HELICS for Integrated Transmission, Distribution, Communication, & Control (TDC+C) Modeling

SETO Workshop on Challenges for Distribution
May 17, 2019
Washington, DC

Presented by: **Bryan Palmintier**

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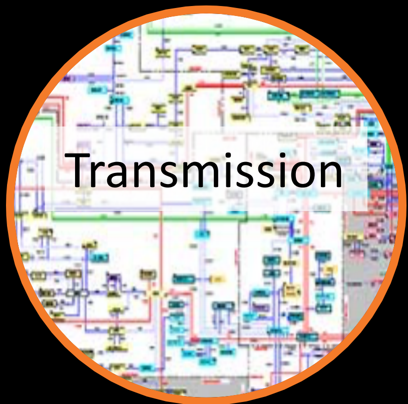
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

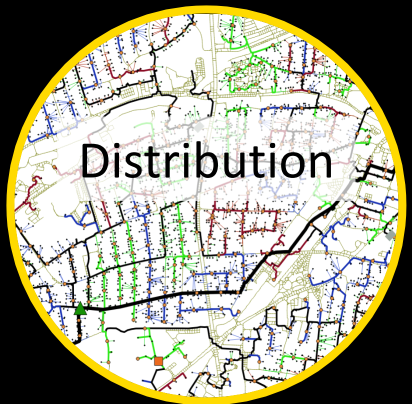
HELICS

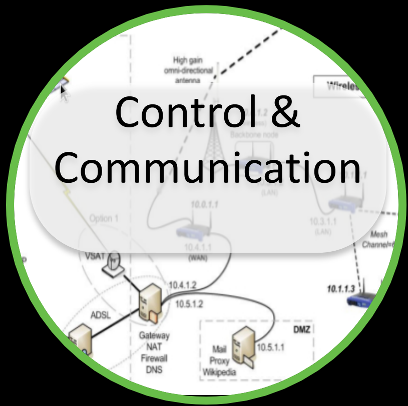
Pacific Northwest NATIONAL LABORATORY
Lawrence Livermore National Laboratory
NREL
Argonne NATIONAL LABORATORY
OAK RIDGE National Laboratory
Sandia National Laboratories
INL Idaho National Laboratory

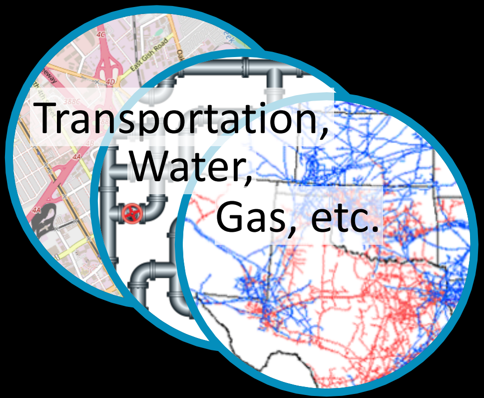
U.S. DEPARTMENT OF ENERGY

Grid modernization requires integrating multiple infrastructures…

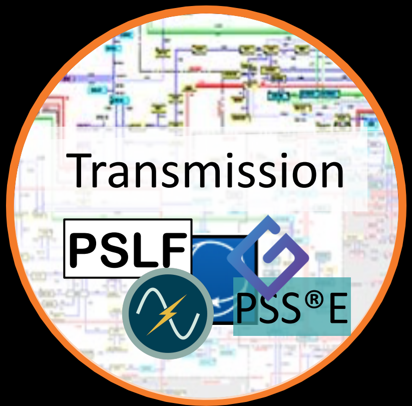


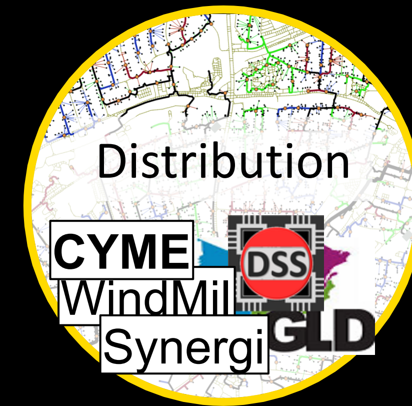


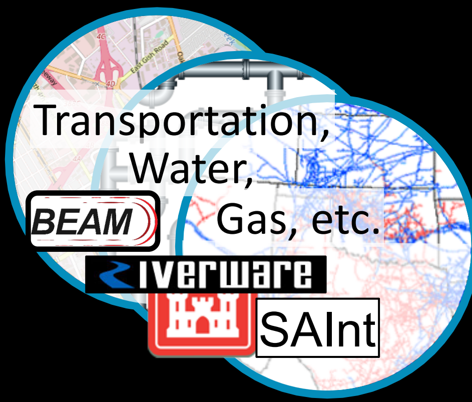




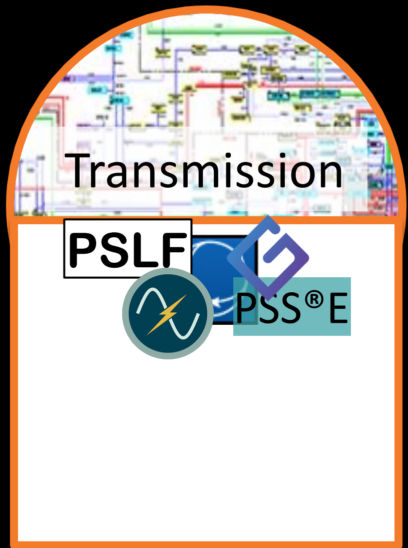
And we have many, well trusted tools to model each…

