NREL Transforming ENERGY

Power Electronic Grid Interface (PEGI) Platform Workshop

October 13, 2020

Presentation will begin shortly

Meeting Reminders

- All participants are muted upon entry, but we want to hear from you – please raise your hand and/or identify yourself via chat if you'd like to make a comment or ask a question
- You are welcome to have your camera on for today's conversation.

Workshop Attendee Engagement

https://pollev.com/nrelwebinars303
or text NRELWEBINARS303 to 22333

- Polling will be done via Poll Everywhere
- Please open this page (or text) to provide valuable input throughout the day

First question: How do you take your morning coffee?

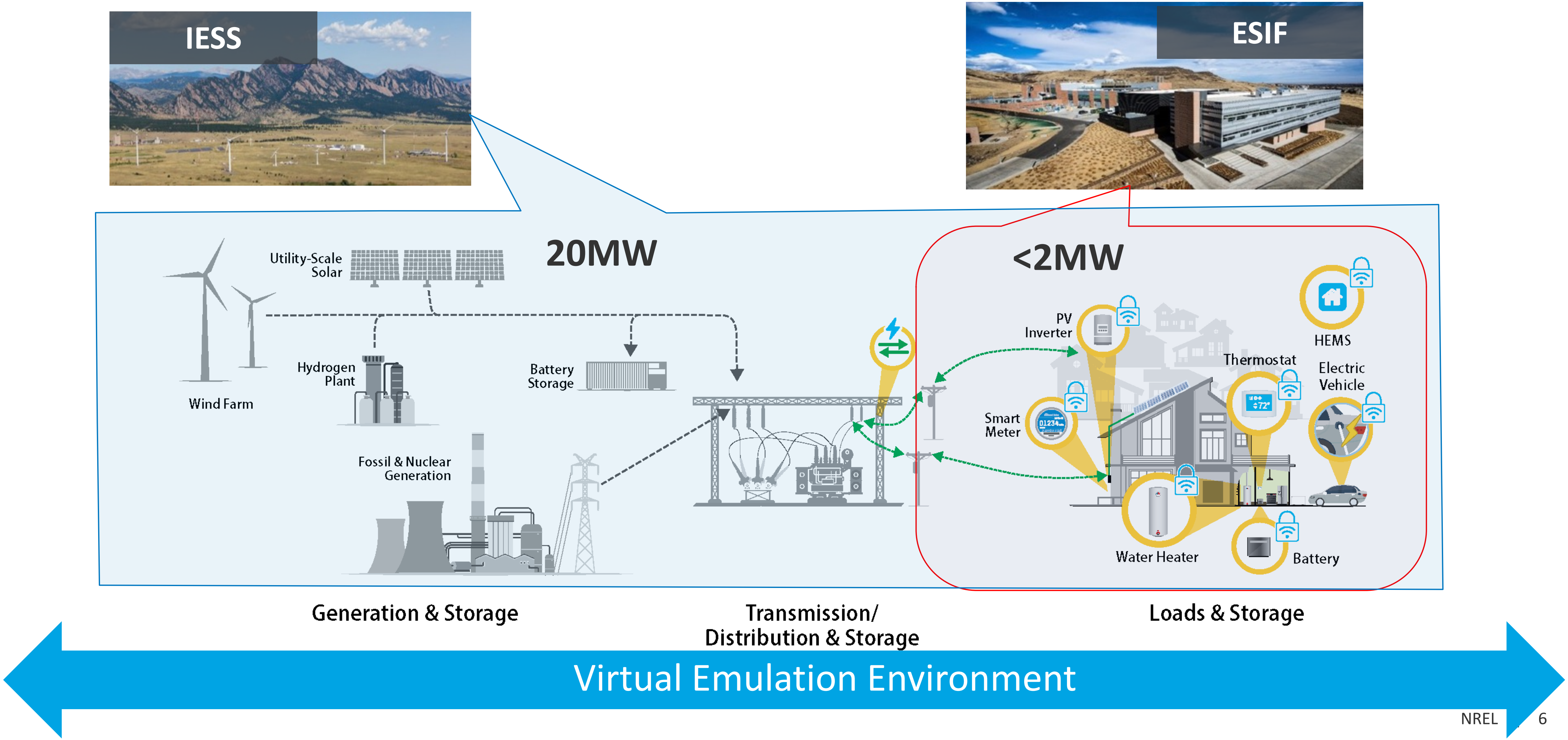
ARIES and PEGI Platform– Overview and Background

