Current Trends in Distributed Wind Energy Technologies

Kamila Kazimierczuk (PNNL), **Jen King** (NREL), **Brent Summerville** (NREL)

Moderated By: **Sarah Barrows** (PNNL)

Distributed Wind Hybrid End-Uses and Applications

September 23, 2025

Kamila Kazimierczuk
Lindsay Sheridan
Jacob Garbe

U.S. DEPARTMENT of ENERGY
BATTELLE
Pacific Northwest NATIONAL LABORATORY

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-216601

Distributed Wind Characteristics

- Distributed wind (DW) installations can be:
  - Scaled in size (ranging from less than 1 kilowatt (kW) to multiple megawatts (MW))
  - Interconnected for onsite, local use, and off-grid applications (or to meet energy needs on the customer-side of the meter, loads on the same distribution line, or loads not connected to any local lines)
  - Combined with other energy resources to achieve a more consistent generation profile (or enhance system resilience and reliability)

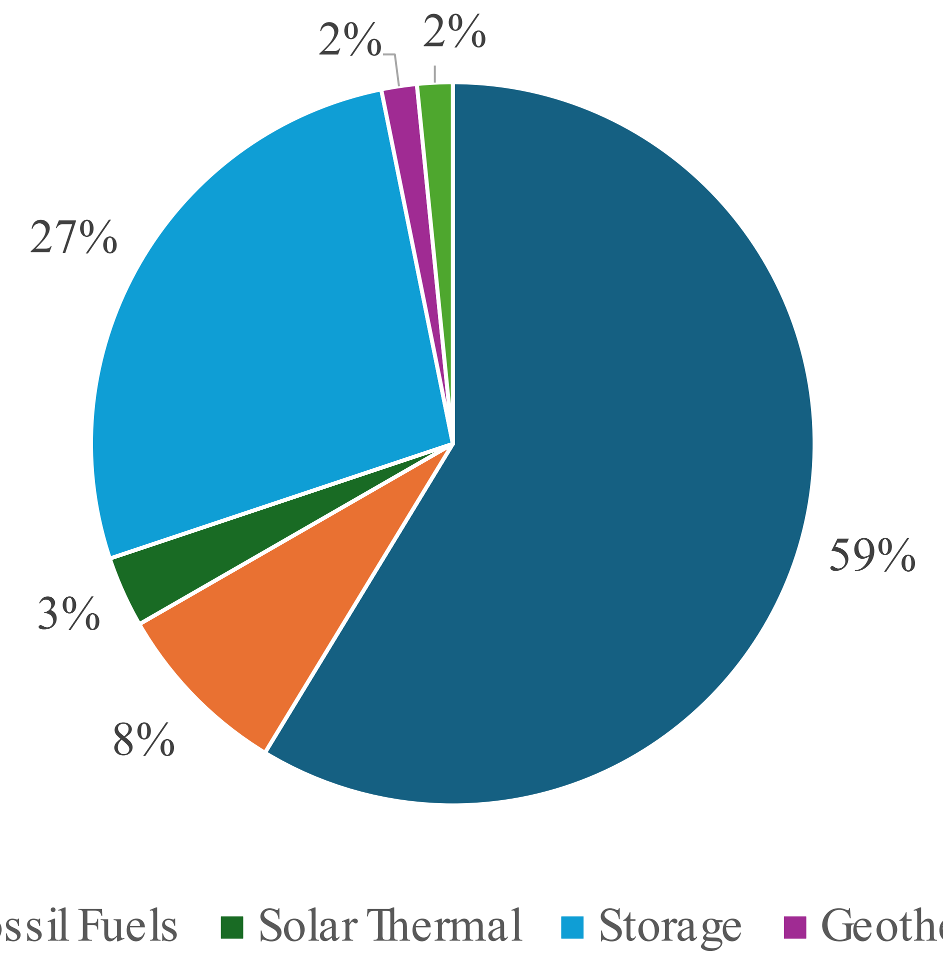
Small Distributed Wind Turbines:
Capacity ≤ 100 kW

Midsize Distributed Wind Turbines:
100 kW < Capacity ≤ 1 MW

Large Distributed Wind Turbines:
Capacity > 1 MW

Hybrid Systems

Hybrid system: refers to co-located and co-operated energy resources with shared components and control strategies



Representation of energy resources in distributed wind hybrid installations (by total number of resources in documented projects), 2015-2024

For a sample of 44 (new and repowered) distributed wind hybrid projects documented between 2015 and 2024:

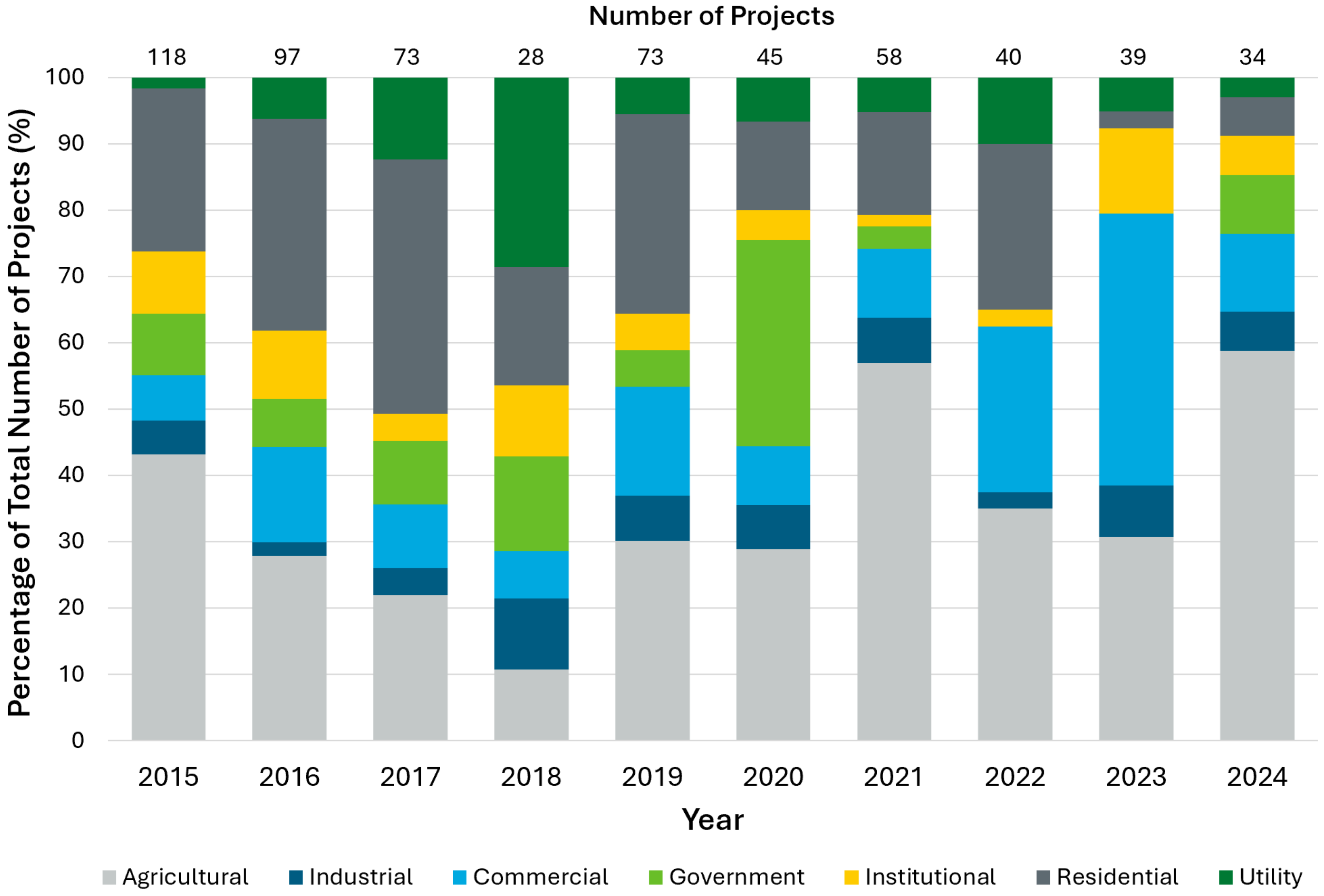
- Solar PV represented 60% of total number of hybrid resources, followed by:
  - Battery storage at 27%
  - Fossil fuels (coal, diesel, natural gas) at 8%
  - Solar thermal at 3%
  - Hydro and geothermal at 2% each

In 2024, PNNL collected reports of 5 new and repowered hybrid projects:

- All (100%) feature solar PV

Pacific Northwest
NATIONAL LABORATORY

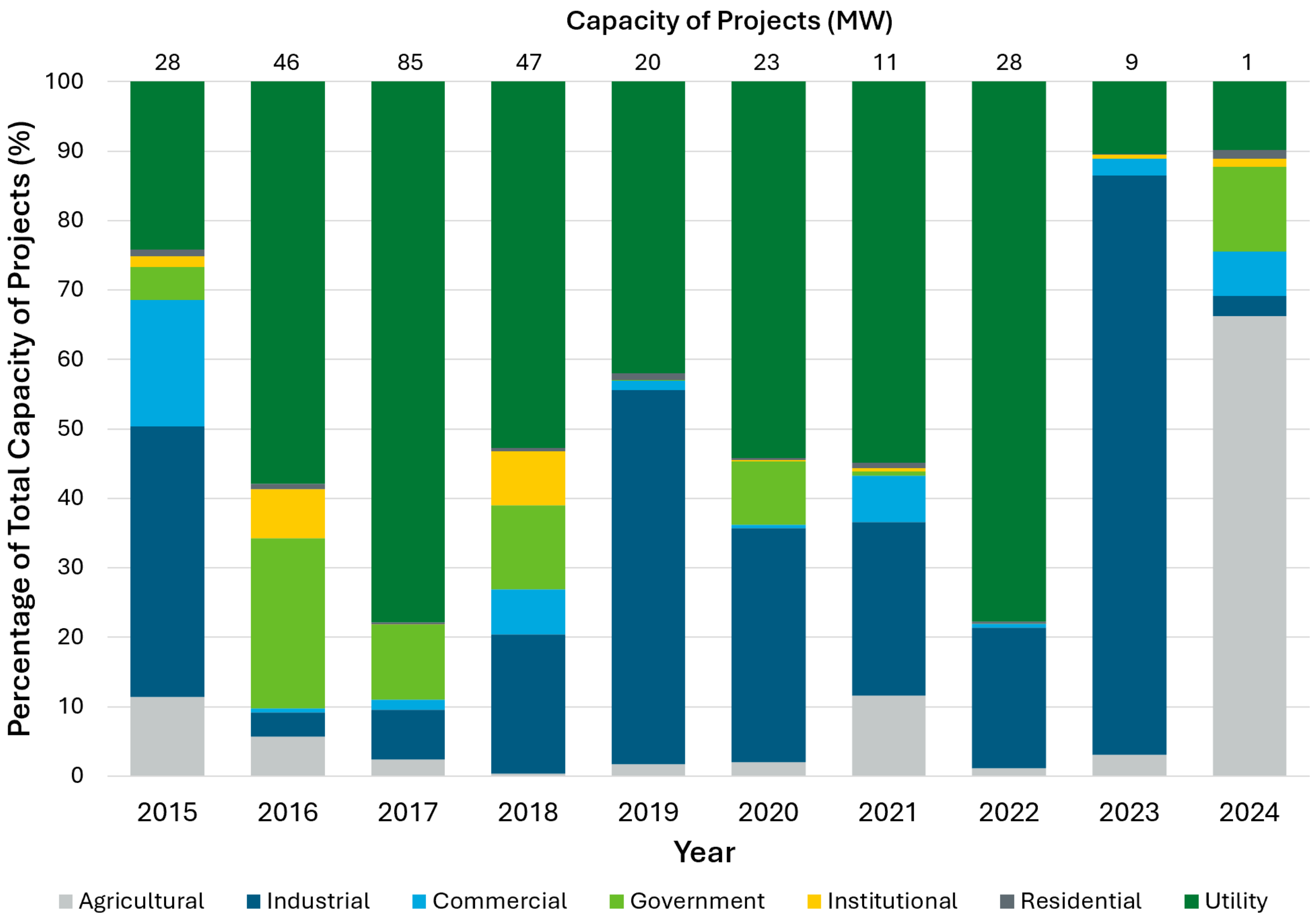
Distributed Wind Customer Trends



Distributed wind end-use customer types by number of projects, 2015-2024

- In 2024, projects for agricultural customers accounted for 59% of the number of projects installed, followed by:
  - Commercial customers at 12%
  - Government customers at 9%
  - Institutional, industrial, and residential customers at 6% each
  - Utility customers at 3%
- Of the five hybrid projects documented in 2024,
  - Two were deployed for residential customers, while the rest were installed for institutional, utility, and commercial customers (respectively)

Distributed Wind Customer Trends

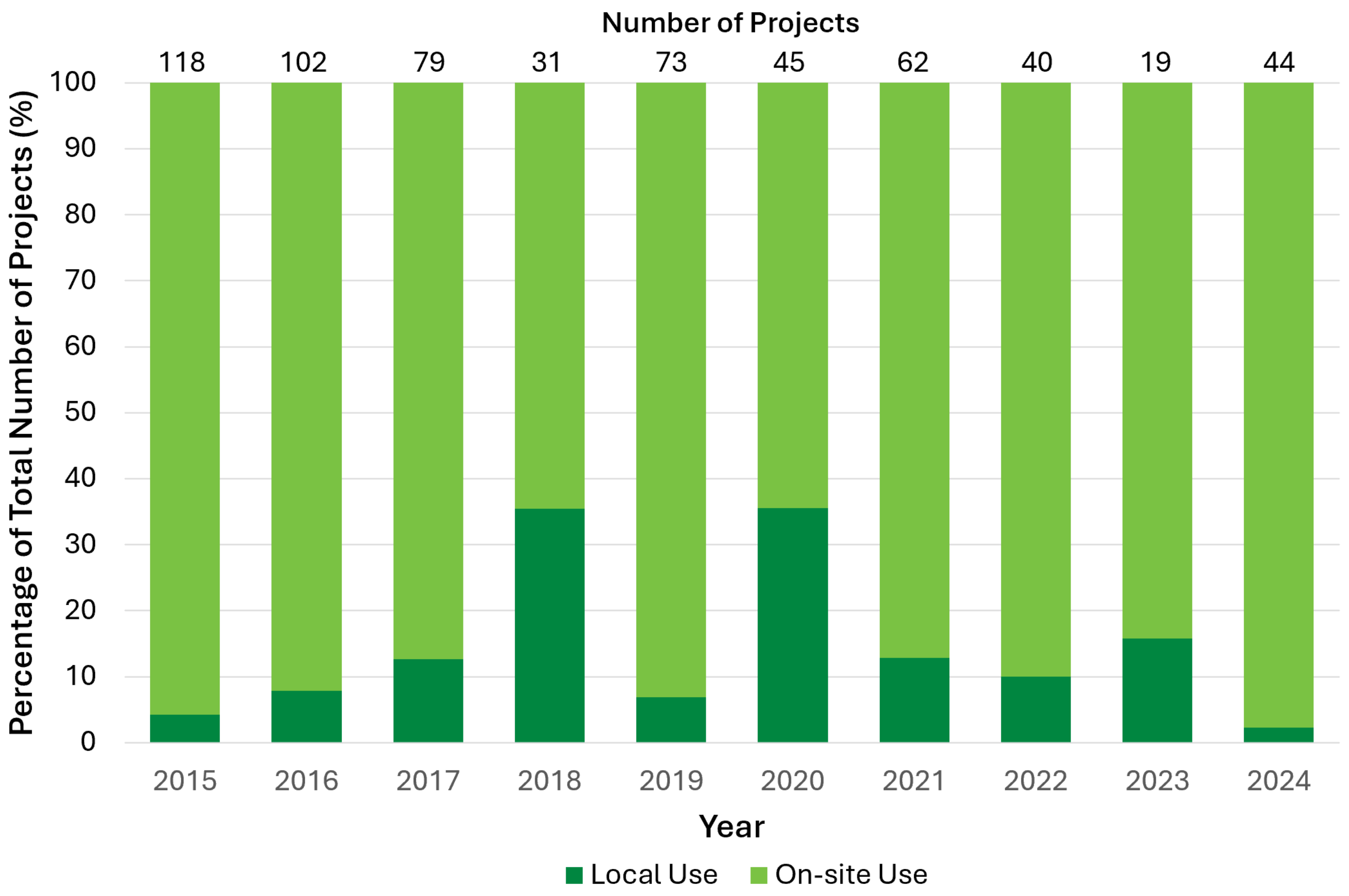


Distributed wind end-use customer types by capacity of projects, 2015-2024

- In 2024: Distributed wind deployed for agricultural customers represented 66% of the total capacity installed
  - Government customers represented the second largest share of total capacity in 2024 with 12%, followed by utility customers with 10%, which is represented by one hybrid project
- While commercial, institutional, and residential customers tend to account for the majority (#) of hybrid distributed wind projects, utility and government customers represent most of the total installed hybrid project capacity

Pacific Northwest NATIONAL LABORATORY

Distributed Wind Interconnection Trends



Distributed wind for on-site use and local loads by number of projects, 2015-2024

Two primary interconnection types exist for distributed wind:

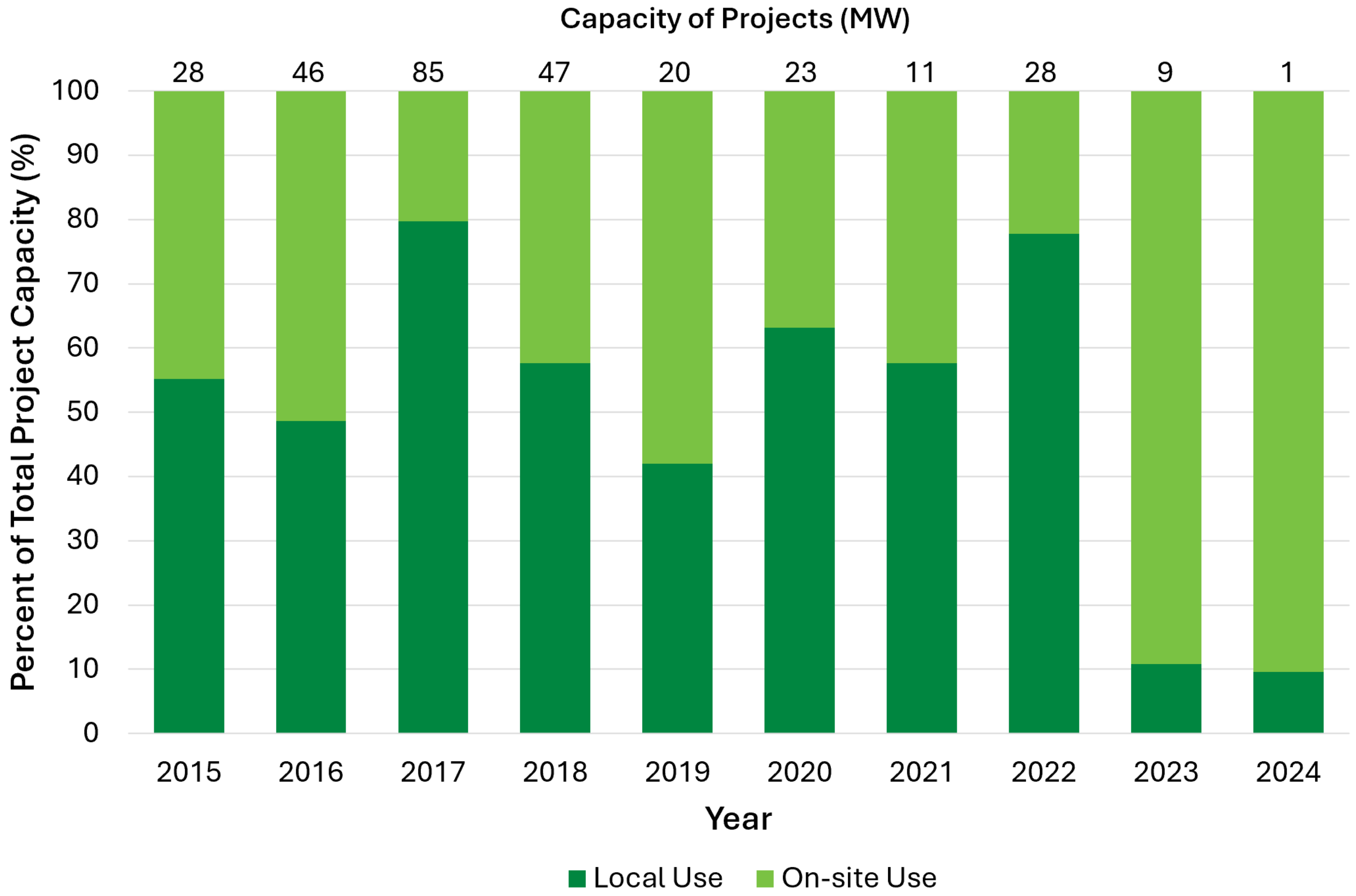
- On-site use
  Behind-the-meter, remote net-metering, grid-connected microgrid, and off-grid applications

- Local use
  Load-serving distribution line and isolated grid applications

In 2024, 98% of distributed wind projects were interconnected to provide energy for on-site use

- 91% were deployed as behind-the-meter installations
- 9% were deployed as off-grid installations, represented by four small wind hybrid projects

Distributed Wind Interconnection Trends



Distributed wind for on-site use and local loads by capacity of projects, 2015-2024

- In 2024, 90% of distributed wind capacity was deployed for on-site use, while 10% was for local use
- Projects for local use have traditionally represented more of the installed distributed wind capacity due to the projects' larger sizes and use of larger wind turbines.
- One local use project was reported in 2024, consisting of grid-connected-microgrid hybrid system with:
  - A 100 kW turbine w/ solar PV, fossil fuels (natural gas & coal), and hydro

Distributed Wind Hybrid Case Studies

Louisville Gas and Electric/Kentucky Utilities (2024)

1 x 100-kW NPS wind turbine co-located with coal-fired power plant unit, a 10 MW solar installation, several gas-fired turbines and a hydroelectric plant


Louisville Gas and Electric/Kentucky Utilities

End-Use Customer: Utility – deployed as a test turbine to gather wind performance data for potential future investment

Interconnection Type: Local use, grid-connected microgrid

System Specifications: Turbine is being paired with existing solar installation as a part of utility's "renewable integration" research

Distributed Wind Hybrid Case Studies

Niagara Fish Farm (2018)

1 x 100-kW wind turbine co-located with 12 kW tracker-mounted solar system

This distributed wind case study was assembled and published by the Distributed Wind Energy Association.

