Autonomous Energy Systems Functional Interoperability

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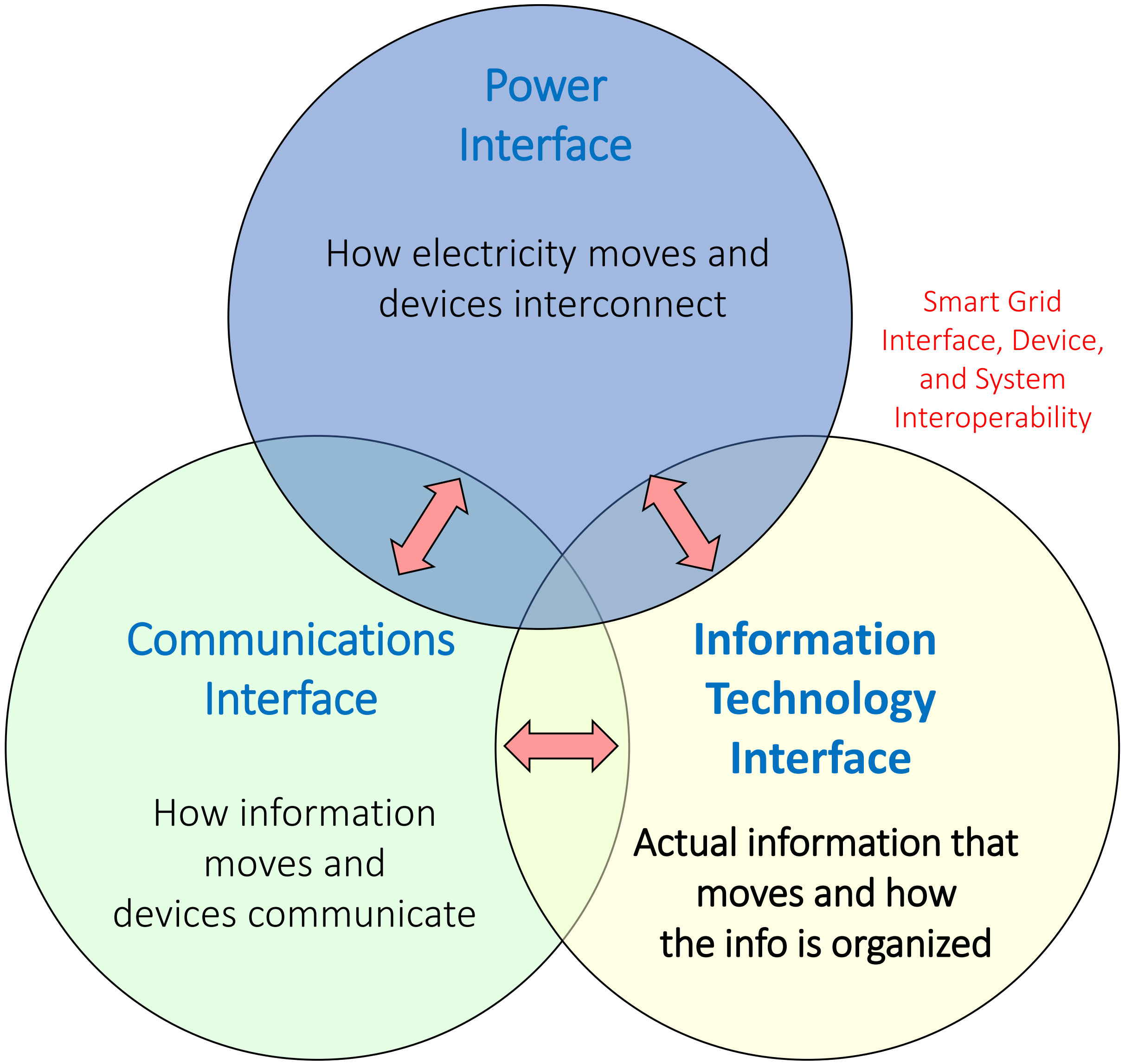
Smart Grid – Unraveling the Components

Smart Grid: The integration of power, communications, & information technologies for an improved electric power infrastructure serving loads while providing for an ongoing evolution of end-use applications. (Std 2030)

Interoperability: The capability of two or more networks, systems, devices, applications, or components to externally exchange & readily use information securely & effectively. (Std 2030)



Why do we want to talk to all of these devices?

Devices

Responsive, flexible end-use loads

- Home appliances (TBD)
- Air conditioners w/ thermostats
- Commercial rooftop units (RTUs)
- Commercial refrigeration
- Commercial lighting
- Electric vehicles (charging only)
- Electrolyzers

Storage

- Battery / inverter systems
- Thermal storage systems
- Electric vehicles (full vehicle-to-grid)

Distributed generation

- Photovoltaic solar (PV) / inverter systems
- Fuel cells

Grid Services

- Peak Load Management (capacity)
- Energy Market Price Response (wholesale energy cost)
- Capacity Market (market value)
- Regulation (market value)
- Spinning Reserve (market value)
- Ramping (new)
- Artificial Inertia (new)
- Distribution Voltage Management (new; e.g., PV impacts management)

Functional Interoperability

- **Functional Interoperability:** The capability of two or more networks, systems, devices, applications, or components to externally exchange & readily use information securely & effectively in order to achieve a stated objective.

- Our proposition is that NREL's ARIES capability is ideal to evaluate functional interoperability:
  - Define use case (objective) and scenarios
  - Integrate systems, devices, applications in a realistic laboratory environment
  - Simulate scenarios.

Background

- Advanced sensing, communication, and control systems are being deployed.
- These new software and hardware systems are not necessarily from the same manufacturer:
  - e.g., an advanced distribution management system (ADMS) from one vendor and a distributed energy resource (DER) management system (DERMS) from another vendor.
- These control systems have to coordinate to fulfill advanced grid control application goals:
  - e.g., operations of PV and battery systems under DERMS need to be coordinated with voltage regulators and capacitors under ADMS to realize integrated volt-var control.
- FERC Order 2222 opens the door for DERs to participate in wholesale markets through DER aggregators:
  - Requires coordination between DER aggregators, the independent system operator (ISO) or regional transmission operator (RTO) who runs the market, and the distribution system operator (DSO) or distribution utility.

Autonomous Energy Systems Functional Interoperability Objectives

To understand, define, and evaluate the functional interoperability for modern power systems:

- Mature a control & communications architecture that encompasses the existence of centralized, decentralized, & distributed systems from the transmission to distribution & down to the grid edge.
- Define the information exchange among these systems.
- Identify supporting communications protocols.
- Use NREL's ARIES capabilities to evaluate how different platforms can work together to fulfill unified grid operation objectives, & study different use cases to identify remaining gaps.
- Develop solutions to address the gaps & provide vendor-neutral research support (e.g., method development, test plan development, workflow design) to industry.

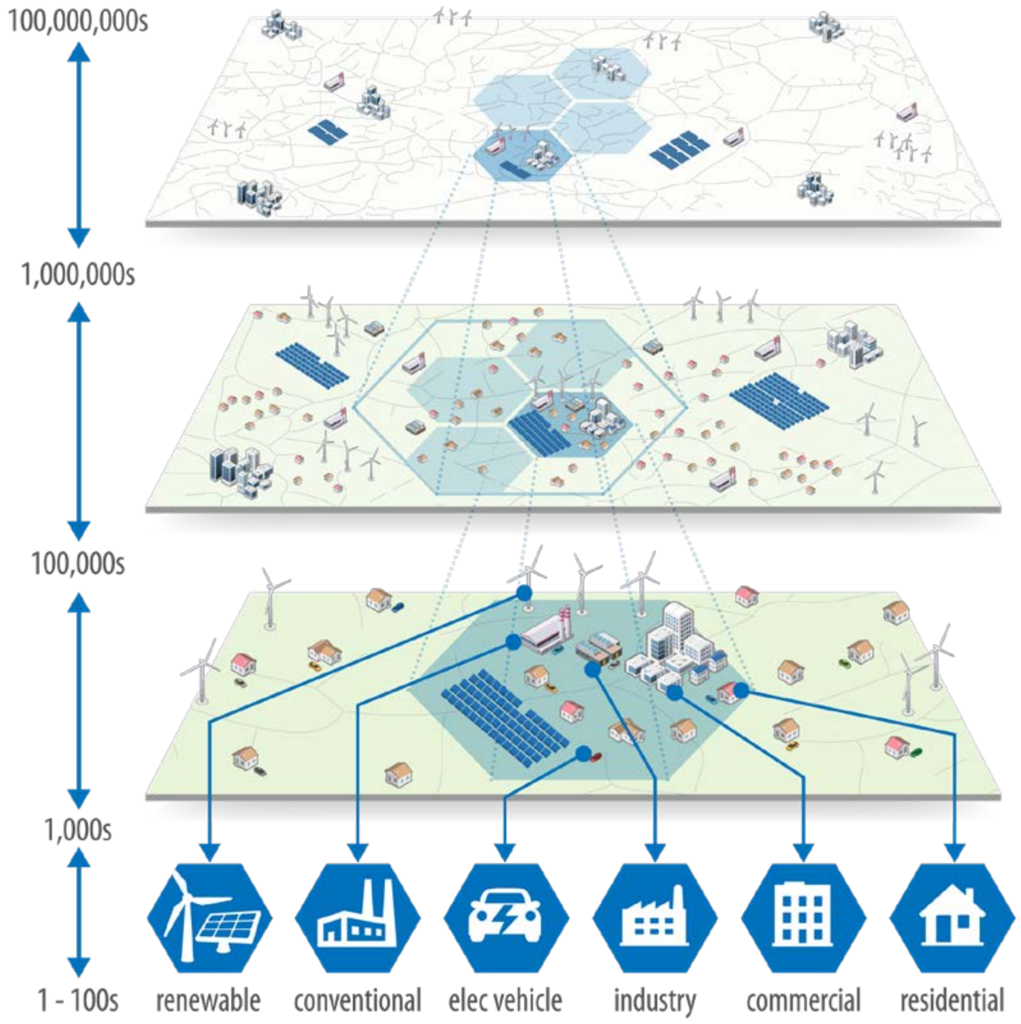
Build on:

- AES LDRD; GMLC Grid Architecture; GMLC FAST-DERMS.

