



U.S. DEPARTMENT OF  
**ENERGY**

**unifi**  
consortium

universal interoperability  
for grid-forming inverters

# UNIFI Consortium Overview

**Ben Kroposki**

**UNIFI Organizational Director**

**June 2022**



universal interoperability  
for grid-forming inverters

Future power systems with any mix of machines and IBRs at any scale that are affordable, secure, reliable, clean, and resilient

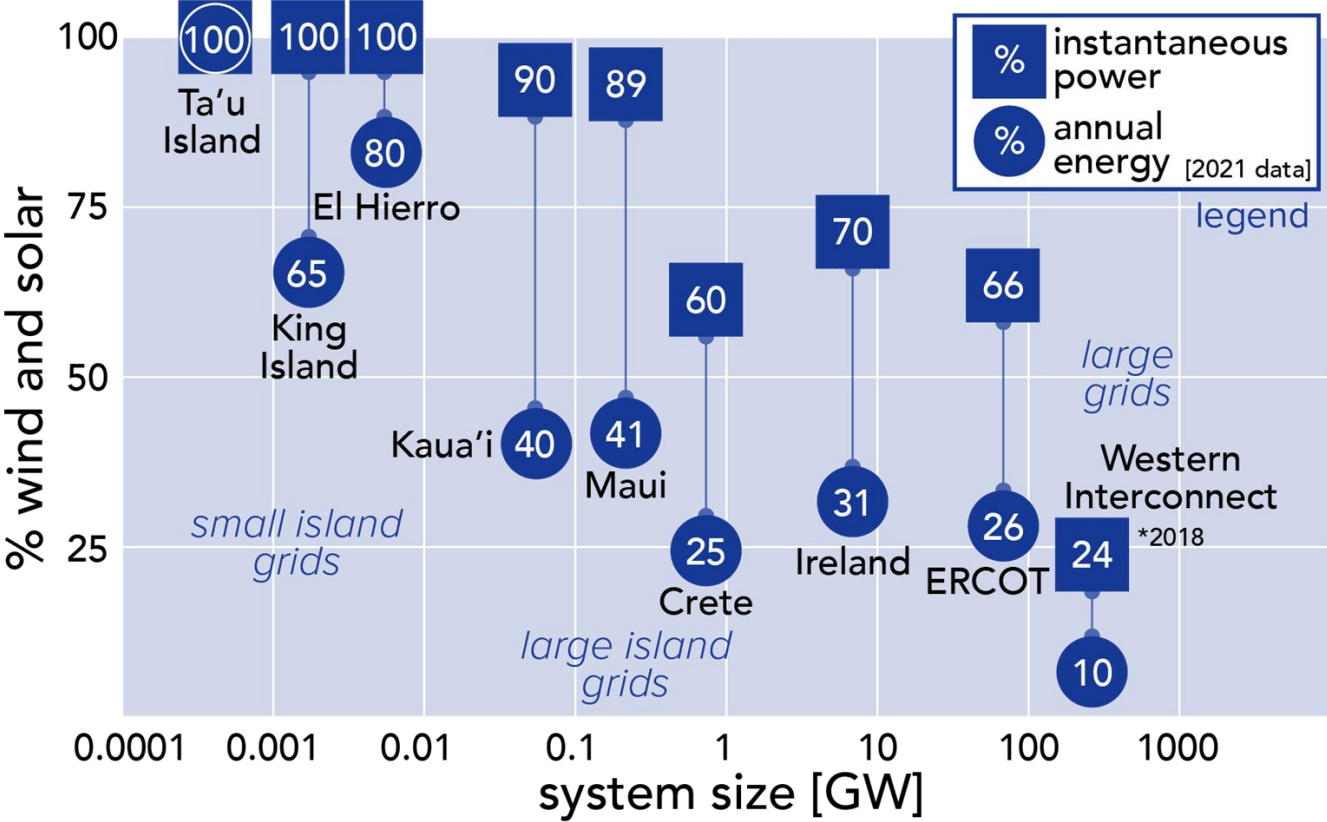
Vision

Forum to address fundamental challenges in seamless integration of grid-forming (GFM) technologies into power systems of the future

Purpose

Conduct research and development, demo concepts at scale, author best practices and standards, train next-generation workforce

Goal



IBRs = inverter-based resources



## universal interoperability for grid-forming inverters

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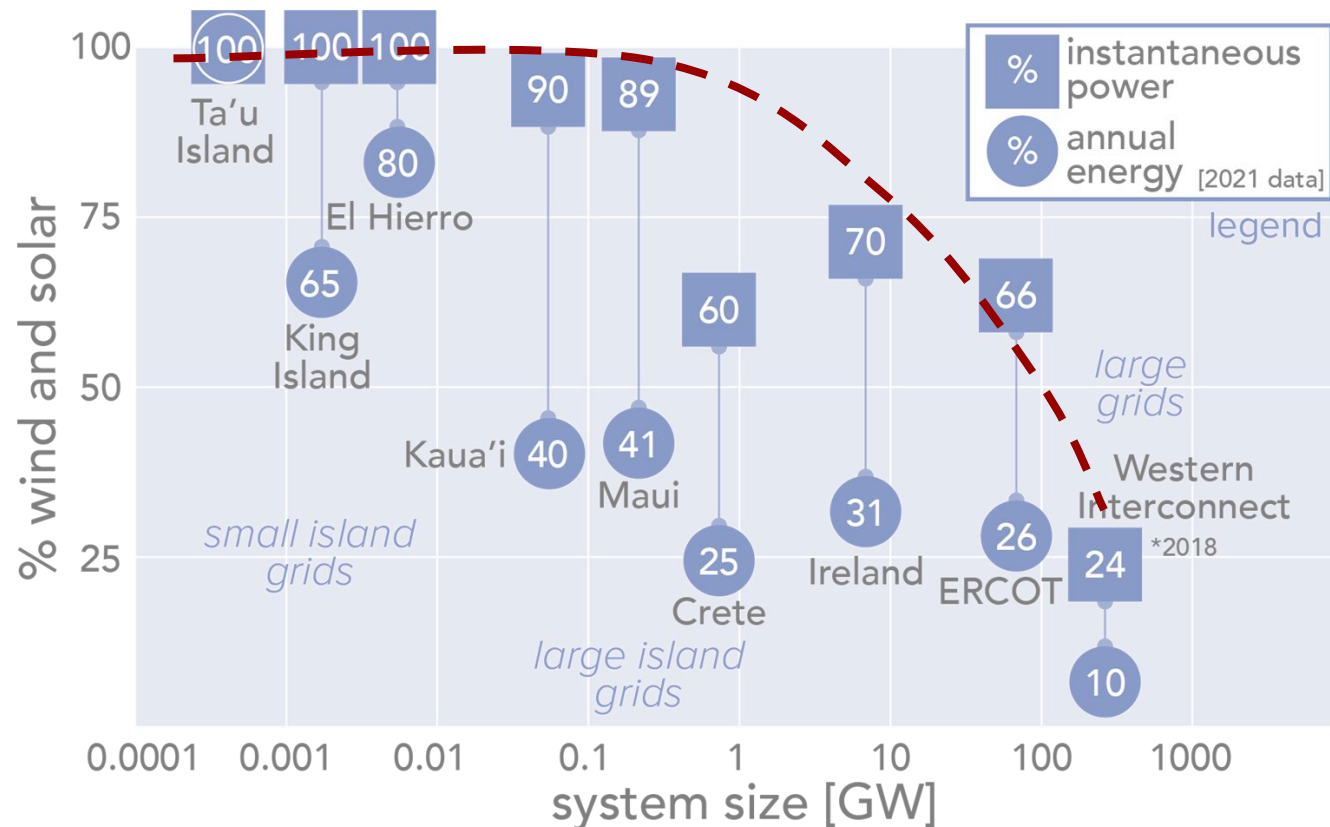
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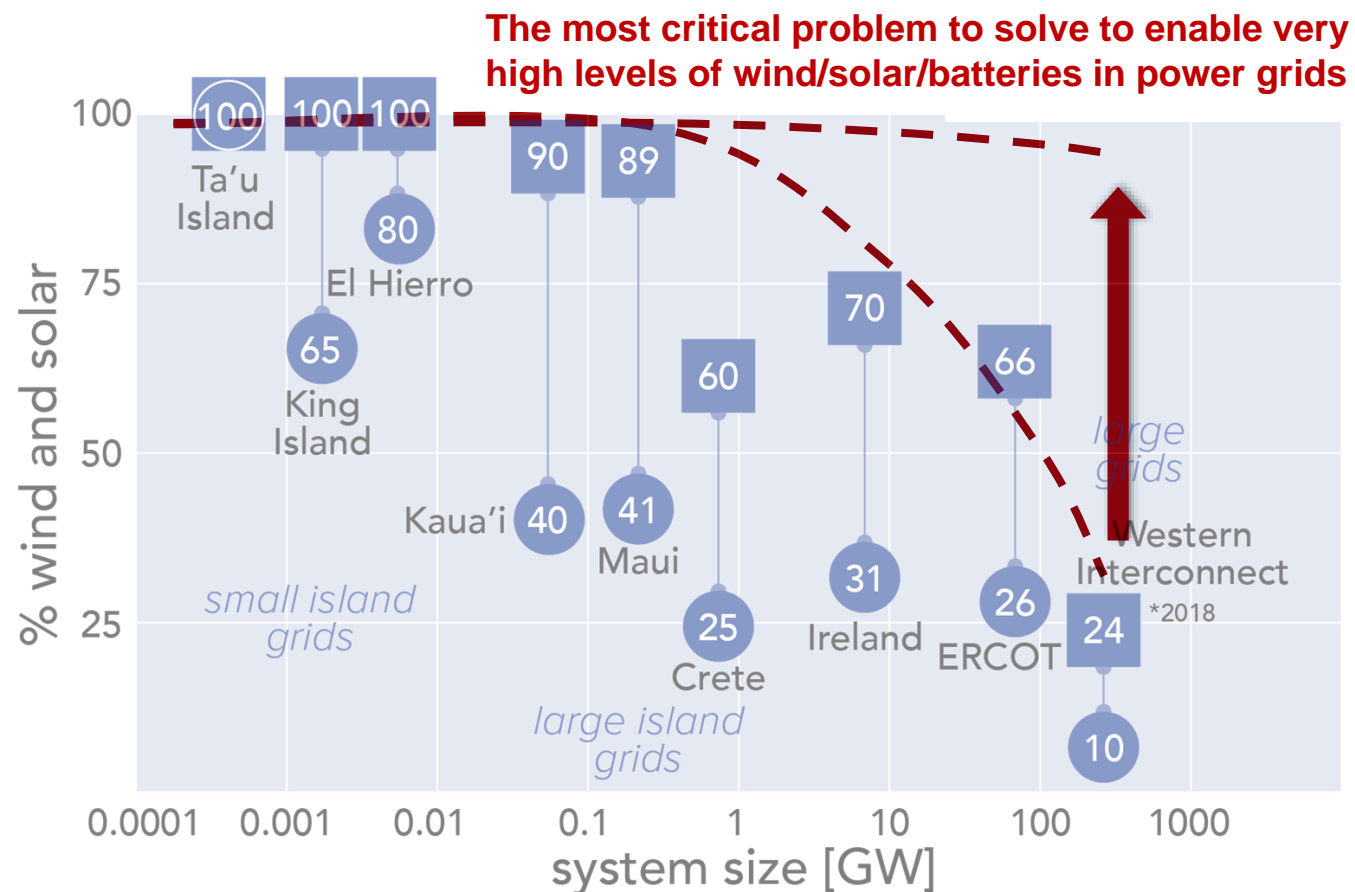
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# Global Landscape