End-Use Customer: Agricultural Farm – deployed to power aquaponic facility and greenhouse

Interconnection Type: Onsite use, behind the meter

System Specifications: Hybrid system meets 100% of farm's energy needs, excess electricity is remote net-metered

Pacific Northwest NATIONAL LABORATORY

For More Information

The Distributed Wind Energy Technology Data Update shares the landscape of installations, costs, performance, incentive impacts, and more for distributed wind projects across the US.

Pacific Northwest
NATIONAL LABORATORY

Thank you

Resiliency Trends in Distributed Wind

23 September 2025

Brent Summerville, NREL

U.S. DEPARTMENT of ENERGY BATTELLE Pacific Northwest NATIONAL LABORATORY

PNNL is operated by Battelle for the U.S. Department of Energy

Resiliency trends in DW

From micro wind turbines to large, multi-megawatt projects, distributed wind projects contribute to **local energy** and **resilience** needs.

Remote, battery-charging wind turbine.
NREL PIX 44231

Small-scale wind + solar hybrid system.
Courtesy PNNL.

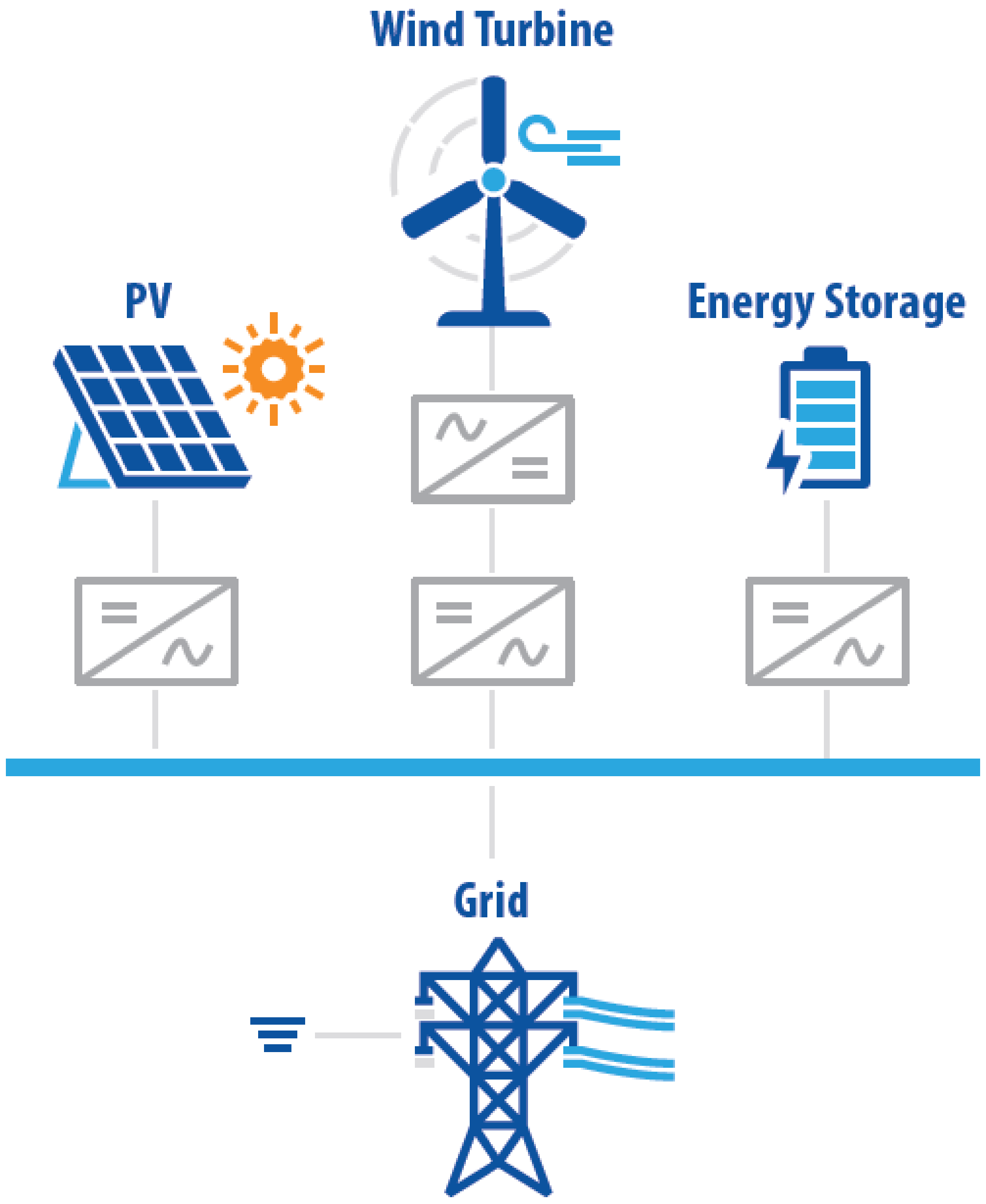
Large-scale wind + solar hybrid system.
Courtesy PNNL.

Pacific Northwest
NATIONAL LABORATORY

Resiliency trends in DW

Distributed wind turbines are setup as:

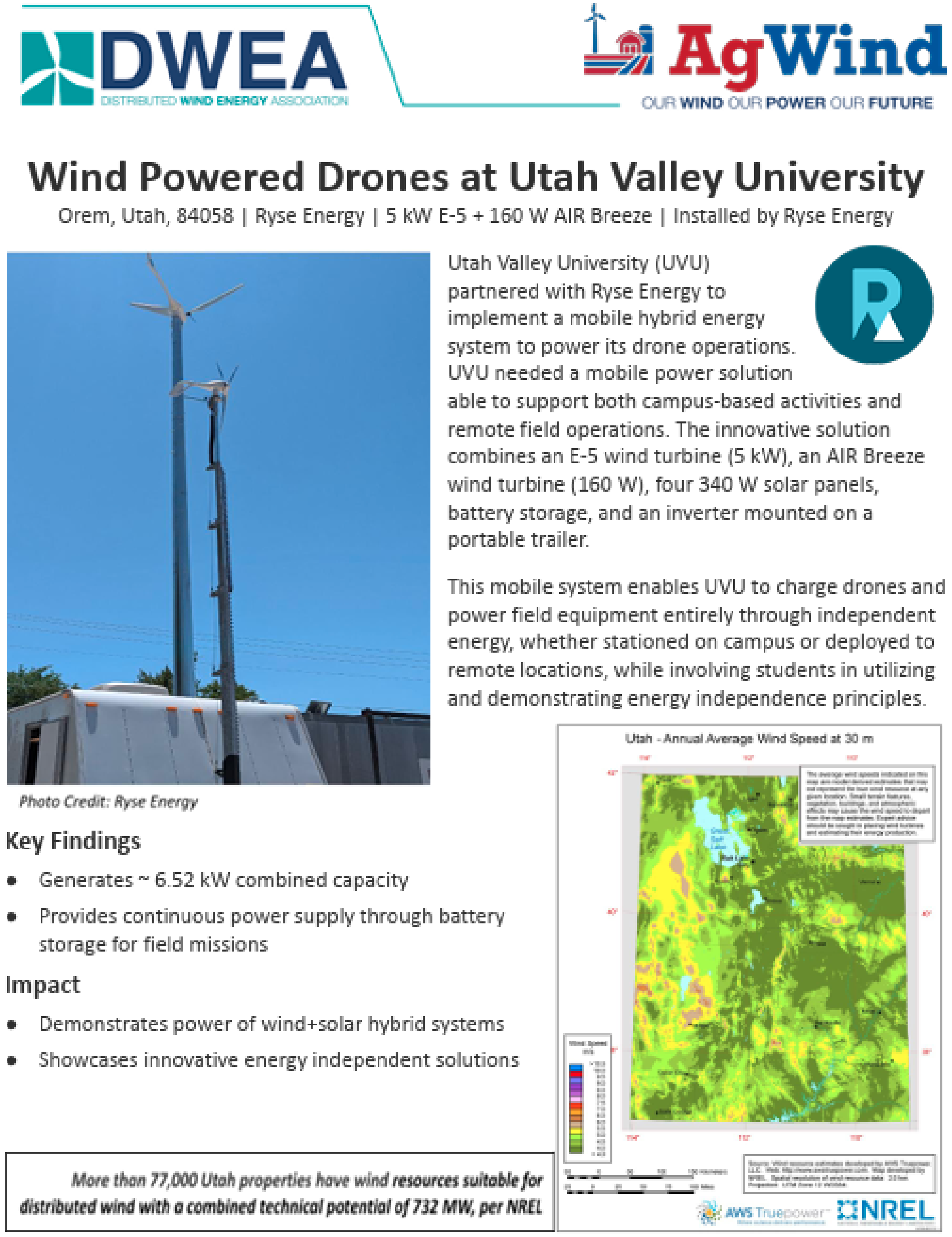
- **Grid-connected** to generate on-site energy with excess energy pushed to the grid under net-metering programs
- **Paired with batteries** to store wind energy
  - Charge batteries when demand is low and extract from batteries when demand is high
  - Provide energy during grid outages
  - Or isolated, remote microgrids
- **Combined with solar**, taking advantage of wind + solar complementarity
  - Wind tends to blow stronger at night and during the winter, overall smoother daily and seasonal energy output when paired with solar



https://inl.gov/content/uploads/2024/05/24-50111-01_Distributed-Wind_Building-Resilience_Fact-Sheet_R3a.pdf

Micro wind turbines

- **Micro wind turbines** are (nearly always) battery chargers and part of small microgrid (wind + battery + PV + loads)
- With 'micro wind turbine' emerging as a new size category in wind standards, we are now seeing **certification** in this market space which is good for consumer protection and accurate ratings. (e.g., Ryse Energy, Skywind)


DWEA DISTRIBUTED WIND ENERGY ASSOCIATION

AgWind OUR WIND OUR POWER OUR FUTURE

Wind Powered Drones at Utah Valley University

Orem, Utah, 84058 | Ryse Energy | 5 kW E-5 + 160 W AIR Breeze | Installed by Ryse Energy

Utah Valley University (UVU) partnered with Ryse Energy to implement a mobile hybrid energy system to power its drone operations. UVU needed a mobile power solution able to support both campus-based activities and remote field operations. The innovative solution combines an E-5 wind turbine (5 kW), an AIR Breeze wind turbine (160 W), four 340 W solar panels, battery storage, and an inverter mounted on a portable trailer.

This mobile system enables UVU to charge drones and power field equipment entirely through independent energy, whether stationed on campus or deployed to remote locations, while involving students in utilizing and demonstrating energy independence principles.

