U.S. DEPARTMENT OF ENERGY

Innovative Grid Deployment: Pathways to Commercial Liftoff

Interim Webinar Update | December 12, 2023

DRAFT. PRELIMINARY. UNDER ONGOING DEVELOPMENT.

Disclaimer

- DOE is only communicating public and non-privileged information during this webinar.
- DOE will not be discussing the details of any specific program opportunity in this webinar (e.g., Request for Information, Notice of Intent, Funding Opportunity Announcement)

Overview: Pathways to Commercial Liftoff

Pathways to Commercial Liftoff represents a new DOE-wide approach to deep **engagement between the public and private sectors**.

The initiative's goal is **catalyzing commercialization and deployment of technologies** critical to our nation's net-zero goals.

Pathways to Commercial Liftoff started in 2022 to:

- **collaborate, coordinate, and align with the private sector** on what it will take to commercialize technologies
- provide a **common fact base** on key challenges (e.g., cost curve)
- establish **a live tool and forum** to update the fact base and pathways

Publications and webinar content can be found at **Liftoff.energy.gov**

Feedback is eagerly welcomed via **liftoff@hq.doe.gov**

Key Messages for Innovative Grid Deployment

Shifting to a **proactive, future-oriented approach** for managing and investing in the T&D grid is critical to ensure system reliability in a rapidly changing energy future

Inaction is not an option – communities and utilities that fail to modernize the grid in the near-term will struggle to provide reliable and affordable power, **threatening human well-being and economic development opportunities**

The **existing T&D grid footprint is a powerful resource that can be unlocked with multiple readily-available, innovative technologies and applications** that can be quickly scaled today

These **innovative grid solutions are technically-proven and commercially-available – yet deployment and associated industry know-how is lagging** due to a lack of sufficient industry incentives and prioritization

Four technologies* in focus for today are high-priority for rapid scaling: **dynamic line rating (DLR), advanced conductors, high voltage direct current lines (HVDC), and Advanced Distribution Management Systems (ADMS) and its advanced applications**

Utilities, regulators, policymakers, solutions providers, and other key **stakeholders can start acting today, taking advantage of unprecedented federal investment & policy incentives** to accelerate deployment of innovative solutions that can unlock meaningful near-term value

**Analysis of the remaining technologies will be included in the full Liftoff report*

Priority actions for key grid stakeholders

	Why prioritize innovative grid investment?	Highest priority actions to take TODAY
Grid operators *(IOUs, co-ops, munis, RTO/ISOs)*	Continue to **provide reliable, safe, and affordable power** in a future with more system stress from greater demand, variable power, and external threats	• **Evaluate innovative grid solutions** in existing investment processes to find “no regrets” bundles • **Deploy “no regrets” solutions** (e.g., benefit cost ratio is >1, addressing pressing needs) • **Start developing a grid modernization strategy** following emerging best practices
Regulators *(PUCs, FERC, NERC)*	Deliver on regulatory mandate to **ensure ratepayers receive reliable electric service at just and reasonable rates**	• Ask for and/or **require innovative grid solutions to be considered** in existing utility plans and proposals • **Explore solutions to align utility business and regulatory models** with the needs of a modern grid
Policymakers *(federal & state legislators, governors, state energy offices)*	**Protect constituents** from undue system costs, extreme weather, power instability, etc. **Enable economic development** as grid reliability becomes a competitive differentiator **Drive key policy objectives** (e.g., energy justice, decarbonization, jobs)	• **Coordinate with state regulators to ensure innovative grid solutions** are considered in existing utility plans and proposals based on local needs and priorities • Coordinate with state regulators on **solutions to align utility business and regulatory models** with grid needs
Solutions Providers *(e.g., tech providers, EPCs, consultants)*	**Capture significant market opportunity** to drive rapid scaling of grid technologies – on near-term grid and future opportunities	• **Proactively articulate, quantify, and value the benefits** of provided solutions to support utility investments and contribute to industry standard setting and education • **Share in performance risk** for proven, but sub-scale technologies to accelerate deployment

Leverage federal funding opportunities to begin future-proofing grid through innovative deployments

Note: In full Liftoff report, longer-term priorities and actions for other stakeholders in the ecosystem will be evaluated (e.g., associations, DOE, investors, etc.)

Agenda

- Today’s grid context and needs
- Liftoff scope
- Technology deep dive
  - Dynamic Line Rating (DLR)
  - Advanced conductors
  - HVDC
  - ADMS & advanced ADMS applications
- Early insights on innovative grid technologies in scope
- Recap

Across the United States, utilities are increasingly investing in innovative grid technologies to modernize the grid

EXAMPLE INNOVATIVE GRID DEPLOYMENTS

NOT EXHAUSTIVE

Dynamic Line Ratings (DLR)

PPL

National Grid

Dominion Energy

AES

Advanced Conductors

SoCal Edison

American Electric Power

NVEnergy

HVDC Systems

Trans Bay Cable

Twin States Clean Energy Link

Neptune RTS

ADMS & advanced applications

Austin Energy

Arizona Public Service

Evergy

Investment needs to grow rapidly for the U.S. T&D grid to respond to increasing system pressures

Grid pressures *(not exhaustive)*

Load growth
35-70% **Increase in electricity demand** by 2035 across a range of expected scenarios*

Changing supply landscape
100-175 GW **additional capacity of distributed generation** expected by 2030**

6-10x **wind & solar capacity increase** by 2035 across a range of expected scenarios***

Aging assets
>60% **of T&D lines estimated to be operating beyond and/or nearing the end of their useful life**

System shocks
78% **Increase in weather-related power outages** over 2011-2021 from 2000-2010

Critical grid needs

Significant increase in T&D line capacity

~64% increase in within-region transmission capacity required by 2035****

Modern grid management capabilities

to reliably manage a more dynamic system across a range of uncertain energy scenarios

Notes: *From NREL's 100% Clean report, upper load growth bound is based on NREL's accelerated demand electrification scenario (ADE), which assumes an aggressive electrification of end-uses; load growth is closer to ~30-35% in NREL's LTS scenario that assumes higher end-use energy efficiency; in DOE's National Transmission Needs Study, load growth of 40% by 2040 is modeled in a moderate load growth/high clean energy growth scenario. **Based on an expected 20-35 GW of annual distributed generation additions from 2025-2030; additional capacity from BTM storage and EV capacity are additional DERs expected, but not included in this estimate. ***~6x increase in wind & solar capacity based on NREL LTS scenario (higher-end use efficiency) that drives ~1200-1400 GW; ~10x increase in wind & solar capacity based on ~2 TW wind & solar needed for a 100% clean grid by 2035. ****An additional 200% increase in interregional transmission capacity needed by 2040; ~64% increase (representing an incremental ~55 TW-mi) is the median within-region transmission capacity expected based on a moderate load growth & high clean energy growth scenario; in a high load growth and high clean energy scenario, within-region transmission needs increase to ~128% by 2035;

Sources: National Transmission Needs Study (DOE, 2023), Virtual Power Plants Liftoff (DOE, 2023), Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035 (NREL, 2022), Modernizing the Electric Grid (NCSL, 2021), Quadrennial Tech Review (DOE, 2015)

Yet investing in innovative grid solutions remains challenging

"We are focused on keeping the current system up and running. **It is hard to prioritize advanced technologies when we need to maintain the old system today."**

- Electricity Cooperative

"**Commissioners are concerned about anything that raises ratepayer costs.** Our teams are under-resourced as it is, so it's hard to understand if this new tech is necessary or just raises rates."