ARIES

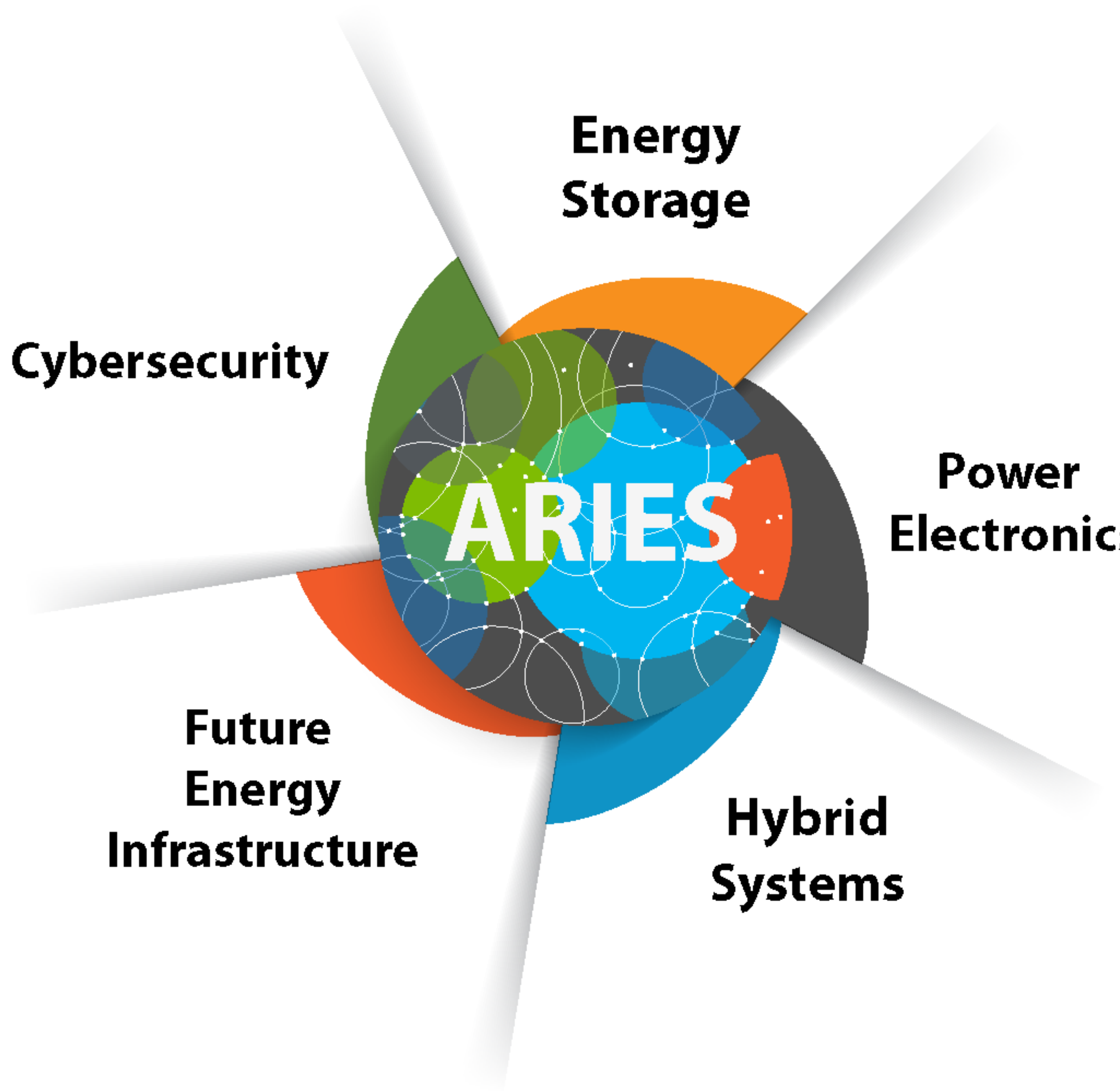
Advanced Research on Integrated Energy Systems (ARIES) is a research platform designed to de-risk, optimize, and secure current energy systems and to provide insight into the design and operation of future energy systems. It addresses the fundamental challenges of:

- Variability in the **physical size** of new energy technologies being added to energy system
- Controlling **large numbers** (millions to tens of millions) of interconnected devices
- Integrating **multiple diverse technologies** that have not previously worked together

ARIES Research Platform - Scale



ARIES Research Areas



ARIES NREL Team

Point of Contact:
Jen Kurtz

Leadership

- Peter Green, Deputy Laboratory Director – Science & Technology
- Johney Green, *Associate Laboratory Director, Mechanical and Thermal Engineering Sciences*
- Juan Torres, *Associate Laboratory Director, Energy Systems Integration*
- Jennifer Kurtz, *Chief Research Engineer, Mechanical and Thermal Engineering Sciences*

Energy Storage

- John Farrell, *Laboratory Program Manager, Vehicle Technologies*
- Jennifer Kurtz, *Chief Research Engineer, Mechanical and Thermal Engineering Sciences*
- Andrew Hudgins, *Project Manager, Energy Systems Integration*

Hybrid Energy Systems

- Rob Hovsapian, *Research Advisor, Energy Systems Integration*
- Ben Kroposki, *Director, Power Systems Engineering Center*

Future Energy Infrastructure

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- Murali Baggu, Laboratory Program Manager, Grid Integration
- Vahan Gevorgian, Chief Engineer, Power Systems Engineering
- Ben Kroposki, *Director, Power Systems Engineering Center*
- Rich Tusing, *Chief Researcher, Architectural Engineering*

Power Electronics

- Barry Mather, *Group Manager, Integrated Devices & Systems*

Cybersecurity

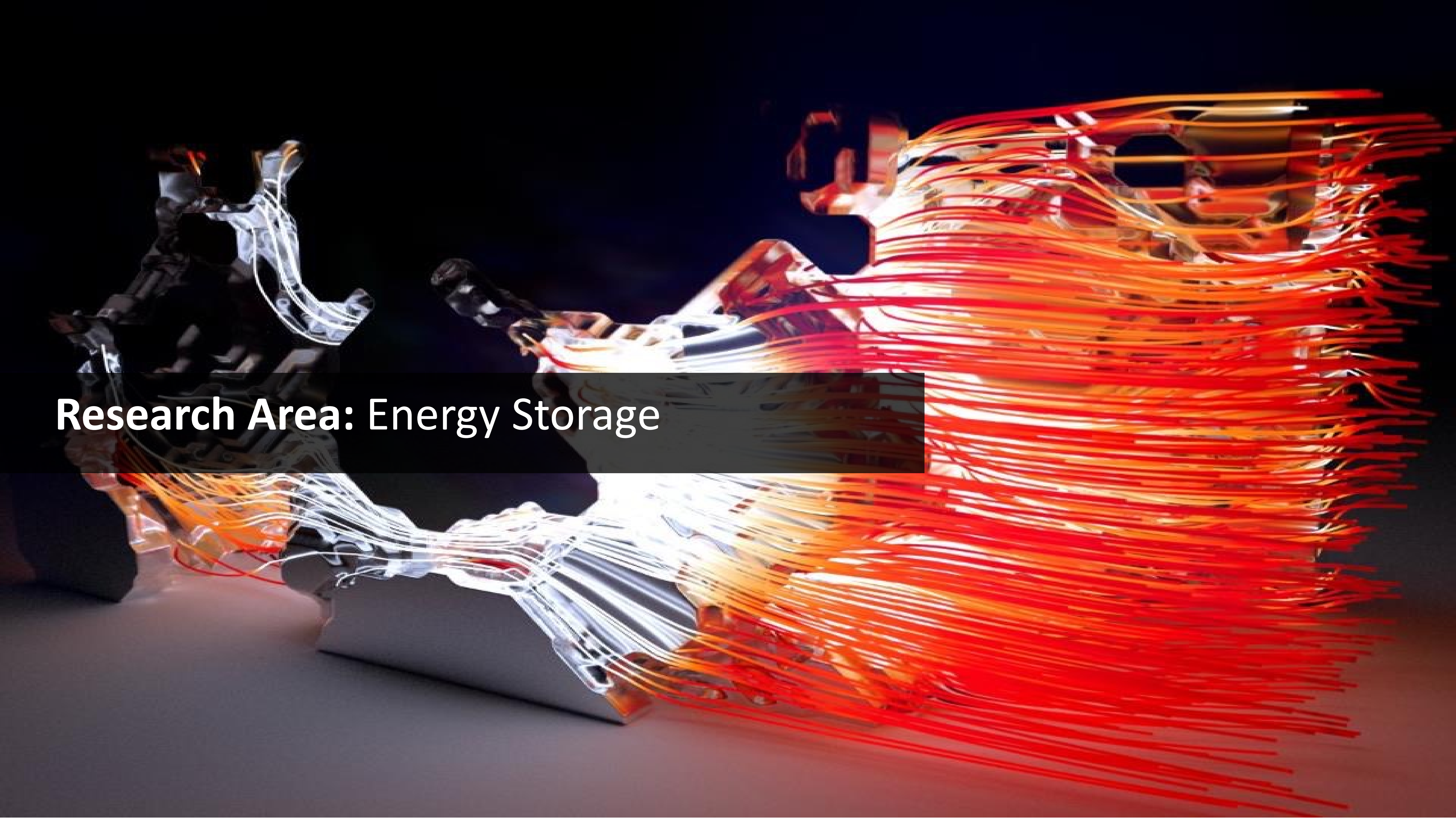
- Jonathan White, *Group Manager, Cyber-Physical Systems Security*
- Maurice Martin, *Senior Researcher, Cyber Security & Resilience*