Photo Credit: Ryse Energy

Key Findings

- Generates ~ 6.52 kW combined capacity
- Provides continuous power supply through battery storage for field missions

Impact

- Demonstrates power of wind+solar hybrid systems
- Showcases innovative energy independent solutions

More than 77,000 Utah properties have wind resources suitable for distributed wind with a combined technical potential of 732 MW, per NREL

Utah - Annual Average Wind Speed at 30 m

AWS Truepower NREL

https://www.agwindenergy.org/dwea-case-studies/

Pacific Northwest
NATIONAL LABORATORY

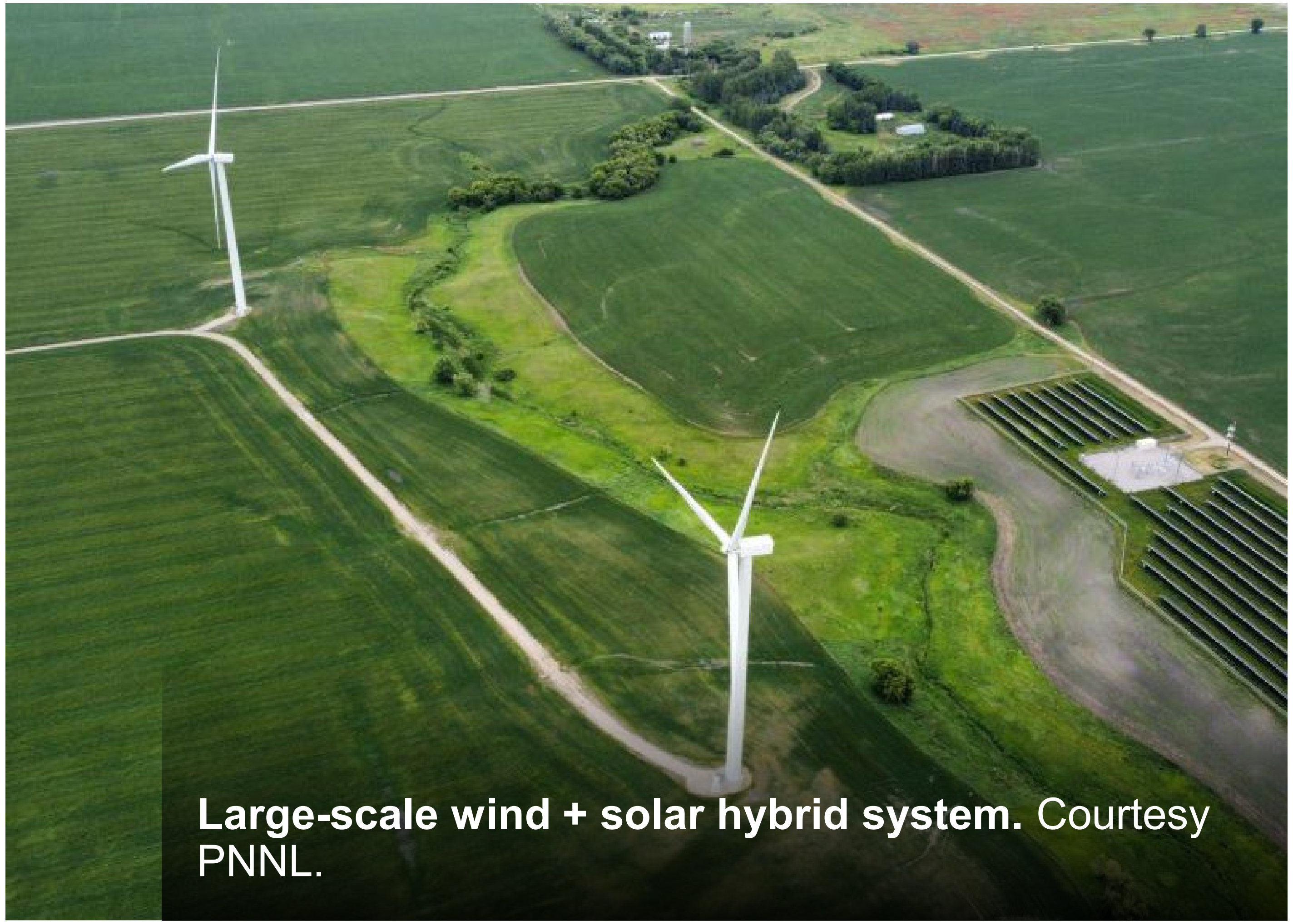
Small/medium turbines

- Majority of small to medium DW turbines sold in the US are **grid connected** (from ~ 3 kW to 300 kW) for residential, farm/ranch, and commercial applications.
- Suppliers of turbines in this size range have been busy keeping up with changing **inverter** requirements in key markets (new or upgraded inverters), **innovating** to reduce costs, and testing/certifying **new turbine models**.
- While most are grid connected, some systems include **battery energy storage.**
  - Remote areas, e.g., Alaska, where microgrids are the norm
  - In demonstration projects (e.g., Kentucky utility >>>)
  - In areas with frequent grid outages or where net metering rules and fees have become unattractive
  - Turbine manufacturers are responding to growing demand for battery storage by working to integrate battery storage into their systems (e.g., Bergey home microgrid).

NPS 100C-27 installed in Kentucky in 2024, paired with solar and battery storage.
https://kentuckylantern.com/2024/01/03/kentuckys-largest-utility-testing-winds-energy-potential-with-states-first-utility-scale-turbine/

Large wind turbines

- For large-scale distributed wind, we are seeing wind + solar + battery systems being developed (e.g., Juhl Energy) as this enables these distributed energy resources to serve as a **dispatchable energy resource**, enabling a more consistent and controllable supply of low-cost power to utilities and rural electric cooperatives.
- Many large turbines in distributed applications continue to be grid connected, **behind the meter** projects (e.g., Foundation Windpower), providing on-site generation to lower energy costs for large energy users.



Large-scale wind + solar hybrid system. Courtesy PNNL.

Battery sizes

Residential scale. *Battery systems for residential or small farm use are typically small in scale and are common in solar applications, such as this Lithium-ion system from the Solar Decathlon in Denver, Colorado (Photo by Dennis Schroeder/NREL 48540)*

Large Scale. *The 1-MW battery energy storage system sits on one of the tests pads at the NREL's Flatirons Campus. The storage system is used to validate large-scale storage solutions for high-renewable power systems. (Photo by Werner Slocum / NREL 65130)*

Pacific Northwest NATIONAL LABORATORY

Isolated Microgrid Example: Kodiak Island

Source: Kodiak Electric Association

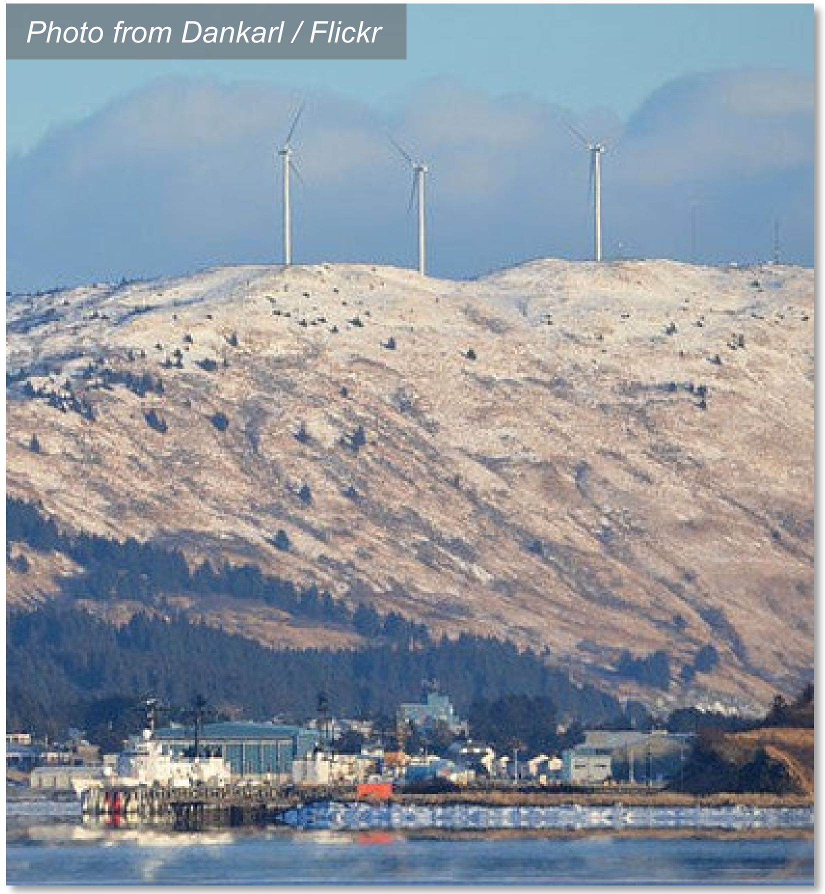


Photo from Dankarl / Flickr

Three 1.5 MW turbines in an isolated microgrid (not connected to larger distribution system) in Kodiak, AK. The island also has hydropower and battery storage systems.


Photo from Eric Keto

A **microgrid** is a self-sufficient energy grid that can operate if the wider energy system has a power outage.

Pacific Northwest
NATIONAL LABORATORY

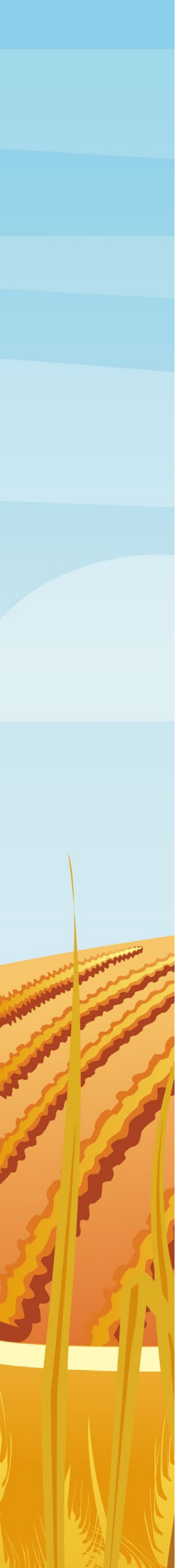
NREL Case Study

"Using a 1.5-megawatt wind turbine, a 450-kilowatt PV system, and a 1-megawatt Lithium-ion battery, NREL was able to demonstrate 72 hours of continuous operation of our buildings' loads using only renewable energy."

https://www.nrel.gov/news/video/resilience-with-100-renewable-power-text

Pacific Northwest
NATIONAL LABORATORY

Thank you



Current Trends in Distributed Wind for End Uses

23 September 2025

Jen King, NREL

PNNL is operated by Battelle for the U.S. Department of Energy

A Scalable Solution for Modern Energy Needs

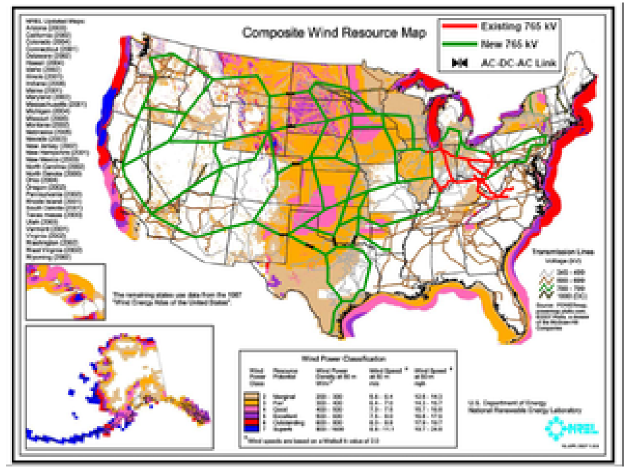
- Distributed wind serves a **wide range of applications** from farms and communities to industry and large loads.
- Plays a critical role in **balancing demand growth** while reducing reliance on new long-distance transmission
- Increasingly paired with other distributed energy resources (DERs) to create **hybrid energy systems**.