- Former PUC Commissioner

"We are piloting these new technologies but **scaling them is a challenge** because traditional solutions are usually the cheapest and easiest option to address immediate needs. Even if we did look at the longer-term **there isn't a standard process for how to quantify the long-term value** for these grid mod technologies."

- Large Investor-Owned Utility

"The rate case process was designed for physical poles and wires that would last decades – not software that might be outdated in a few years. **With a process that was designed 100 years ago, it's hard for PSCs be as quick and agile as the needs of today demand.**"

- Former PUC Commissioner

"**Utilities are very risk averse and hesitant to adopt new technologies.** Our regulatory and business models were all designed around reliability and limited risk taking, so it can be hard to first justify investments and then overcome organizational hurdles to actually deploy a new technology."

- Large Investor-Owner Utility

Legacy capital investment frameworks based upon running assets to failure worked in the past but can no longer meet the needs of the T&D grid today (and tomorrow)

NOT EXHAUSTIVE

	Legacy realities	≠	Current needs
Operating context	• Limited and predictable load growth • Sufficient infrastructure base (installed in 1950-80s)		• Greater load demand and variability • Aging electricity infrastructure • Greater resilience & reliability needs • Interconnected information & control systems
T&D grid investment approach	• Reactive maintenance and operation-focused approach • Short-term planning timelines (3yr) • IOU business models based on energy sales and guaranteed CAPEX returns		• Proactive planning & construction approach • Long-term oriented planning timelines (10-15yr) • Greater capital efficiency to ensure affordability • Business and regulatory models aligned with customer needs (e.g., efficiency, performance)

Ensuring a reliable and modern T&D grid in the future requires shifting from "business-as-usual", maintenance-focused approaches to proactive, forward-looking investment strategies

DOE investments and initiatives present opportunity to drive innovative grid deployment through industry partnership

Example DOE Funding Programs

Grid Resilience and Innovation Partnership (GDO)
$10.5b in grants to enhance grid flexibility and resilience against extreme weather in innovative ways

Grid Resilience State and Tribal Formula Grants (GDO)
$2.3b in formula grants for grid resilience against extreme weather

Transmission Facilitation Program (GDO)
$2.5b in funding to build out interregional transmission

Qualifying Advanced Energy Project Credit (48C)
Tax credit for investments in advanced energy projects

Energy Improvements in Rural and Remote Areas (OCED)
$1b in funding to improve the resilience, reliability, and affordability of rural energy systems

Energy Infrastructure Reinvestment Programs 1706 (LPO)
Loan authority to finance projects that repurpose/replace energy infrastructure to mitigate emissions

Distributed Energy Systems Demonstrations Program (OCED)
$50m to demonstrate aggregated approaches to managing distributed energy systems that show solutions to long term operations.

Example DOE Grid Initiatives

Technology Commercialization	Technology R&D	Supply Chain	Permitting	Policy & Regulatory
Innovative Grid Deployment Pathways to Commercial Liftoff *Today's Focus*	Grid Modernization Initiative (GMI)	Transformer Resilience and Advanced Components (TRAC)	Coordinated Interagency Transmission Authorizations and Permits Program (CITAP)	Electricity Advisory Committee (EAC)

Focus of the *Innovative Grid Deployment* Liftoff Report

Identifying pathways to **accelerate the near-term deployment of innovative, commercially-available grid technologies & applications on the existing T&D system** to expand T&D capacity and build critical modern grid capabilities.

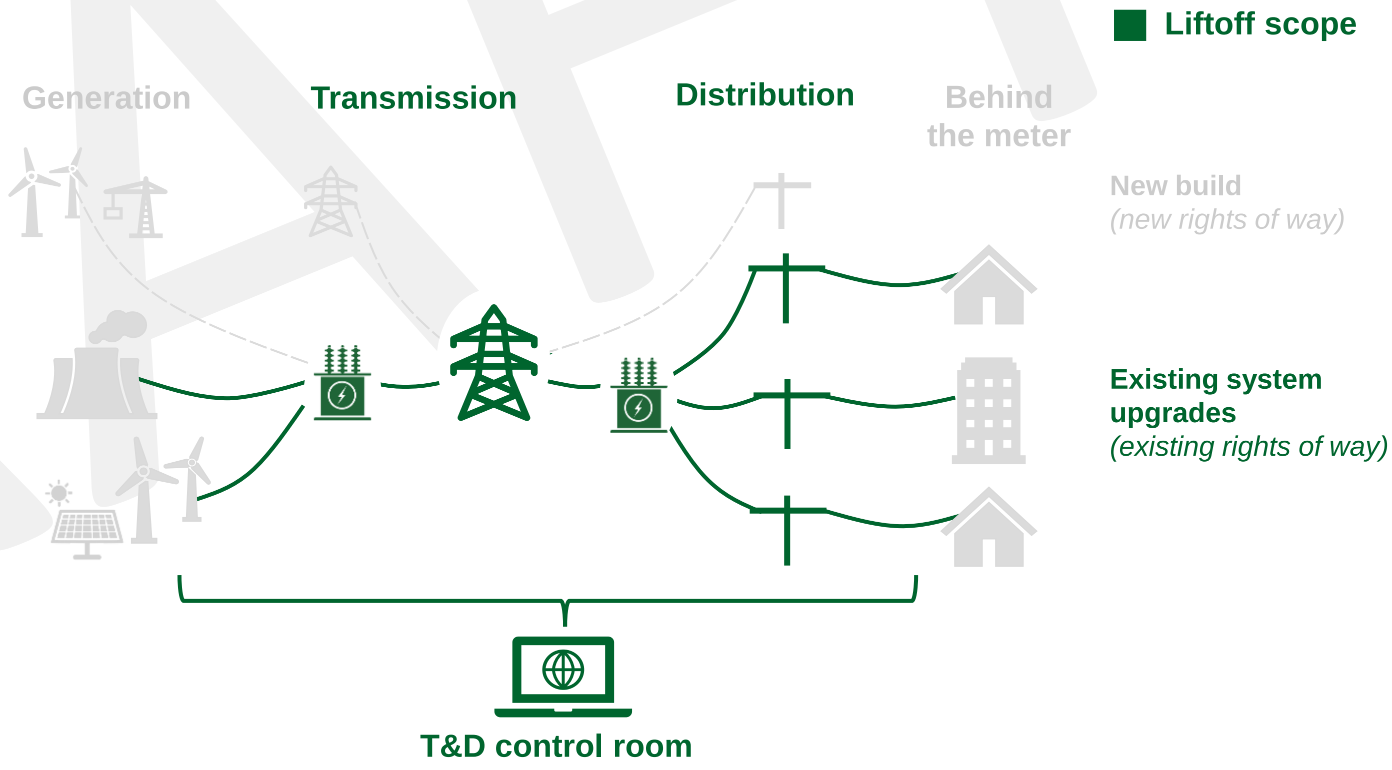
Summary of Liftoff Scope

✓ **Commercially-available, innovative** grid technologies & applications
(focus on large-scale demonstration & deployment ready)

Note: Important future grid technologies currently in pre-commercial stages are not included in this effort.

✓ **Existing transmission & distribution system**
(focus on existing rights of way)

Note: Deployment challenges associated with new rights of way (e.g., permitting & siting), and applications specific to generation and behind-the-meter resources are not addressed in this effort.