Grid codes and roadmaps around the world recognize the role of grid-forming (GFM) inverter-based resources (IBRs)

## Challenges

- Poor definitions of capability and functionality across technologies; lack of standardization
- Limited-to-no consensus on expected performance from unit and system levels
- Vendors/Manufacturers and Utilities/Operators appear to be locked in circular death spirals

## Solutions

- Standardize Requirements
- Validate through models, controls, testing, demonstrations at scale
- Educate the industry

### Research Roadmap on Grid-Forming Inverters



### High Penetration of Power Electronic Interfaced Power Sources and the Potential Contribution of Grid Forming Converters

Technical Report



### Application of Advanced Grid-scale Inverters in the NEM

August 2021

White Paper

An Engineering Framework: report on design capabilities needed for the future National Electricity Market



Yashen Lin,<sup>1</sup> Joseph H. Eto,<sup>2</sup> Brian B. Johnson,<sup>3</sup>  
Jack D. Flicker,<sup>4</sup> Robert H. Lasseter,<sup>5</sup> Hugo N. Villegas Pico,<sup>6</sup>  
Gab-Su Seo,<sup>7</sup> Brian J. Pierre,<sup>8</sup> and Abraham Ellis<sup>9</sup>

With editing and support from Hariharan Krishnaswami,<sup>10</sup>  
Jeremiah Miller,<sup>11</sup> and Guohui Yuan<sup>12</sup>

<sup>1</sup>National Renewable Energy Laboratory  
<sup>2</sup>Lawrence Berkeley National Laboratory  
<sup>3</sup>University of Washington  
<sup>4</sup>Sandia National Laboratories  
<sup>5</sup>University of Wisconsin  
<sup>6</sup>U.S. Department of Energy Solar Energy Technologies Office

# What is UNIFI ?

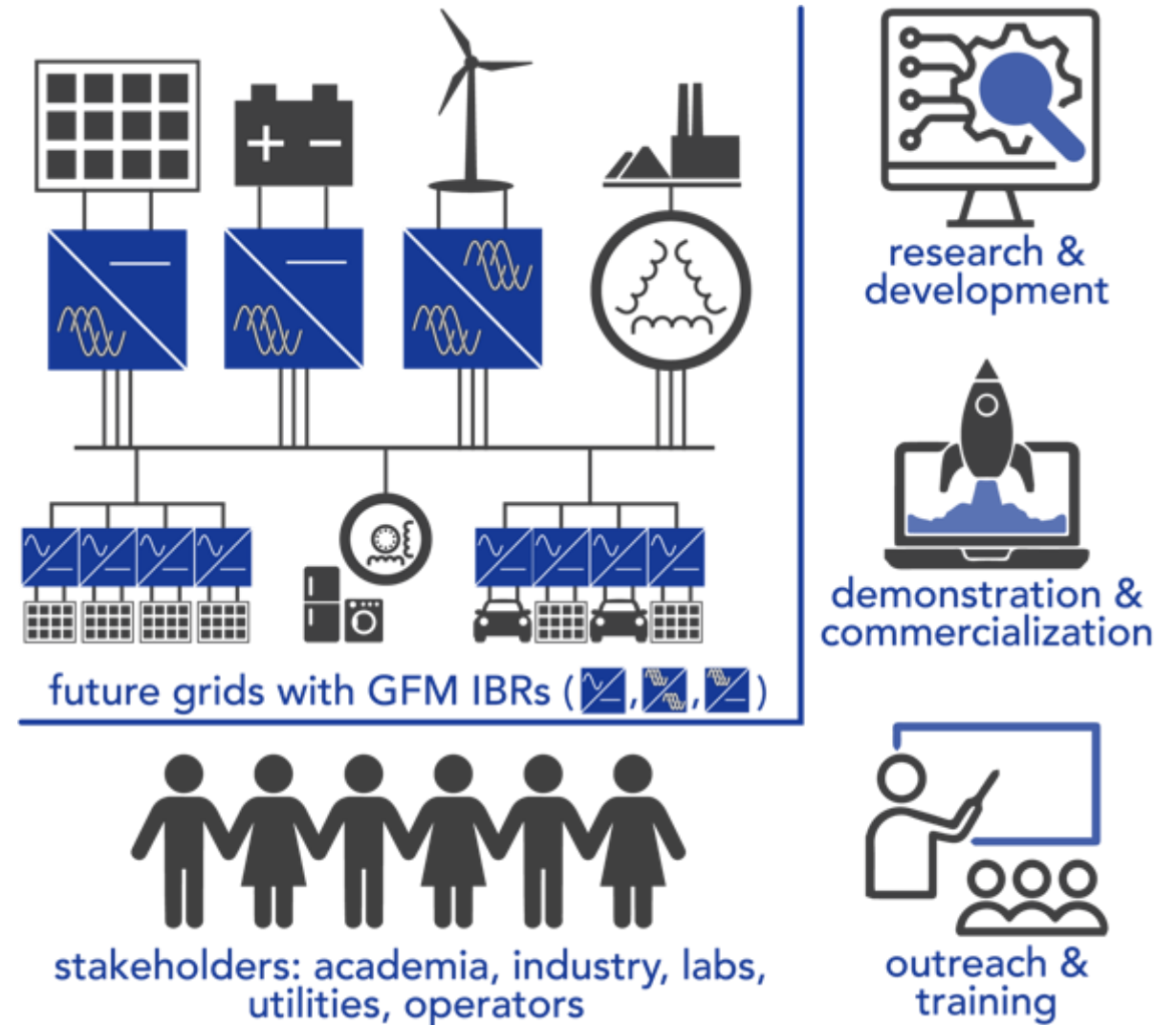
The **UNIFI Consortium** is a forum to address fundamental challenges in the seamless integration of grid-forming (GFM) inverter-based resources (IBR) into power systems of the future.

