Overview: Design of a Macrogrid to Support High Levels of Clean Electricity

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April 2022

Why Do We Need to Study a Macrogrid?

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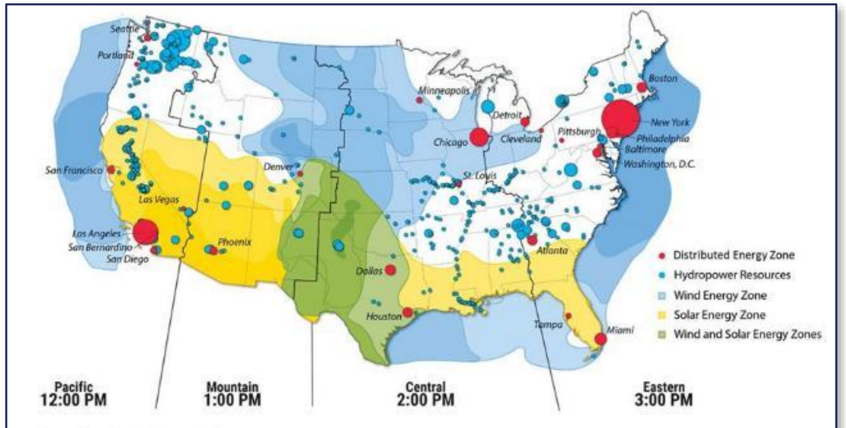
If we want reliable, affordable and clean energy…

we need significant, national transmission expansion

We need transmission to…

Deliver resources to loads



Source: Energy Systems Integration Group.

Nickell, SPP, WIEB CREPC Spring meeting, 2017; Joint and Common Market contour map, see [Goggin, *Transmission Makes the Power System Resilient to Extreme Weather*, July 2021]; [MISO, Renewable Integration Impact Assessment, Feb 2021]

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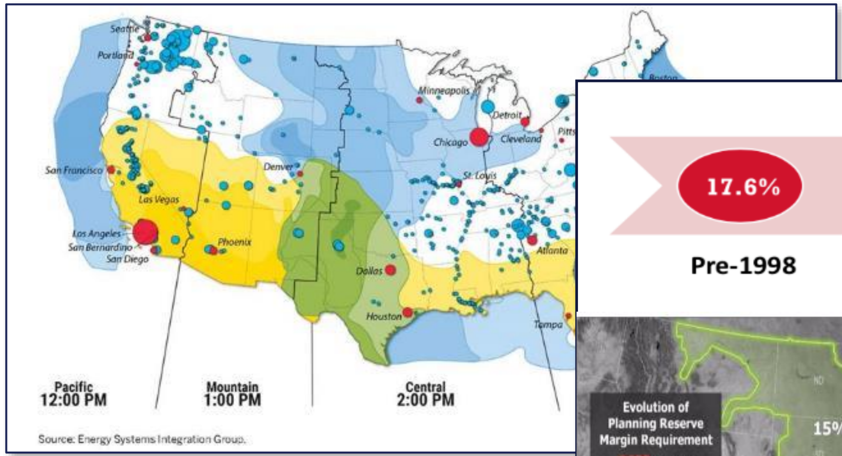
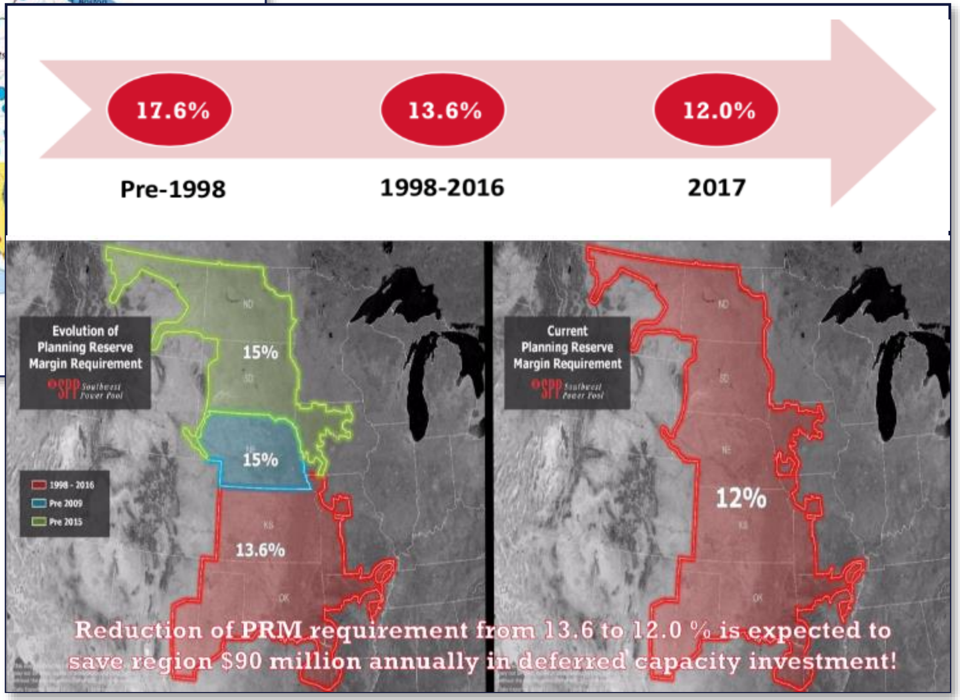


