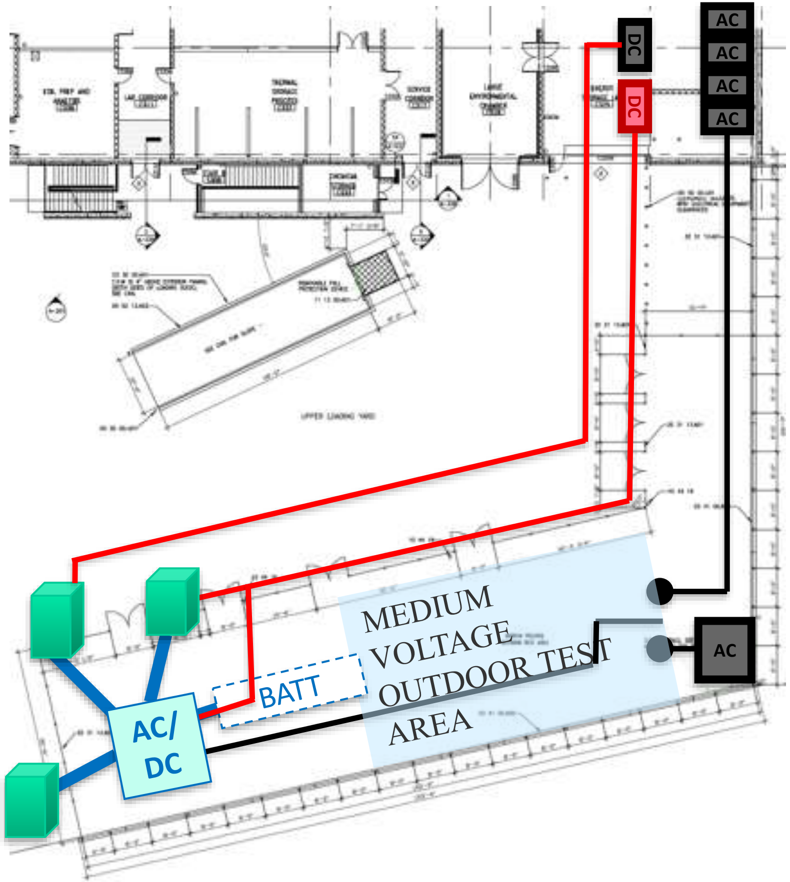
- ✓ 13.2 kV utility connection 1 MVA
- ✓ 13.2 kV or 480 Vac PHIL grid simulation 2 x 1 MVA
- ✓ PHIL DC power supply for vehicle load or battery emulation 660 kW
- ✓ Test yard with heavy vehicle access

Upgrades In Process

- ➢ 1000 Vdc, 1 MW distribution feeders (REDB DC) x 2
- ➢ Additional PHIL DC power supply for vehicle emulation

XFC EVSE and VEHICLE

- Supplied by technology partners (or purchase at additional cost)
- Research to Understand Real-World Utilization and Barriers