Bringing the industry together to unify the integration and operation of inverter-based resources and synchronous machines

Three major focuses:

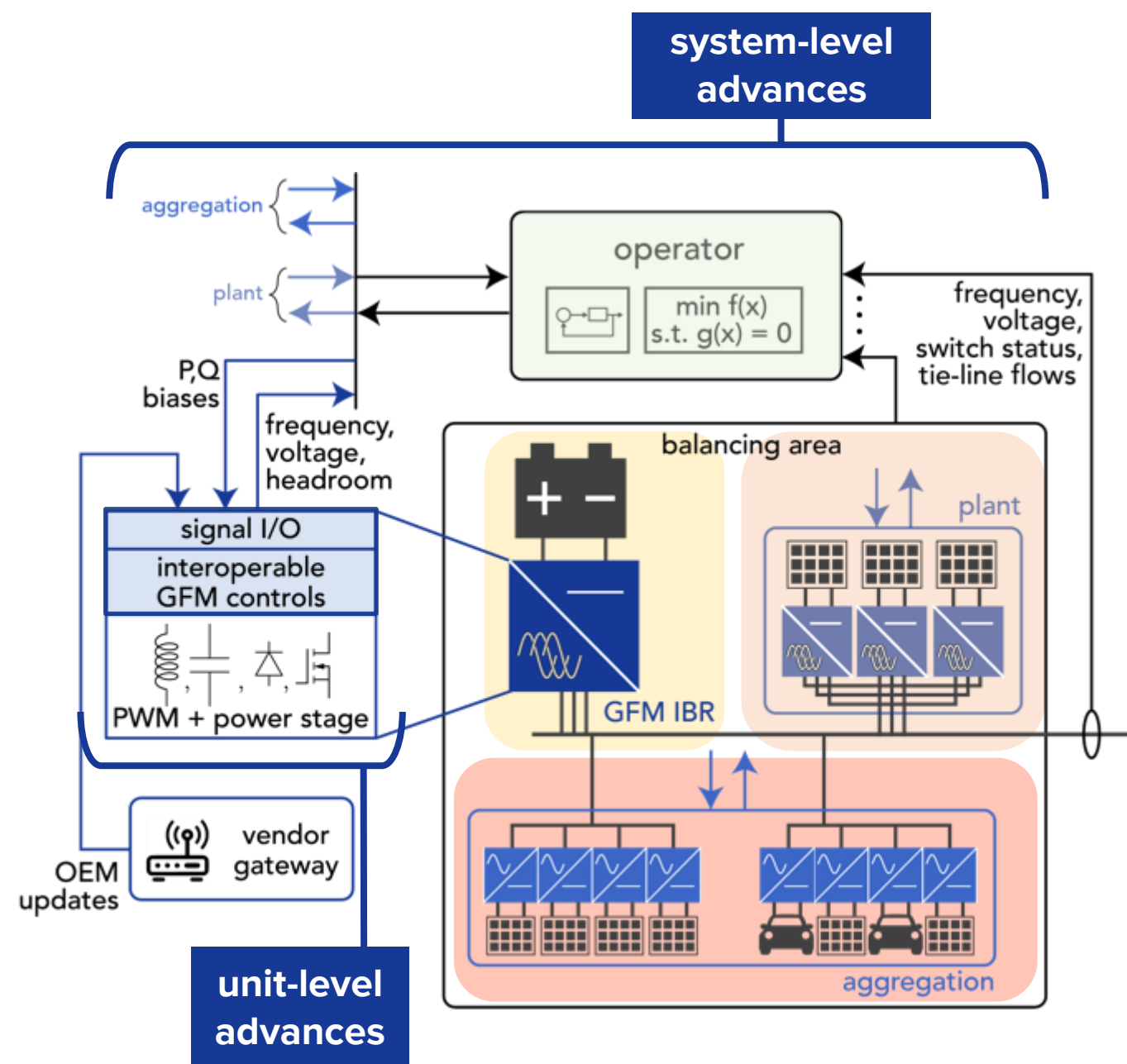
- Research & Development
- Demonstration & Commercialization
- Outreach & Training

DOE is funding a 5-year project – Started in January 2022. Idea is to create a sustainable organization through memberships.



# Envisioned System Architecture

- GFM technologies: individual **GFM IBRs**, **plants** or **aggregations**
- GFM unit-level functionality includes vendor-specific proprietary controls aided by a middle-layer (labelled **interoperable GFM controls**) that translates system-level control objectives
- Exchange standardized signals through suitable interface (**signal I/O**) in a cyber-secure manner with the system operator to regulate frequency & voltages via secondary control, and manage operations (e.g., black-start)
- Distributed optimization and control algorithms within and across grid **balancing areas** may be required
- Will require both unit-level and system level advances



GFM = grid-forming inverter    IBRs = inverter-based resources

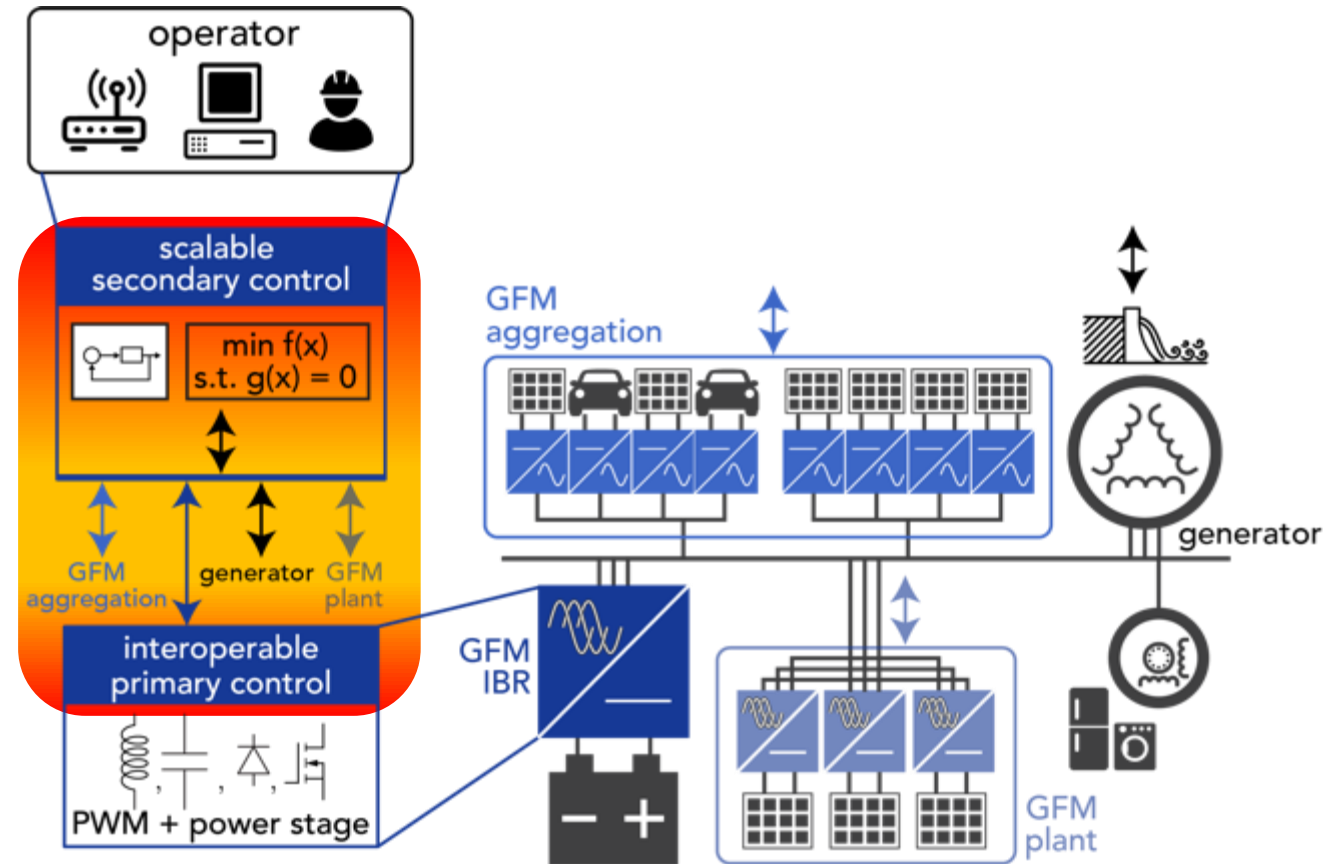
# UNIFI Goals

**Curate** vendor- and technology-agnostic **“UNIFI Specifications”** that standardize performance and benchmark capabilities of GFM technologies across scales