RFI

- Martha Symko-Davies*, Laboratory Program Manager, Energy Systems Integration*

External Advisor

Gary Smyth, *External Advisor, Retired Executive Director of General Motors Global Research & Development*



Research Area: Energy Storage

Energy Storage Overview

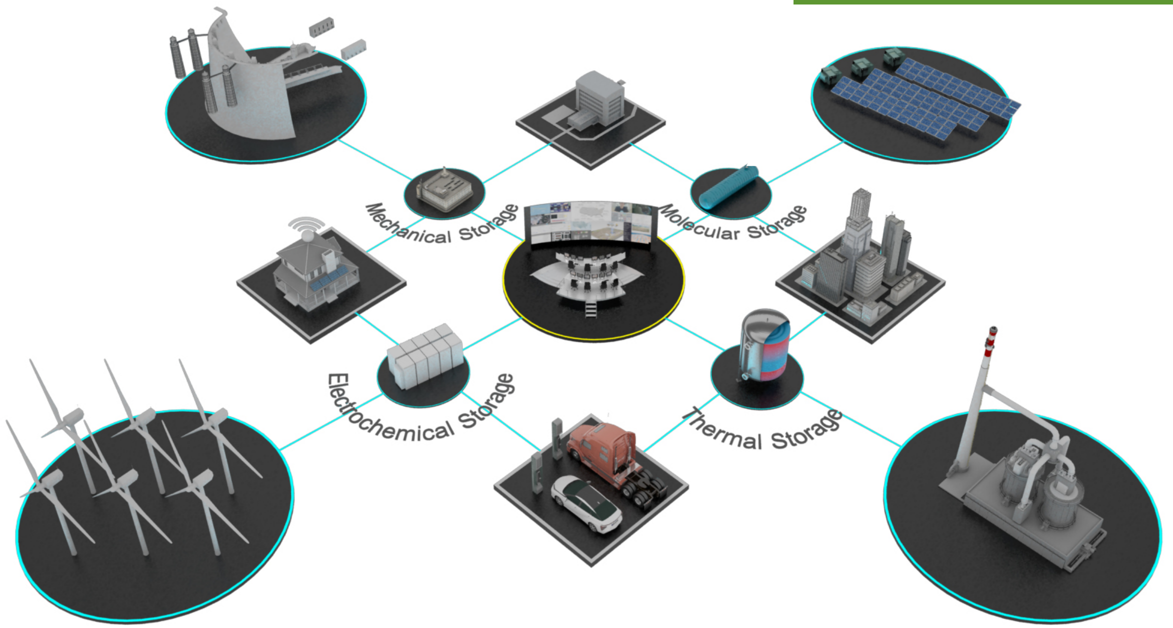
Advanced energy storage is essential to meeting Americas most critical energy needs.

ARIES research on integrated energy storage systems at-scale will accelerate technologies focused on:

- Electric grid modernization, reliability, and resilience
- Sustainable mobility
- Flexibility for a diverse and secure, all-of-the-above electricity generation portfolio
- Enhanced economic competitiveness for remote communities and targeted micro-grid solutions.

Fundamental ARIES Challenge:

- Variability in the **physical size** of new energy technologies
- Controlling **large numbers** of interconnected devices
- Integrating **diverse technologies** that have not previously worked together



Core Challenges This Research Area Addresses

Identify clean, resilient, at-scale, integrated, and cost-effective storage solutions that:

Facilitating Evolving Grid
Maintain and enhance the provision of electricity services to end users as the grid increases in complexity and diversity

Serving Remote Communities
Provide remote communities with electricity for critical and beneficial public services

Electrified Mobility
Facilitate a large-scale adoption of electric vehicles while maximizing beneficial coordination with the power grid

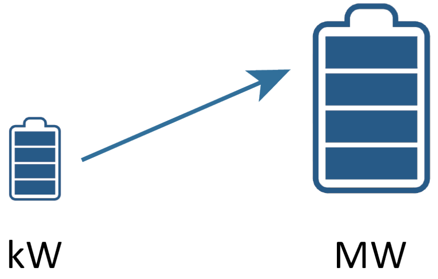
Interdependent Network Infrastructure
Sustain and enhance normal operations amidst short term disruptions of energy inputs

Critical Service Resilience
Maintain critical services for a sufficient duration following extended power outages.