Collaborate with:

- Office of Electricity Grid Architecture, e.g., Distribution Transformation/operational coordination
- EPRI TSO/DSO working group
- NREL Control Room of the Future.

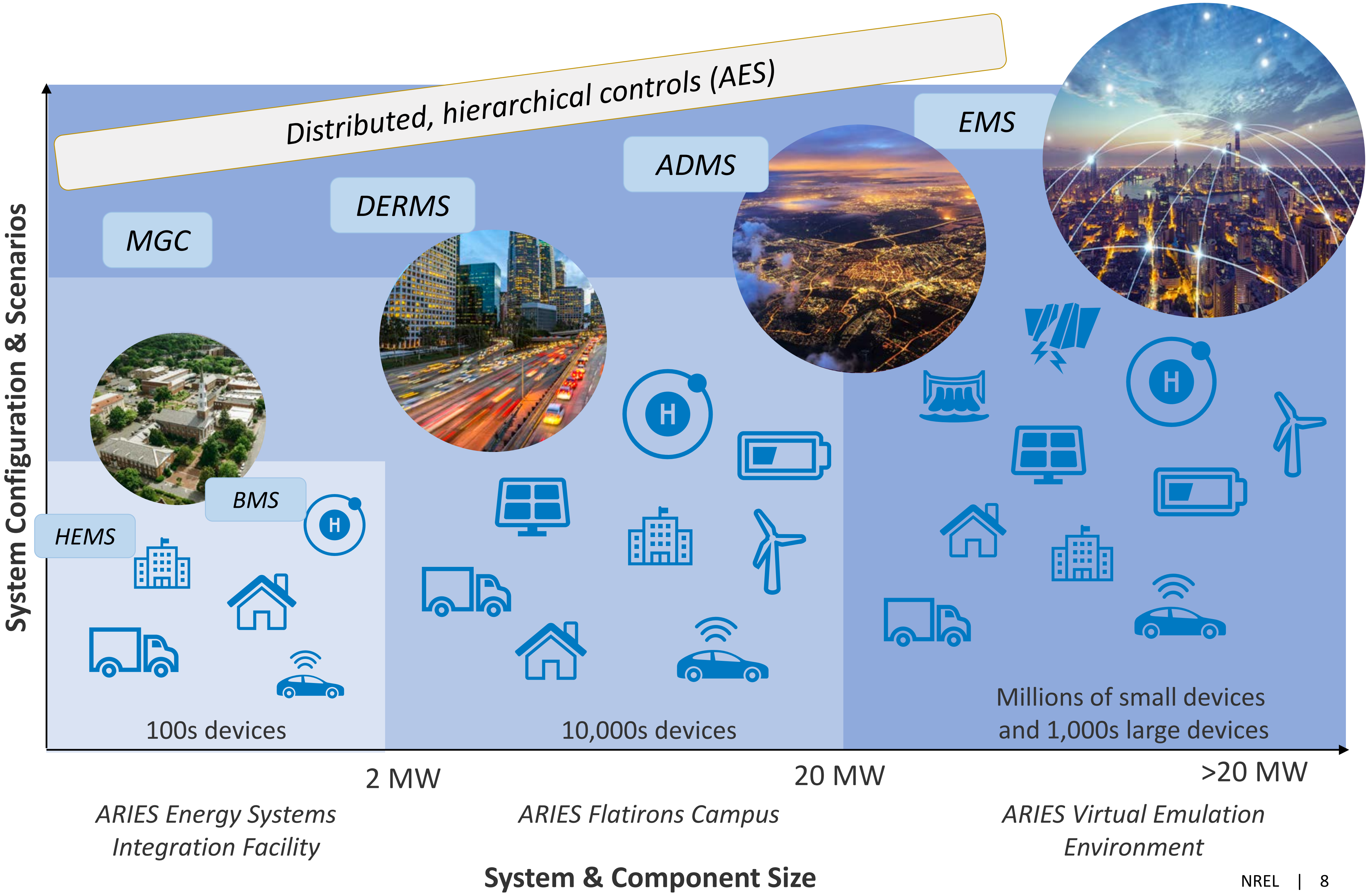
Autonomous Energy Systems



Autonomous Energy Systems (AES) aim to use **cutting-edge optimization algorithms and hierarchical, distributed control architectures** to

- Integrate heterogenous energy sources to deliver improved outcomes such as electrification, energy justice, reliability, resiliency, and security
- Operate and manage massively deployed distributed energy resources, including generation, storage, loads, and mobility in real-time
- Leverage data and communications available at all levels for improving energy system operations.

ARIES Scale



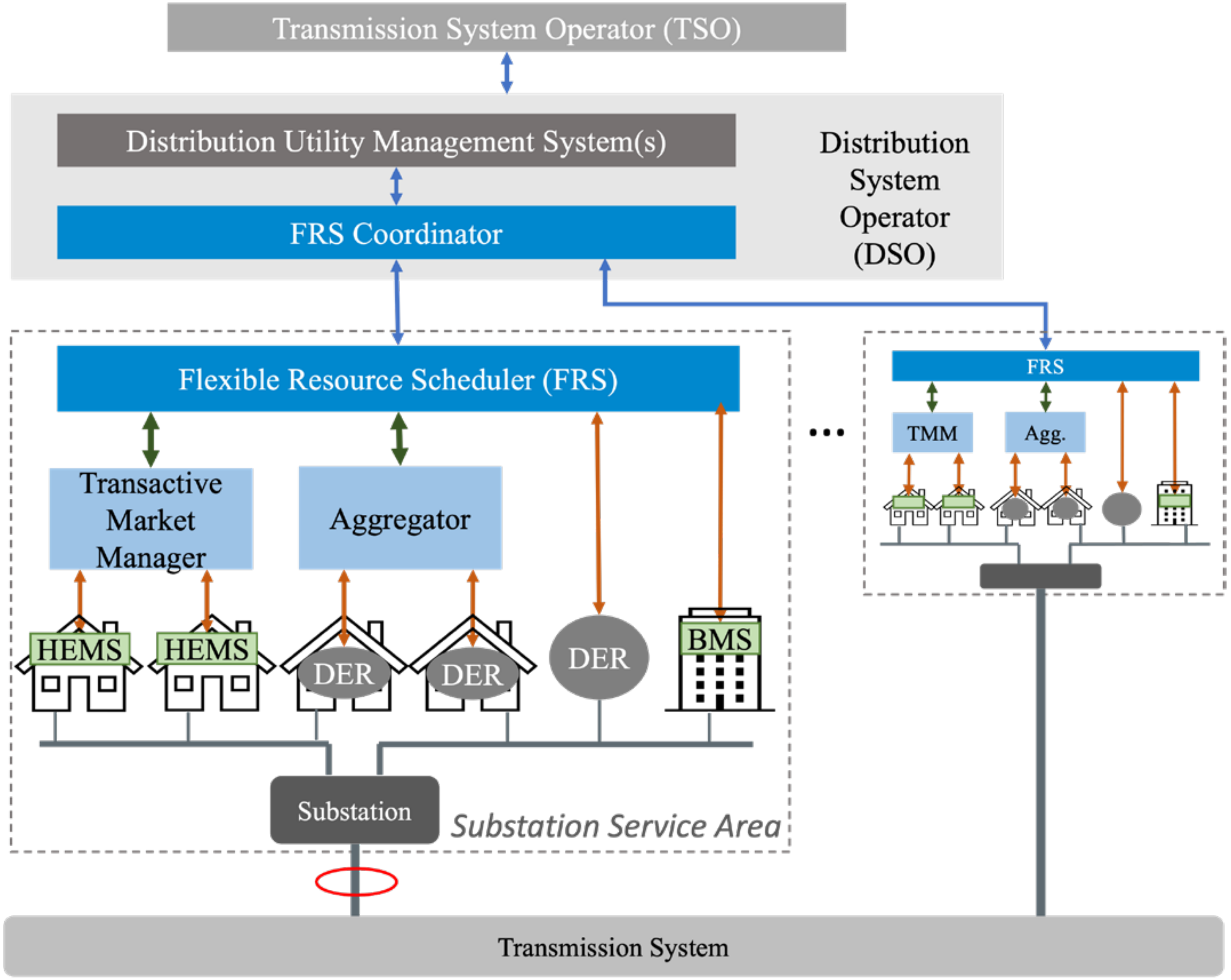
Distributed, hierarchical controls (AES)
EMS
ADMS
DERMS
MGC
BMS
HEMS
System Configuration & Scenarios
100s devices
10,000s devices
Millions of small devices and 1,000s large devices
2 MW
20 MW
>20 MW
ARIES Energy Systems Integration Facility
ARIES Flatirons Campus
ARIES Virtual Emulation Environment
System & Component Size

Examples

- GMLC: FAST-DERMS (Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions)
- Connected Communities: Smart Grid Test Bed Collaboration (SALMON)
- ADMS Test Bed: DER Control strategies for T&D Grid Services
- BMS-DERMS integration
- Cyber Range integration with ADMS Test Bed.