- **System Level - Interoperability Guidelines** - that promote the coordinated and seamless operation of GFM technologies from multiple vendors while ensuring stable and reliable power grids
- **Inverter Level - Functional Requirements** – that define GFM-IBR capabilities which are specified in a vendor-agnostic fashion to satisfy all system-level interoperability guidelines

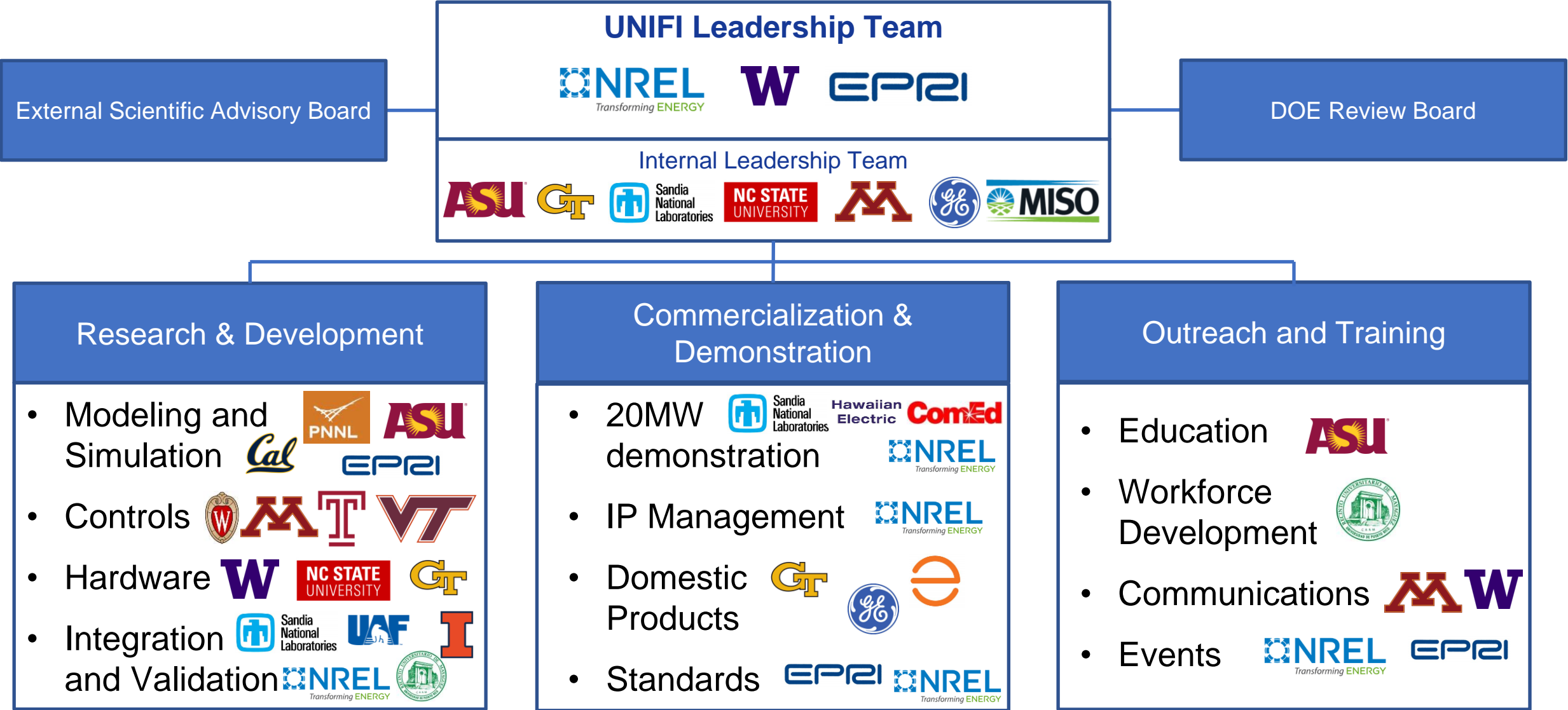
**Convene** continuous collaboration between inverter manufacturers (on one end) and system operators and utilities (on the other) to bridge gaps between power-systems and power-electronics industries

**Cultivate** inclusive culture and leverage member cooperation for sustained innovation





# UNIFI Organizational Structure





# UNIFI Working Groups (WG)


- **UNIFI Specifications**
  - Defining specifications and requirements for GFM
- **Modeling and Simulation Area**
  - GFM Model Development and Theoretical Innovations WG
  - Use Case, Software Testbed, and Interoperability
- **Controls Area**
  - Real-time Control and Dynamic Stability WG
  - Communication-coordinated Control and Cybersecurity WG
- **Hardware Area**
  - Open-source Code Development and Experiment Planning & Design WG
- **Integration and Validation Area**
  - Validation of UNIFI Specifications WG
  - 1MW Multi-vendor Experiment WG
- **20MW Demonstration Area**
  - 20MW Demo Specifications WG
- **Standards Area**
  - Standards Coordination WG
- **Education Area**
  - Education WG
- **Workforce Development Area**
  - Seminar Series WG
  - Tutorials WG


# UNIFI Members - Project Team

National Labs & Research Institutes





  
*Transforming ENERGY*





  
BERKELEY LAB





  
Sandia National Laboratories






Universities

















Industry













Utilities & System Operators





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# Additional Partners

UNIFI is working with a broader spectrum of partners to ensure industry-wide acceptance

Utilities & Consultants



Software



System Operators



Vendors



Consortia





# Research & Development (R&D) Thrust

- **Modeling & Simulation:** Develop and Publish GFM-specific models for use in power system simulations. Bridge gaps to HIL.
- **Controls:** Unit- and system-level to ensure grid stability and cybersecurity
- **Hardware:** Anticipate industry needs and develop open-source prototyping
- **Integration & Validation:** Conduit to demonstrations, 1MW experiment at NREL