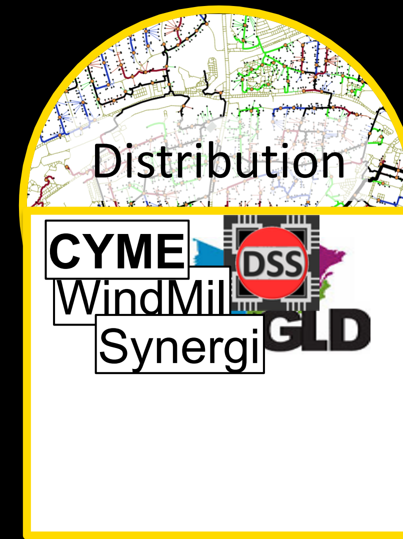


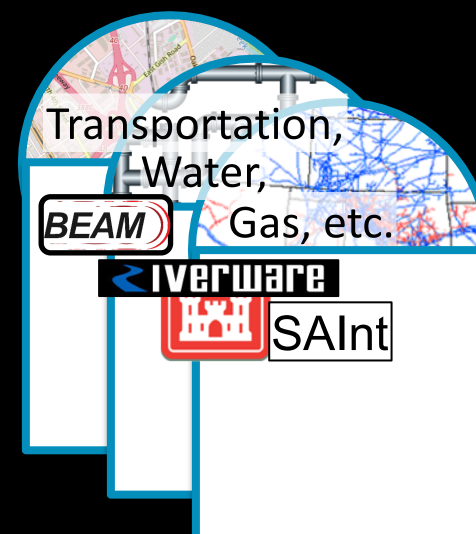




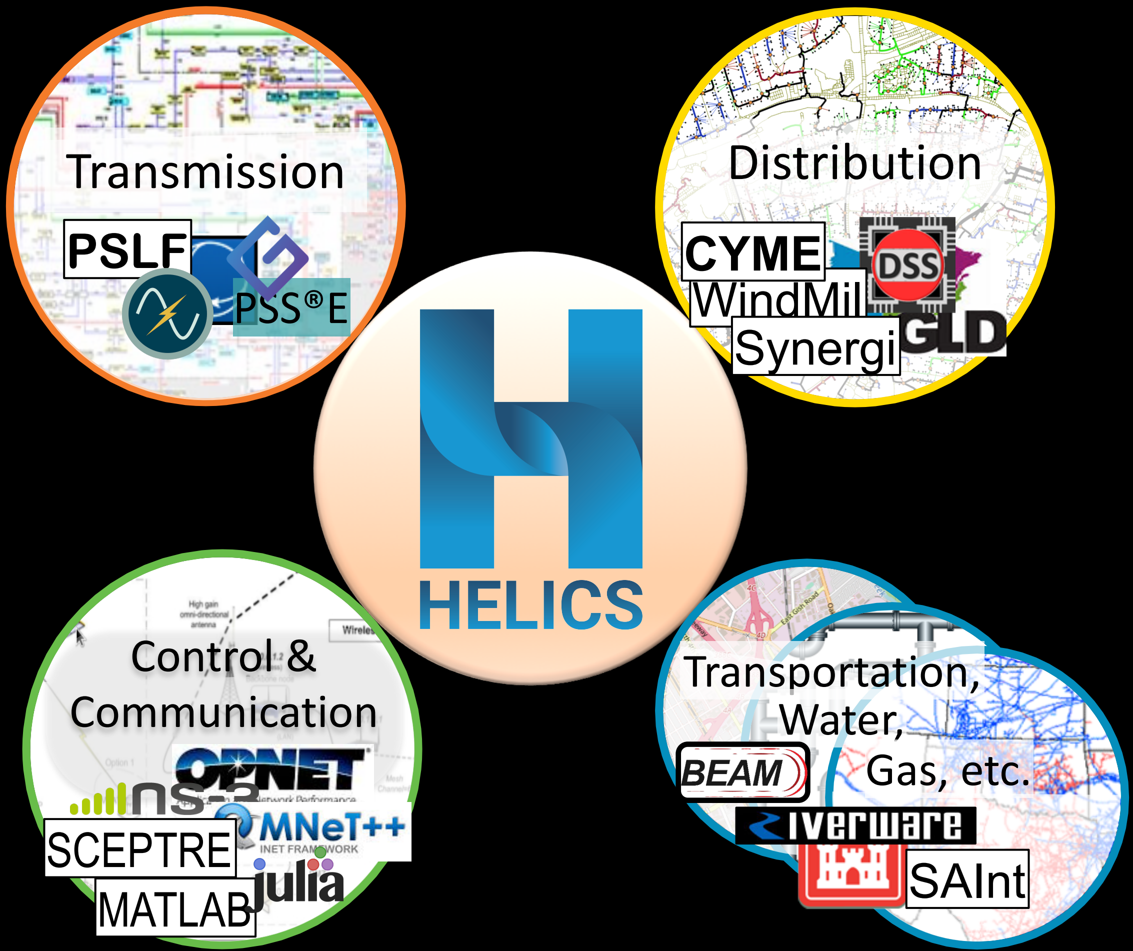
However they are largely used within their own silos of excellence.







HELICS enables easily bringing together two or more existing tools, exchanging data as time advances, to form a tightly integrated ***co-simulation***.



HELICS™: Hierarchical Engine for Large-scale Infrastructure Co-Simulation

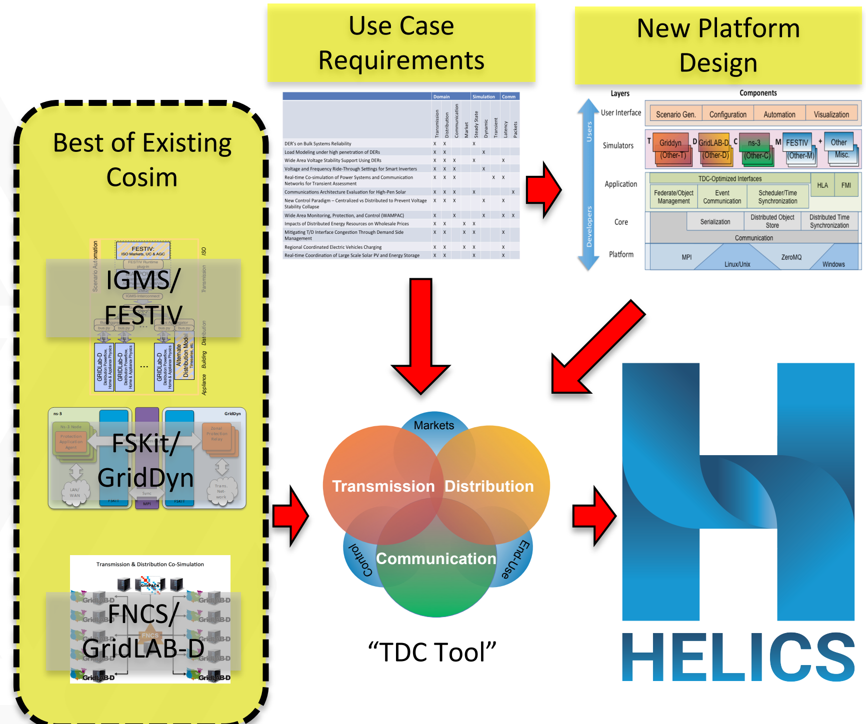
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project funding: GMLC 1.4.15