FAST-DERMS Architectural Features

- Employ **"Total DSO" architecture** model such that the DSO represents the aggregated resource response in the bulk transmission system.
- Perform **network-aware optimization** to maintain distribution health while simultaneously providing bulk service.
- Demonstrate **distributed intelligence** by managing aggregations at the distribution substation through our Flexible Resource Scheduler (FRS).
- **Simplify T&D interaction** by defining and measuring transmission services provided at the distribution substation.

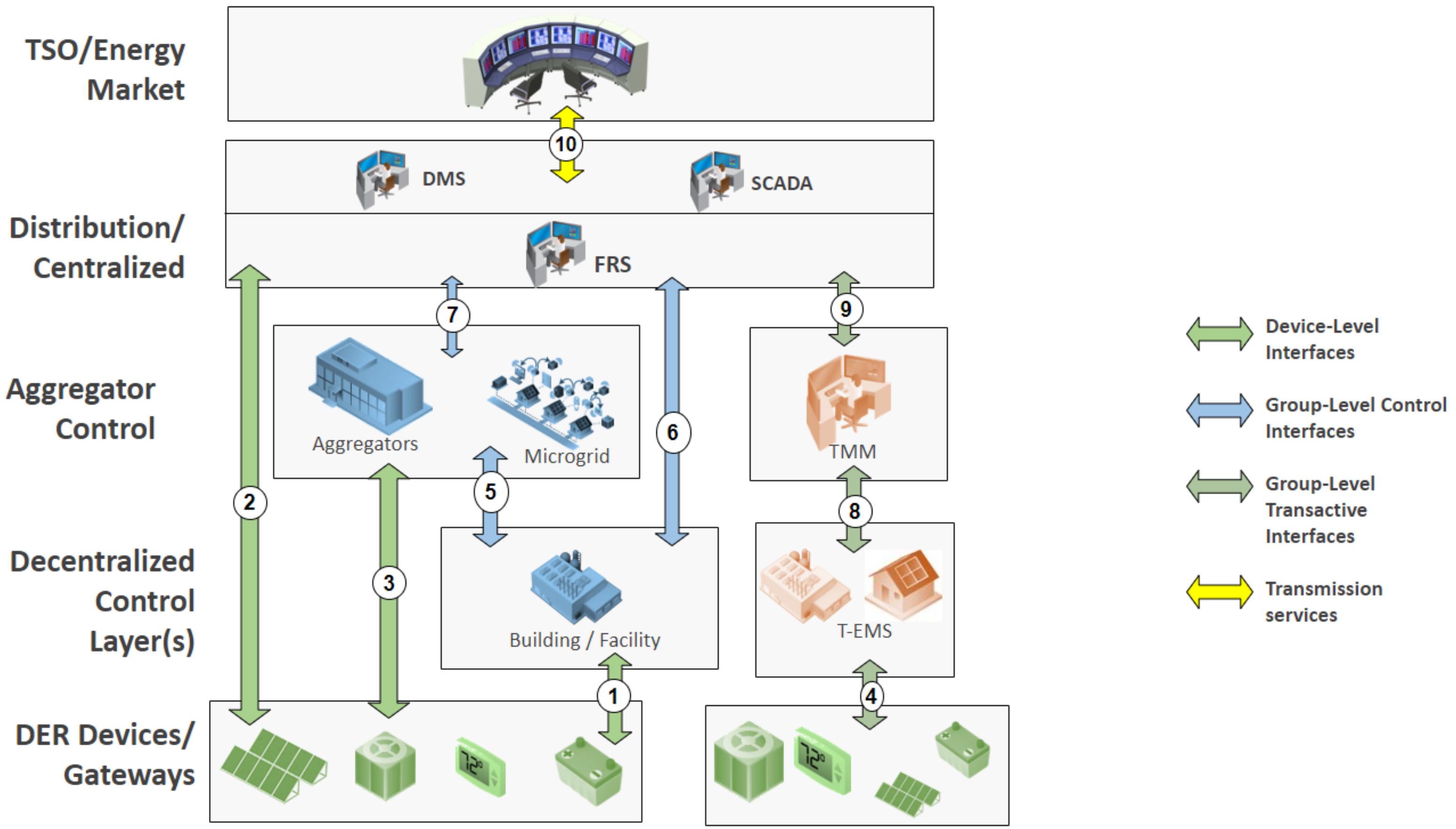


FAST-DERMS Communications

Develop a communications architecture to support implementation of FAST-DERMS.

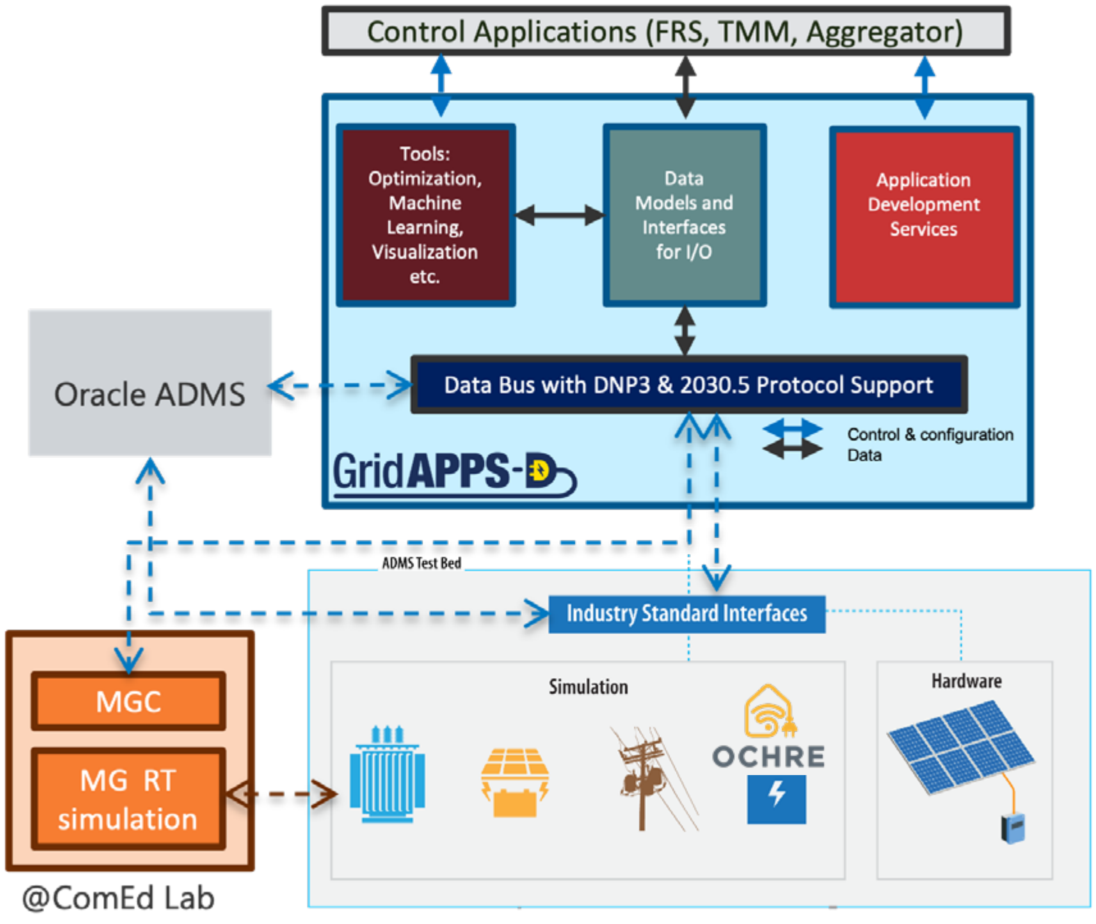
Led by the Electric Power Research Institute (EPRI).

- Complex communication landscape across multiple layers
- Standards-based
- Interoperable.