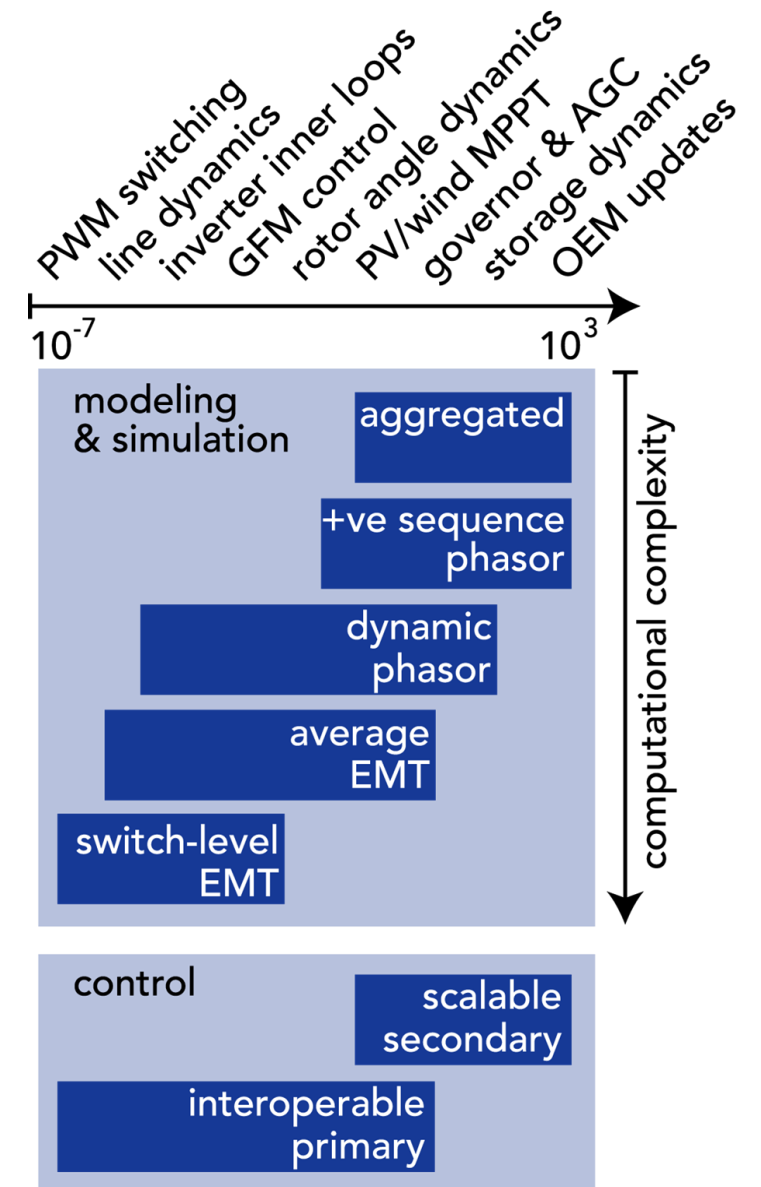




# Modeling & Simulation Area

## Snapshot of Innovations:

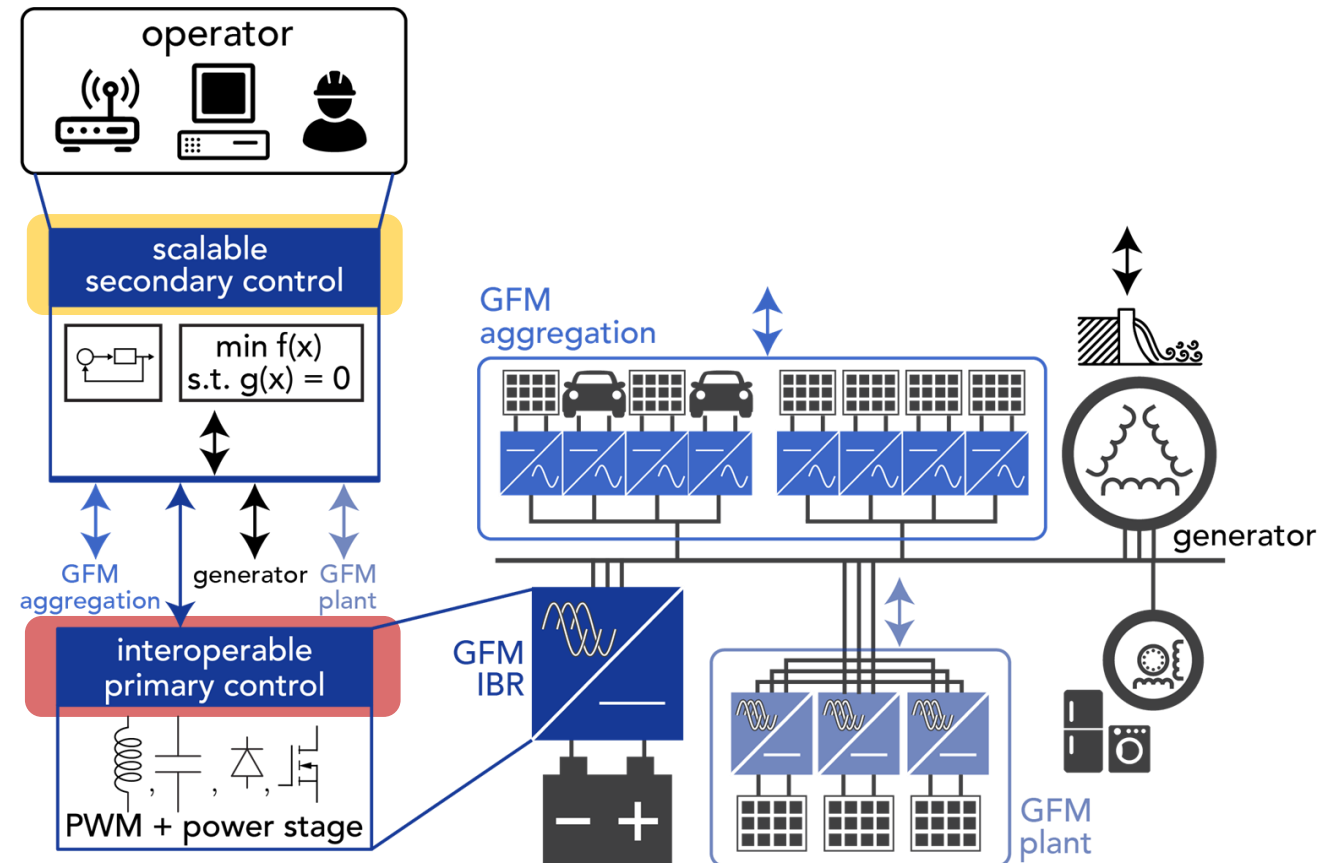
- Interoperability standards and application programming interfaces (APIs) to allow GFM models to be directly used by different software vendors
- Develop HIL-compatible software models:
  - Hybrid between virtual power stage model & controller in the loop
  - Integrated into commercial and open-source simulation tools
- Model interoperability tests on a virtual platform that provides a secure workspace for tool vendors and a means for utilities to participate and evaluate solutions
- UNIFI has partnerships and collaborations with **all** commercial power-system simulation-software vendors that cover timescales ranging from real-time through micro-/milli-second simulations:
  - EMT simulation (PSCAD, EMTP, HYPERSIM, PLECS)
  - Positive-sequence simulation (PSLF, PSS/E, TSAT, PowerWorld)
  - Real-time simulation (Opal-RT and Typhoon HIL)