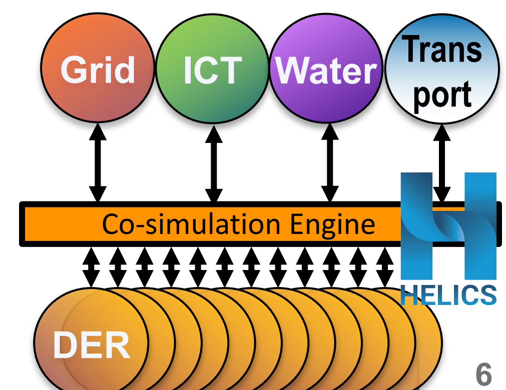
Scalable, High-performance co-simulation to combine best-in-class tools for breakthrough grid modernization simulation and analysis

Capabilities:

- **Scalable:** 2-100,000+ Federates
- **Cross-platform:** HPC (Linux), Cloud, Workstations, Laptops (Windows/OSX)
- **Modular:** mix and match tools
- **Minimally invasive:** easy to use lab/commercial/open tools
- **Open Source:** BSD-style.
- **Many Simulation Types:**
  - Discrete Event
  - QSTS
  - Dynamics
- **Co-iteration enabled:** “tight coupling”
- **APIs:** C++,. C, Python, Java, Matlab, Julia, FMI



v2.0.0 available now at https://www.github.com/GMLC-TDC/HELICS-src



B. Palmintier, et al., “Design of the HELICS High-Performance Transmission-Distribution-Communication-Market Co-Simulation Framework,” Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, Pittsburgh, PA, 2017.

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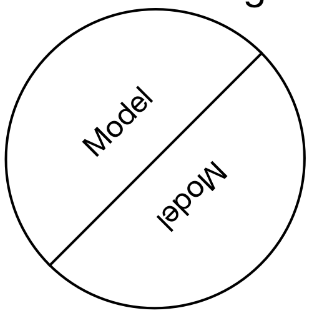
Computational Integration Workflows

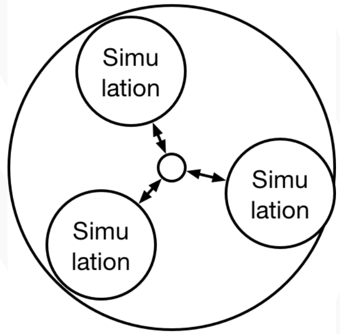
Slide adapted from Dr. Wes Jones, NREL

Co-Modeling



SIIP Optimization
Julia-JuMP

Co-Simulation



IGMS
HELICS/CoSim

Co-modelling is "w[h]ere **models are described in a unified language**, and then simulated."[1]

Co-simulation "consists of the theory and techniques to enable global simulation of a coupled system via the composition of simulators. **Each simulator is a black box** mock-up of a constituent system, developed and provided by the team that is responsible for that system."[1]

[1] Gomes, Cláudio et al. "Co-simulation: State of the art." CoRR abs/1702.00686 (2017): n. pag.
Figures: Gomes, Cláudio et al. "Co-Simulation: A Survey." ACM Comput. Surv. 51 (2018): 49:1-49:33.

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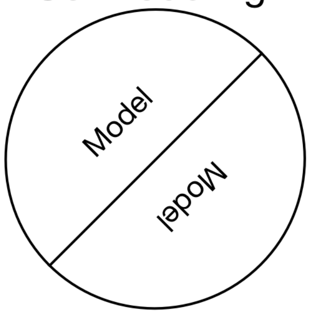
Co-Modeling



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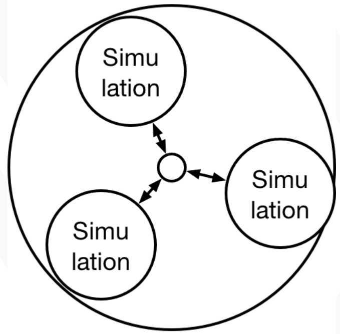
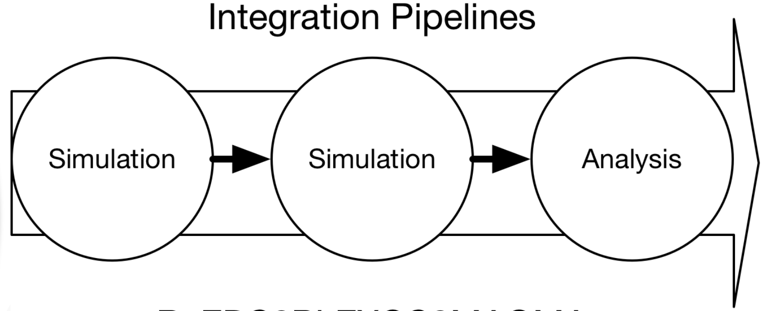