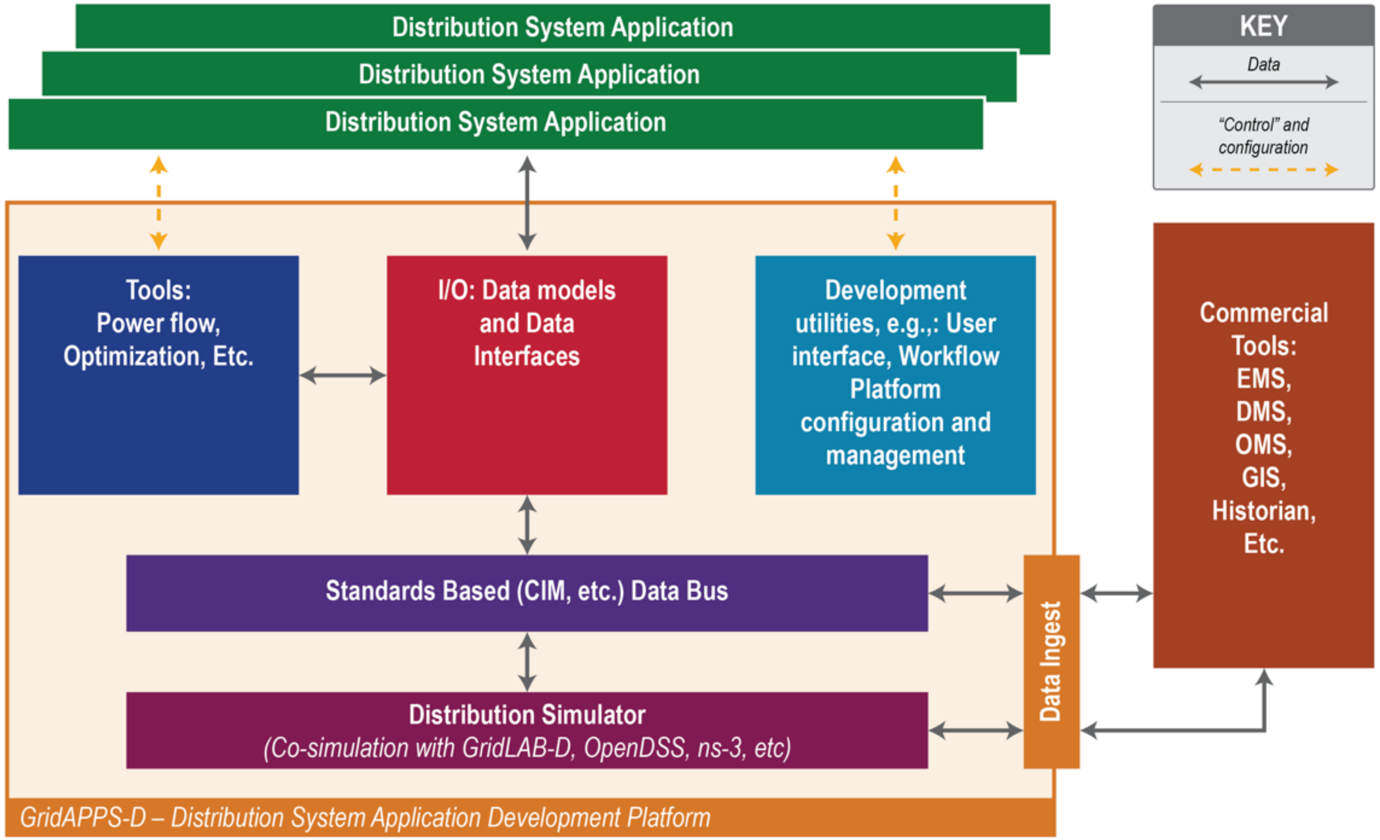
Laboratory Demonstration

- Demonstrate reference controls in a realistic laboratory setting.
- NREL's ADMS Test Bed emulates the utility environment
  - Co-simulation with Bronzeville microgrid at ComEd.
- FAST-DERMS controls are implemented as applications on PNNL's open-source GridAPPS-D platform.
- Integrated with Oracle ADMS.
- Demonstration use case: wholesale electricity market participation with high afternoon prices.



GridAPPS-D Overview

- An open-source platform for ADMS application development
- Built-in distribution simulator, co-simulation, and common services for developers and applications
- Can integrate with external software systems using standard communications (e.g., DNP3).



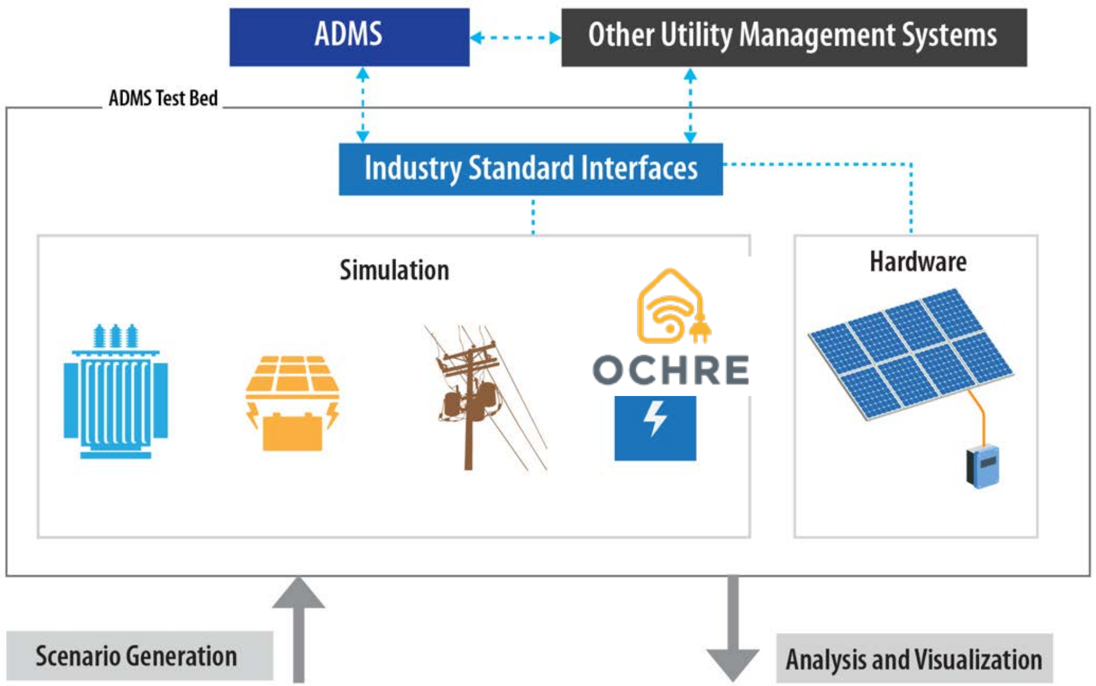
ADMS Test Bed

Goal: Accelerate industry adoption of ADMS to:

- Improve normal operations with high levels of distributed energy resources (DERs).
- Improve resilience and reliability.

Approach: Partner with utilities and vendors to evaluate specific use cases and applications to:

- Set up a realistic laboratory environment.
- Simulate real distribution systems and buildings using NREL's OCHRE tool.
- Integrate distribution system hardware.
- Use industry-standard communications.
- Create advanced visualization capabilities.



