Innovation for the Transformer Supply Chain

Andre Pereira
Program Manager, Transformer Resilience and Advanced Components

U.S Department of Energy

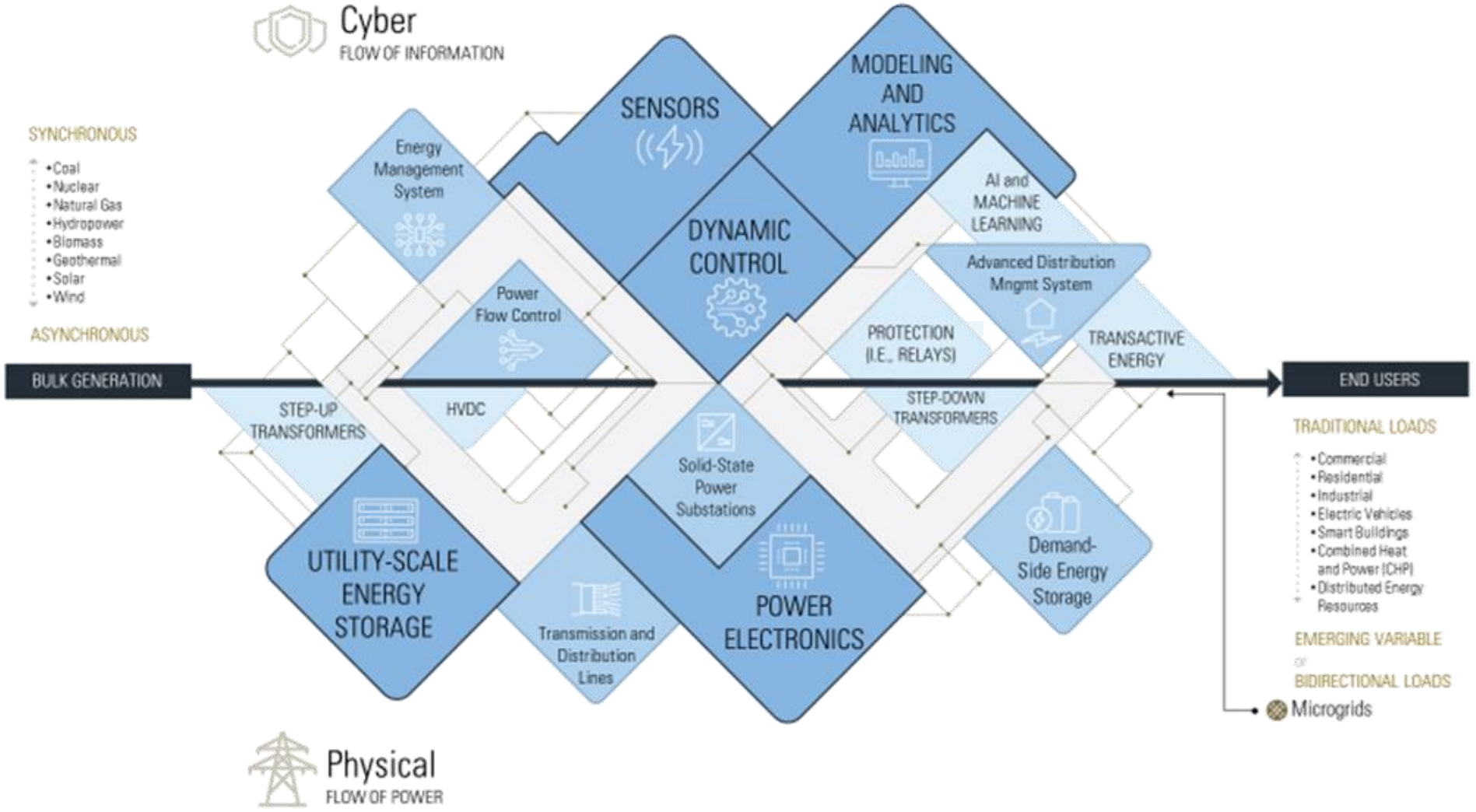
Mission: To ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

+10,000 federal workers with an additional +80,000 management and operating contractors and other contractor employees at the Department's headquarters in Washington, D.C., and at 85 field locations.

17 National Laboratories first launched 79 years ago, they have delivered solutions to some of the most pressing national challenges, garnering +118 Nobel Prizes and discovering 22 elements on the periodic table along the way.

4 Power Marketing Administration that deliver more than 44 percent of the nation's hydropower via 133 federal hydropower facilities and 34,000 miles of federal high-voltage transmission lines. The energy generated and delivered serves more than 60 million homes and businesses, or approximately 150 million people, in 33 states.

Office of Electricity



OE Priorities: Strengthening Grid Reliability and Security, and Unleashing American Energy Innovation

Overarching OE Themes

- Strengthening the Nation's electricity system and reducing costs for American families
- Prioritizing innovation towards affordable, reliable, and secure grid technologies on a pathway to global energy dominance

Top Mission Priorities

- Satisfying *escalating energy growth*, including growing demand from data centers and AI, while bolstering reliability, security, and affordability
- Addressing the *supply of critical grid components*, including transformers and breakers, to facilitate grid buildout, replacement, and resilience
- Ensuring reliability, safety, and security in an *increasingly sophisticated and aggressive threat environment*

Why are transformers a concern?