IGMS
HELICS/CoSim

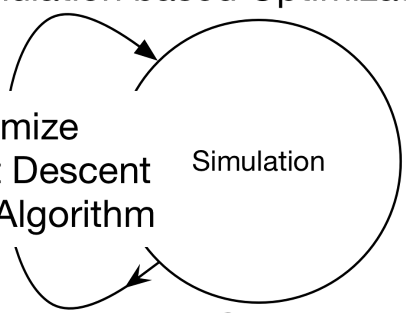
Integration Pipelines



ReEDS2PLEXOS2MAGMA
Luigi

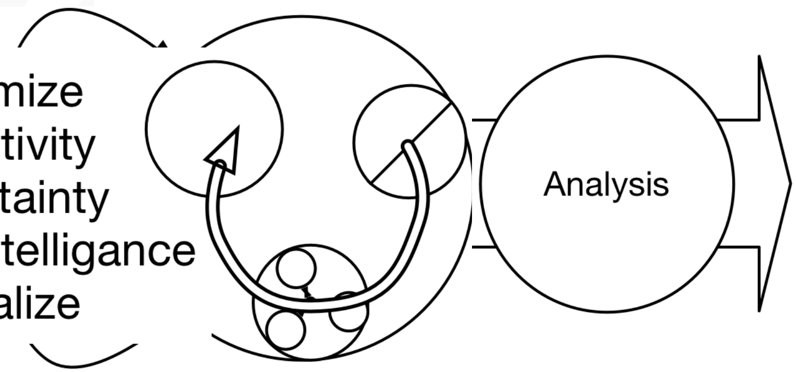
Simulation based Optimization

Optimize
Gradient Descent
Genetic Algorithm



WISEDEM
MDAO

Optimize
Sensitivity
Uncertainty
Artificial Intelligence
Visualize



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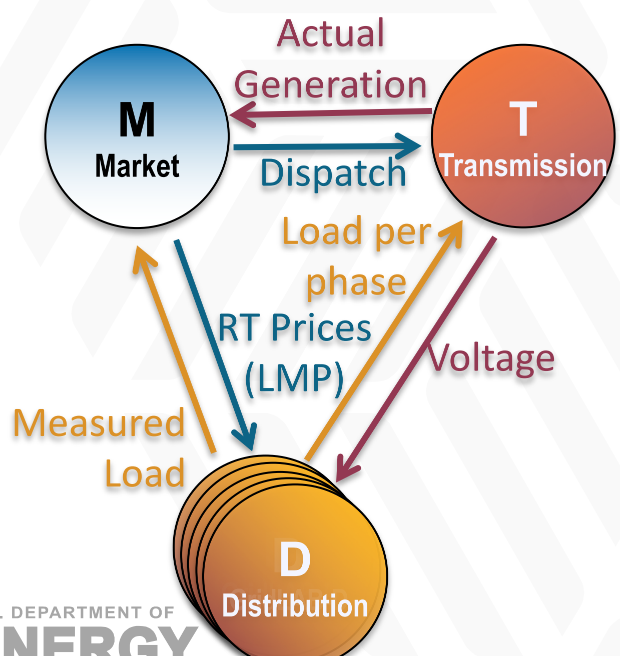
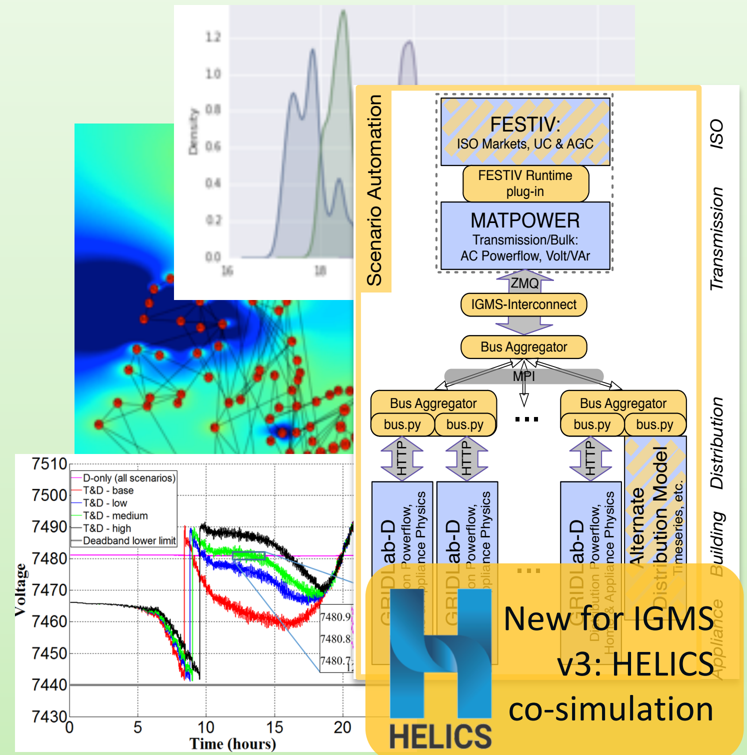
"Cyber"-Physical Simulation

e.g. Transmission-Distribution-Market

- Physical Data (Values)
  - Voltage, Frequency, Current
- Market Data (Messages)
  - Measured Load, LMPs



Large-scale DER-Market Interactions

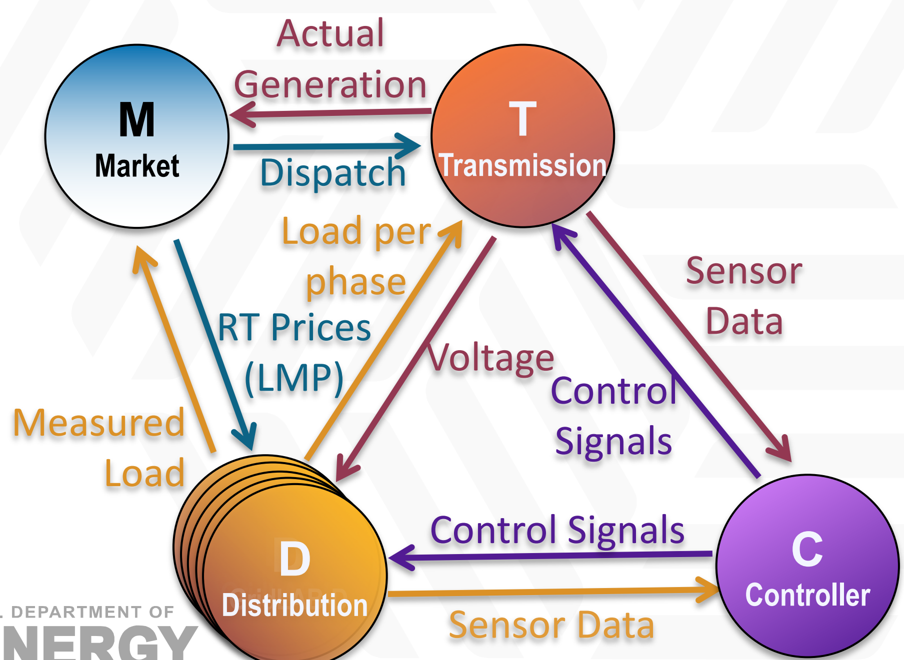


NREL's Integrated Grid Modeling System (IGMS) provides a full-scale co-simulation with transmission-level markets, 1000s of distribution feeders, and 1Ms of DERs