A Scalable Solution for Modern Energy Needs

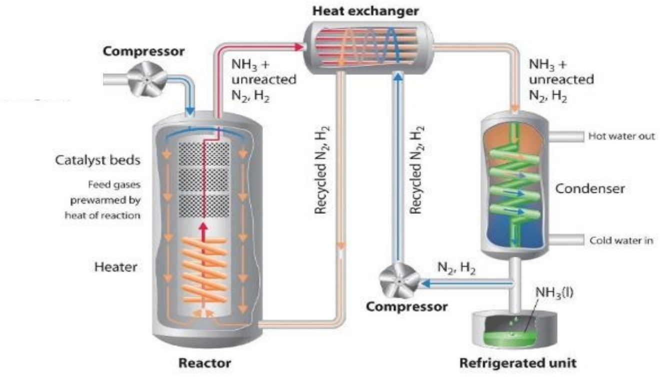
- Distributed wind serves a **wide range of applications** from farms and communities to industry and large loads.
- Plays a critical role in **balancing demand growth** while reducing reliance on new long-distance transmission
- Increasingly paired with other distributed energy resources (DERs) to create **hybrid energy systems**.

Today's Focus – Industrial and Large Load Growth

DERs and Grid

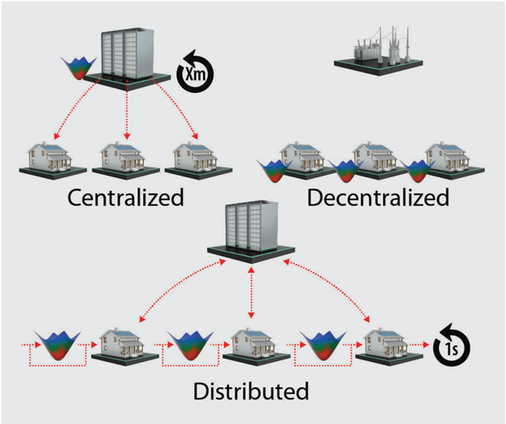


Ammonia



Haber-Bosch process

Computing

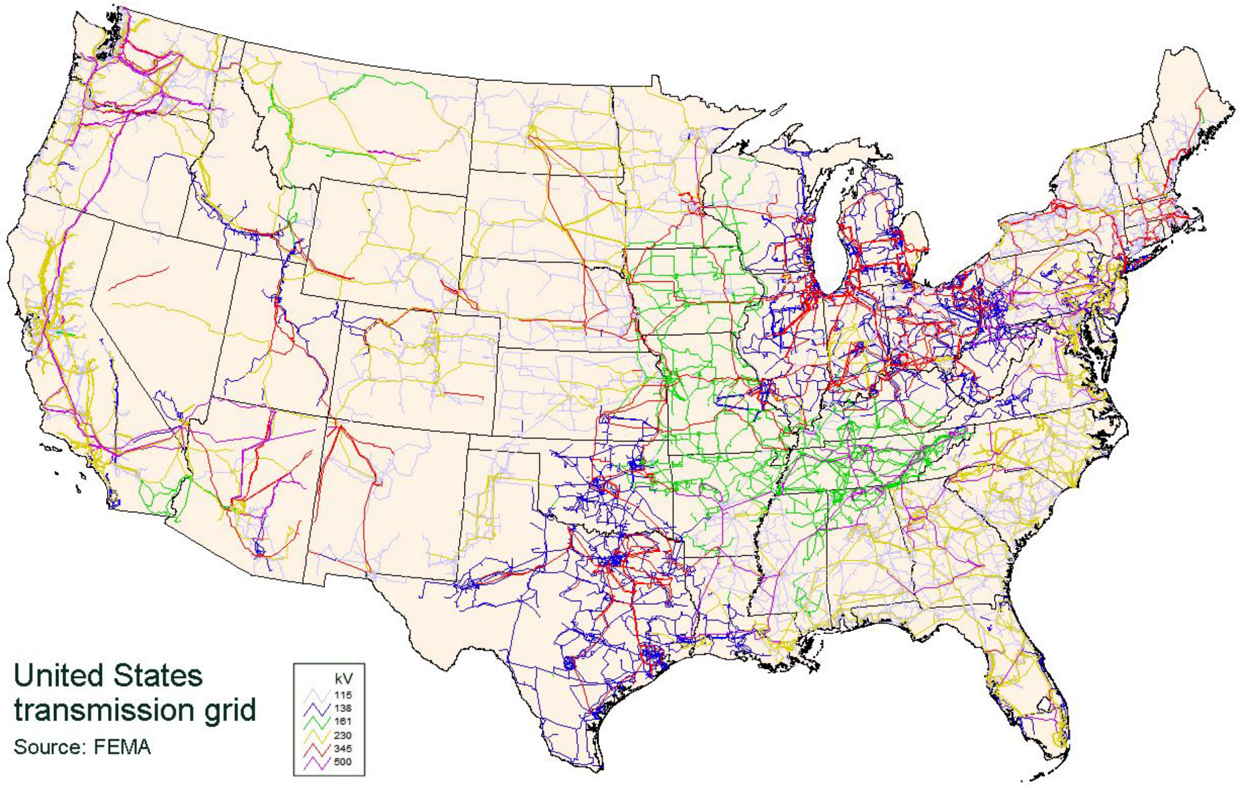


"We can't build our way out of this"

DERs and Grid Needs

The Challenge: ”We Can’t Build Our Way Out of It”

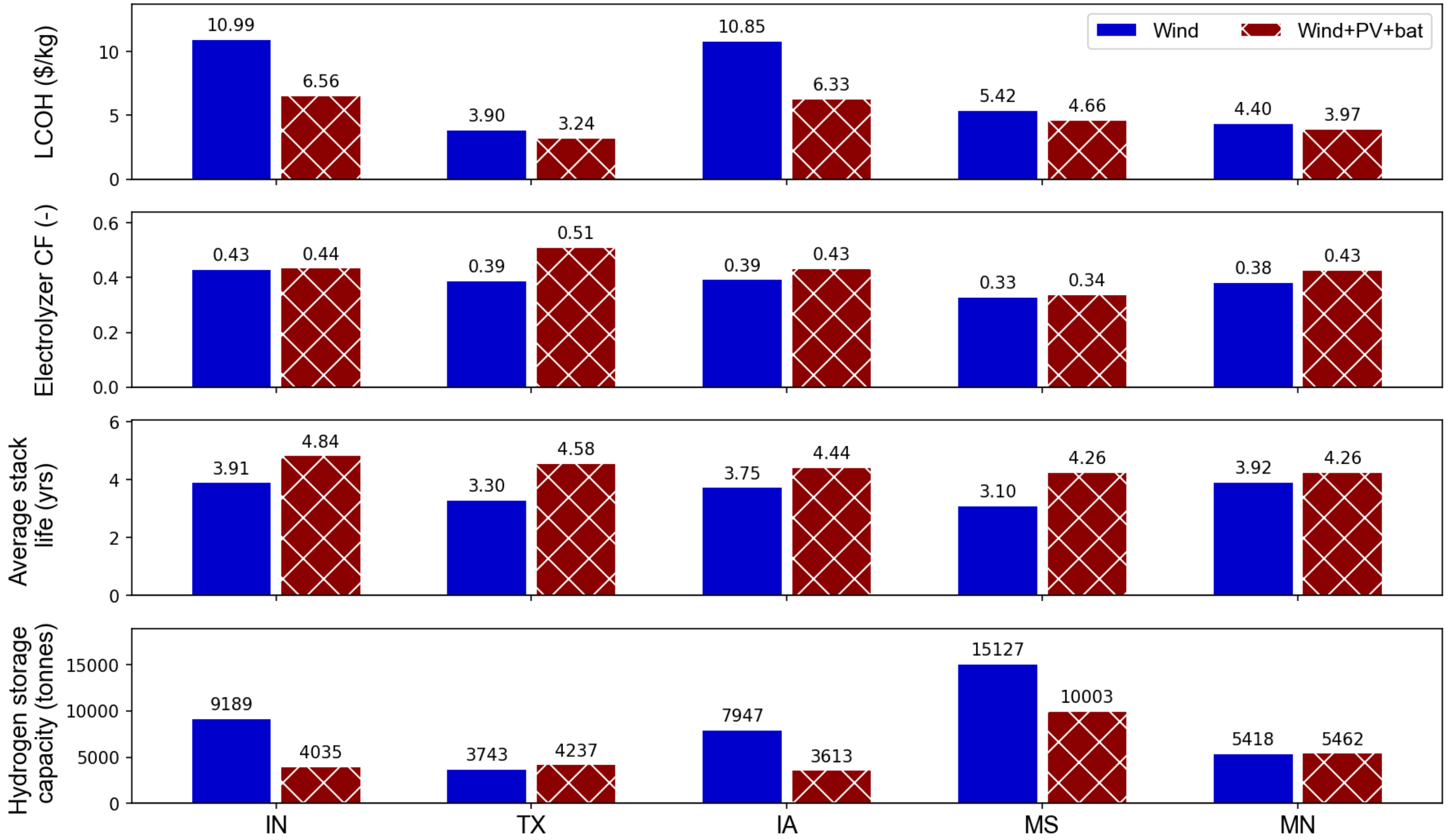
- **Transmission bottlenecks:** long lead times, high costs
- **Demand growth:** increasing electricity needs, industry, and new loads outpace buildout
- **Takeaway:** DERs, including distributed wind, can relieve pressure



United States transmission grid
Source: FEMA

Solution Pathways – Multi-Technology

- Distributed wind + DERs provide local capacity – hybrids matter
- Hybrid microgrids with multiple technologies and demand flexibility