https://www.nrel.gov/grid/advanced-distribution-management.html

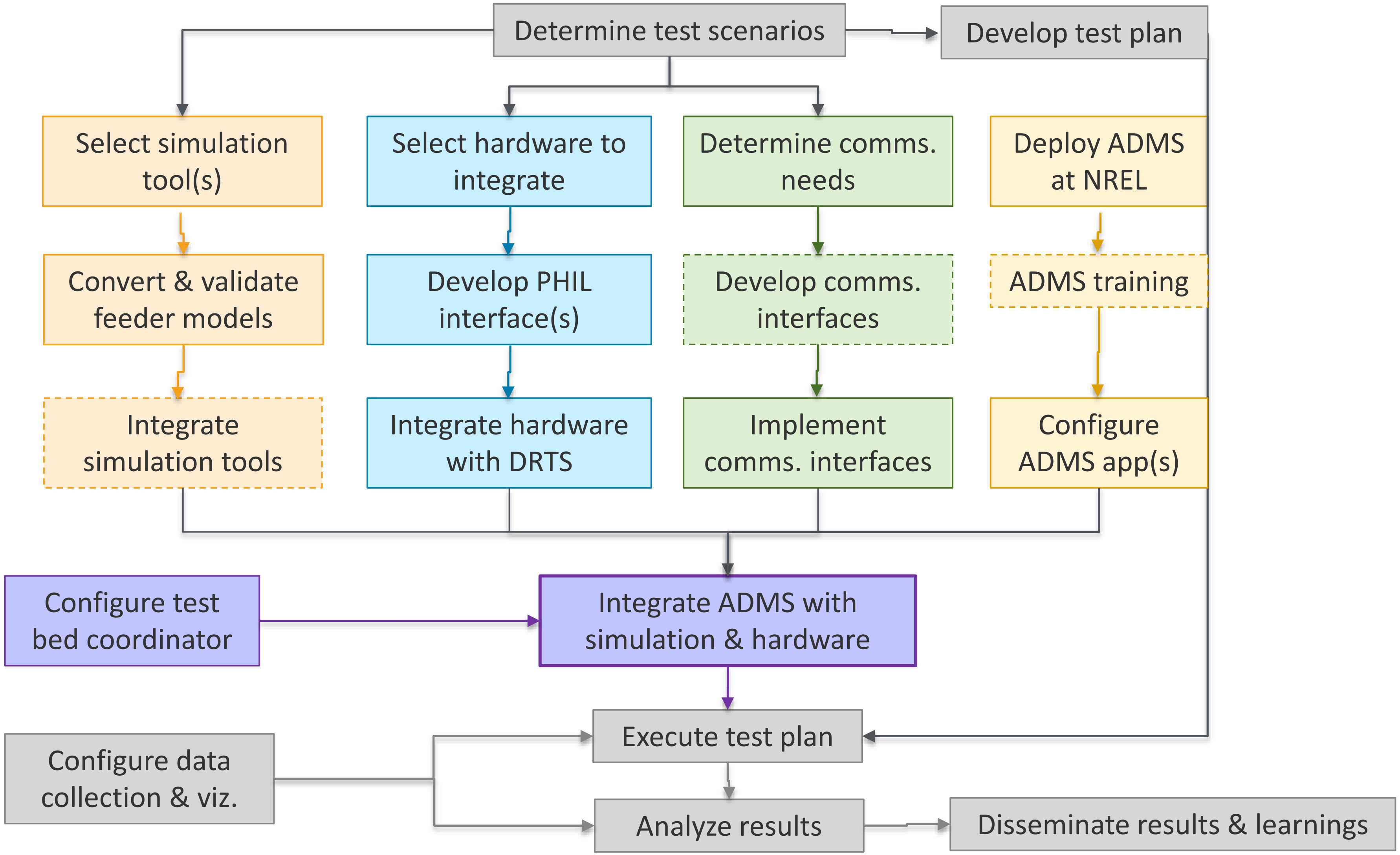
https://www.nrel.gov/grid/ochre.html

ADMS Test Bed
Use Case Development

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

	Utility	NREL	Vendor
❶ Define question	Determine question/ challenge to address →	Define use case	← Identify value proposition
❷ Create test to answer question		Define test plan	← Provide equipment capabilities
❸ Run test	Provide field data (models, load data) →	Configure test bed and execute test plan	← Provide technical support
❹ Get answer to question	Improve operations, reduce costs, gain new insights ←	Results analysis	→ Product performance insights

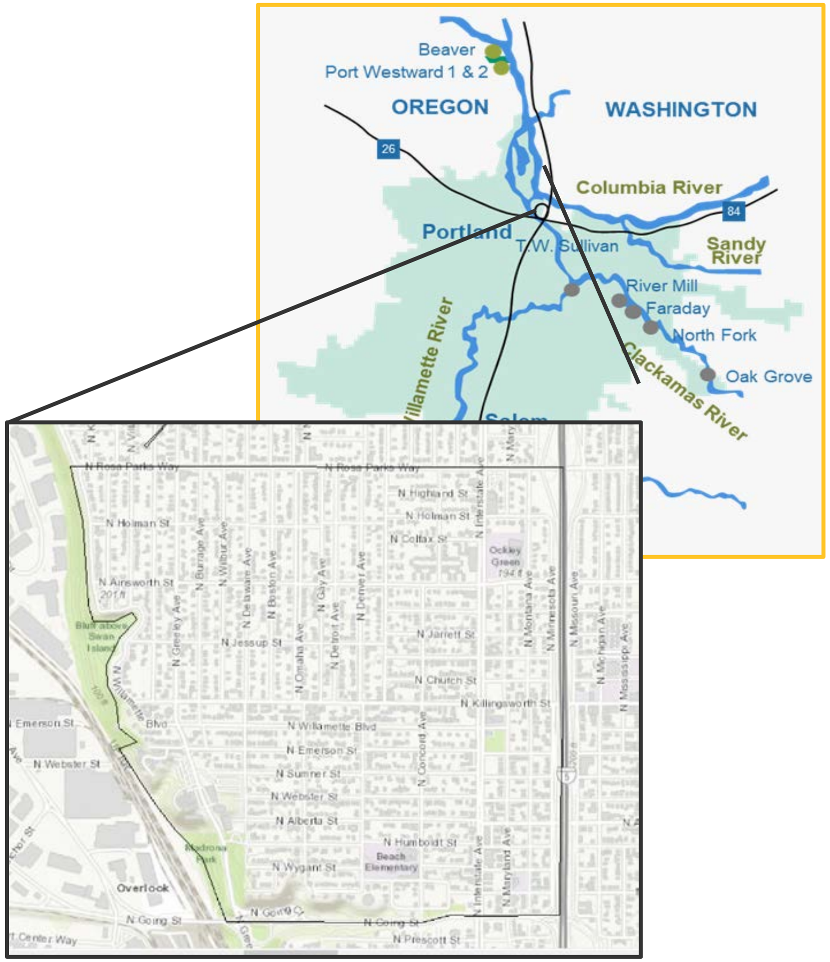
Configuring the Test Bed



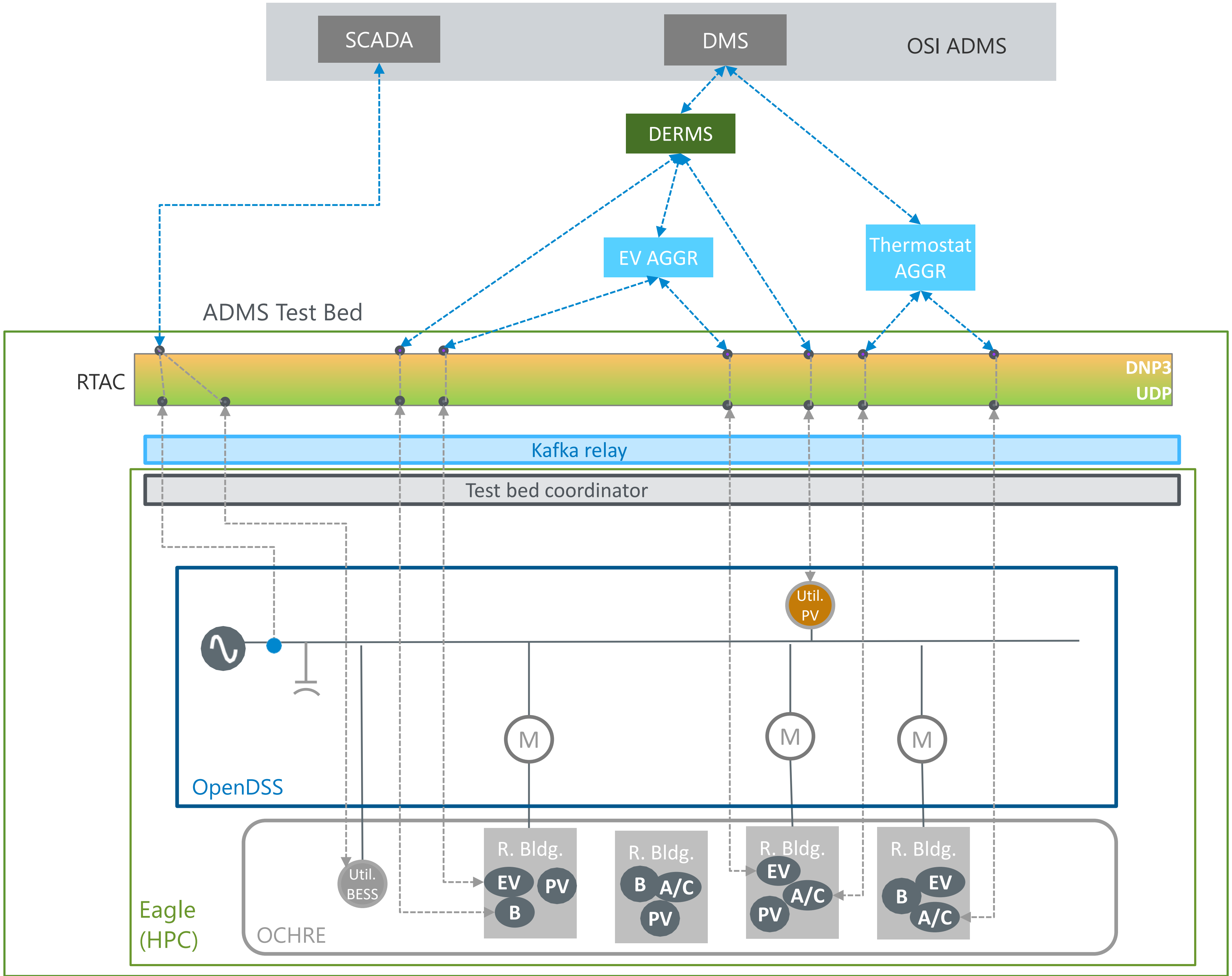
Smart Grid Test Bed Collaboration

SmartGrid Asset Load Management & Optimized Neighborhood (SALMON)

- 5-year timeline (June 2022–June 2027)
- $11.667M budget ($6.65M federal*, $5.017M match)
- Retrofit 580 of 2,800 buildings (~21%)
- Build 1.4 MW flexible load resource
- 10% efficiency improvement across treated buildings.