Adding Controllers…

e.g. Control Architecture Scaling & Performance

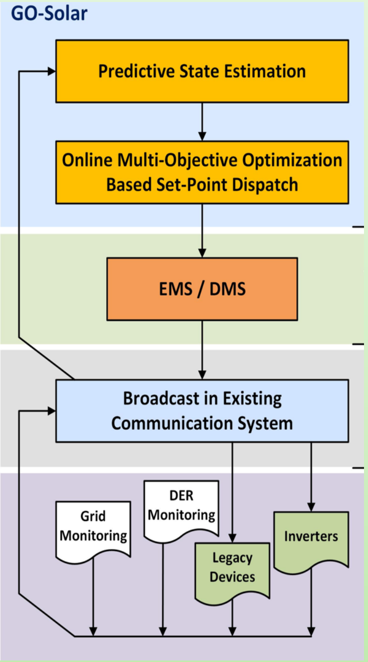
- Physical Data (Values)
  - Voltage, Frequency, Current
- Market Data (Messages)
  - Measured Load, LMPs
- Controller Data (Messages)
  - Sensor Readings, Control Signals



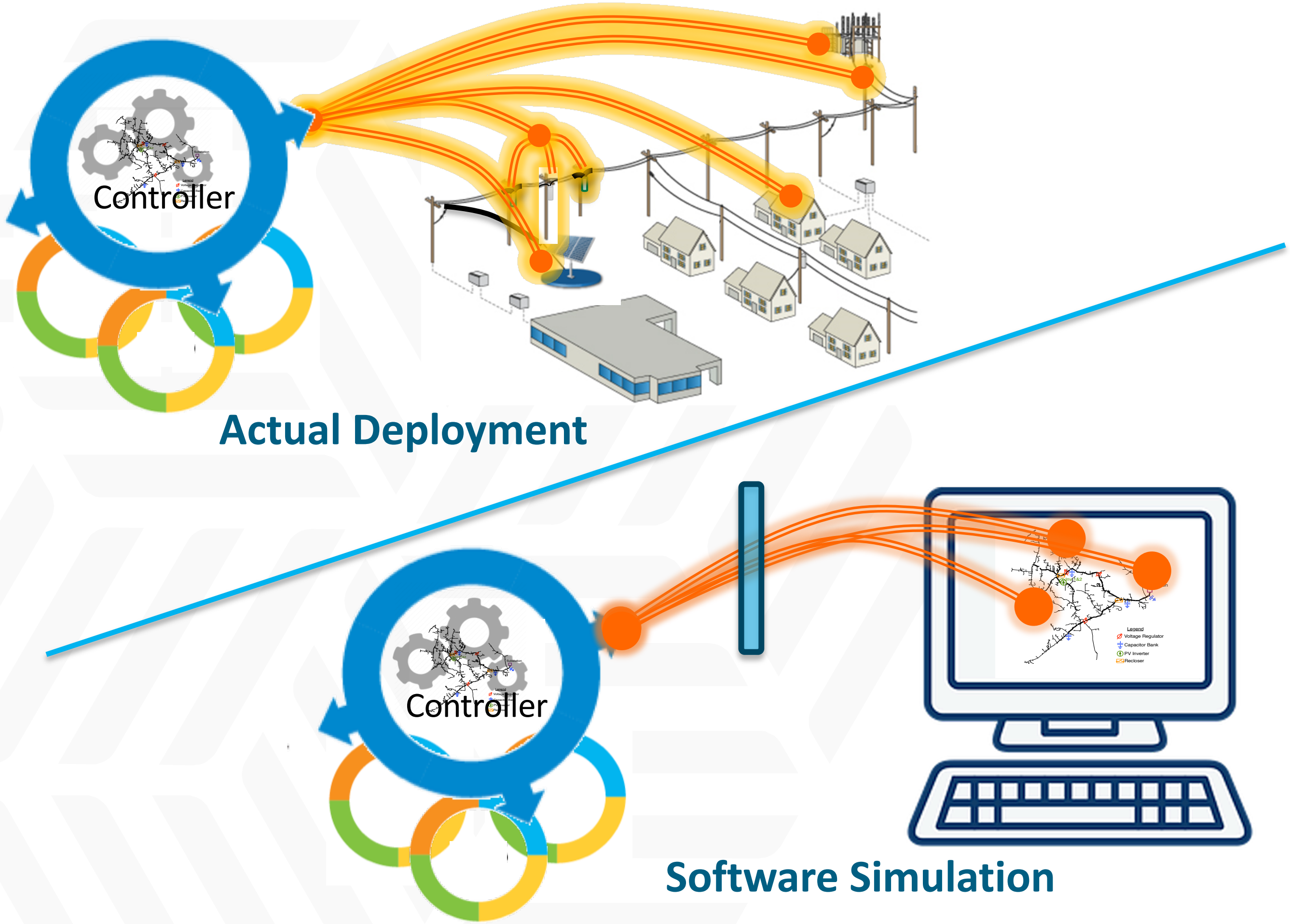
Novel T&D Control Architecture

__Design:__ Predictive State Estimation & Machine Learning Control

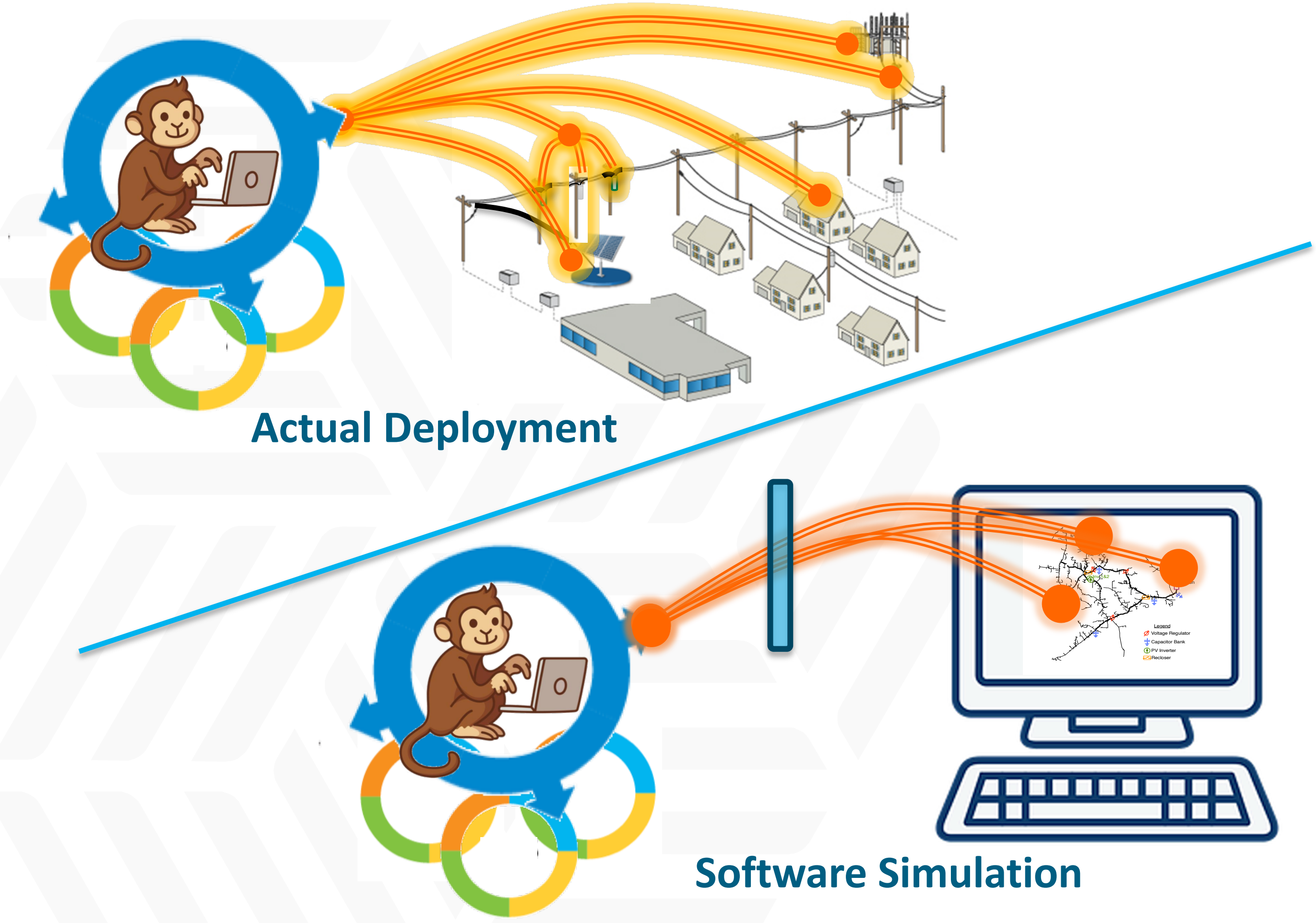