# Controls Area

## Snapshot of Innovations:

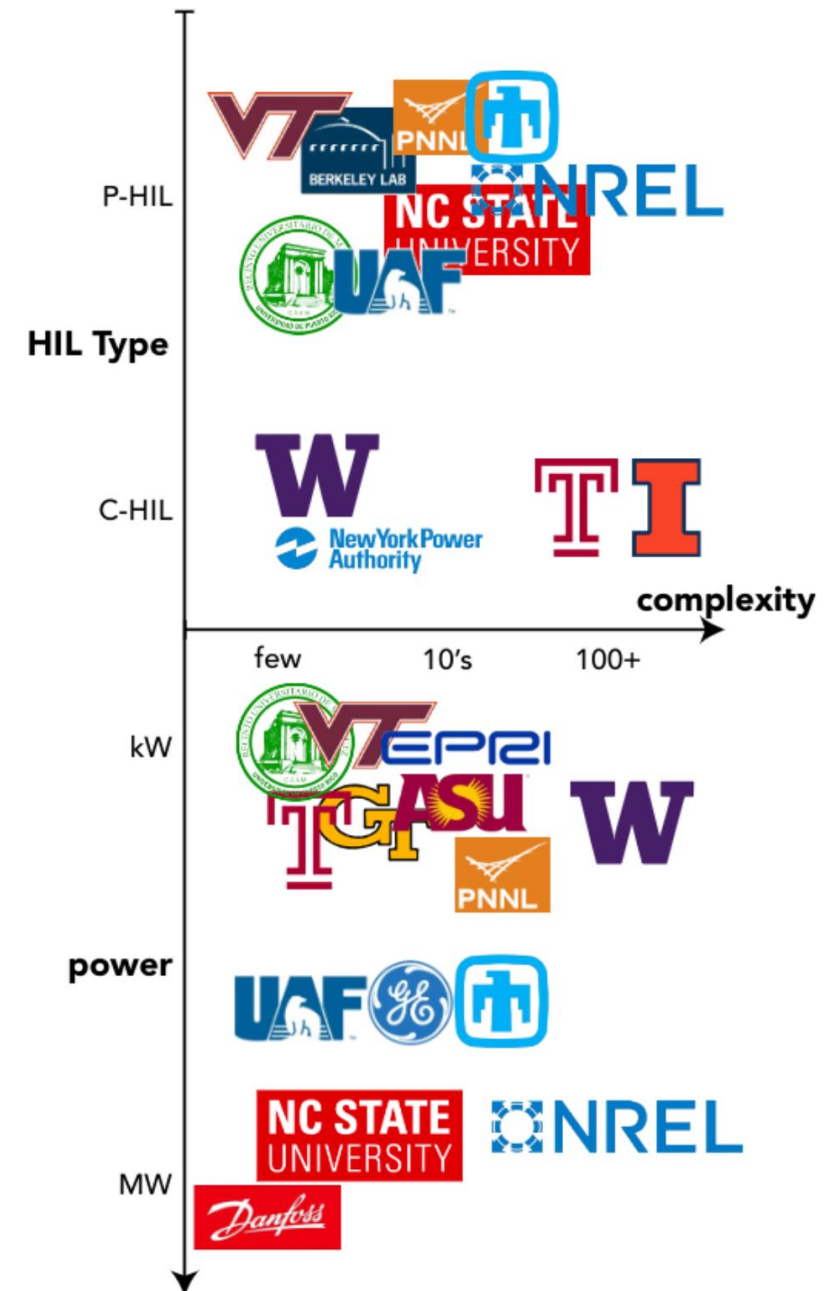
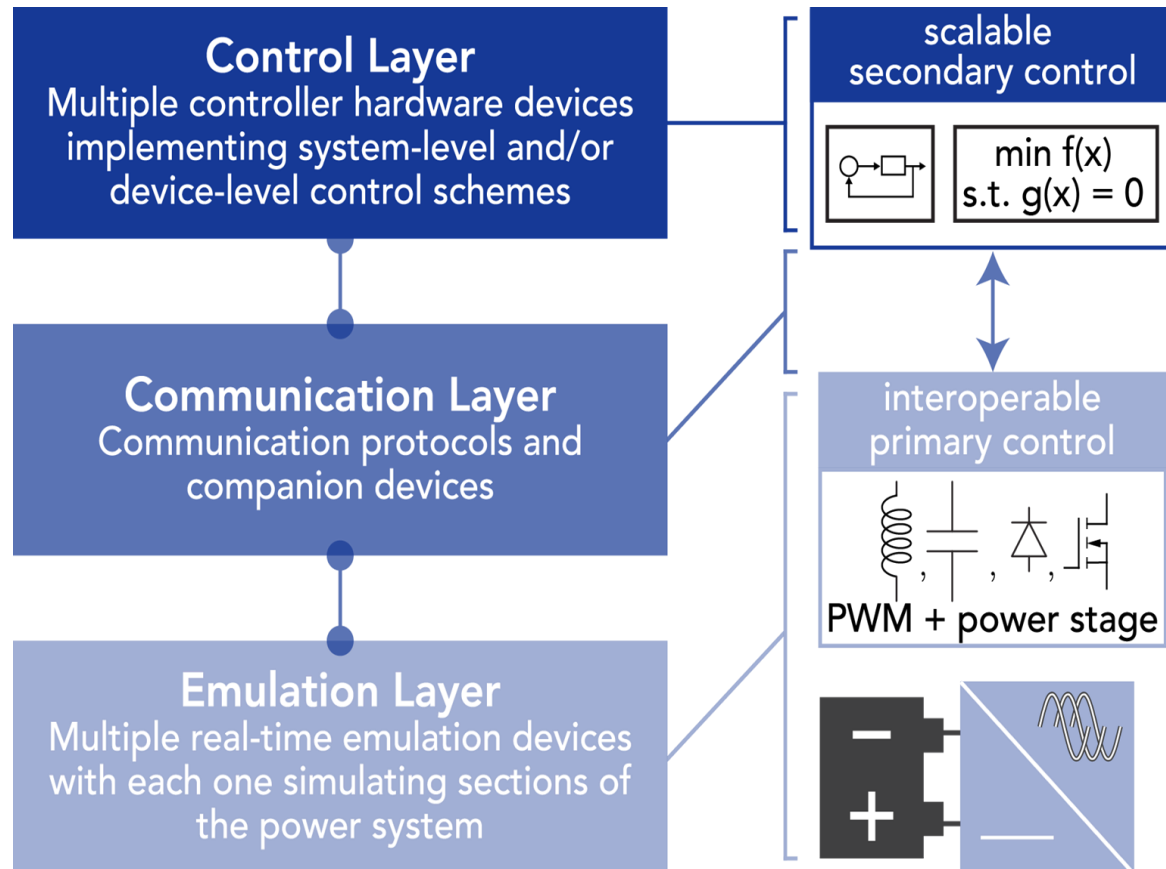
- **Interoperable GFM primary-control architecture:**
  - Compatible with generation and storage technologies via vendor-agnostic middle-layer that translates system-level control signals
  - Coordinates energy transfer within hybrid IBR-plants, large-scale PV, and wind energy conversion systems while managing IBR-level source-side and inverter limits
- **Scalable secondary-control architecture:**
  - Generalize area control error (ACE) beyond frequency (to include, e.g., voltage magnitude, phase imbalance)
  - Coordinate and prioritize between different balancing areas while accounting for IBR limits



# Integration & Validation Area

## Snapshot of Innovations:

- Federate and standardize testing and characterization facilities across partnering institutions
- Use cases → testing, evaluation, communication protocols → certification-type testing environment → user facilities for fee



# Integration & Validation Area

## 1 MW Experiment – at NREL in Year 3

- Create a hardware testbed that all vendors that follow the UNIFI Specifications for interoperability should be able to plug and play with other vendors
- Includes various physical sizes (250W-1MW)
- Three-phase, single-phase generation & loads
- Multiple source-side resources (PV, energy storage, wind (if possible))
- 50%, 75%, 90%, and 100% power contribution from GFM IBRs
- Connections to multiple laboratories: integrated testing and validation approach to realize multiple 1MW demos





# Demonstration & Commercialization (D&C) Thrust

- **20+MW Demo:** Demonstrate UNIFI specifications at utility scale demo
- **IP Management:** Identify “Core” IP needed to meet UNIFI Specifications
- **Domestic Products:** position US as world leader in PV, wind, and storage
- **Standards:** Align with standards cycles to address gaps coving GFM

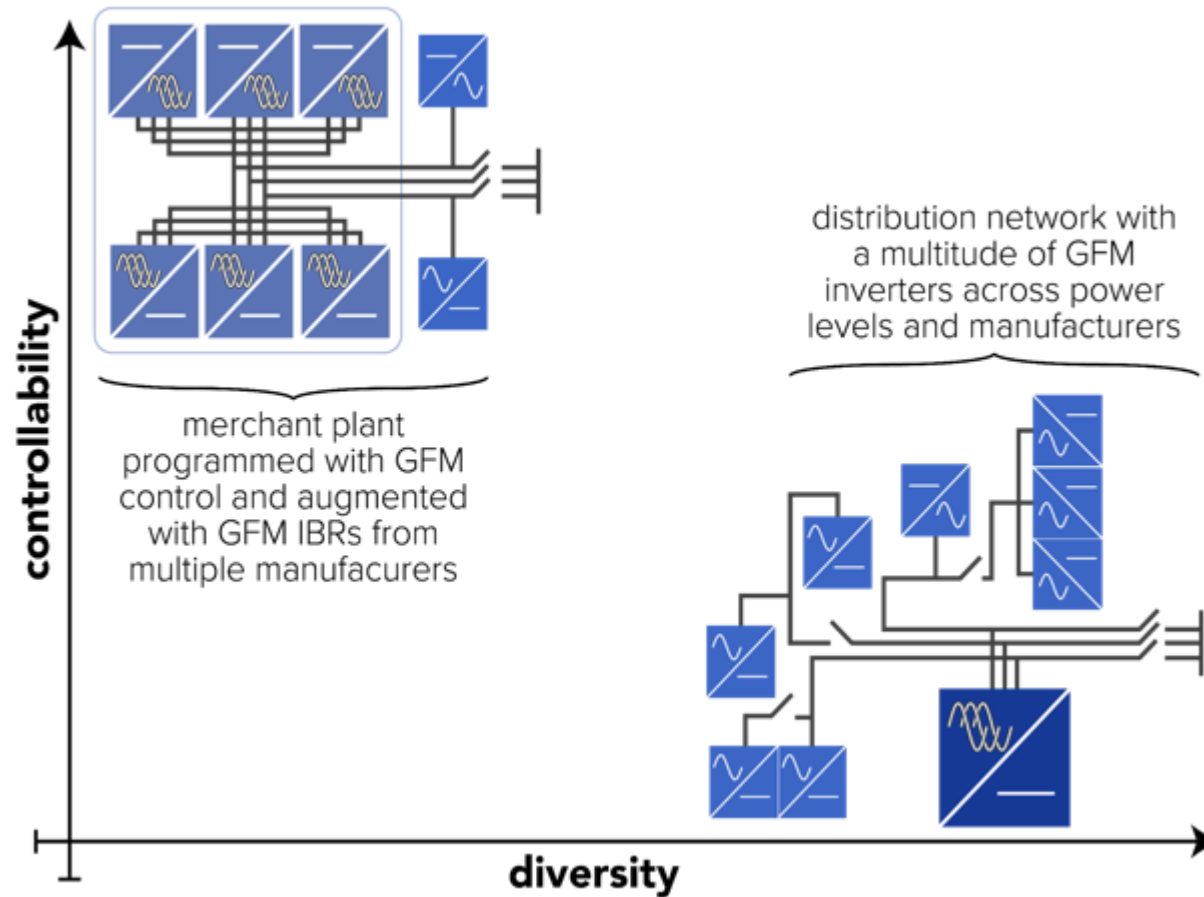




# 20+MW Demonstration



Large-scale Plant Integration  
[Barilla Solar, TX]