>20 commercially-available[1], innovative grid technologies & applications can help future-proof the grid across four strategic priorities

1

Retrofit system with advanced transmission technologies to expand capacity and improve efficiency

- Advanced conductors
- HVDC Lines

2

Build situational awareness & system automation to improve visibility and decision making

- Advanced Distribution Management Systems (ADMS)
- Volt/VAR Optimization (VVO)
- Distributed Energy Resource Management (DERMs)
- Fault Location, Isolation, Service Restoration (FLISR)
- Substation automation & digitization
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors

3

Deploy grid enhancing solutions to better optimize and adaptively control a dynamic grid

- Dynamic Line Rating (DLR)
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Virtual Power Plants (VPPs)
- 4-10hr energy storage
- Advanced Flexible Transformers
- Substation efficiency & hardening
- Alternate Synchronization & Timing

4

Deploy foundational systems to support innovative solutions

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

[1]Technologies were identified and prioritized based on commercial readiness but are not comprehensive of all DOE T&D grid priorities (i.e., technologies not commercially available today are not included). DOE welcomes input on this preliminary list via liftoff@hq.doe.gov.

DOE funding and support is available to address key commercialization challenges to accelerate near-term deployment

How public sector funding can help address key deployment challenges:

Dynamic Line Ratings (DLR)

- Reduce upfront costs to help mitigate misaligned incentives
- Enhance standard setting to streamline performance testing, certification, and deployment

Advanced Conductors

- Reduce upfront costs to support project economics, which can be harder to justify in current short-term oriented least-cost investment processes

HVDC Systems

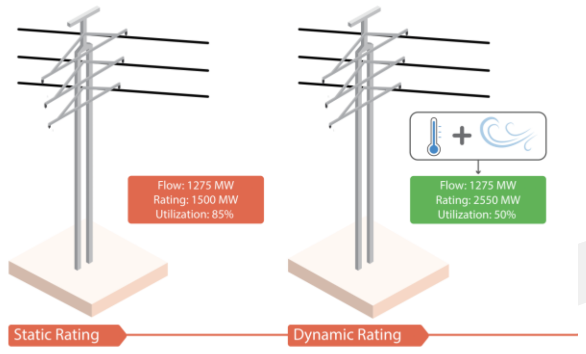
- Reduce costs of HVDC projects to stimulate demand and drive domestic supply chain
- Incentivize HVDC supply chain development

ADMS & advanced applications

- De-risk investments to mitigate current benefit and cost uncertainties and prove out investment value

DLR | Dynamic Line Rating (DLR) improves the utilization of the existing T&D system to increase effective system capacity

Definition



Source: WATT Coalition

- **DLR is a real-time calculation of a power line's thermal capacity** (effectively power current capacity) based on local environmental and weather conditions
- Grid operators can use real-time dynamic rating to manage power flows, better utilizing existing system
- **Without DLR, grid operators use conservative static ratings** to determine T&D power flows – often underutilizing a line's true capacity

Value Proposition

- **Increases effective T&D capacity on existing ROW** (~10-30%+)
  - Avoids challenges of new T&D builds (e.g., permitting, cost, time)
  - Relieves system congestion, reduces curtailment, and improves interconnection
  - Real-time capacity rating vs. static and ambient adjusted ratings alternatives
- **Cost-effective capacity enhancing solution** (typical payback period of <1-6 months in congested areas)
- **Easy to implement** without outages (typically <3-12 months to implement)
- **Supports improvements to system reliability, efficiency, and planning**

Key Barriers

- **Lack of investment incentives under traditional models** (e.g., low CAPEX, utility incurs cost while benefits largely accrue to customer)
- **Technology misperceptions and limited awareness** (e.g., performance reliability & quality, implementation process)
- **Changes to operational practices required** to integrate DLR
- **Lack of industry standards for testing and certifying DLR performance**

Capacity increase of 10-30% based on average DLR outcomes; potential for greater capacity increases of >40-55%+ in some locations based on industry experience
Source: Industry interviews; WATT Coalition; A Guide to Case Studies of GETs (Idaho National Lab, 2022)

DLR | DLR is a mature technology that has been deployed in the US (and widely overseas) to address congestion and unlock Tx capacity

National Grid

LineVision

Utility: National Grid (NY/IOU, 2022)

Location: Western New York

Motivator: Wind curtailment

Solution: Install DLR (LineVision sensors) on two 30-mile 115 kV transmission lines

Expected benefits:

- Reduce wind curtailment by 350 MW
- Expand transmission corridor's capacity by 190 MW
- Strategic approach to DLR alongside Tx capacity upgrades brought down total cost

Oncor

Utility: Oncor (Electric Delivery Company, 2014)

Location: Texas

Motivator: Reduce line congestion

Solution: Install DLR on 8 lines ranging from 138 to 345 kV

Realized benefits:

- ~6-14% increase line rating above AAR
- 5% additional capacity relieved 60% congestion; 10% capacity relieved 100% congestion
- $4.8M installation cost addressing $349M in congestion costs

PPL

Utility: Pennsylvania Power & Light (PA, IOU, 2023)

Location: Pennsylvania

Motivator: Congestion costs

Solution: Install DLR sensors on two 230-kV lines

Expected benefits:

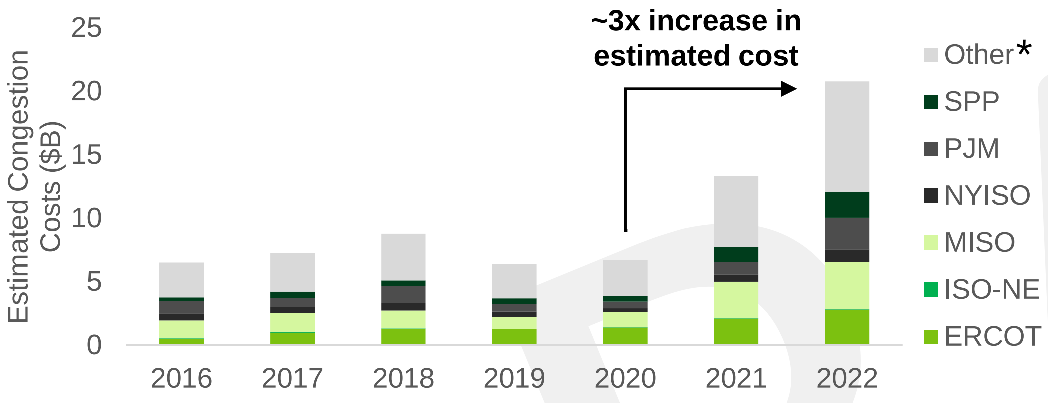
- $50M in costs vs. alternatives considered (new build, reconductoring)
- $23M annual congestion cost savings
- ~18-19% capacity increase on "normal" lines, 9-17% on "emergency" lines
- One line had congestion costs in 2011/22 and 2022/23 winters decrease from $60M to $1.6M

Note: DLR has been deployed widely across Europe (ex: Belgium deployed DLR across 28 high voltage lines in 2008, driving 5-20% increase in ratings, 30% increase in current, and 10% increase in import/export capacity while resolving congestion issues and increasing renewables deployment)

Source: *National Grid, WIRES panelists call for 'grid-enhancing technologies' to quickly boost transmission capacity* (Utility Dive, 2022), *Dynamic Line Rating Activated by PPL Electric Utilities* (PJM Inside Lines, 2022), *Belgium Electricity Security Policy* (IEA, 2022), *Dynamic Line Rating Innovation Landscape Brief* (IRENA, 2020), *PPL's Dynamic Line Ratings Innovation* (PPL, 2023), *A Guide to Case Studies of GETs* (Idaho National Lab, 2022)

DLR | Deploying DLR can help quickly address the rising transmission congestion that have risen significantly across the US

US congestion costs are rising



- **Congestion expected to continue increasing** if not addressed as capacity is strained from limited new builds, greater renewables penetration, and load growth
- **Congestion increases costs for ratepayers**