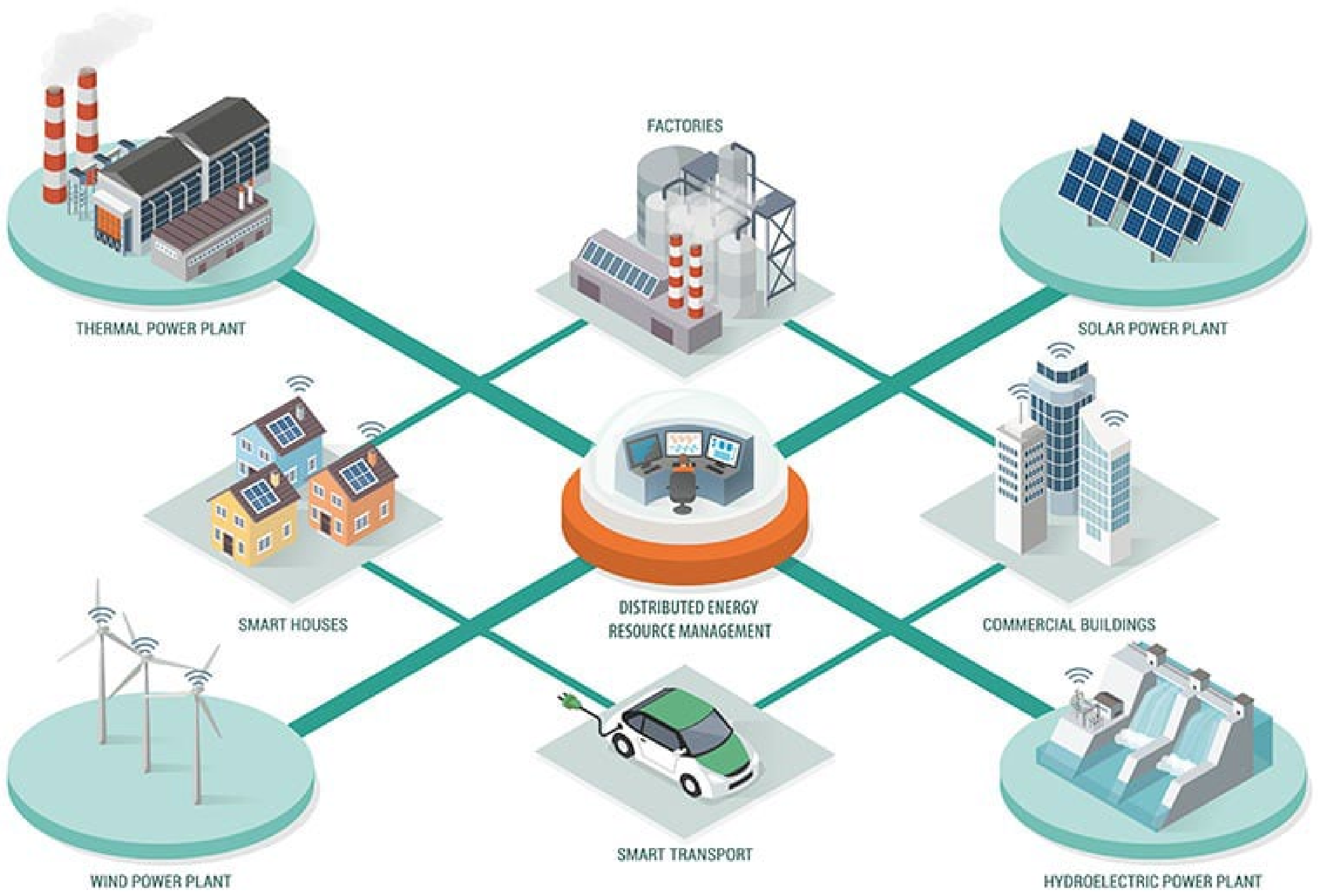


Key Insight:
Hybrids can have significant impact on technology costs

Blue – single energy generation technology
Red- multi energy generation technology

Industry Impact

- Benefits for industrial sites: reliability, local control, lower curtailment
- Distributed wind as part of demand growth solution
- **Key takeaway:** DERs can enable industry to grow without waiting for transmission



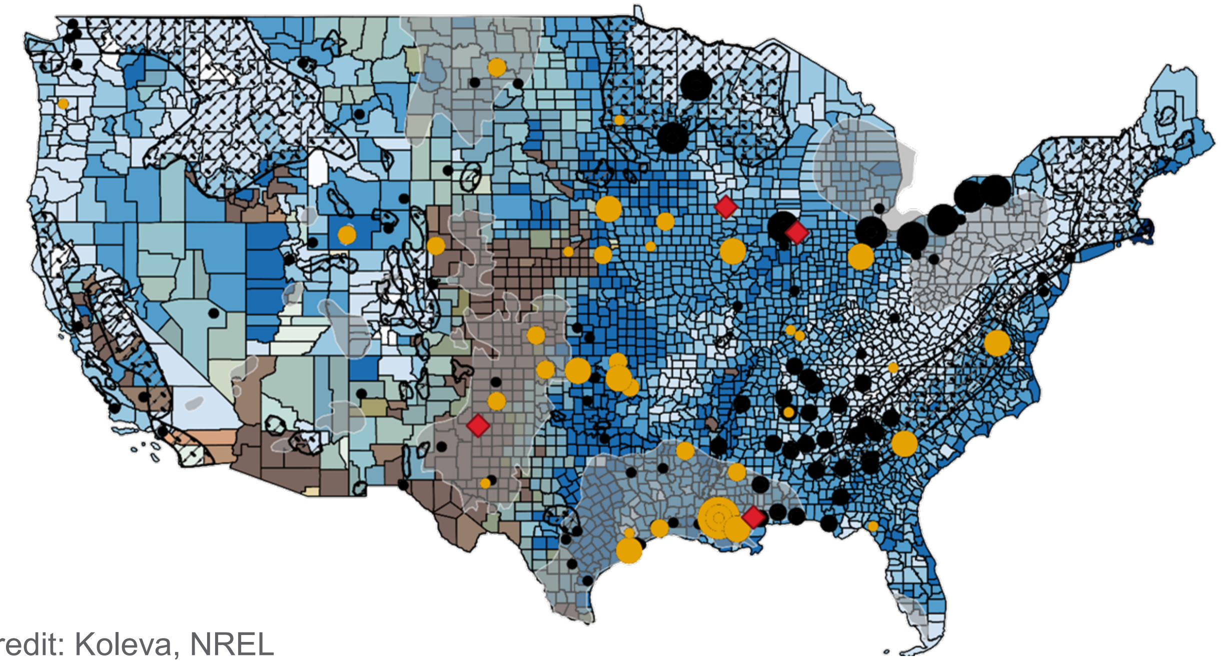
Co-location can increase speed to market

Distributed Ammonia

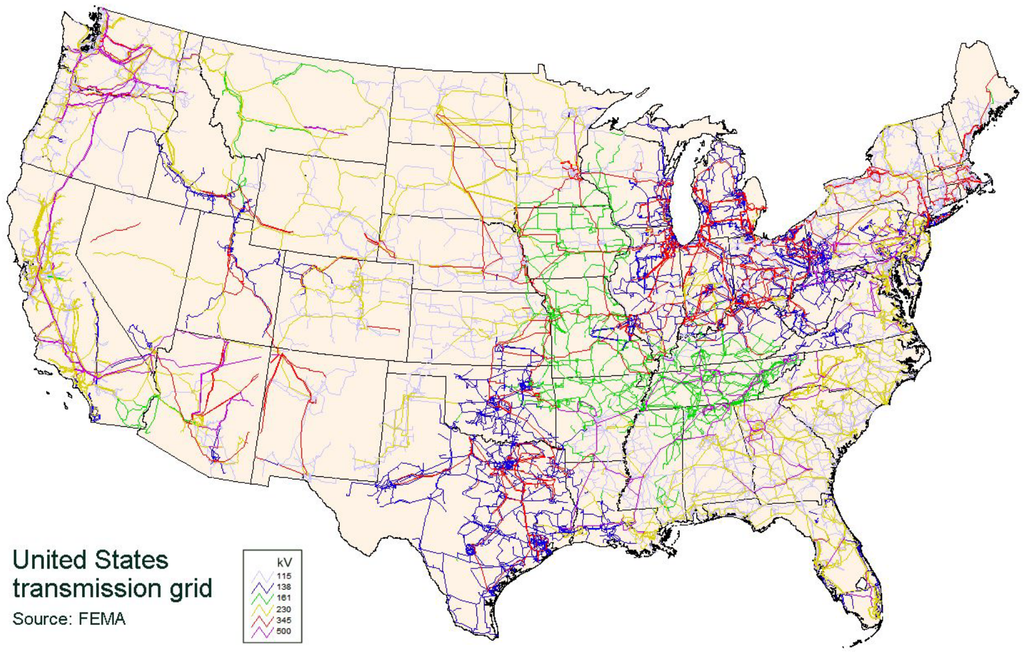
Challenge

- Ammonia demand rising for fertilizer, fuels, etc.
- Centralized ammonia plants create grid and siting challenges
- Transmission constraints limit where they can be located

- *Attend Mike Reese's panel on Distributed Wind Stories to learn more!



Credit: Koleva, NREL



Challenge of Centralized Plant: Why Distributed Ammonia

Solution Pathways:

- Distributed ammonia plants paired with distributed wind
- Local production reduces transport needs and grid dependence

10s of sq miles of energy generation for a single plant

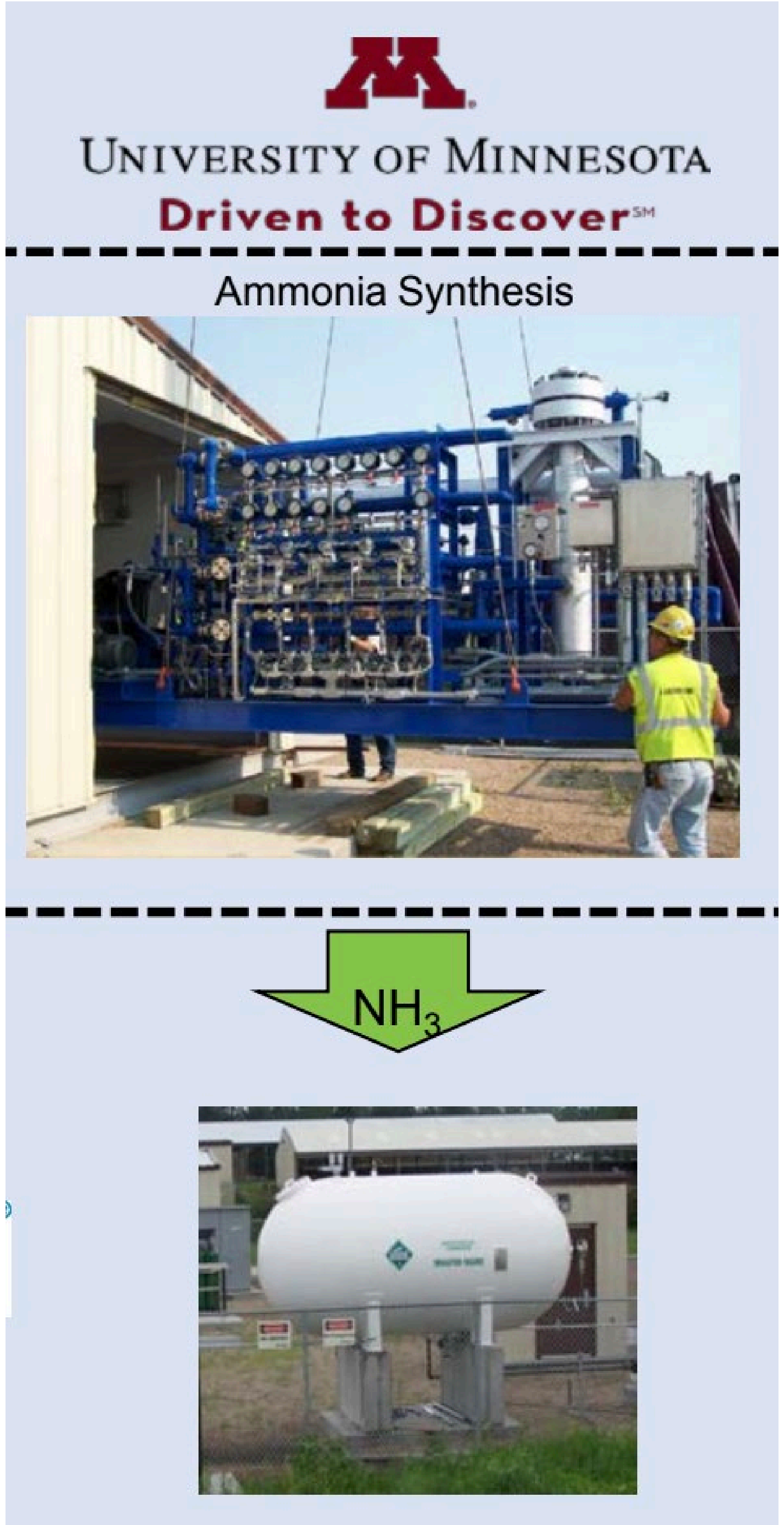
Opportunity for distributed ammonia for optimized land use