Distribution Networks with high PV integration



[Chicago, IL]



[Oahu, HI]

- Examining a range of possible sites that trade off controllability and diversity of resources and IBR size
- Also looking for demonstrating much larger than 20MW sizes and at possibly at multiple sites
- Demonstrate a full range of GFM services and validate *Interoperability Guidelines & Functional Requirements*
- Would like to examine unique objectives if possible such as energy justice (collocate with underserved communities)

# 20+MW Demonstration

*We are looking for sites that include some or all of the following:*

- a mix of three-phase/single-phase resources
- a mix of GFM IBRs, GFL IBRs, and machines
- devices that have a wide range of power ratings (from 250W to MW)
- solutions from multiple vendors a plurality of source-side energy sources (PV, energy storage, wind)
- plant-level controls and SCADA as required
- range of load types and sizes (resistive/inductive, single-/three-phase)

*Would like to validate the UNIFI system interoperability guidelines and functional requirements*

- interoperable and scalable primary and secondary control
- frequency and voltage control
- power sharing among units
- black-start
- transient operation during balanced and unbalanced faults
- operations to achieve up to 100% power contribution from IBRs during medium- and high-demand periods

**Let us know if you have potential demonstration sites**

# Prior Work



## Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant

Clyde Loutan, Peter Klauer, Sirajul Chowdhury,  
and Stephen Hall  
*California Independent System Operator*

Mahesh Morjaria, Vladimir Chadliev,  
Nick Milam, and Christopher Milan  
*First Solar*

Vahan Gevorgian  
*National Renewable Energy Laboratory*

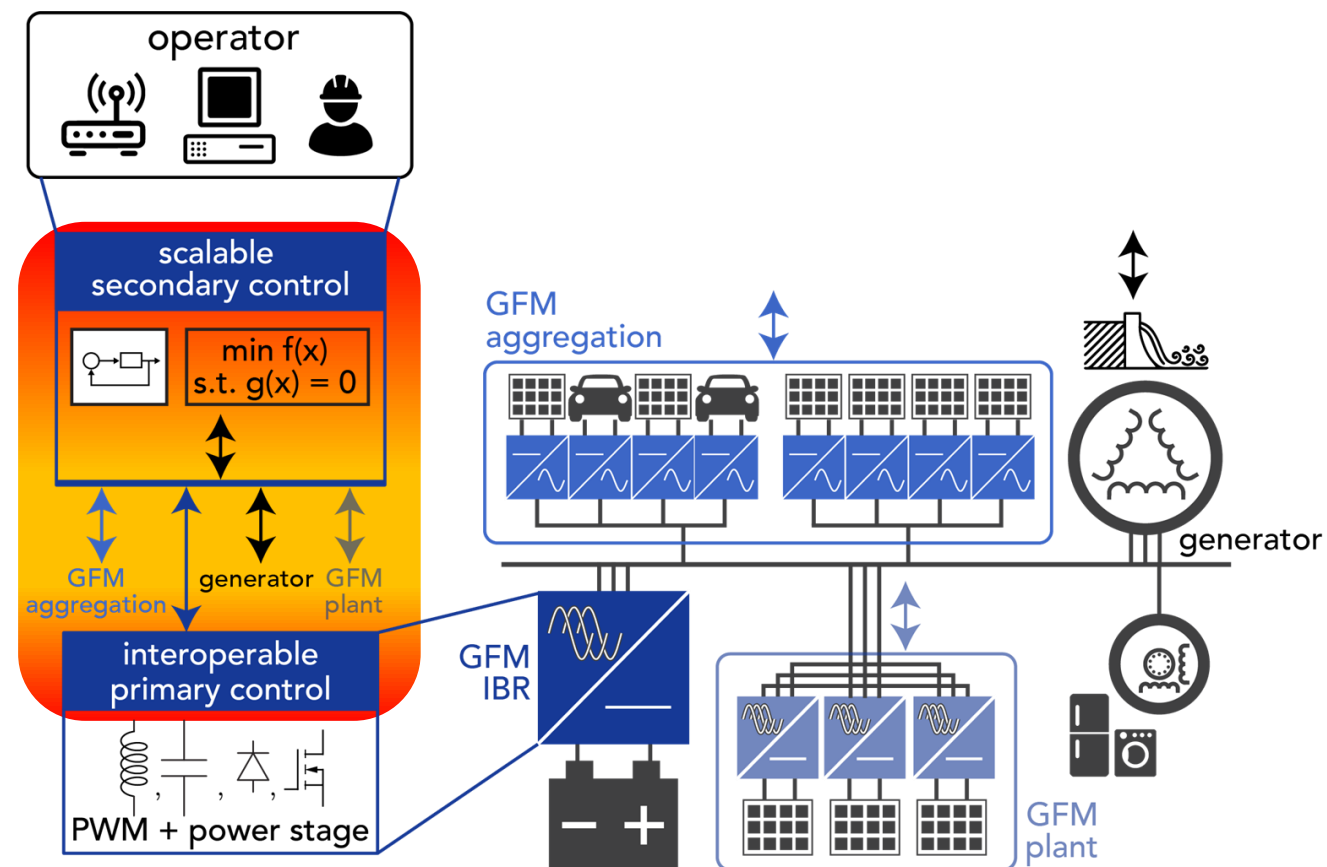


**NREL/FirstSolar/CAISO experiment:** 300-MW plant following Automatic Generator Control (AGC) signal

**Source:** C. Loutan, P. Klauer, S. Chowdhury, S. Hall, M. Morjaria, V. Chadliev, N. Milam, C. Milan, V. Gevorgian, *Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant*, <http://www.nrel.gov/docs/fy17osti/67799.pdf>

# IP Management and Product Development

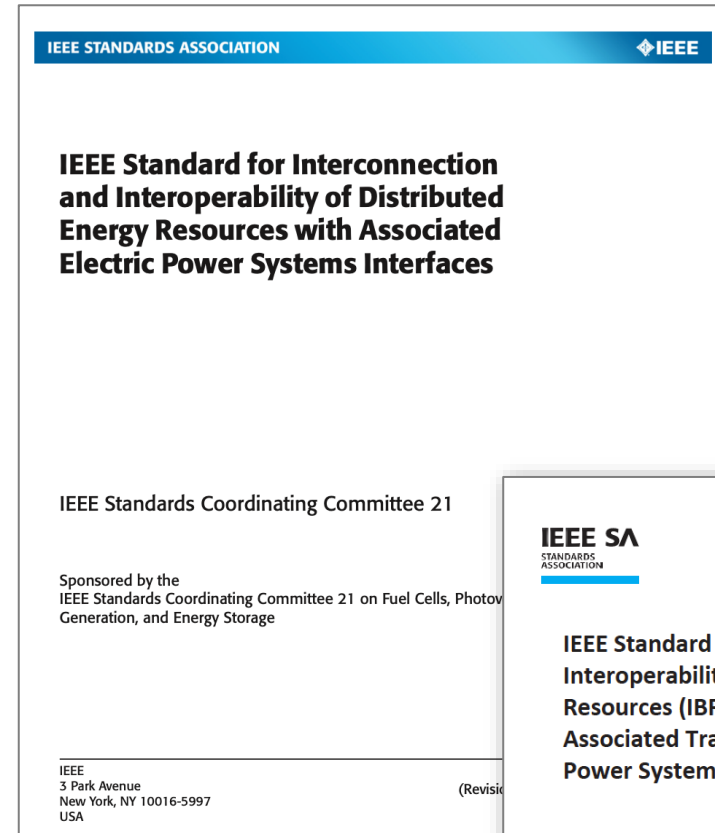
- UNIFI plans to work with members to determine and develop “Core Stack” IP that will enable GFM technologies to meet the Interoperability Guidelines and Functional Requirements
- Ensure that members have ability to meet UNIFI Specifications





# Standards

- Current standards for interconnecting IBR to power systems do not specifically address GFM technologies
  - IEEE 1547 - Distribution
  - IEEE 2800 - Transmission
- Conducting a gap analysis on existing IEEE 1547 and 2800 standards along with development of technical minimum capabilities for GFM devices
- UNIFI will focus on developing specification for GFM technologies
- Working closely with Standard Development Organizations, UNFI will bring expertise on GFM to future updates of these standards





# Outreach & Training (O&T) Thrust

- **Education:** develop educational material, certificate programs, and certification for teachers
- **Workforce development:** develop short courses & tutorials, safety-certification courses
- **Communication:** website and e-newsletter(s)
- **Events:** annual meetings, webinars



<https://pes-gm.org>

# Outreach & Training (O&T) Thrust



Industry-led training events



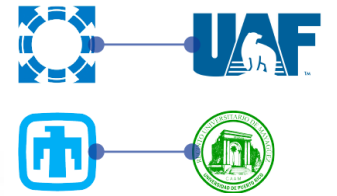
Interoperability Events



Workshops (in person!)