__Grid Sim:__ Entire Island of Oahu, HI with >1M electric nodes.



Keeping the wires uncrossed



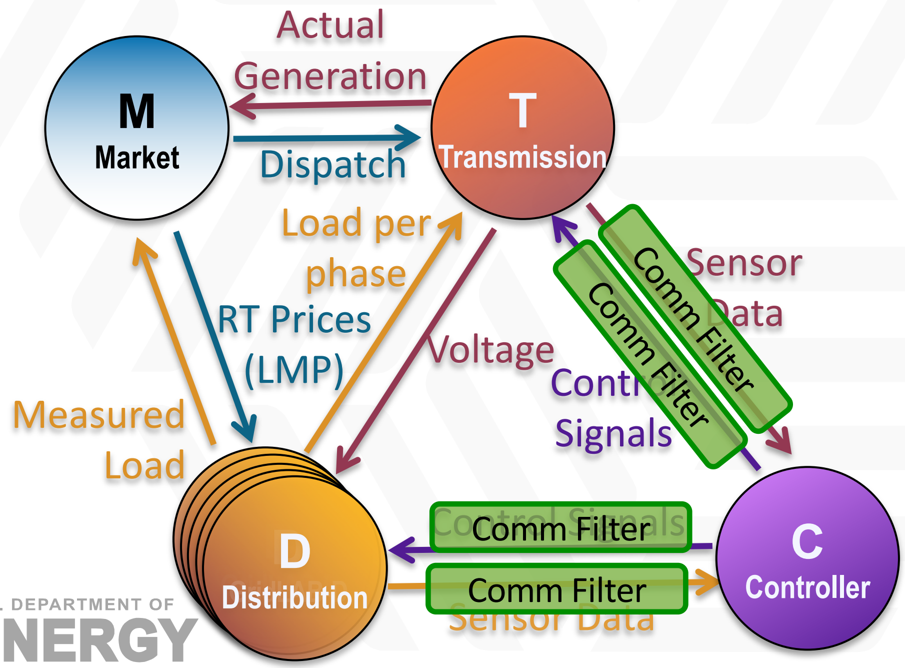
Keeping the wires uncrossed



… and Simple Communication

e.g. Design-stage Cybersecurity Evaluation

- Built in "Filters" for
  - Delays
  - Random drops
  - Other message effects (e.g. packetization)
  - And more
- No changes to domain models