Connecting grid, hydrogen & mobility

Renewables

Wind and solar electricity

Production

Hydrogen production via electrolysis

Distribution

Hydrogen storage & distribution via liquid, truck, pipeline

Fueling

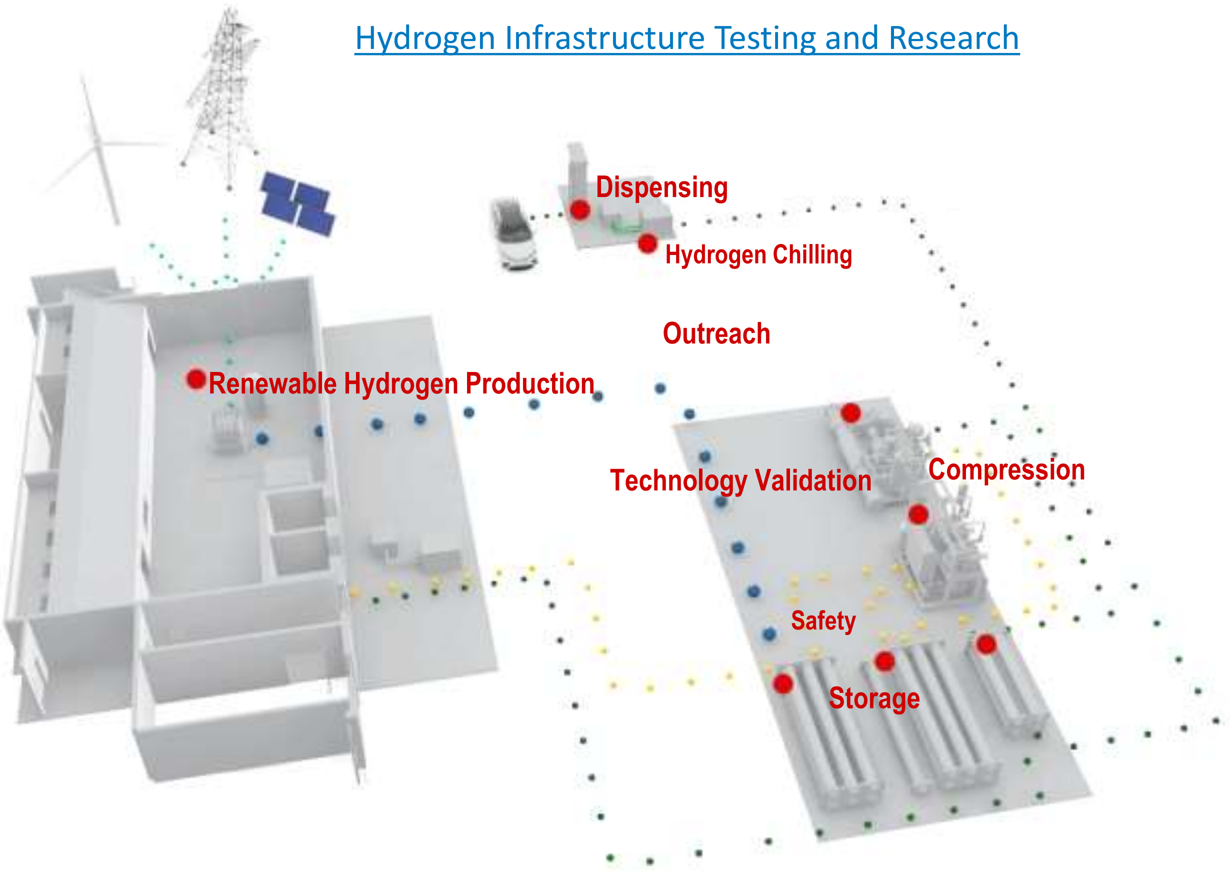
Hydrogen fueling cars, trucks, buses, and forklifts

Mobility

Zero emission mobility for people and goods

Analysis guiding new hydrogen infrastructure innovation

[Hydrogen Infrastructure Testing and Research]



Fully integrated system capable of experiments on advanced components and sub-systems and innovative component/system concepts.

Fuel Cell Trucks

“Toyota’s Heavy-Duty Fuel Cell Truck Finally Hits the Road”
Trucks.com 10/12/2017

roject Portal hydrogen fuel cell Class 8 truck. (Photo: Toyota)

“Nikola to Start Fuel Cell Truck Field Tests in Late 2018”
Trucks.com 11/09/2017

Nikola Two electric fuel cell truck. (Photo: Nikola Motor)

Work with Us

Tools and Publicly Available Data (AFDC)

NREL Expertise and Analysis

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Thank You

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided predominantly by the DOE Office of Energy Efficiency and Renewable Energy's Vehicle Technology Office and Fuel Cell Technologies Office. The views expressed in this presentation do not necessarily represent the views of the DOE or the U.S. Government.

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