DLR is an available and underutilized solution

- **DLR can reduce and/or eliminate congestion** (~60-100% congestion reduction found in previous deployments)
- **Cost-effective method** to increase effective transmission capacity and mitigate congestion costs (DLR payback periods of <1-6 months)
- **Easy to implement** on individual systems without outages
- **Proven technology** ready for increased deployment with multiple successful US and international deployments

DLR is a high-impact opportunity to increase effective transmission capacity and reduce congestion, lowering energy bills for ratepayers

Federal funding (e.g., GRIP) is available to help address implementation hurdles and accelerate deployment

*Extrapolated to non-ISO/RTO regions proportional to total electricity load. Congestion cost data is limited in non-RTO regions.
Source: *Transmission Congestion Costs Rise Again in U.S. RTOs* (GridStrategies, 2023), *A Guide to Case Studies of Grid Enhancing Technologies* (Idaho National Laboratory, 2022), industry interviews

Advanced Conductors | Reconductoring with advanced conductors can increase line capacity & improve efficiency – but higher cost is a concern

Definition

Image Source: CTC Global

- Category of T&D lines that are made from **higher-performing materials**
- Typically, **composite-based core** (e.g., aluminum composite core (ACCC)) with high strength and high temp resistance (limited sag)
- Higher line capacity may require upgrades to supporting equipment (e.g., substations)

Value prop

- **Cost-effective solution to double T&D capacity on existing ROW**
  - Avoids cost, time, and permitting challenges of new T&D builds
- **Higher energy efficiency due to lower electrical resistivity**
  - 20-40% lower energy losses reduces ratepayer and overall system costs (e.g., reduced need for peak generation)
- **Reduced sag improves reliability during severe weather events** (e.g., high temperatures, heavy snow/ice, high winds) due to greater strength-to-weight ratio

Key barriers

- **Higher upfront costs vs. conventional ACSR/ACSS conductors harder to justify in least-cost investment models** (~2-4x higher CAPEX*, but lower OPEX)
- **Traditional models do not holistically value or incentivize full benefits for ratepayers (e.g., energy efficiency)**
- **Implementation challenges** due to new installation practices that require training field crews and a need for greater standardization across advanced conductor technologies and accessories

Note: ACSR = Aluminum Conductor Steel Reinforced; ACSS = Aluminum Conductors Steel Supported ; ACCC = Aluminum Conductor Composite Core
*Additional costs from associated equipment upgrades (e.g., expanding substation capacity) to handle higher ampacity can further increase initial costs, though these investments may already be required due to standard repair and replacement costs required to manage aging grid infrastructure.
Sources: Industry interviews; Advancing Transmission Expansion by Using Advanced conductors on Existing Rights of Way (Energy Institute at HAAS, 2023) ; Advanced Conductors on Existing Transmission Lines to Accelerate Low Cost Decarbonization.(Grid Strategies, 2022) ; Technology Radar: Advanced Conductors (BNEF)

Advanced Conductors | Advanced conductors offer many benefits over conventional alternatives to meet grid needs

	Expanded Tx capacity	Reduced energy losses	Reliability & Resilience improvements	Shorter timelines
Example grid needs	• Near-term **capacity need,** e.g., due to: ◦ Increases in load size and variability ◦ Long interconnection queues ◦ Increasing line congestion	• **High energy losses** (overused, older lines) • **Rising ratepayer costs**	• **Extreme weather events** (e.g., strong winds) impacting grid reliability	• Near-term **capacity need** • **Limited new ROW** readily available
How advanced conductors could help	• **Increase capacity by ~2x** vs. conventional ACSR conductors • **~Half the cost** of new Tx capacity build	• **Reduces energy losses by 25-40%** • Reduced energy losses **lowers ratepayer costs**	• **Increase line thermal limit 2-3x** vs. conventional ACSR • Reduced sag **decreases risk of outage**	• Use of **existing ROW** means ACs can avoid time-intensive permitting requirements and can be **operational in <1-3 yrs** *(varies by context)*

Advanced conductors should be evaluated as a cost-effective and higher performing option to expand capacity when replacing aging infrastructure or considering capacity expansion options

Sources: Industry interviews; Advancing Transmission Expansion by Using Advanced conductors on Existing Rights of Way (Energy Institute at HAAS, 2023) ; Advanced Conductors on Existing Transmission Lines to Accelerate Low Cost Decarbonization.(Grid Strategies, 2022) ; Technology Radar: Advanced Conductors (BNEF)

Advanced Conductors | Advanced conductors are a mature technology that have been successfully deployed around the world

In the U.S....

AEP

Lower Rio Grande Valley (2012-2015)

Motivator:
Increased load due to population growth

Solution:
ACCC conductor used to replace 240-miles of aging, conventional conductors

Outcomes:

- **~2x line capacity increase**
- **30% reduction in line energy losses** saving customers $15 million per year
- **Same day approval** by ERCOT and project completed 8 months ahead of schedule
- Lines **remained energized** during reconductoring process, avoiding the need for alternative generation

SoCal Edison

Big Creek Transmission Corridor (2016)

Motivator: Sag clearance issues, increase Tx capacity

Solution: ACCC conductor used on two Tx lines

Outcomes:

- **~2x corridor capacity increase**
- **Saved customers $85 million** in comparison to ACSR project to increase line capacity
- **Reduced construction time** from planned 48 months to 18 months
- Reduced sag avoided damage during Sept. 2020 wildfire

...and abroad

Belgium (2009-today): Deployed advanced conductors in 2009 and on track to ~2x national Tx capacity by 2035.

India (2010s-today): 180+ projects (~9,300 miles) of advanced conductors installed.

Brazil (2012): A Rio de Janeiro utility reconductoring project with a low-sag advanced conductor increased capacity by 72.5%.

Netherlands/Germany (2020): TenneT expanded Tx capacity with advanced conductors to interconnect ~20.5 GW of offshore wind to the German grid by 2026.

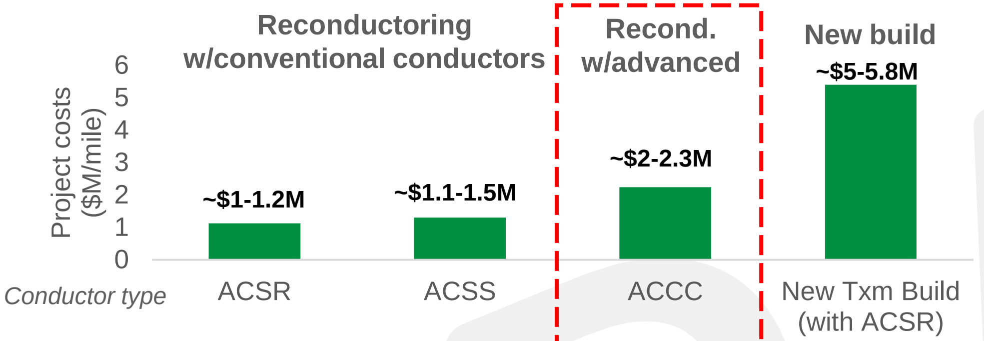
China (2020): 291 km of advanced conductors used in critical grounding line to enable Tx capacity expansion to support HVDC system deployment.