Critical grid equipment:

- Changes voltage levels at different points in the transmission and distribution system, enabling electric power delivery from generators to consumers
- Susceptible to damage from major weather events, physical attacks, and supply chain disruptions

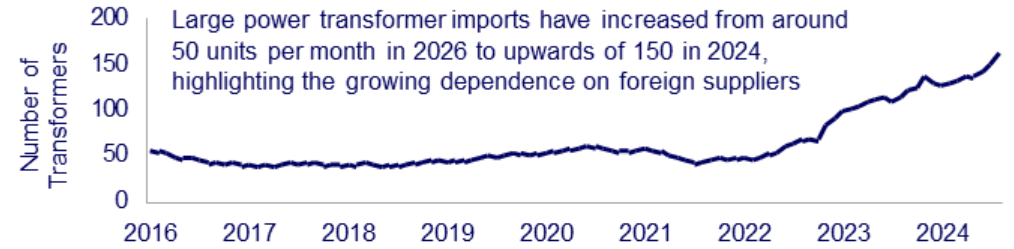
Large power transformers:

- Limited interchangeability (~1.3 made per design)
- Long delivery lead times, few U.S. manufacturers
- Difficult to transport (largest ~400 tons)
- Often located in isolated and unprotected areas

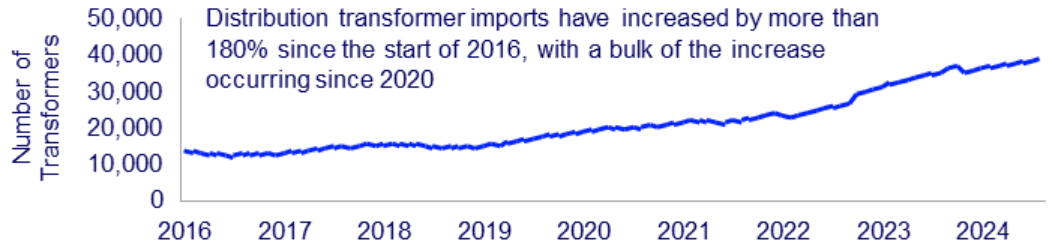
Distribution transformers:

- Estimated 160–260% capacity increase above 2021 levels needed by 2050 to meet projected demand
- Delivery times have increased from months to years
- Over 80,000 configuration types, limiting manufacturability

Monthly Large Transformer (>100 MVA) Imports (2016 – 2024)



Monthly Distribution Transformer Imports (2016 – 2024)



Source: US Trade Census

Addressing transformer supply chain challenges with a comprehensive, integrated approach

Innovative Transformer Technologies

- Flexible LPTs
- Hybrid Transformers
- Solid State Transformers

Improving Reliability

- Advanced Health Monitoring
- Seismic Resilience R&D

Advanced Materials R&D

- Alternative Core Materials
- Advanced Transformer Insulation

Streamlining Transformer Specifications

- Distribution transformer taxonomy
- Configuration matrix
- Interchangeability matrix

Innovative Transformer Technologies

Flexible and Innovative Transformer Technologies (FITT) FOA

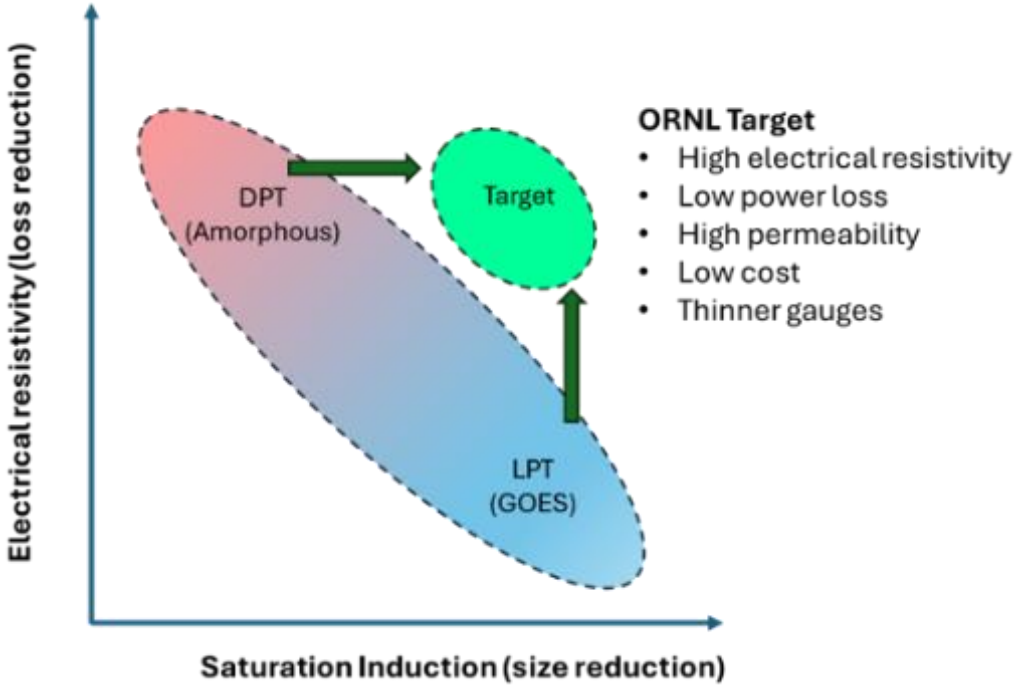
- FOA Objective: To stimulate innovative prototypes, and field demonstration exercises for advanced distribution and/or power transformers (e.g., flexible, modular, scalable, hybrid, and solid-state transformers) that can be readily utilized across a range of distribution to transmission scale applications.
- Selections were announced on **Dec 3rd, 2024**.
- Nine projects selected to receive over $20M in federal funding. Projects selected are **currently** ongoing award negotiations.