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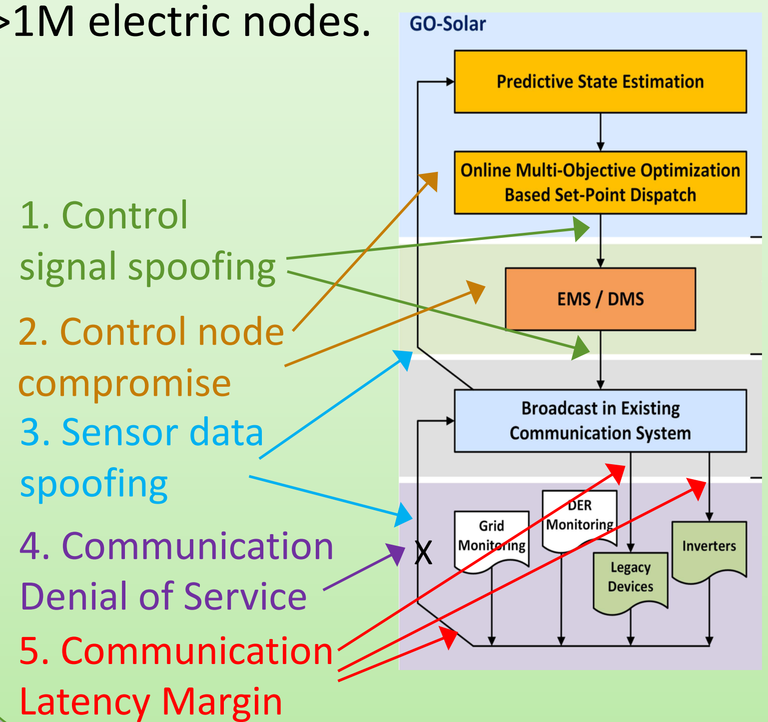
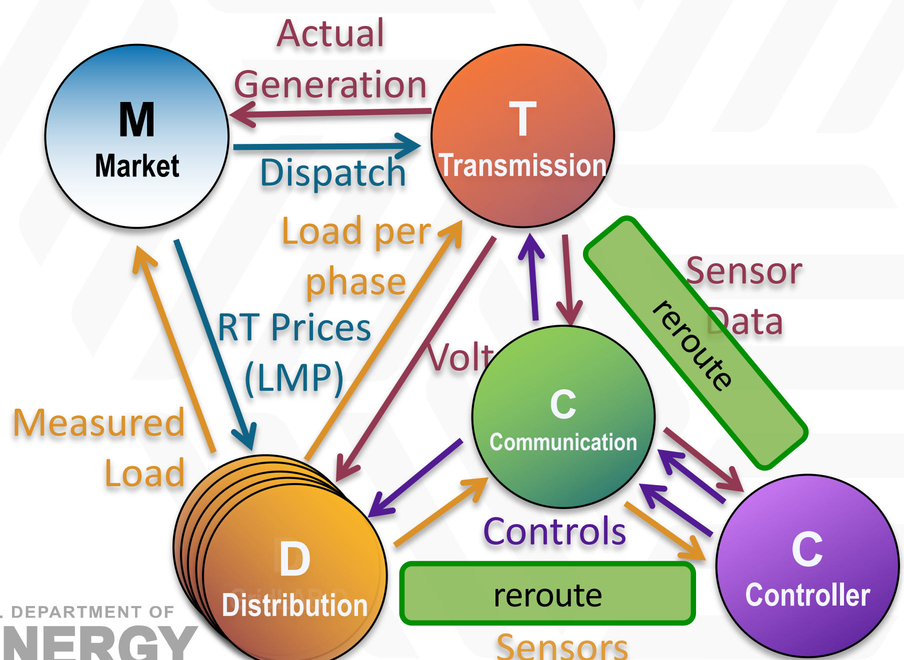


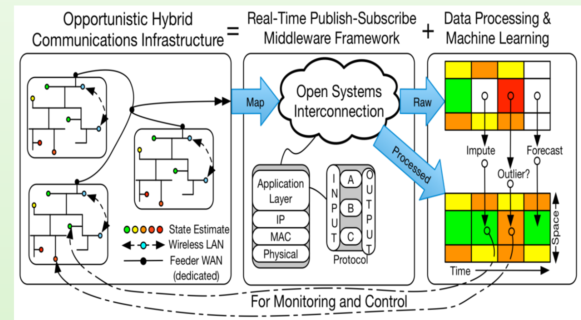
Or Detailed Communication

e.g. Protocol Comparison for Situational Awareness

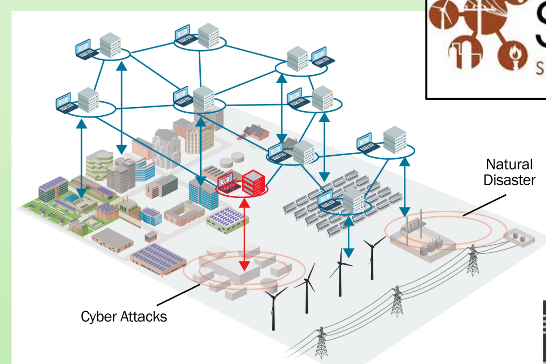
- Full communication simulation:
  - Shared bandwidth
  - Network Specific Vulnerabilities
  - Potential Tools: ns-3, Opnet++, SCEPTRE, etc.
- No changes to domain models