Sources: Industry interviews; Advancing Transmission Expansion by Using Advanced conductors on Existing Rights of Way (Energy Institute at HAAS, 2023) ; Advanced Conductors on Existing Transmission Lines to Accelerate Low Cost Decarbonization.(Grid Strategies, 2022); Technology Radar: Advanced Conductors (BNEF); American Electric Power – Energized Reconductor (Quanta Energized Services); ACCC® Installation in China on Milestone 1100 kV DC Project in China (CTC Global); SCE Uses ACCC® Conductor to Mitigate Sag and Increase Capacity (CTC Global)

U.S. DEPARTMENT OF ENERGY

Advanced Conductors | Considering the long-term benefits of advanced conductors often justifies higher upfront costs

Benefits & costs vs. alternatives



Conductor type	ACSR	ACSS	ACCC	New Txm Build (with ACSR)
Upfront CAPEX cost	✓ (Cheapest)	✓	~Med	X (Most expensive)
Capacity	X	~Med	✓	✓
Reliability	X	X	✓	X
Energy efficiency	X	X	✓	X
Implementation speed	✓	✓	✓	X
Existing ROW	✓	✓	✓	X

Benefits not typically considered in current valuation methods (Reliability, Energy efficiency, Implementation speed, Existing ROW)

Key takeaways

- **Advanced conductors should be evaluated for deployment** where performance benefits can have significant long-term value (e.g., capacity-constrained corridors, extreme weather)
- Grid planning and valuation methodologies should be updated to holistically value benefits and costs

Strategically deploying advanced conductors can quickly and cost-effectively expand transmission capacity on existing ROW

Federal funding (e.g., GRIP, LPO 1706) is available to reduce upfront costs and accelerate adoption today

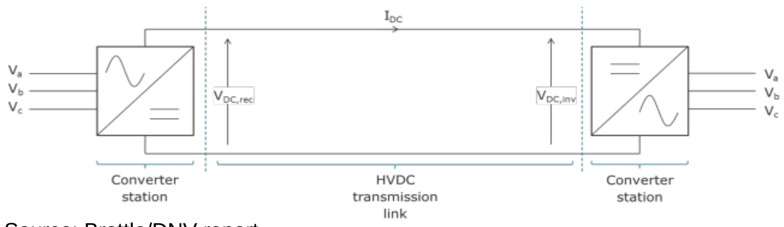
Notes: Project costs estimated from MISO's Transmission Cost Estimation Guide and stakeholder interviews. Additional costs to upgrade substations from ACCC deployment often required regardless of use of advanced conductors due to capacity needs & replacement of aging infrastructure

Sources: Industry interviews; Advancing Transmission Expansion by Using Advanced conductors on Existing Rights of Way (Energy Institute at HAAS, 2023) ; Advanced Conductors on Existing Transmission Lines to Accelerate Low Cost Decarbonization.(Grid Strategies, 2022); Technology Radar: Advanced Conductors (BNEF); Transmission Cost Estimation Guide (MISO, 2023)

HVDC | HVDC systems increase capacity while providing reliability and resiliency solutions to the grid

Definition

FIGURE 1. ILLUSTRATION OF A POINT-TO-POINT HVDC TRANSMISSION SYSTEM



Source: Brattle/DNV report

HVDC system includes:

- **Efficient and high-capacity direct current (DC) transmission links** (e.g., long distance overhead lines, underground cables, or submarine cables)
- **Converter stations** connecting HVDC links to the AC system (primarily Voltage Sourced Converters (VSC) for modern HVDC projects)

Value prop

- **Increased Tx capacity with limited energy losses** over long distances, underground, or underwater
- **Market optimization capabilities** (e.g., congestion mitigation, usage control)
- **Improved system reliability** from greater active and reactive power control to support AC grid (e.g., dampening oscillations, regulating voltage, power control)
- **Provides contingency event support** (e.g., emergency energy imports at high ramp rates, black start and system restoration capabilities)

Key barriers

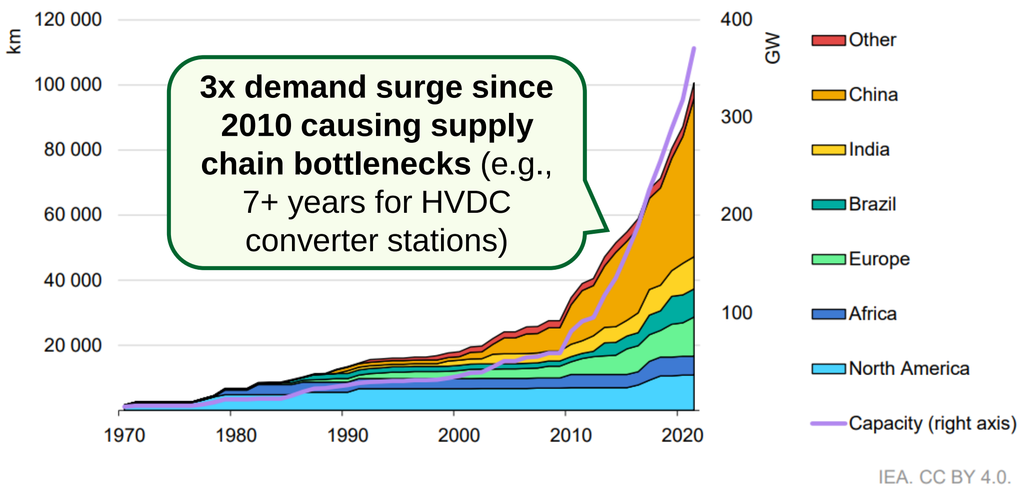
- **Global supply chain bottlenecks** increasing HVDC project uncertainty, timelines, and costs
- **Greater technical standardization** needed for HVDC integration (e.g., VSC-HVDC standards)
- **Multi-stakeholder collaboration needed** to ensure buy-in and successful project execution
- **Current investment processes do not value holistic system benefits** of HVDC vs. HVAC alternatives
- **Typical challenges for new, large-scale Tx builds** (e.g., permitting, ineffective cost recovery, fragmented transmission planning, long timelines)

Sources: The Operational and Market Benefits of HVDC to System Operators (Brattle Group/DNV, 2023); Electric Grid Supply Chain Review (DOE, 2022)

HVDC | Stimulating domestic HVDC demand will incentivize U.S. based manufacturing and grow domestic supply chains

Rising global demand is outpacing manufacturing capacity – creating global supply chain challenges

Global HVDC transmission line lengths by country/region



Notes: Data are for year end. “Capacity” refers to global HVDC transmission capacity, but excludes the capacity of HVDC back-to-back systems, which are used to link two AC grids.
Sources: IEA analysis based on RTE International (2022).

Building domestic supply chains is an opportunity to secure HVDC inputs – but requires a strong demand signal

- **Limited domestic supply chain capacity** due to low HVDC demand historically
- **Higher risk of project uncertainty and failure** if overdependent on already strained foreign markets
- **Clear demand signal and industry collaboration** is necessary to incentivize supply chain build out and protect future US demand

Accelerating HVDC projects can create a strong demand signal to drive domestic manufacturing build out, with public funding (e.g., GRIP, LPO, 48C tax credits) available to support HVDC projects and component manufacturing

Global HVDC transmission line length source note: IEA 2023; Electricity Grids and Secure Energy Transition, https://iea.blob.core.windows.net/assets/ea2ff609-8180-4312-8de9-494bcf21696d/ElectricityGrids andSecureEnergyTransitions.pdf.
Other sources: The Operational and Market Benefits of HVDC to System Operators (Brattle Group/DNV, 2023); Electric Grid Supply Chain Review (DOE, 2022)

HVDC | There are many cost-effective HVDC use cases eligible for public investment that can stimulate demand to build a domestic supply chain