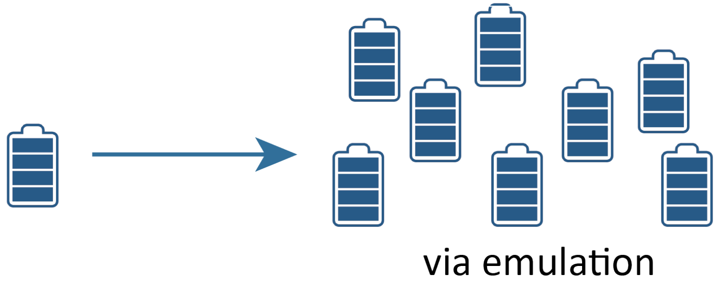
Facility Flexibility, Efficiency, and Value Enhancement
Maximize the total value obtained from the process of interest.

Research Scope

Challenge 1: Variability in the physical size of new energy technologies



Challenge 2: Controlling large numbers of interconnected devices



Challenge 3: Integrating multiple diverse technologies that have not previously worked together

Electrochemical Storage
- o Li-ion batteries
- o Flow battery
- o Ultracapacitor

Molecular Storage
- o Hydrogen
- o Methane
- o Carbon-neutral renewable fuels

Thermal Storage
- o Hot particle
- o Molten salt
- o Phase change
- o Reservoir

Mechanical Storage
- o Flywheel
- o Compressed Air
- o Pumped Hydro

Flexible Loads
- o Buildings

Research Area: Hybrid Energy Systems

Research Area Overview – Hybrid Energy Systems

A hybrid energy system (HES) consists of a combination of energy generation, storage, and/or energy conversion subsystems that are managed by a single entity and integrated together via an overarching, optimization control framework to achieve enhanced capabilities, value, and/or cost savings compared to the standalone alternative.

- Can be **co-located** or virtually coupled system(s)
- Can also include energy conversion (Power-to-X) systems
- Size can be up to 20MW (ARIES Focus)

Key Priorities in This Space:

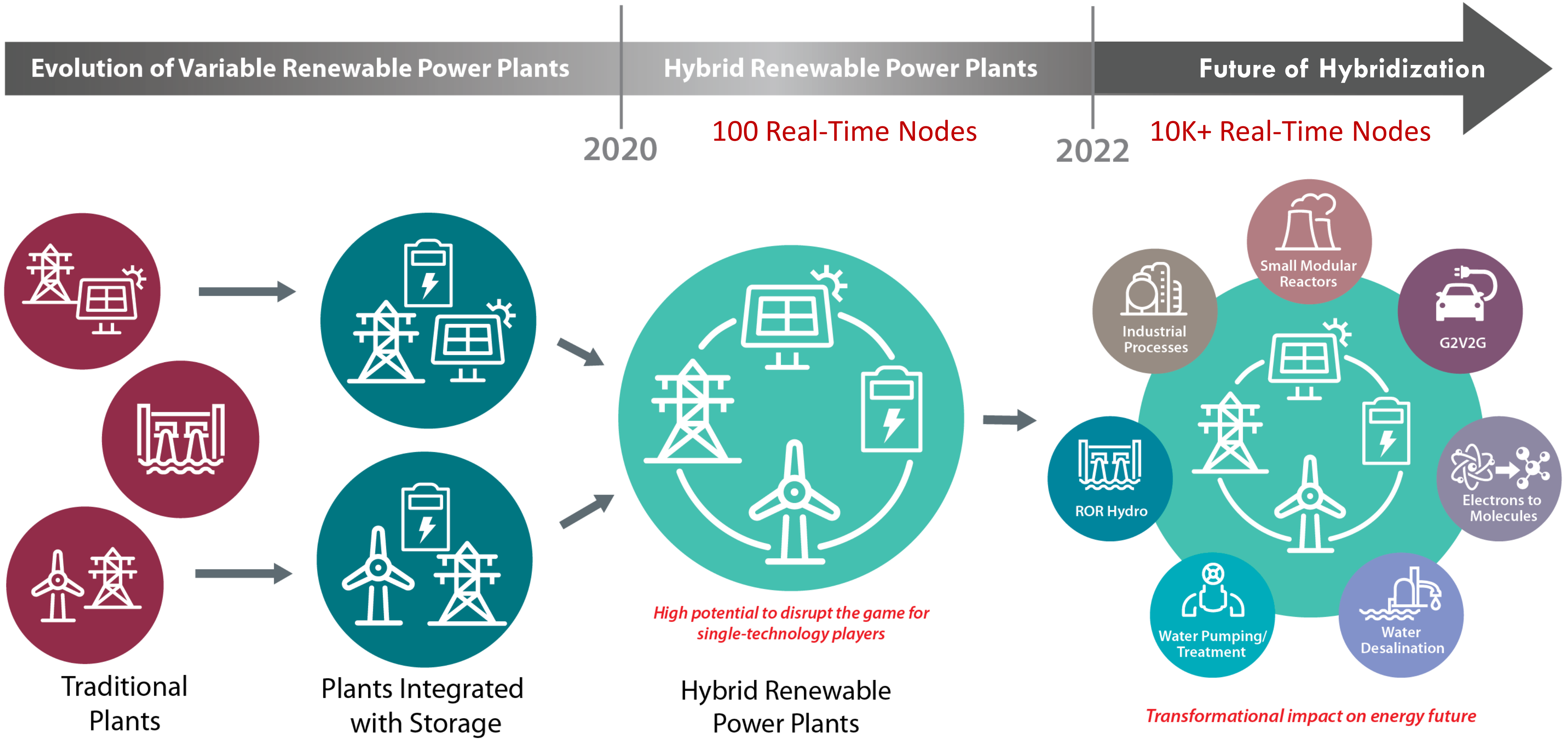
- Optimal hybridization of multi-technology energy systems under multi-timescale dynamics and interdependencies.
- Understand the effects that various parts of hybrid energy systems can cause on one another
- Quantify the benefits of such multi-technology hybrid systems in terms of **cost**, system **reliability**, and **flexibility**

Fundamental ARIES Challenge:

- ■ Variability in the **physical size** of new energy technologies
- ▲ Controlling **large numbers** of interconnected devices
- ● Integrating **diverse technologies** that have not previously worked together