*Funded by U.S. DOE through the Connected Communities program.

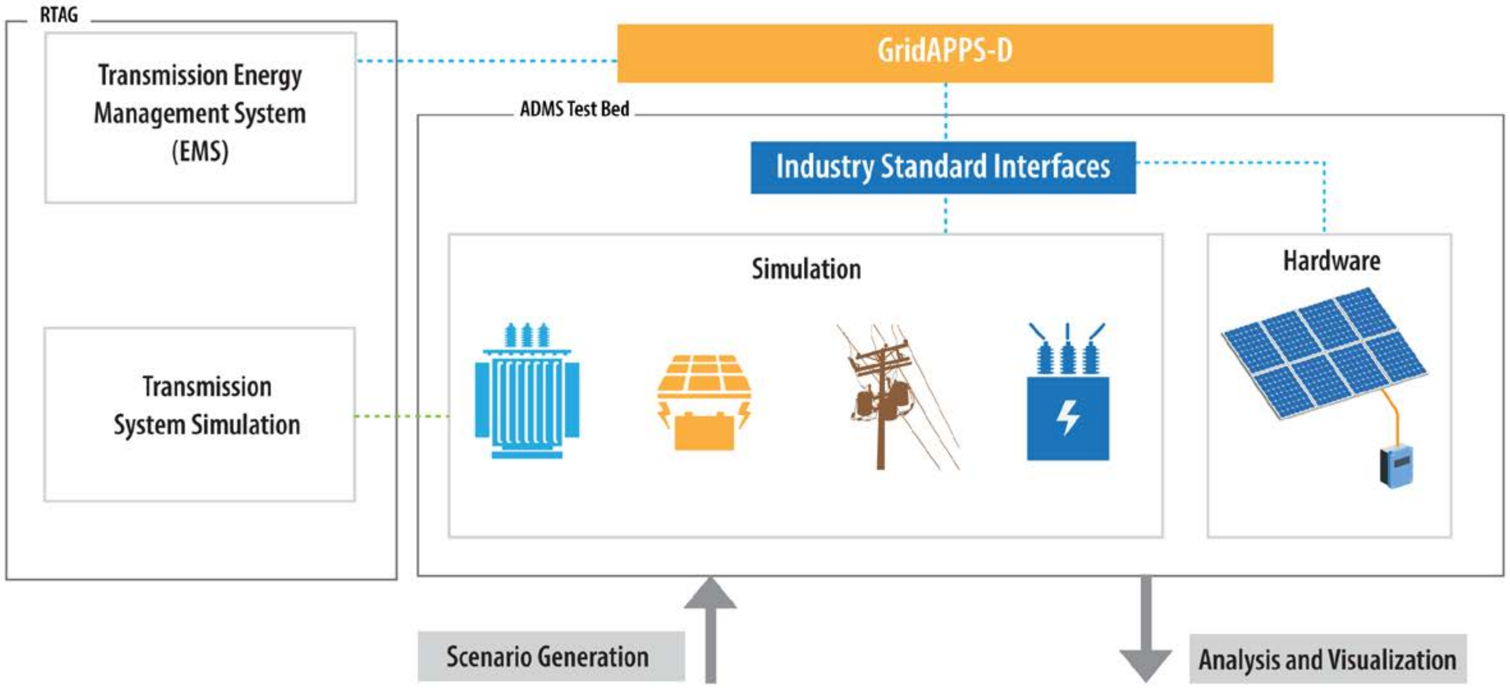


>4,000 houses modeled with NREL's OCHRE

DER Control Strategies for T&D Grid Services Use Case

<u>Objective:</u> Evaluate and demonstrate DER control strategies to provide grid services at the transmission level.

- Validate the effectiveness of DERs in providing transmission grid services.
- Evaluate the impacts on distribution grid operation.
- Demonstrate T&D co-simulation capability.



<u>Partner</u>: Xcel Energy

RTAG
Transmission System Simulation

ARIES (Advanced Research on Integrated Energy Systems)

- Control Center operation

ARIES

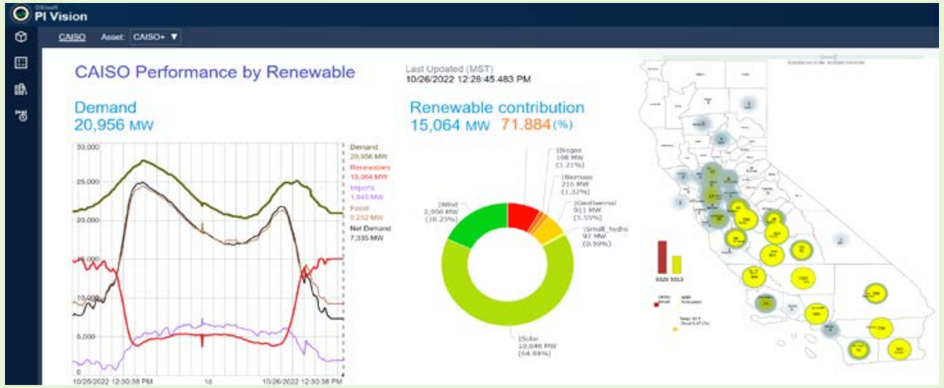
RTAG

ADMS Test Bed (R&D)

- T-D integration
- Co-simulation

HELICS | Historian | AI/ML

PSS®E | PowerWorld | PowerTech



NREL AWS Private Cloud (External Collaboration)

- North American Energy Resilience Model (NAERM)
- National Transmission Planning (NTP)

Control Room of the Future Tool

Digital Twin, AI/ML, resiliency, cybersecurity, etc.

Dispatcher Training Simulator (DTS)

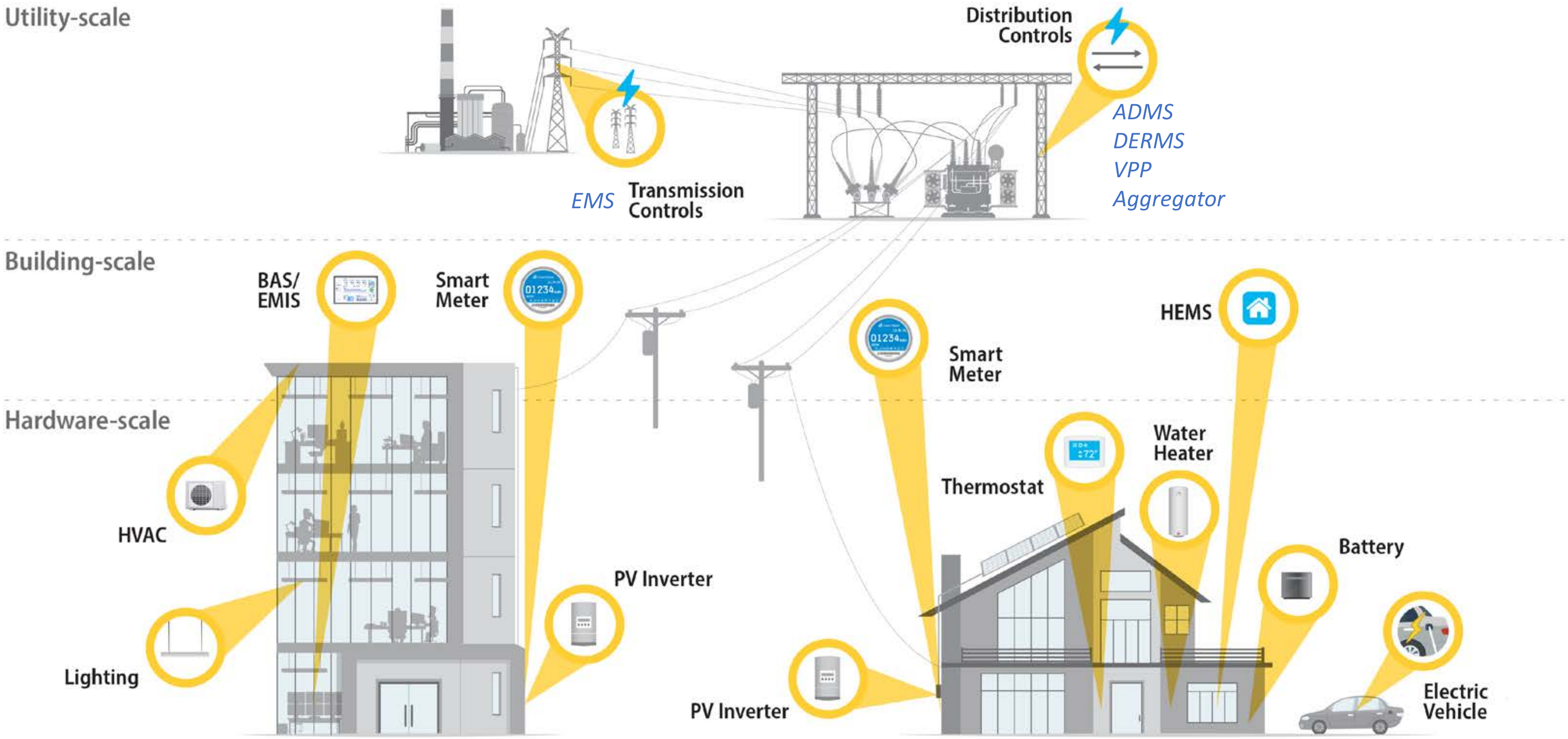
Simulation vs. replay

Power flow, prime movers, protective relays and events processor, etc.