Pacific Northwest
NATIONAL LABORATORY

NREL

Industry Impact

- Resilience for agriculture and chemical supply chains
- **Co-benefits:**
  - Local resources serve local loads – add a level of resilience
  - Ammonia can act as both industrial product and DER
- See Mike Reese’s panel session shortly!

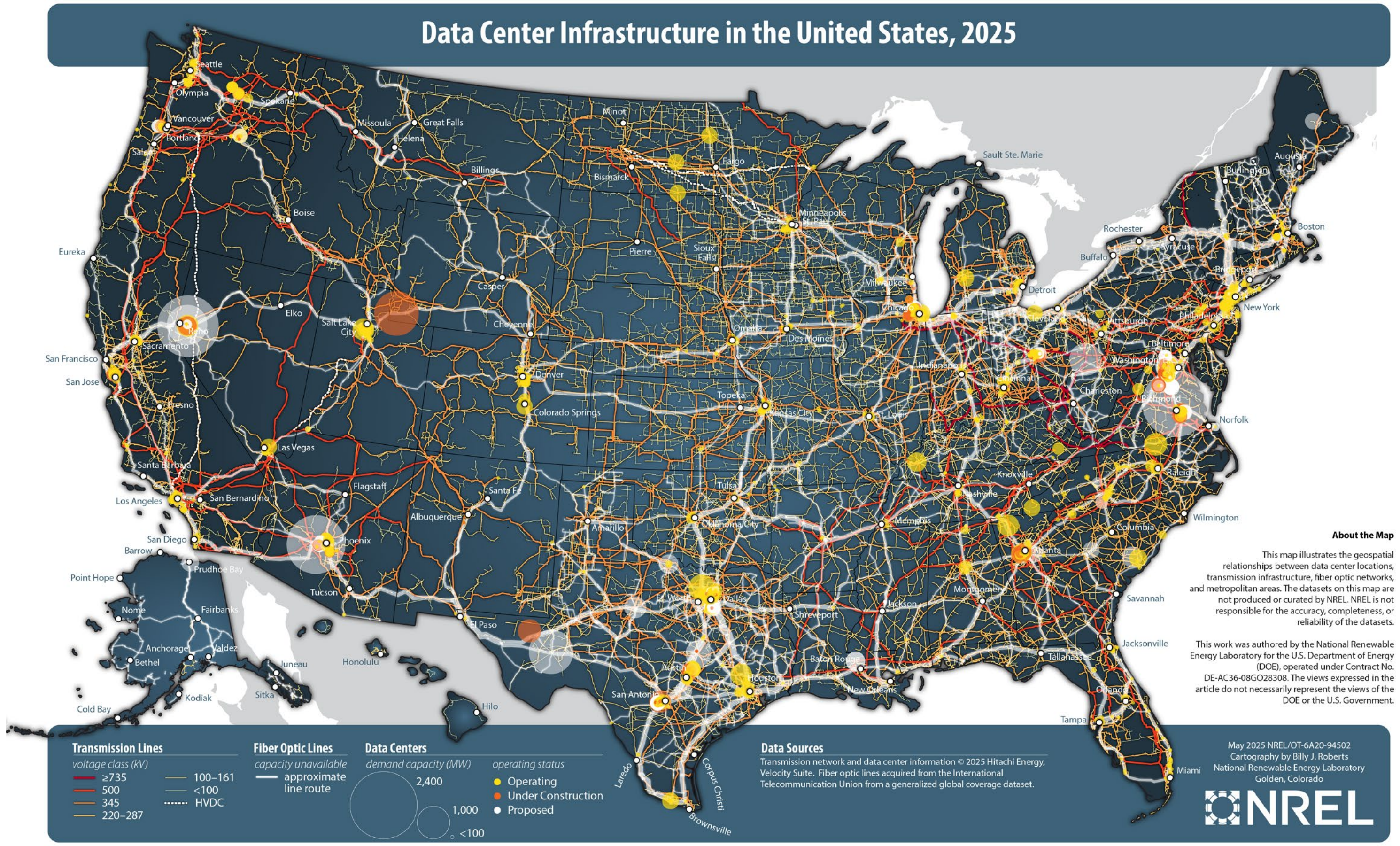


Credit: West Central Research and Outreach Center

Distributed Computing

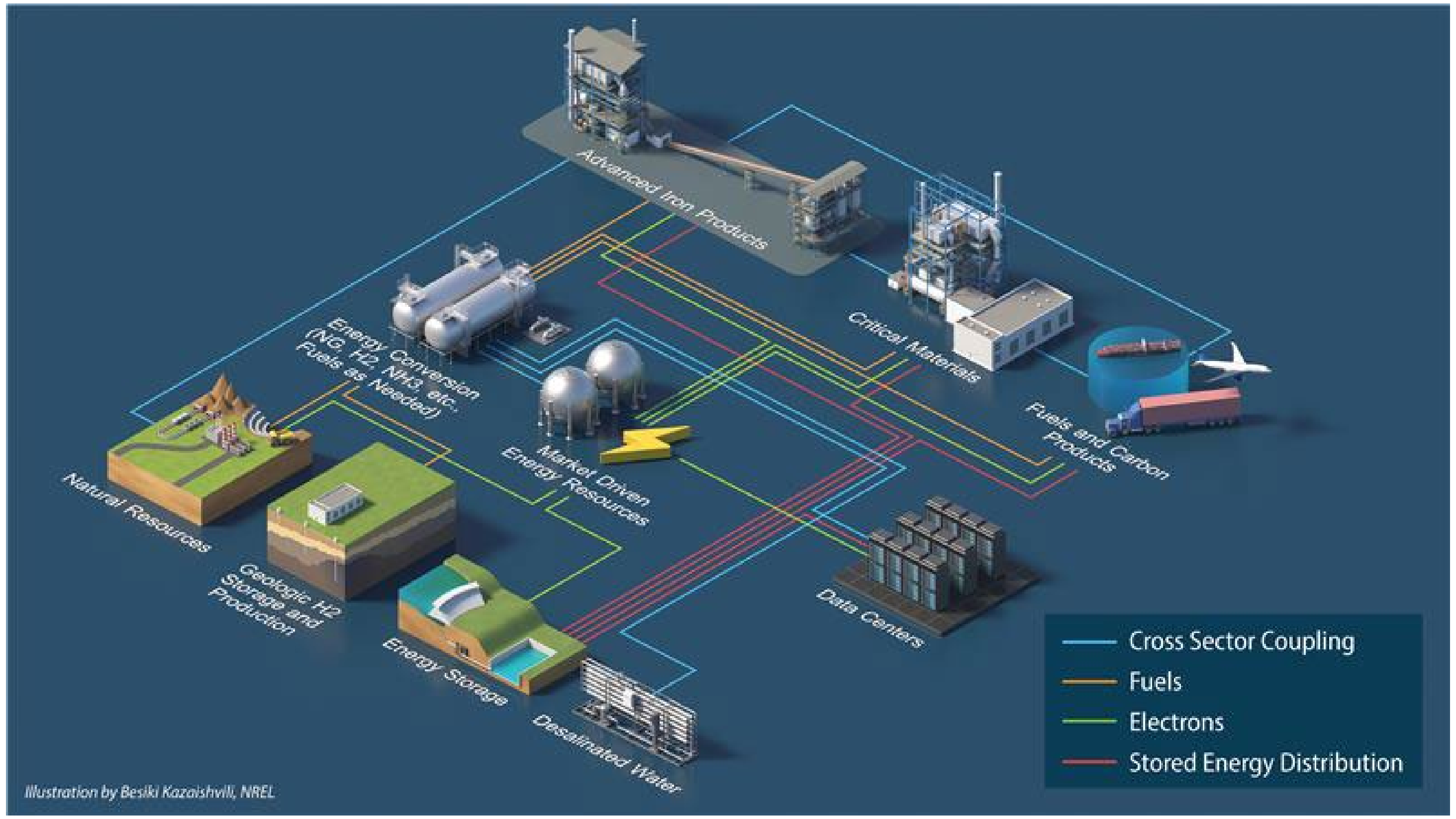
Challenge

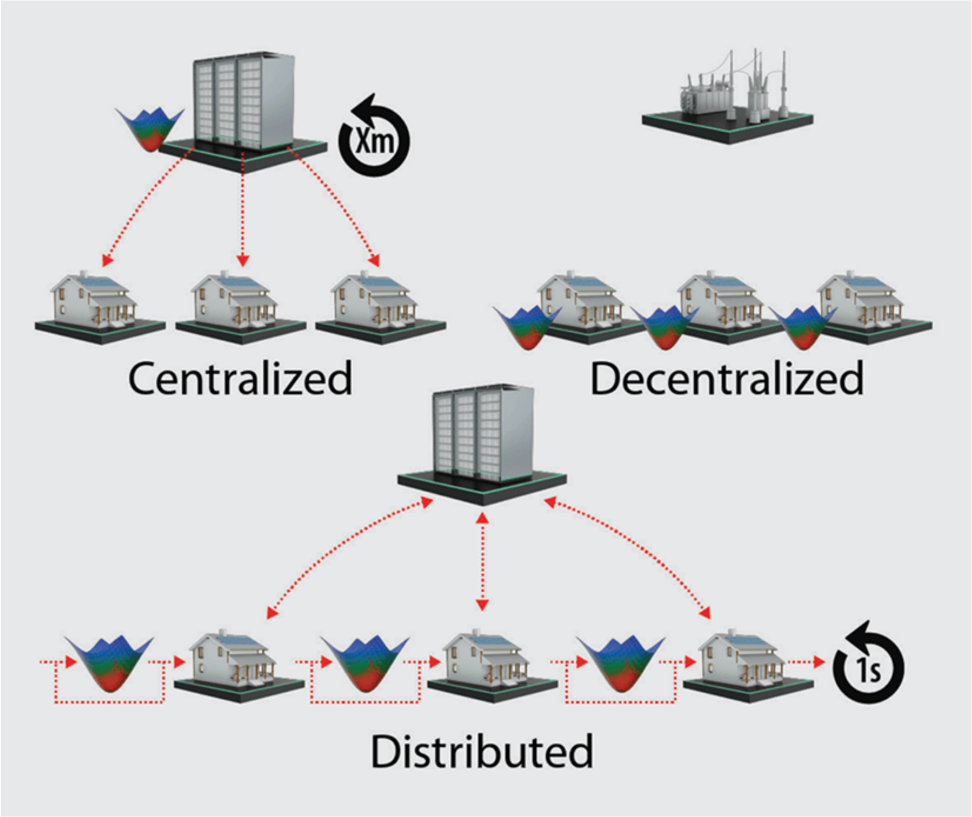
- Demand explosion from AI, cloud, and HPC workloads
- Centralized datacenters strain grids, compete for transmission, water, and siting
- Increasing community pushback
- Computing may be headed towards more distributed computing with inference needs and minimized latency for local demands