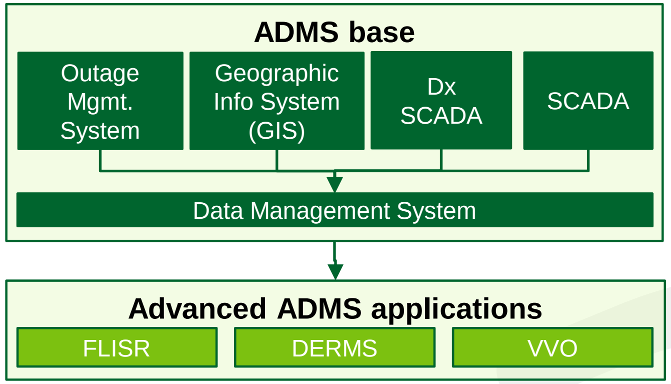
Key use cases	**High-capacity infeed to large load centers**	**Upgrading existing ROW** *(HVAC conversion, upgrading aging HVDC)*	**Integration of offshore wind**	**Interconnection of asynchronous grids and balancing areas**	**Long-distance bulk transmission** (e.g., national HVDC backbone, renewables tie-in)
Implementation complexity	*Low*				*High*
*Size of current and planned HVDC deployments by 2033**	<2 GW	<2 GW	~10 GW	~5 GW	~60 GW
Economics	Cost-effective for capacity expansion where new ROW are expensive/limited	Least cost when reconductoring aging HVDC	Least cost for subsea transmission lines >~40 mi	HVDC is only technically feasible solution for asynchronous grids	Least cost at lengths >~125-300 mi for overhead cables

Overhead HVAC conversions are least cost if >60% capacity increase is required, and ROW can't be expanded

Notes: *Current and planned HVDC deployments for all categories except "upgrading existing ROW" are based on DNV's forecast of planned HVDC transmission in North America by 2033 (see Brattle's *Operational & Market Benefits of HVDC* report). "Upgrading existing ROW" was estimated from stakeholder interviews and literature review. Least cost lengths published by DOE Office of Electricity.
Source: The Operational and Market Benefits of HVDC to System Operators (Brattle Group/DNV, 2023); Connecting the country with HVDC (DOE, 2023); City center infeed solution (Hitachi Energy)

ADMS | ADMS (and advanced ADMS applications) is the cornerstone Dx Operational Technology system for efficiency, reliability and resilience

Definition



- **ADMS is a software platform that integrates several sub-systems**
- **ADMS base** typically integrates SCADA, outage mgmt., and data mgmt. systems
- ADMS is the **enabling technology platform** for other advanced applications:
  - *VVO*: distribution system optimization
  - *FLISR*: reliability and resilience improvements
  - *DERMs*: connects large-scale and BTM distribution energy resources

Value prop

- **Provides situational awareness to improve Dx system operational efficiency** by enhancing system visibility in real-time
- **Increases resilience and reliability** by improving ability to withstand or recover from a disruption quickly and with minimal customer interruption
- **Increased data granularity** to better inform maintenance and investment decisions
- **Enables additional system value (e.g., capacity, decarbonization, reliability)** through unlocking advanced applications

Key barriers

- **Significant shift in grid management approach is required** to operate an *automated* ADMS system vs. legacy *manual* approach
- **Technically and operationally complex to implement** -- including sufficient IT systems to support ADMS components and several pre-requisite technologies (e.g., sensors, comms equipment, data)
- **Current investment processes typically do not account for holistic set of benefits realized over longer period** (10y vs. 3y traditional investments, situational awareness is not a typically monetized benefit)

Sources: Modern Distribution Grid Project (DOE), Guidehouse Insights

ADMS | ADMS brings together known, proven technologies with many successful deployments across the country

Arizona Public Service

Schneider Electric | **Power Engineers**

Motivator: Manage growing numbers of advanced grid technologies (e.g., DERs)

Solution: Built robust ADMS system on top of preexisting GIS and data management systems

Outcomes:

- ✓ Enhanced safety (e.g., wildfire response improvement)
- ✓ Increased situational awareness, including DER visibility
- ✓ Improved system performance and efficiency

Unitil

Motivator: Enhance storm management and manage DER assets

Solution: ADMS implemented in 2021 to enable advanced applications:

- VVO deployed by the end of 2023
- Option to activate DERMS license in the future to manage company and customer-owned DERs

Outcomes:

- ✓ Improved outage response and restoration times
- ✓ Lowered system peak load
- ✓ Reduced costs to ratepayers

FirstEnergy

Oracle Utilities

Motivator: Merge legacy management systems of 10 utilities (~270k miles of distribution lines) to manage increasing grid complexity and build smart grid foundation

Solution: Layered ADMS platform over existing SCADA system to enable real-time visibility, predictive modeling, and advanced applications (i.e. VVO, FLISR)

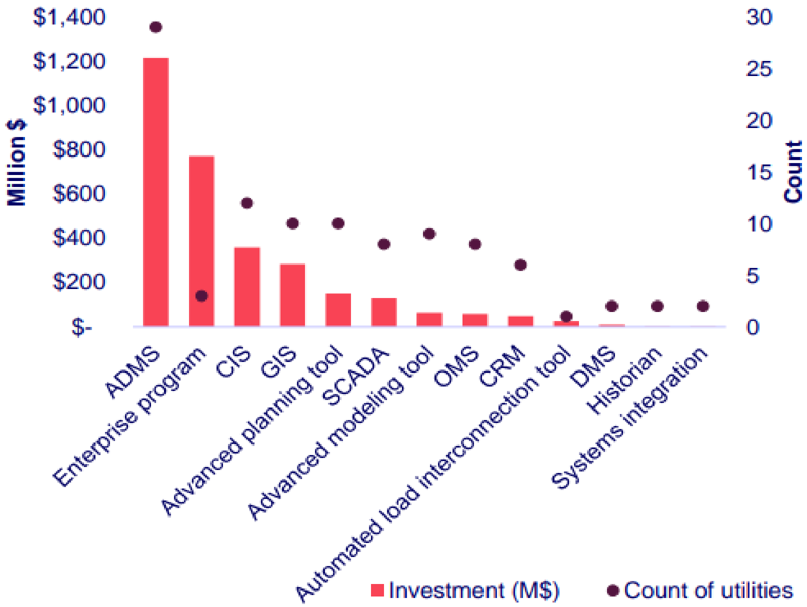
Outcomes:

- ✓ Increased situational awareness, including DER visibility
- ✓ Faster outage restoration times
- ✓ Reduced operational costs

Sources: Arizona Public Service Leverages Data for Advanced Distribution Management (T&D World, 2018), FirstEnergy, Oracle Sync Up ADMS Across 10 Utilities (T&D World, 2023); A Holistic Approach to Storm Planning and Restoration (T&D World, 2021); MA Electric Sector Modernization Plan (Unitil, 2023); Utility Investment in Grid Modernization: H2 2023 (WoodMackenzie, 2023).