Production-Grade Operational Models

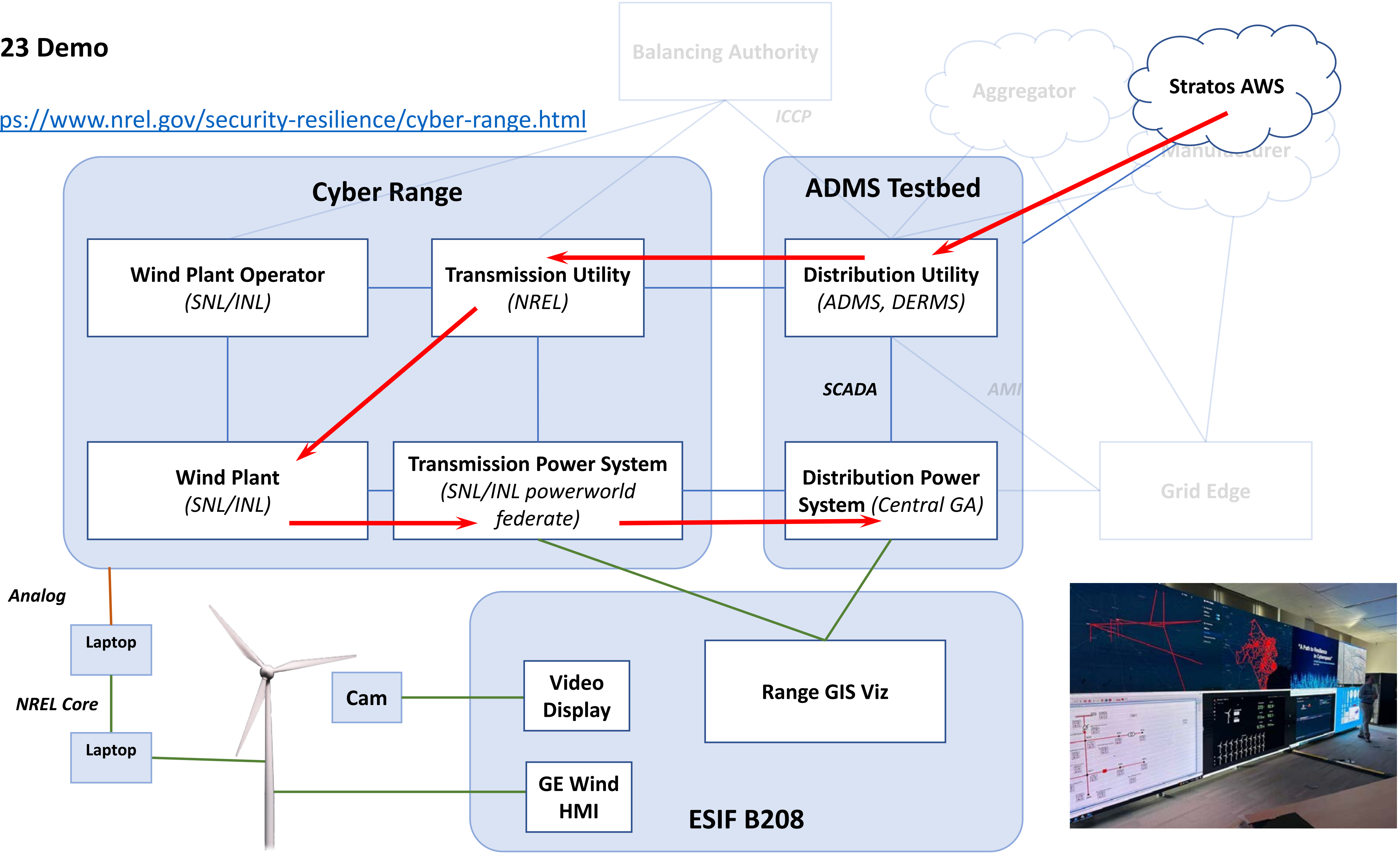
Covers the entire Western Interconnection (WI).

Building Controls Integration



2023 Demo

https://www.nrel.gov/security-resilience/cyber-range.html



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Thank You!

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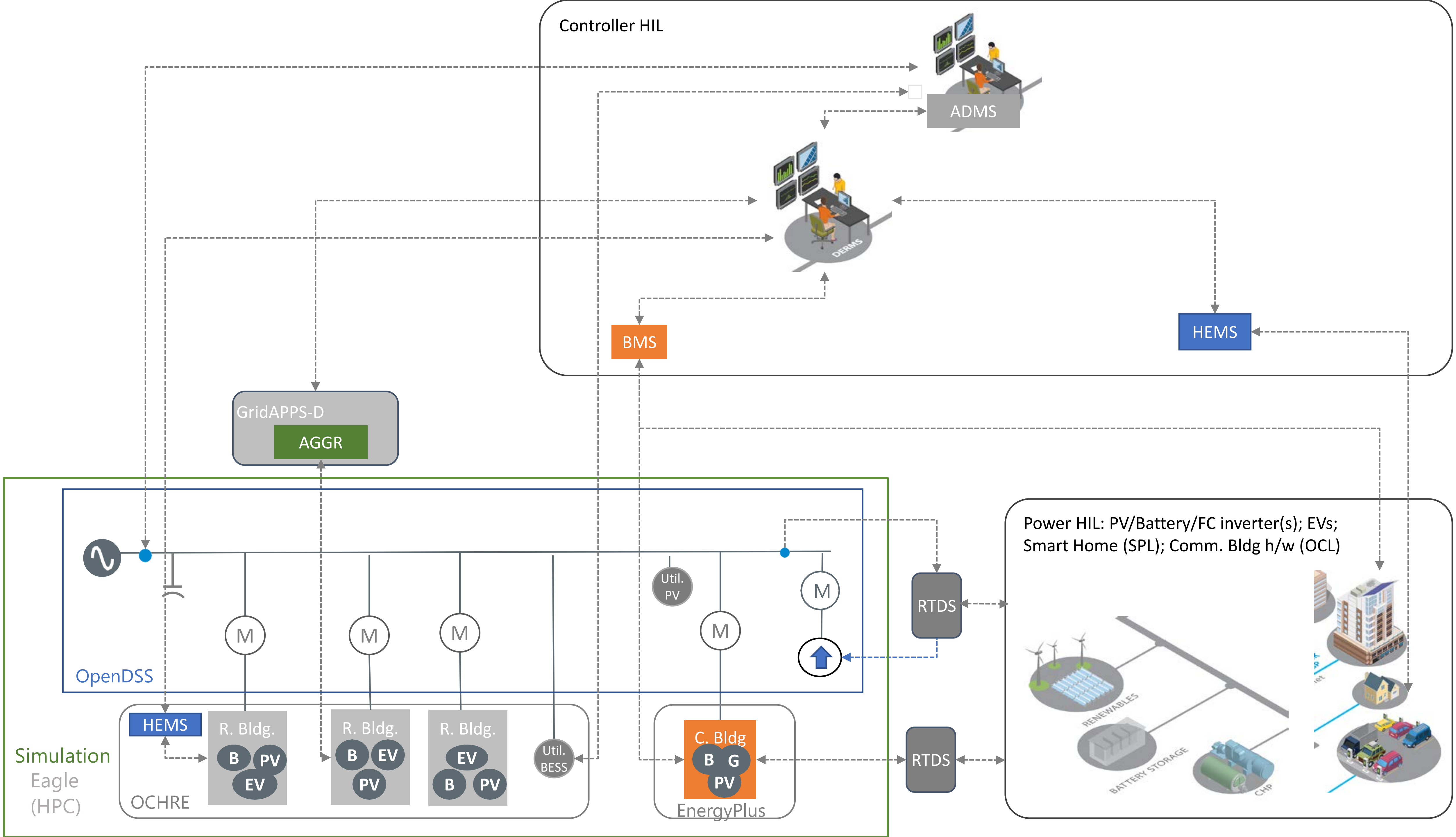
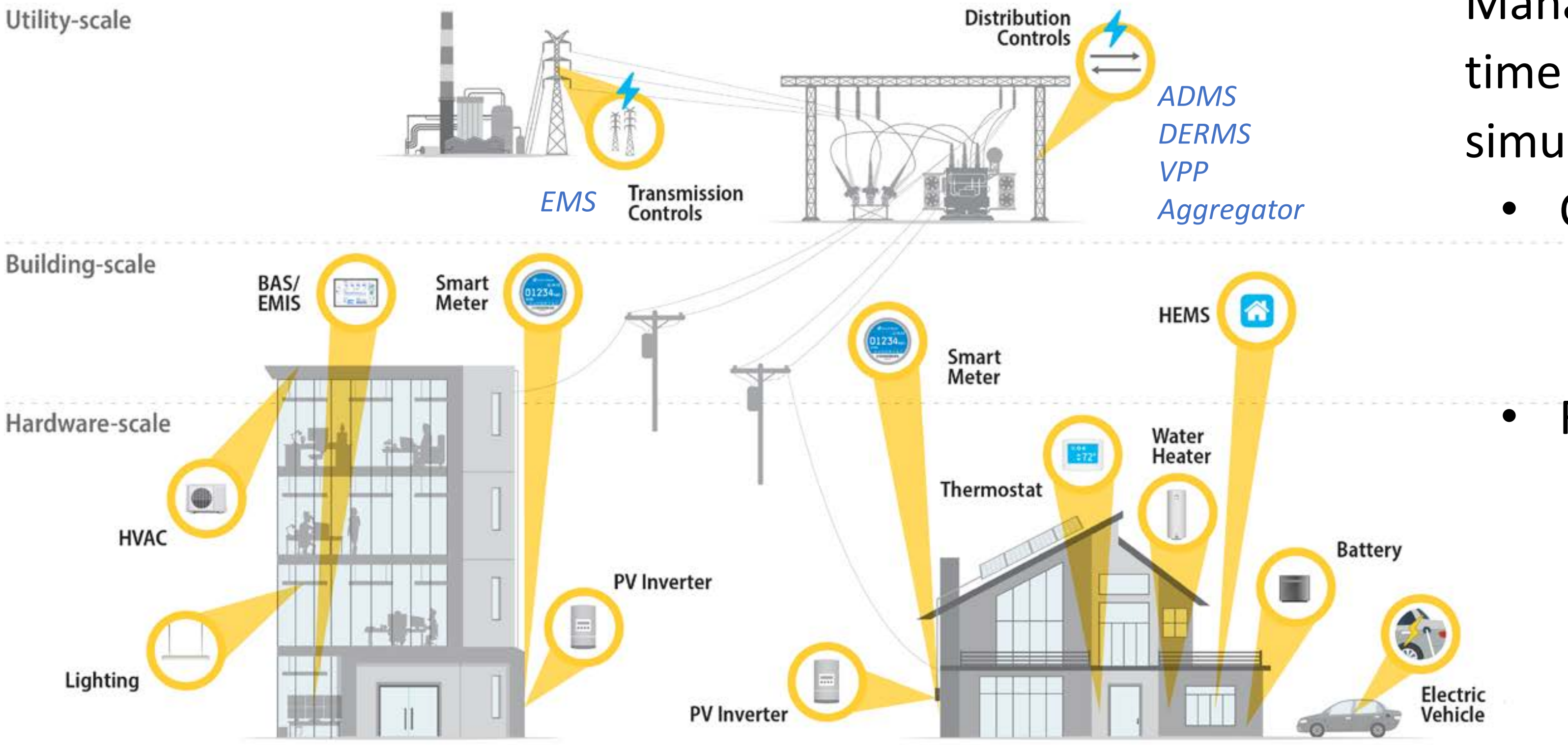