Leverage Institutional partnerships





# UNIFI Seminar Series

15 seminars every Spring and Fall for the next 5 years – Mondays at 4-5pmET/1-2pmPT

**unifi consortium**  
universal interoperability for grid-forming inverters

## Fall 2021 Seminar Series on Grid-Forming (GFM) Technologies

**Who** Organized by UNIFI (see [here](#)) & UC Berkeley  
**Where** Zoom • Register [here](#)  
**When** Mondays in the Fall  
4-5 ET • 3-4 CT • 2-3 MT • 1-2 PT  
**Contact** Duncan Callaway • [dcal@berkeley.edu](mailto:dcal@berkeley.edu)

**Berkeley**  
UNIVERSITY OF CALIFORNIA  
ENERGY MODELING, ANALYSIS, & CONTROL  
ENERGY & RESOURCES GROUP

<b>Aug 30 • Ben Kroposki (NREL)</b> The Need for Grid-Forming Inverters in the Future Power System	<b>Nov 1 • Deepak Ramasubramanian (EPRI)</b> Modeling & Control of Grid-Forming Inverters for Large System Studies
<b>Sep 13 • Deepak Divan (Georgia Tech)</b> Realizing Grid-Forming Inverters at Scale: Challenges & Opportunities	<b>Nov 8 • Ivan Celanovic (Typhoon) &amp; Humberto Pinheiro (UFSM)</b> Primary Controllers for Grid-Forming Converters
<b>Sep 20 • Julia Matevosyan (ERCOT)</b> Survey of Grid-Forming Inverter Applications	<b>Nov 15 • Brian Johnson (UW-Seattle)</b> Experiments to Accelerate Innovation in Grid-Forming Inverter-based Power Systems
<b>Sep 27 • Julie Cohn (U-Houston)</b> The Grid: Biography of an American Technology	<b>Nov 22 • Isbel Hussain (NCSU)</b> Grid-Forming Converters for Ride-Through of Symmetric and Asymmetric Faults
<b>Oct 4 • Donny Zimmerman (Enphase)</b> Plug and Play: Creating a Simple and Universal Inverter Microgrid Ecosystem	<b>Nov 29 • Mariko Shirazi (U-Alaska Fairbanks)</b> Operation of Grid-Forming Inverters in Today's Diesel-based Microgrids
<b>Oct 11 • Sairaj Dhole (U-Minnesota)</b> Power system Modeling for the Era of Inverter-based Resources	<b>Dec 6 • Ulrich Muenz (Siemens)</b> Dynamic Security Optimization for N-1 Secure Operation of Hawaii's Power Systems with 100% Inverter-Based Resources
<b>Oct 18 • Vijay Vittal (Arizona State)</b> WECC Models for Representing Inverter Interfaced Generation in Transient Stability Studies	<b>Dec 13 • Vahan Gevorgian (NREL)</b> Large-scale Grid-Forming Inverter Experiments at NREL
<b>Oct 25 • Dominic Gross (U-Wisconsin Madison)</b> Rethinking GFM Control: A Universal Control Paradigm and Protection Challenges	

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universal interoperability for grid-forming inverters

## Spring 2022 Seminar Series on Grid-Forming (GFM) Technologies

**NREL** **U.S. DEPARTMENT OF ENERGY**  
Transforming ENERGY

**Who** Organized by the DOE UNIFI Consortium  
**Where** Zoom • Register [HERE](#)  
**When** Mondays at 4-5 ET • 3-4 CT • 2-3 MT • 1-2 PT From Jan 24 to May 2, 2022  
**Contact** Diane Littau • [diane.littau@nrel.gov](mailto:diane.littau@nrel.gov)

<b>Jan 24 • Ben Kroposki (NREL)</b> UNIFI Consortium Overview	<b>Mar 21 • Karen Moriano-Martinez &amp; Sushrut Thakur (ANU)</b> Steady-State Presentation: Detailed Primary and Secondary Distribution System Model Enhancement Using AMI Data
<b>Jan 31 • Wei Du (PNM)</b> Transient and Dynamic Modeling of Droop-Controlled, Grid-Forming Inverters at Scale	<b>Mar 28 • Rodrigo Henriquez-Auba &amp; Jose Daniel Larrañaga (U-Berkeley)</b> Steady-State Presentation: Resilient Power System Simulation Classification and Assumptions in the Presence of Inertia-Based Resources
<b>Feb 7 • Marija Ilic (MIT)</b> Unified energy dynamics based approach to establishing standards/protocols in support of efficient and reliable large-scale integration of microgrids	<b>April 4 • Federico Milano (UC-Dublin)</b> Complex Frequency: A Geometric Approach to unravel the link between Power & Frequency in AC Power Systems
<b>Feb 14 • Wenzong Wang (EPRI)</b> Specifications and requirements for grid forming inverters in microgrid applications	<b>April 11 • Jin Tan (NREL)</b> Comparative Stability Analysis of Grid-Forming and Grid-Following Inverters in Low-Inertia Power System
<b>Feb 21 • President's Day</b> No Seminar	<b>April 18 • Ali Mehrizi-Sani (Virginia Tech)</b> Control, Communication, and Cybersecurity for Grid-forming Inverters
<b>Feb 28 • Addison Li (Hawaiian Electric Company)</b> Hawaii's Path to 100% Renewables	<b>April 25 • Sudipta Chakraborty (OPAL-RT), Axel Seibel and Tobias Erckrath (Fraunhofer IEE)</b> Challenges and needed functionalities of grid forming units for multi-inverter, interoperable, and resilient operation: From HW-design, control interoperability and HIL validation
<b>Mar 7 • Pedro Arsuaga (General Electric)</b> GE's Perspectives on Grid Forming Technologies	<b>May 2 • Jack Flicker (Sandia)</b> HIL evaluation of GFM Inverters
<b>Mar 14 • Xiaonan Lu (Temple University)</b> Large-Scale DER Integration through Scalable & Secure Secondary Control in Dynamic Microgrids	

Free and Publicly Available

# How to get involved with UNIFI?

- UNIFI has a paid membership structure to allow organization that were not part of the original project to join.



Check for the the “**UNIFI Consortium**” Group on LinkedIn



## Benefits of Membership

- Seat at the table alongside other vendors, utilities, system operators
- Participate in (and drive) cutting-edge R&D through UNIFI working groups
- Access UNIFI specifications that will leapfrog traditional standardization process
- Access to core stack IP that is key to interoperability of GFM technologies across scales
- Participate in 1MW and 20MW demos
- Network with wide student pool across universities that will enter workforce
- UNIFI events (training, job fairs, workshops) will be key to educate on novel technology area
- Access to educational and training material in up-and-coming technology space

For more information on Memberships Contact: Ben Kroposki ([benjamin.kroposki@nrel.gov](mailto:benjamin.kroposki@nrel.gov)) or Iqbal Hussain ([ihusain2@ncsu.edu](mailto:ihusain2@ncsu.edu))

The background of the slide is a dense, repeating pattern of various icons in shades of blue and grey. These icons represent a wide range of fields: technology (laptops, tablets, Wi-Fi symbols, circuit boards), science (molecules, graphs, waveforms), industry (factories, cars, wind turbines), and people (groups of figures, a person with a hard hat). The overall theme is interdisciplinary collaboration and innovation.

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consortium

**Thank you**