ADMS | Public funding can help de-risk complex ADMS investments; following emerging best practices can support successful deployments

30 out of 50 IOUs interviewed across the country are investing in ADMS, but costs are meaningful



Federal funding (e.g., GRIP) is available to de-risk early investments in ADMS and its advanced applications to support broader deployment

Best practices for successful ADMS deployment

Implement a targeted, incremental strategy

- **Identify opportunities for quick wins,** modularly deploying and phasing in ADMS across the system
- Define a stepped or **incremental path** to operationalization
- Ensure **organizational buy-in** and vision alignment to desired capabilities

Develop holistic, long-term benefits case

- **Incorporate non-traditional benefits into business case** (e.g., situational awareness, cost avoidance, faster outage response times)
- **Take a long-term view:** ADMS is often cost effective when evaluated over a 10-year horizon (incl. advanced applications)

Build upon foundational investments

- Time investments (e.g., sensor installs, software upgrades) during **existing equipment replacement and change-outs** to support system integration and reduce costs
- ADMS **can either supplement or replace existing systems** so can be flexibly deployed to maximize value

Source: Wood Mackenzie Utility Investment in Grid Modernization: H2 2023, Guidehouse Insights

Reminder: >20 commercially-available[1], innovative grid technologies & applications can help future-proof the grid across four strategic priorities

1

Retrofit system with advanced transmission technologies to expand capacity & improve efficiency

- Advanced conductors
- HVDC Lines

2

Build situational awareness & system automation to improve visibility and decision making

- Advanced Distribution Management Systems (ADMS)
- Volt/VAR Optimization (VVO)
- Distributed Energy Resource Management (DERMs)
- Fault Location, Isolation, Service Restoration (FLISR)
- Substation automation & digitization
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors

3

Deploy grid enhancing solutions to better optimize and adaptively control a dynamic grid

- Dynamic Line Rating (DLR)
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Virtual Power Plants (VPPs)
- 4-10hr energy storage
- Advanced Flexible Transformers
- Substation efficiency & hardening
- Alternate Synchronization & Timing

4

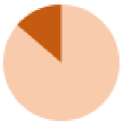
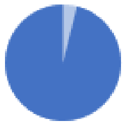
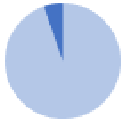
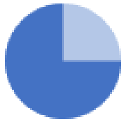
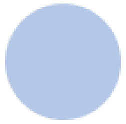
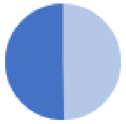
Deploy foundational systems to support innovative solutions

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

[1]Technologies were identified and prioritized based on commercial readiness but are not comprehensive of all DOE T&D grid priorities (i.e., technologies not commercially available today are not included). DOE welcomes input on this preliminary list via liftoff@hq.doe.gov.

These solutions are technically-proven and ready for larger-scale demonstrations & deployments

Legend
- Full – 100%
- Empty – 0%
- Lagging expectations

Deployment stage category	Market Adoption	Deployment Readiness	Technologies & Applications
Scale Commercial Deployments	 ~5-20% market penetration *(lagging expected deployment given technical maturity)*	 Technically mature solutions, ready for rapid deployment *TRL ~9, ARL ~4-8*	VVO (ADMS) FLISR (ADMS) ADMS (base) Advanced sensors Advanced Conductors Power Factor Corrections 4-hour storage HVDC lines* Smart reclosers Dynamic Line Rating (DLR)** VPP demand response (residential and C&I loads)
Early Commercial Deployments	 ~2-5% market penetration	 Technically proven and demonstrated technologies, ready for early scaling *TRL ~7-8, ARL ~3-7*	DERMS (ADMS) Adv. Power Flow Controllers (PFC)** 10-hour storage VPP behind-the-meter (batteries, EV charging) Substation Automation, Digitization, Efficiency, and Hardening
Operational Demonstrations	 <2% market adoption	 Technically proven, but large-scale operational demonstrations required *TRL ~5-6, ARL ~2-6*	Alternative Synchronization and Timing Topology Optimization Advanced Flexible Transformers VPP vehicle-to-grid

Note: Foundational technologies (e.g., computation and communications technologies, Data Management Systems) are excluded from bucketing due to technical maturity. *HVDC deployment is higher internationally (North America has 3% of operational VSC-HVDC systems globally); **DLR and APFC deployment is significantly higher in Europe (e.g., in 2020, Horizons Europe invested over $90B in the deployment of DLR, APFC and other advanced grid technologies)

Sources: Modern Distribution Grid Report (DOE); Linevision; Sense; GridWise Technology Assessment; Transitions AI; Brattle Group; DOE Liftoff Reports

Each innovative grid solution contributes multiple benefits to enhance T&D capacity and build a modern grid

Key	Impact to objective
1	Indirect, limited impact
2	Direct, moderate impact
3	Direct, operationally significant impact
4	Direct, primary impact

Grid Technologies & Applications		T&D Capacity			Modernized Grid Objectives					
		Increase physical capacity	Improve T&D utilization	Reduce T&D need (*e.g., reduce load*)	Afford-ability	Sustainable (decarb.)	Reliability	Resilience	Safety	Security
Advanced Tx technologies	Advanced Conductors	4	N/A	N/A	3	3	3	3	2	1
	HVDC systems	4	N/A	N/A	3	4	3	3	2	2
Situational awareness & system automation	Advanced Sensors	N/A	2	N/A	3	2	2	1	1	2
	Power Factor Correction	N/A	3	3	2	2	2	4	2	2
	Smart Reclosers	N/A	N/A	1	2	1	4	2	1	1
	Substation automation & digitization	N/A	2	N/A	1	1	3	4	3	2
	ADMS – *Base ADMS: e.g.,* **D-SCADA, OMS**	N/A	N/A	3	2	2	4	3	1	2
	ADMS – *System efficiency:* **VVO**	N/A	4	4	4	4	2	2	1	1
	ADMS – *DER integration:* **DERMS**	N/A	N/A	4	1	4	2	2	3	2
	ADMS – *Reliability:* **FLISR**	N/A	N/A	1	2	1	4	2	2	2
Grid enhancing solutions	Dynamic Line Ratings (DLR)	N/A	4	N/A	4	3	3	2	2	2
	Adv. Power Flow Control (PFC)	N/A	4	N/A	3	2	3	3	3	3
	Topology Optimization	N/A	3	N/A	4	2	3	3	1	2
	4-10 hour Energy Storage	N/A	3	2	3	3	3	4	2	2
	Advanced Flexible Transformers	N/A	1	N/A	2	2	4	2	1	2
	Substation Efficiency & Hardening	N/A	2	N/A	1	1	3	4	2	2
	Virtual Power Plants (VPPs)	N/A	3	4	3	3	2	2	2	1
	Alternate Synchronization and Timing	N/A	1	1	2	2	2	2	2	4
Foundational Systems	System digitization & visualization	*Foundational systems are key to enabling other grid solutions but do not necessarily achieve grid outcomes standalone, so are not mapped to specific outcomes here*								
	Data Management Systems									
	Computational & Communications Technologies									

Note: Values are representative of relative impact for a specific technology (within each row) and not for comparison between technologies (between rows)
Scoring represents the positive impact on these outcomes and does not include potential downside risks introduced (e.g., security risks associated with VPPs), which will be discussed in the full Liftoff report

U.S. DEPARTMENT OF ENERGY

Many innovative grid solutions are part of broader systems that can drive meaningful cost and benefit synergies when considered holistically

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
  - Distributed Energy Resource Mgmt. System (DERMS)
  - Fault Location, Isolation, Service Restoration (FLISR)
  - Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors
- Substation automation & digitization

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- Dynamic Line Rating (DLR)
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives

(direct significant or primary impacts, e.g. score of 3 or 4)

- T&D Capacity
- Reliability
- Decarbonization
- Resilience
- Affordability
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

U.S. DEPARTMENT OF ENERGY

Example: Dynamic Line Rating
(advanced application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors
- Substation automation & digitization

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- **Dynamic Line Rating (DLR)**
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives
(direct significant or primary impacts, e.g. score of 3 or 4)

- T&D Capacity
- Reliability
- Decarbonization
- Resilience
- Affordability
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Example: Dynamic Line Rating

(advanced application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors
- Substation automation & digitization

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- **Dynamic Line Rating (DLR)**
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives

(direct significant or primary impacts, e.g. score of 3 or 4)

- **T&D Capacity**
- **Reliability**
- **Decarbonization**
- Resilience
- **Affordability**
- Safety
- Secure

Dynamic Line Rating (DLR) → T&D Capacity, Reliability, Decarbonization, Affordability

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Example: Dynamic Line Rating

(advanced application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- **Advanced Sensors**
- **Substation automation & digitization**

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- **Dynamic Line Rating (DLR)**
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives

(direct significant or primary impacts, e.g. score of 3 or 4)

- **T&D Capacity**
- **Reliability**
- **Decarbonization**
- Resilience
- **Affordability**
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Example: Dynamic Line Rating
(advanced application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems
- **Computational & Communications technologies**
- **Data Management Systems**
- System digitization & visualization

Situational awareness & system automation
- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- **Advanced Sensors**
- **Substation automation & digitization**

Arrows on the slide connect both highlighted Foundational Systems boxes to Advanced Sensors and to Substation automation & digitization.