Research Area Overview – Evolution of Hybridization of Energy Systems

* NODE = electrical nodes in hardware/emulation/simulation



Single Renewable Technology Players

Hybrid Technology Players

Further Hybridization with Other Technologies

Research Area: Future Energy Infrastructure

Core Challenges

Immediate Challenge:
Today's grid is reliably accommodating low levels of variable renewable energy penetration, but it's incapable of handling high levels of renewable energy. Technical issues need to be addressed:

- Advanced protection
- System-level Black Start (integration of grid-forming inverters)
- Frequency stability
- Voltage stability
- Resonances and control interactions
- Control of grid components, generation, storage, and loads at the grid edge
- Increased cyber risk with more connected technologies
- ***Increased grid resilience, reliability, and operational efficiency***

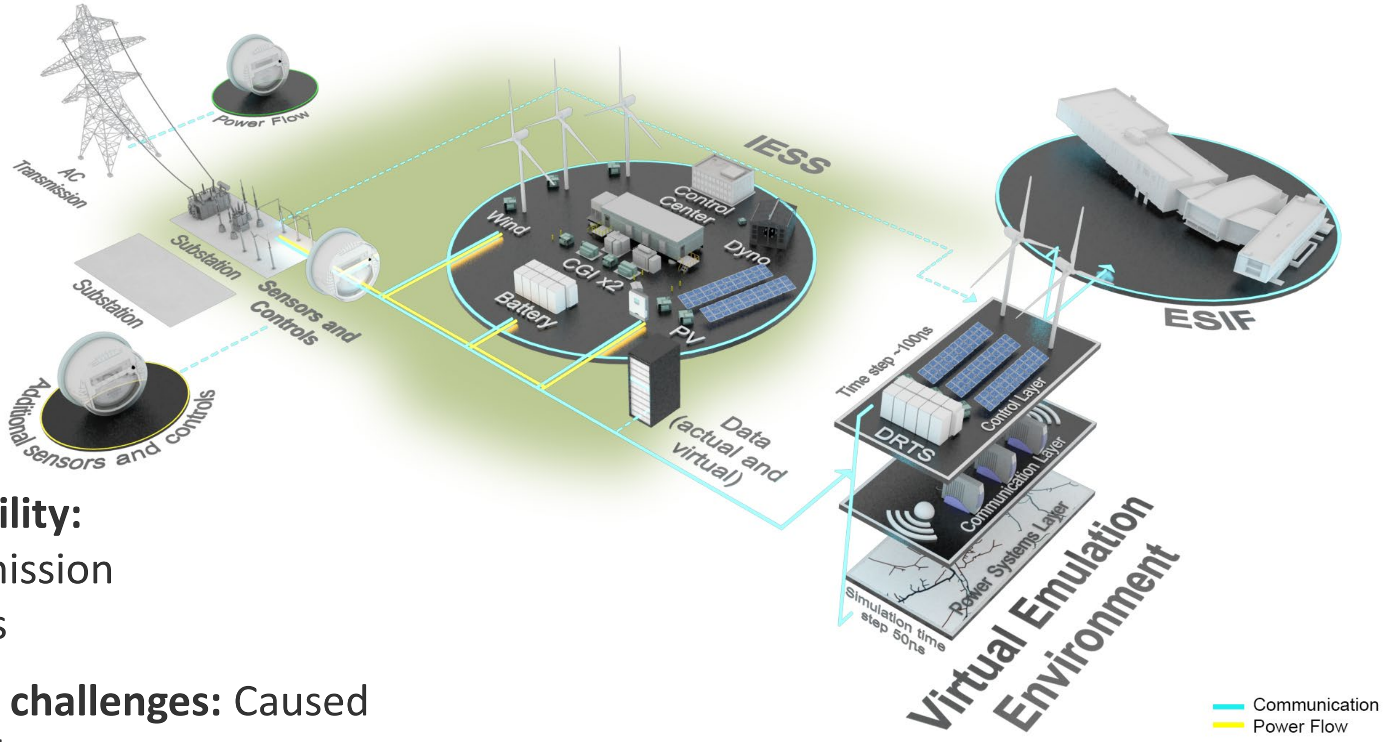
Emerging Challenge:
Merging tomorrow's grid with transportation, buildings, and industrial energy sectors.

Fundamental ARIES Challenge:

- Integrating **diverse technologies** that have not previously worked together

Example Use Cases

Use Cases that cost effectively support modern, reliable, resilient, flexible, sustainable, and secure delivery and transmission systems:



- **System Black Start:** Restarting grids with high levels of inverter-based resources (IBR)
- **Protection Systems:** Advanced techniques for High RE Grids
- **Real-time grid monitoring and management:** Integration of massive amounts of sensors into grid operations
- **Improve T&D efficiency, robustness and controllability:** Evaluate and validate future distribution and transmission equipment under controlled realistic grid conditions
- **Evaluate and develop mitigation for new reliability challenges:** Caused by interactions between synchronous and non-synchronous resource
- **MVDC Microgrids Research Platform:** Evaluate control strategies for DC grid and infrastructure components such as circuit breakers and solid-state devices for next-generation applications (locomotives, trucks, buses, ships, and airplanes)

Research Area: Cybersecurity

Research Area Overview

The modernizing grid is a "system of systems" that brings together dissimilar forms of energy generation, load management, control networks and communication platforms. In this system of systems, advances in device and network security are necessary but insufficient. **Cybersecurity research must also close the system-level security gaps that inevitably emerge when so much hardware and software are brought into harmonious operation**.

To this end, ARIES has identified three broad programs for its initial cyber research:

- **Proactive Defense and Automated Response:** Move beyond traditional cybersecurity hardening to automated detection, response, and endurance, leveraging research into **Autonomous Energy Systems**.
- **Improved Situational Awareness for Cybersecurity:** This will aid both manual responses and monitoring of automated responses during rapidly unfolding cyber events.
- **Communication Innovation, 5G and Beyond:** Connect and control consumer-owned DERs more securely than current approaches; assess operational effectiveness and security.