Anticipated Project Leads and Participants

Advanced Materials R&D

GOES Alternative Electrical Steels for Transformers (GOAST)

- **Project Summary:** Develop high efficiency electrical steels as a replacement for existing GOES in the LPT and high induction new amorphous steels for DPT's.
  - Objective 1: Amorphous alloys for distribution power transformers and high frequency transformers.
  - Objective 2: Development of Fe-3%SI GOES replacement steel for transformers



Multiphysics Optimization of Iron Nitride Based Transformers

- **Project Summary:** Multiphysics Optimization of Iron Nitride Based Transformers uses multi-objective optimization to design, build, and demonstrate the world's first soft magnetic iron nitride line frequency transformer.
  - A path to 50% reduction in core energy losses for line frequency transformers compared to Si steel (at equivalent or greater flux densities)
  - Iron nitride powder composed of very abundant elements

Spark plasma sintering (SPS) instrument at Sandia Labs

Minnealloy: Critical-Material-Free, High-Power, High-Frequency Transformer Cores

Sandia National Laboratories

University of Minnesota

- **Project Summary:** Provide supply chain resilient, critical-material-free transformer cores which outperform today's state of the art in power transfer, size, and frequency response.

Soft Magnet Material	Saturation Flux Density (T)	Coercivity (A/m)	Electrical Resistivity (Ωm)	Critical Materials
Minnealloy (Fe, C, N)	≥ 2.47	5 - 197	≥ 30 x 10^{-8}	No
$Fe_{67}Co_{18}B_{14}Si_1$ (Metglas)	1.8	3	123 x 10^{-8}	Yes
$Fe_{73.5}Si_{13.5}Nb_3B_9Cu_1$ (FineMet)	1.32	1.4	120 x 10^{-8}	Near Critical
$Fe_{70}Ni_{30}$ (Permalloy)	1.6	14.4	14 x 10^{-8}	Yes
$Fe_{78}Ni_{17}Mo_5$ (Supermalloy)	0.82	0.5	58 x 10^{-8}	Yes
$Fe_{49}Co_{49}V_2$ (Hiperco® 50)	2.4	16 - 398	40.1 x 10^{-8}	Yes
$Fe_{97}Si_3$ (Si-Steel)	2.0	6	82 x 10^{-8}	Near Critical

Improving Reliability

Sandia National Laboratories

Hitachi Energy

NMRSense

- **Project Summary:** To develop a novel sensor, called NMRSense, to characterize transformer oil based on the microNMR (nuclear magnetic resonance) technology for real-time monitoring of transformer health

Small Business Innovation Research (SBIR) Program - Extending Distribution Transformer Lifetime and Increasing Reliability Through Innovation

Advanced Cooling Technologies

Resonet Energy Corp

Sensanna Incorporated

Sensible Photonics

Addressing Seismic Risks

Resonance Frequency Bushing Decoupler for LPTs

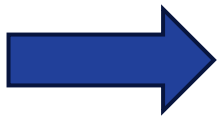
- **The Problem:** power transformers are a critical component to the united states power grid and have known vulnerabilities to seismic events
  - Dynamic coupling of bushings with tank
  - Short circuiting in the core
  - Oil leak reducing cooling ability
- **Proposed solution:** Bushing mount decoupler
  - Cost effective
  - Retrofit flexibility
  - Fits wide range of transformer designs

Full scale (**first of a kind!**) shake table test with fully dressed power transformer

Streamlining Distribution Transformer Specifications

Throughout most of 2024, DOE , Executive agencies and industry leaders held multiple meetings to discuss supply chain issues, and how to best streamline distribution transformer specifications. The DT convening was industry led, and government supported.

- Participants:
  - Trade groups
    - NEMA , IEEE, APPA, EEI, NRECA
  - There where a minimum of 5 utilities selected by each of their trade association
  - ORNL provided support
  - DOE
  - Transformer manufactures
    - Howard, Hitachi, EATON, WEG, Prolec GE, ERMCO



- DOE is currently working with a few volunteer utilities on a pilot implementation stage

Questions?

Contact Information:

Andre Pereira
Program Manager
Office of Electricity
U.S. Department of Energy
andre.pereira@hq.doe.gov

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