Grid enhancing solutions
- VPPs
- Alt. Synchronization & Timing
- **Dynamic Line Rating (DLR)**
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies
- Advanced Conductors
- HVDC Lines

Grid Objectives
(direct significant or primary impacts, e.g. score of 3 or 4)
- **T&D Capacity**
- **Reliability**
- **Decarbonization**
- Resilience
- **Affordability**
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Example: Dynamic Line Rating
(advanced application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- **Computational & Communications technologies**
- **Data Management Systems**
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- **Advanced Sensors**
- **Substation automation & digitization**

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- **Dynamic Line Rating (DLR)**
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives
(direct significant or primary impacts, e.g. score of 3 or 4)

- **T&D Capacity**
- **Reliability**
- **Decarbonization**
- Resilience
- **Affordability**
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Example: Topology Optimization
(advanced application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors
- Substation automation & digitization

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- Dynamic Line Rating (DLR)
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives
(direct significant or primary impacts, e.g. score of 3 or 4)

- T&D Capacity
- Reliability
- Decarbonization
- Resilience
- Affordability
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

U.S. DEPARTMENT OF ENERGY

Example: Advanced Power Flow Control
(advanced distribution system application)

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems
- **Computational & Communications technologies**
- **Data Management Systems**
- **System digitization & visualization**

Situational awareness & system automation
- **Adv. Distribution Mgmt. System (ADMS)** (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- **Volt/VAR Optimization (VVO)**
- Smart Reclosers
- **Power Factor Corrections**
- **Advanced Sensors**
- **Substation automation & digitization**

Grid enhancing solutions
- VPPs
- Alt. Synchronization & Timing
- Dynamic Line Rating (DLR)
- **Adv. Power Flow Control (PFC)**
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies
- Advanced Conductors
- HVDC Lines

Grid Objectives
(direct significant or primary impacts, e.g. score of 3 or 4)
- **T&D Capacity**
- **Reliability**
- Decarbonization
- **Resilience**
- **Affordability**
- **Safety**
- **Secure**

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

U.S. DEPARTMENT OF ENERGY

Example: Advanced Conductors

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors
- Substation automation & digitization

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- Dynamic Line Rating (DLR)
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives
(direct significant or primary impacts, e.g. score of 3 or 4)

- T&D Capacity
- Reliability
- Decarbonization
- Resilience
- Affordability
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Many innovative grid solutions are part of broader systems that can drive meaningful cost and benefit synergies when considered holistically

EXAMPLE / NOT COMPREHENSIVE

Foundational Systems

- Computational & Communications technologies
- Data Management Systems
- System digitization & visualization

Situational awareness & system automation

- Adv. Distribution Mgmt. System (ADMS) (base)
- Distributed Energy Resource Mgmt. System (DERMS)
- Fault Location, Isolation, Service Restoration (FLISR)
- Volt/VAR Optimization (VVO)
- Smart Reclosers
- Power Factor Corrections
- Advanced Sensors
- Substation automation & digitization

Grid enhancing solutions

- VPPs
- Alt. Synchronization & Timing
- Dynamic Line Rating (DLR)
- Adv. Power Flow Control (PFC)
- Topology Optimization
- Efficient & Agile Substation tech.
- Advanced Flexible Transformers
- 4-10hr energy storage

Advanced Transmission Technologies

- Advanced Conductors
- HVDC Lines

Grid Objectives

(direct significant or primary impacts, e.g. score of 3 or 4)

- T&D Capacity
- Reliability
- Decarbonization
- Resilience
- Affordability
- Safety
- Secure

Legend

Topology Optimization	Dynamic Line Rating (DLR)	Advanced Conductors	Adv. Power Flow Control (PFC)

Barriers to and solutions for modernizing the existing T&D grid

Barriers	Solutions
1 **Limited common understanding of and standard methodologies to holistically evaluate innovative grid technologies**	Development and **adoption of standardized methodologies** to evaluate multi-value and long-term oriented solutions **Capacity building** among regulatory bodies to understand grid tech
2 **Traditional utility and regulatory incentive structures do not align with the needs of a modern grid –** particularly lacking monetization for avoided costs and improved performance and disincentivizing innovation	**Updating regulatory and utility business models** to reward and value performance (incl. for costs of avoided events) instead of CAPEX, enable new risk and cost sharing models, and encourage innovation
3 **Operational and implementation complexity slowing adoption** (e.g., organizational change required; changes to standard operating processes – incl. at utility, regulator, and RTO level; technology integration with existing systems)	**Proactive utility organizational transformations** to align operating, investment, and planning practices with modern grid management and innovation **Updating existing market assumptions and SOPs** (e.g., at RTO level) to integrate advanced grid control solutions and appropriately incentivize grid resources
4 **Competing priorities and uncertainty on how to strategically plan investments** (e.g., prioritization strategy, tech sophistication needed, stranded tech assets concerns)	Shifting to **long-term oriented integrated regional planning processes** with **coordination across stakeholders** (utilities, regulators, policymakers, communities, solutions providers, RTOs)
5 **Technology maturity concerns, particularly for some advanced adaptive control grid solutions**	**Greater transparency and information sharing**, especially for operational demonstrations of earlier stage tech; **increased investment to improve quality of available solutions** with solution providers sharing tech risks

Recap: Key Messages for Innovative Grid Deployment

Shifting to a **proactive, future-oriented approach** for managing and investing in the T&D grid is critical to ensure system reliability in a rapidly changing energy future

Inaction is not an option – communities and utilities that fail to modernize the grid in the near-term will struggle to provide reliable and affordable power, **threatening human well-being and economic development opportunities**

The **existing T&D grid footprint is a powerful resource that can be unlocked with multiple readily-available, innovative technologies and applications** that can be quickly scaled today

These **innovative grid solutions are technically-proven and commercially-available – yet deployment and associated industry know-how is lagging** due to a lack of sufficient industry incentives and prioritization

Four technologies* in focus for today are high-priority for rapid scaling: **dynamic line rating (DLR), advanced conductors, high voltage direct current lines (HVDC), and Advanced Distribution Management Systems (ADMS) and its advanced applications**

Utilities, regulators, policymakers, solutions providers, and other key **stakeholders can start acting today, taking advantage of unprecedented federal investment & policy incentives** to accelerate deployment of innovative solutions that can unlock meaningful near-term value

**Analysis of the remaining technologies will be included in the full Liftoff report*

Thank you!

Feedback is welcome at liftoff@hq.energy.gov and will be used as input into the *Innovative Grid Deployment* Liftoff report.

- Do you have any feedback on the technology content covered today (e.g., technology commercial readiness, technology impacts, barriers & solutions, etc.)?
- Where can DOE support (e.g., funding, technical assistance) best catalyze market adoption of innovative grid solutions at scale?