Controller HIL
ADMS
DERMS
BMS
HEMS
GridAPPS-D
AGGR
Power HIL: PV/Battery/FC inverter(s); EVs;
Smart Home (SPL); Comm. Bldg h/w (OCL)
RTDS
RTDS
RENEWABLES
BATTERY STORAGE
CHP
Util.
PV
M
M
M
M
M
M
OpenDSS
HEMS
R. Bldg.
B
PV
EV
R. Bldg.
B
EV
PV
R. Bldg.
EV
B
PV
Util.
BESS
OCHRE
C. Bldg
B
G
PV
EnergyPlus
Simulation
Eagle
(HPC)

CoPPER at NREL

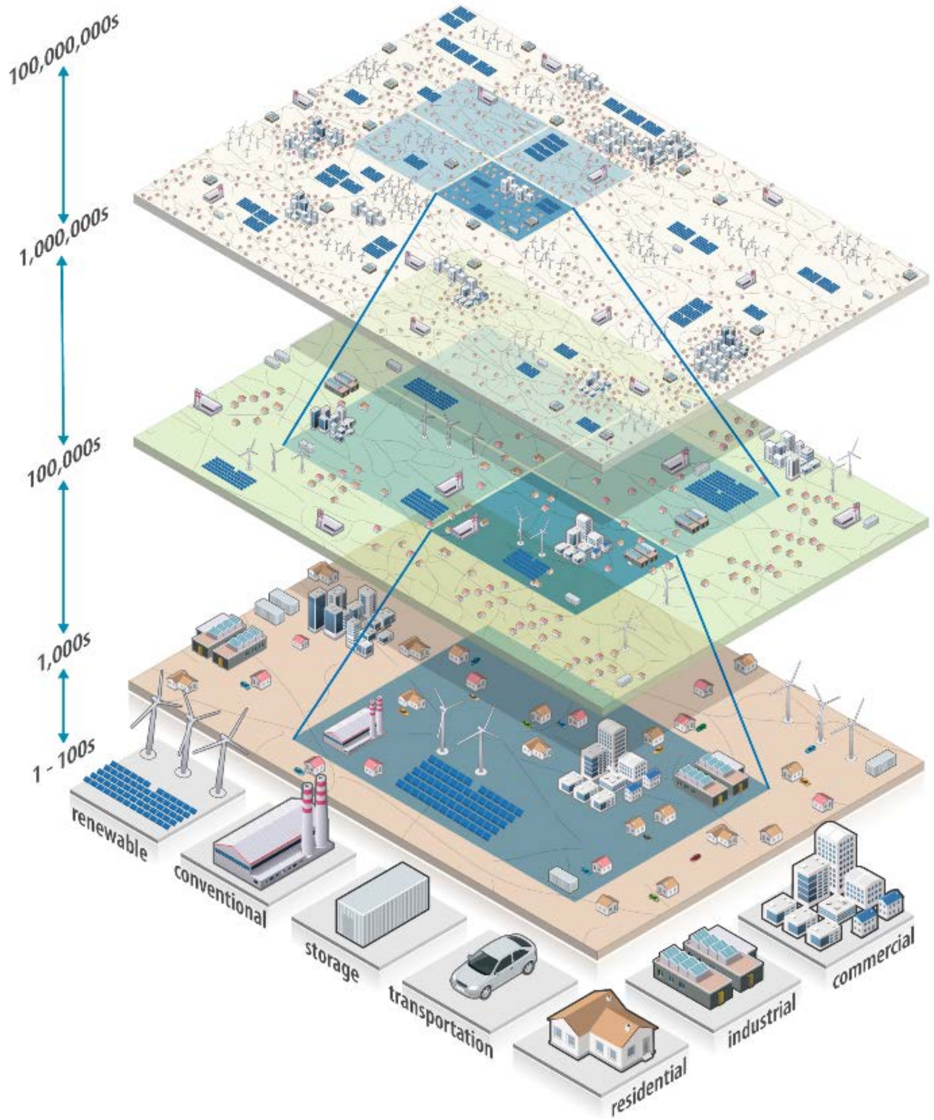
Example projects and partners:
- ADMS network model quality impact on VVO
  - Xcel Energy/Schneider Electric
- Peak load management with ADMS and DERMS
  - Holy Cross Energy/Survalent
- DER controls strategies for T&D grid services
  - Xcel Energy + GridAPPS-D.



Opportunity to integrate with SPL and CBRI.

ESIF's Grid Integration Capabilities:
- Offers end-to-end control evaluation
- Transmission level = Real-Time Analytics for Bulk Grid **(RTAG)**: real-time transmission simulation with GE's energy management system (EMS)
- Distribution level = Advanced Distribution Management System **(ADMS) Test Bed**: real-time distribution system and building co-simulation
  - Commercial ADMS and/or DERMS
    - GE, SE, OSI, Survalent ADMS
    - Upcoming SGS.
  - Research controls and platforms
    - FAST-DERMS reference controls on GridAPPS-D
    - NREL aggregator in Python
    - foresee HEMS.

Key Features of AES: A New Operation Paradigm



- Deconstructs large-scale, centralized control and operations into smaller decisions via **hierarchical and distributed intelligence**.
- **Real-time operations** to balance demand and generation every second with optimized controls.
- **Robust tolerance** to disturbances, faults, outages, and failures in cyber and physical networks.
- **Interoperability** with the integration of decisions, devices, platforms, and data with the aid of standard-based protocols.
- **Scalability** to control millions of distributed generation points and billions of buildings, vehicles, and more.