Fundamental ARIES Challenges:

- ■ Variability in the **physical size** of new energy technologies
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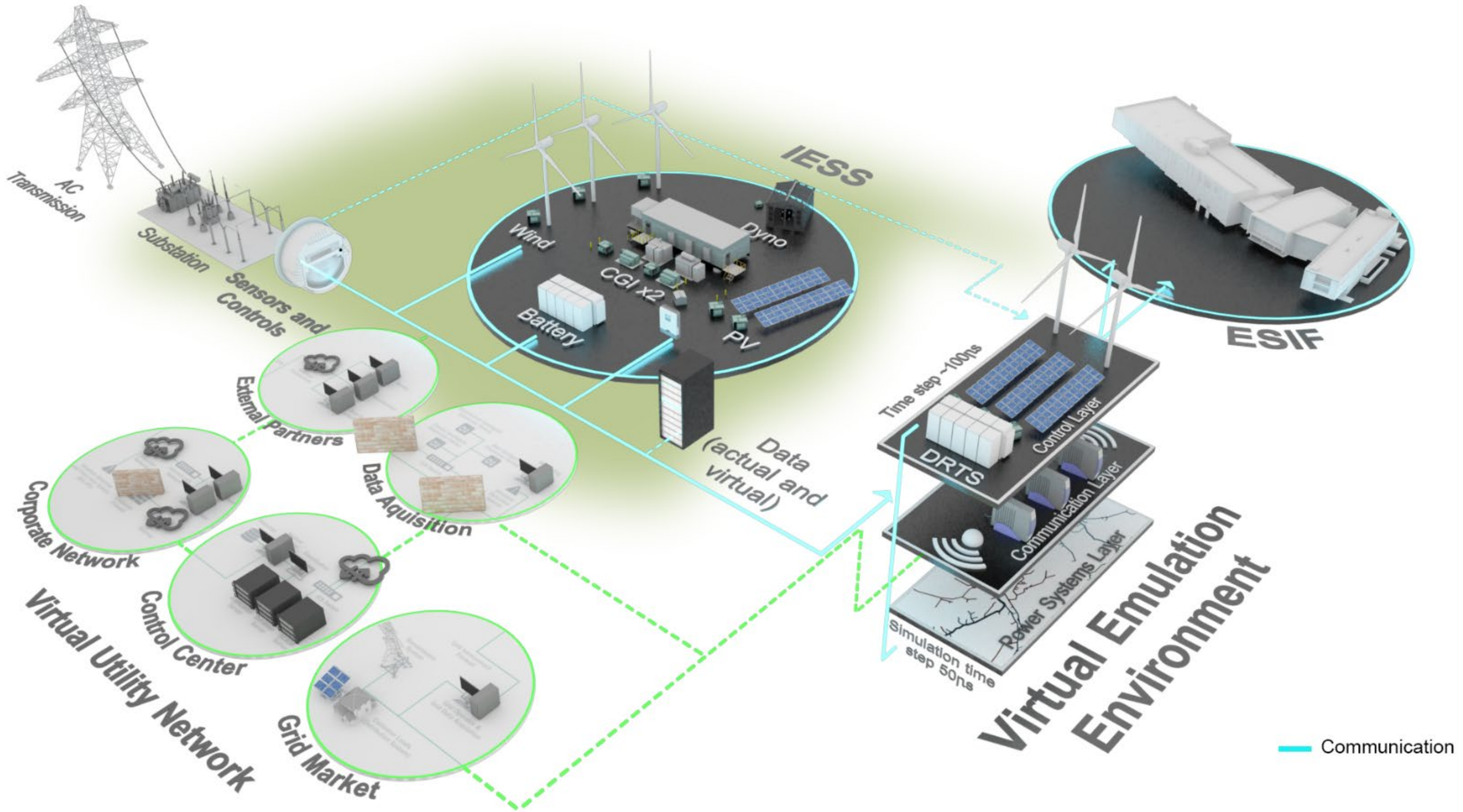


Research Area Platform

Research Area: Power Electronics

Power Electronics Research Area Overview

Power electronic-based grid interfaces are becoming the predominant way generation sources and loads connect to the power grid.

ARIES will build capabilities to:

- Address the challenges of operating grids at very high-levels of power electronic-interfaced generation and load
  - Examples: grid forming inverters, black start/protection coordinated capabilities, advanced load control/flexibility, microgrid applications
- Integrate, utilize and develop new power electronic technologies specifically for future grid applications
  - Examples: wide-bandgap (WBG) semiconductor devices, converter architectures, energy storage elements, advanced thermal management

Fundamental ARIES Challenge:

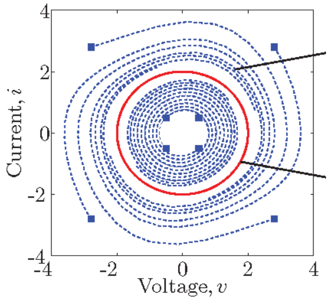
■ Variability in the **physical size** of new energy technologies

▲ Controlling **large numbers** of interconnected devices

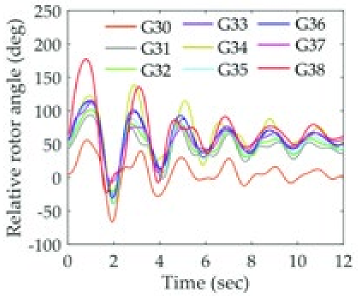
● Integrating **diverse technologies** that have not previously worked together

Power Electronics Research Area Core Challenges

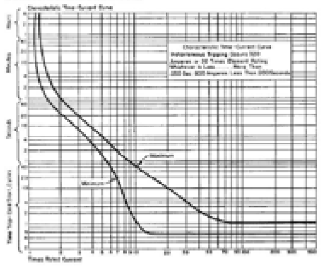
Ever higher levels of power electronics in power grids:



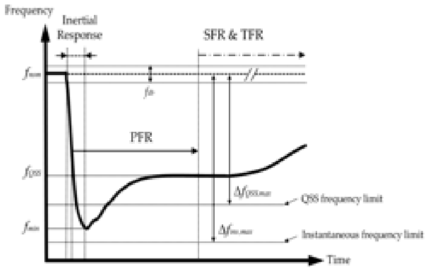
Small-signal stability



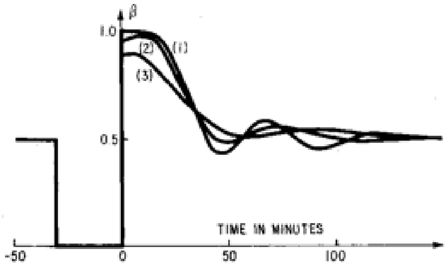
Large-signal stability



System protection

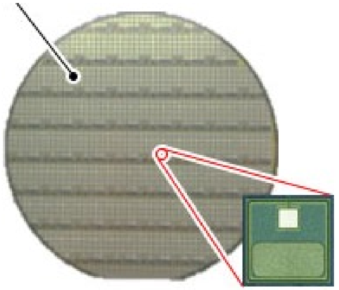


Frequency Response



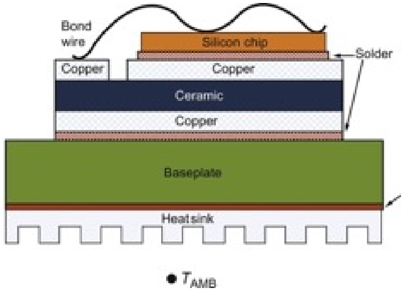
Black Start

New power electronic technologies enabling grid applications:

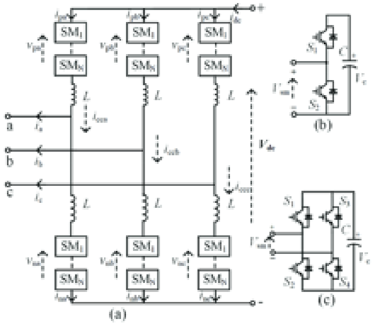


New semiconductors

Magnetics

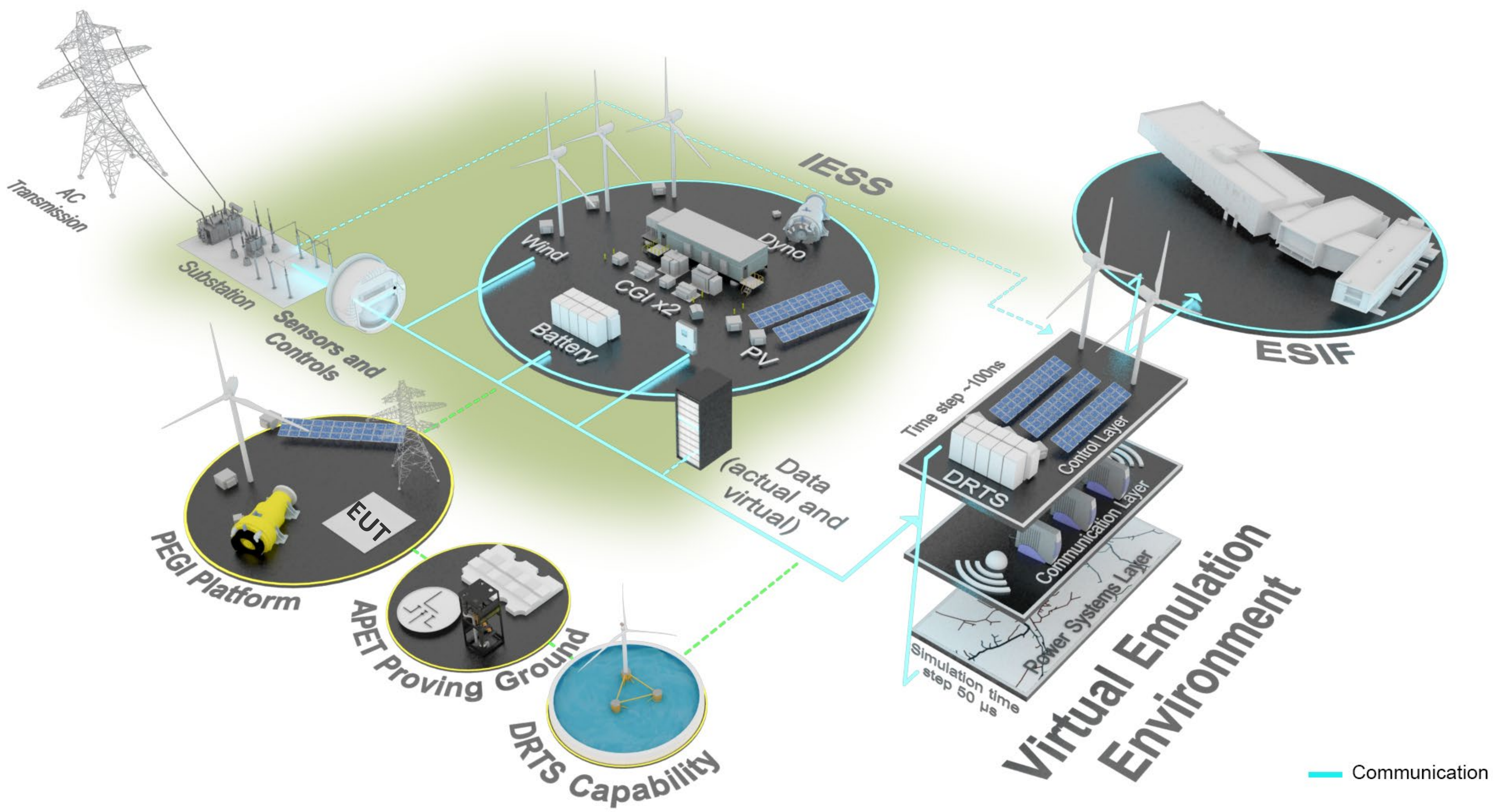


Thermal Management

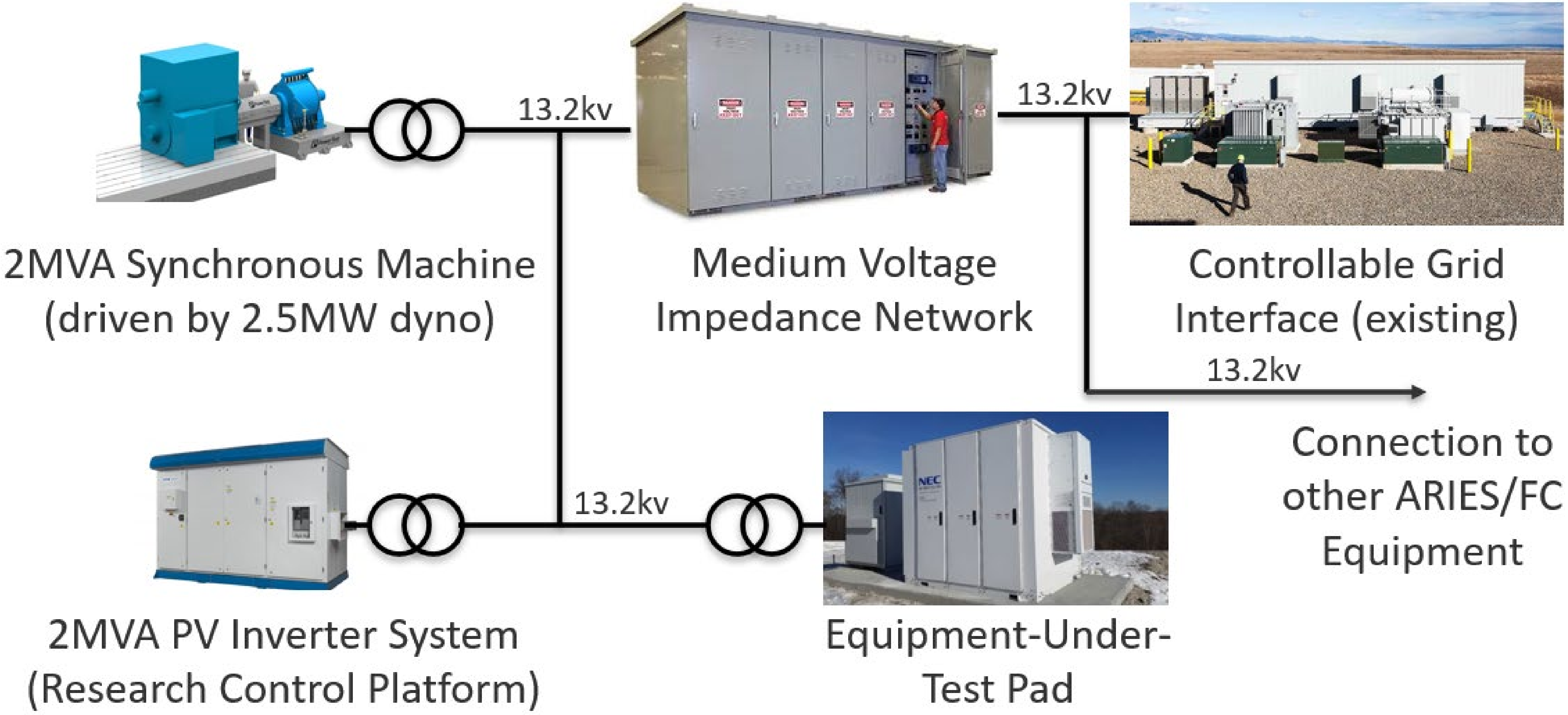


Topology

Application



Power Electronics R&D Focused Capabilities



Power Electronic Grid Interface (PEGI) Platform

Equipment Under Test Pad

- Place for direct interface of commercial equipment to the rest of the PEGI Platform
- Rated at 2 MVA and 13.2 kV
- Located at the Flatirons Campus

2 MVA PV Inverter System

- Research controls development platform at the switching-level
- Powered from local PV array or DC supply
- Rated at 2 MVA and connects at 13.2 kV (probably through a xfmr)
- Located at the Flatirons Campus

2 MVA Synchronous Machine

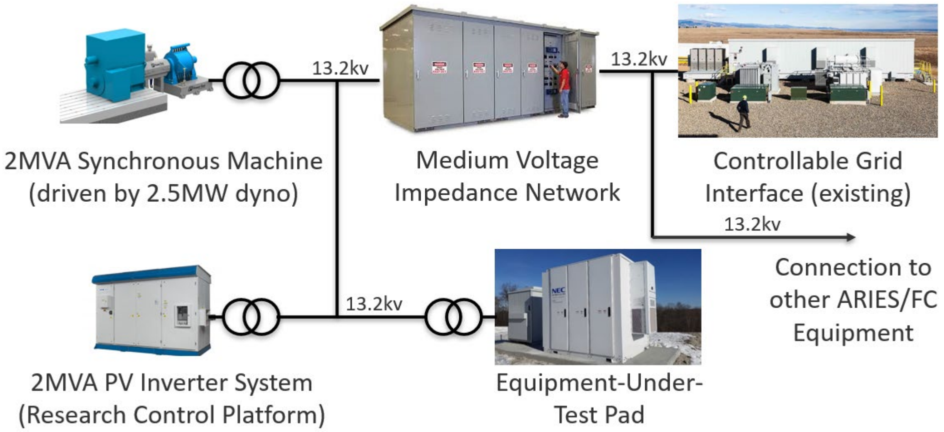
- Driven by existing 2.5 MW wind dynamometer
- Multiple uses
  - Proxy for conventional generation share on the grid
  - Synchronous condenser operation
  - Coordination of fault response
  - Simulate other generation source profiles
- Rated at 2-2.5 MVA and connects at 13.2 kV

Medium Voltage Impedance Network

- Passive impedance network at 13.2 kV
- Multiple uses
  - Multiple points of common-coupling for power electronic grid interface interaction studies
  - Used in conjunction with controllable grid interface to improve PHIL capabilities at high frequencies
  - PHIL tuning, bandwidth improvement

Example PEGI Platform capabilities:

- Development and evaluation of grid-forming inverter controls
- Laboratory evaluation of SNSP stability limits
- Demonstration of black start using inverter-based resources (IBRs)
- Abnormal/fault condition response development
- De-risking renewable interconnection via tuning of inverter controls for specific grid locations
- Enhanced hybrid power plant development and demonstration
- …



SETO Systems Integration Investment:

Phase 1 – build out of the foundational elements of PEGI

Phase 2 – partner with industry on critical research addressing the challenges of high power electronic generation/load in the power system

- start developing proposals in late FY21
- $1.8M in DOE funds for $3.6M+ in research value (50/50% cost match)

Foundational PEGI Platform Elements and Goals

Thank You

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