Protocol/Full-Stack Performance



Project Ex: SuNLaMP Hybrid Comms



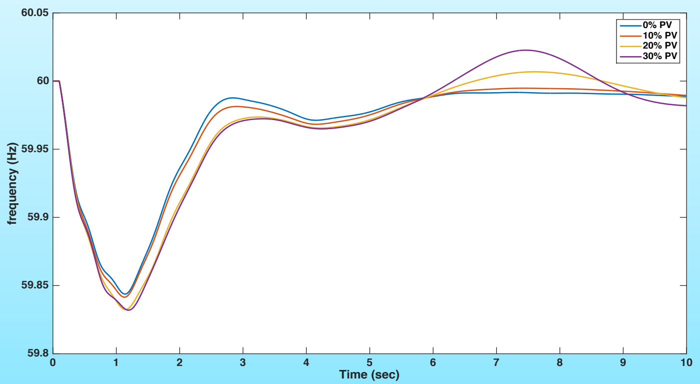
SCEPTRE scada-as-a-plaftorm™

HELICS

DSS

Ex: Power-Comm. Emulation

Some Other Use Cases

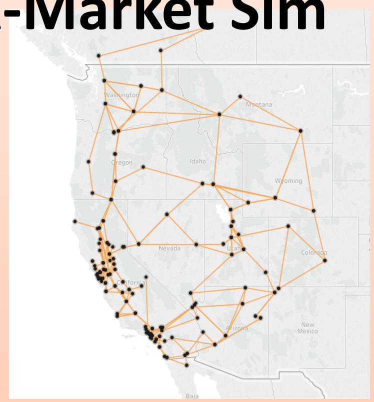


T&D frequency stability with high DER

ADMS Testbed and other PHIL

Large-scale DER-Market Sim

- 35k feeders
- WECC-240 trans.
- 25M homes
- Simplified CAISO-style Market



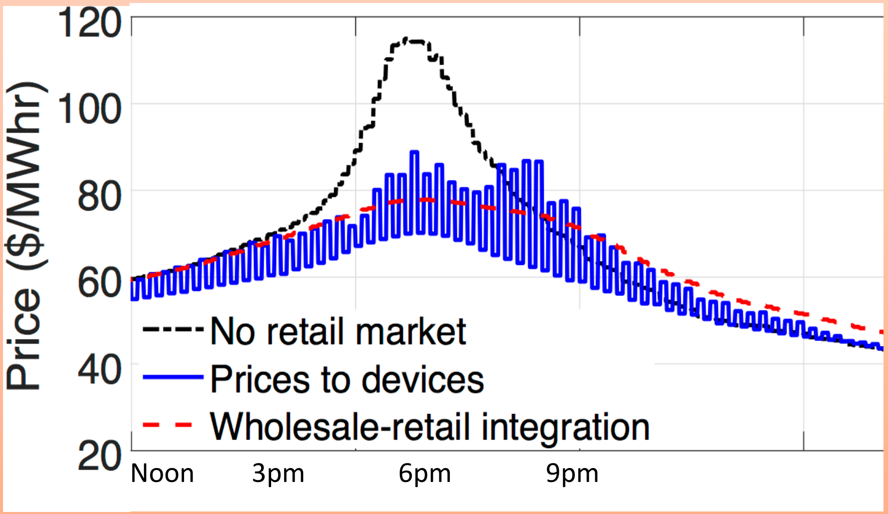
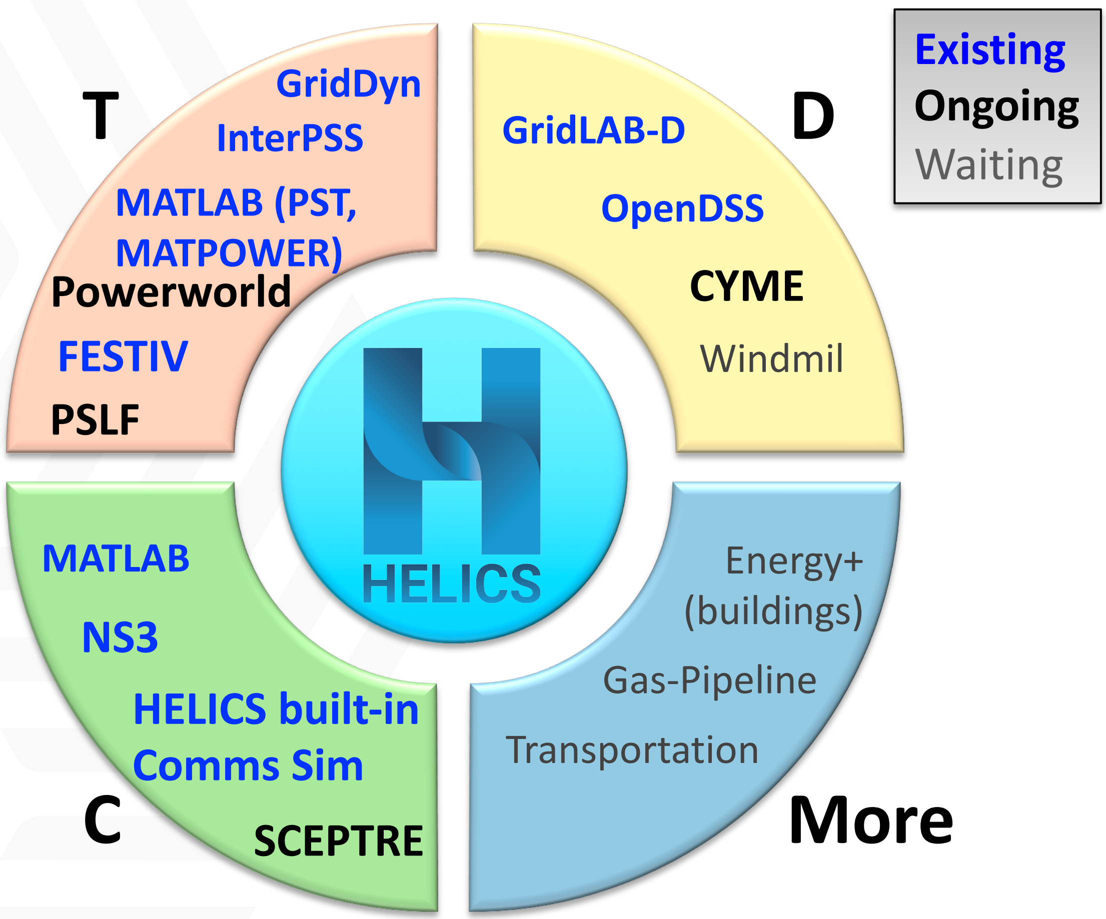


Figure from Trevor Hardy, PNNL

HELICS Interfaces to Domain Simulators

Not exhaustive lists.

- Growing mix of tools
- Enable large-scale interdependency all-hazards studies: scale to 100,000+ domain simulators
- Diverse simulation types:
  - Continuous, discrete event, time series
  - Steady-state/dynamic/transient
  - Any energy system
- Support standards: HLA, FMI, …
- **APIs:** C++,. C, Python, Java, Matlab, Julia, FMI



Thank You

HELICS v2.0.0 available at https://www.github.com/GMLC-TDC/HELICS-src

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NREL/PR-5D00-73977

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