Solution Pathways

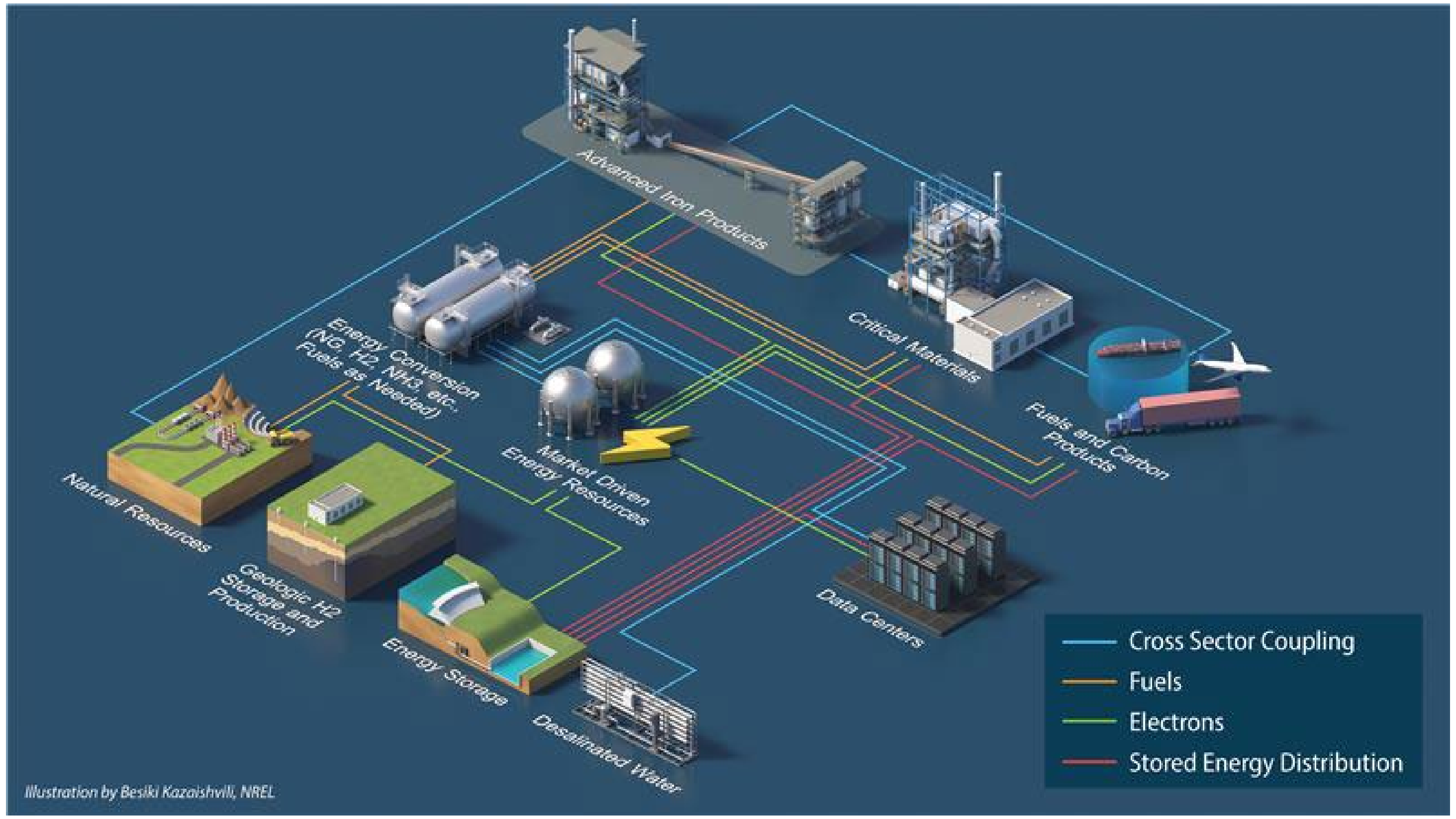
- Distributed computing nodes near distributed energy resources
- Direct integration with hybrid microgrids
- Concept of modular datacenters co-located with energy and other industrial loads

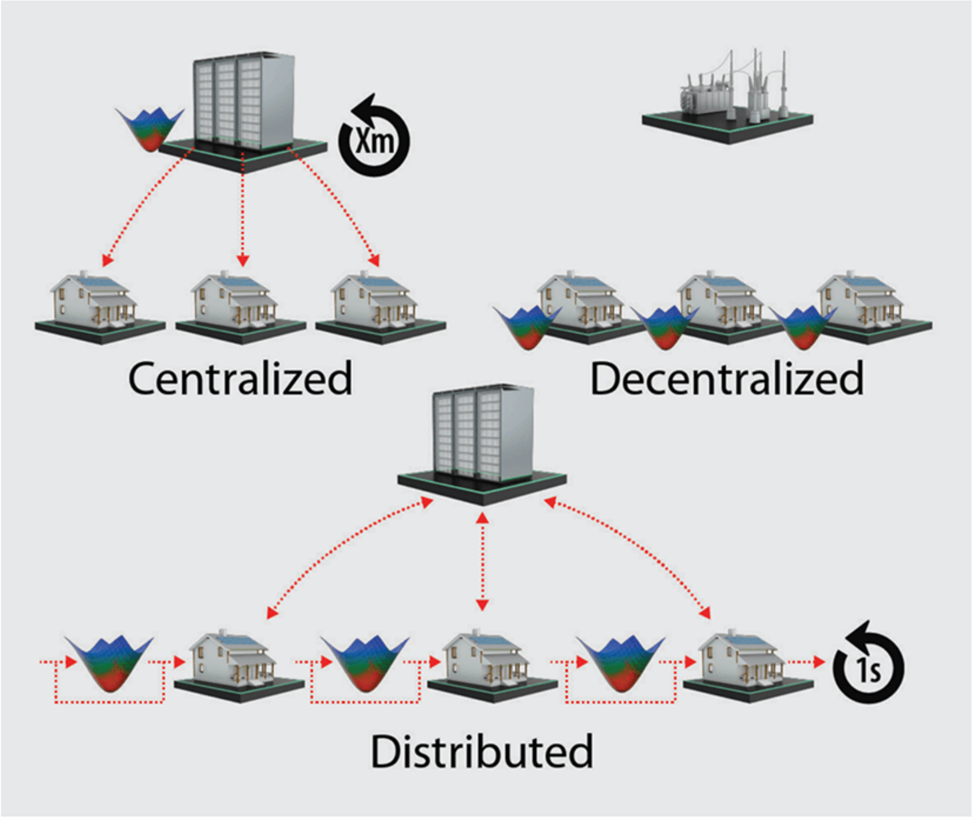




Industry Impact and Future

- Higher efficiency, reduced congestion, local economic benefits
- Distributed computing may become the default design for datacenters
- **Takeaway:** Distributed wind can align with future of compute infrastructure



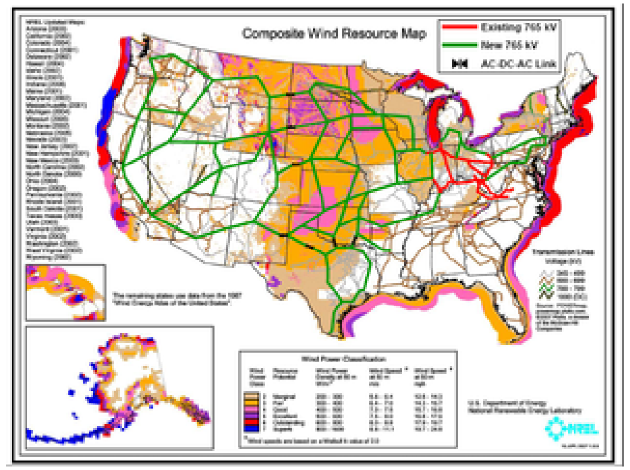


Summary – Current Trends

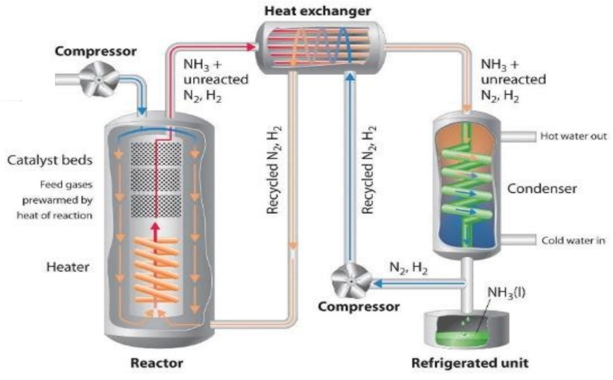
- **Transmission relief** – enabling demand growth without massive buildout.
- **Industrial synergy** – distributed ammonia as a flexible, valuable DER.
- **Digital future** – distributed computing aligned with renewable nodes.
- *Distributed wind/hybrids are not just a power source; they can accelerate progress toward our nation's energy and industrial priorities.*

Today's Focus – Industrial and Large Load Growth

DERs and Grid

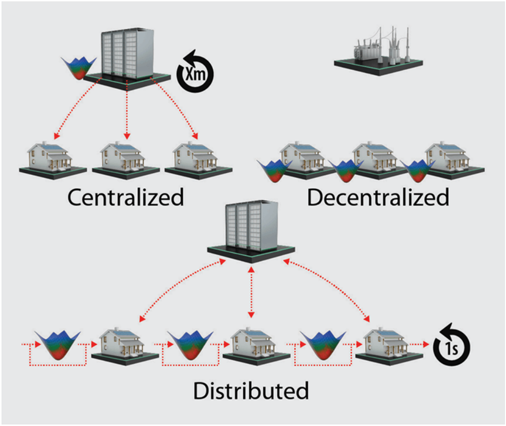


Ammonia



Haber-Bosch process

Computing



"We can't build our way out of this"

Pacific Northwest NATIONAL LABORATORY

NREL

Thank you

This work was authored by NREL for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.