Contribute to resource adequacy



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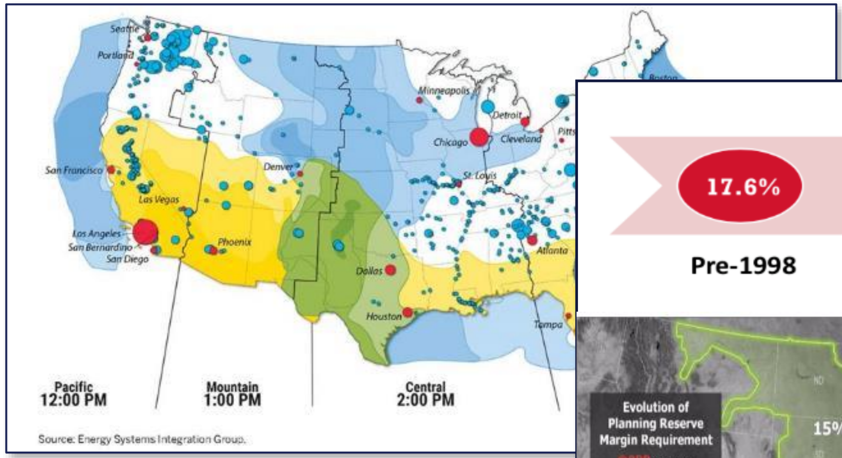
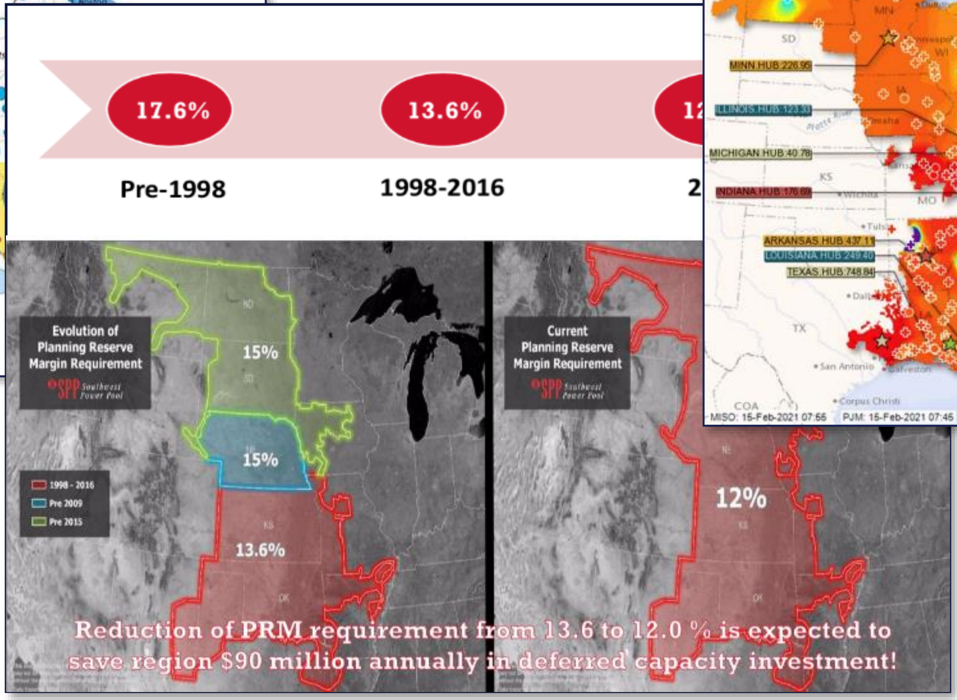
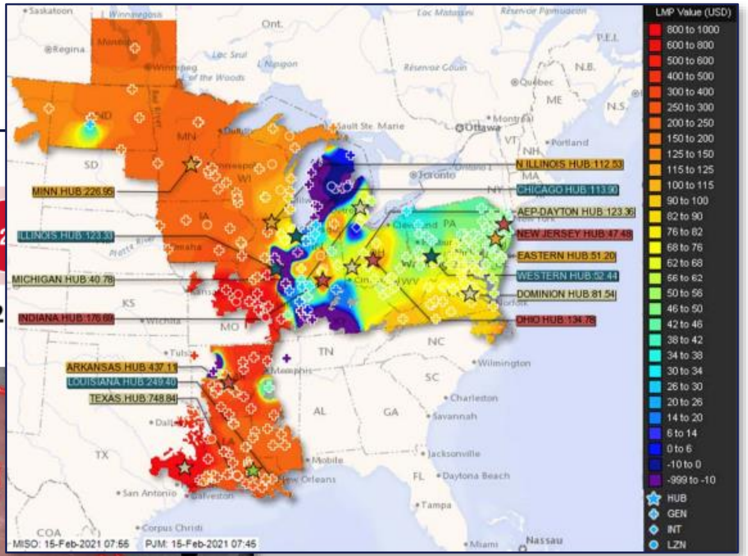


Contribute to resource adequacy



Provide resilience



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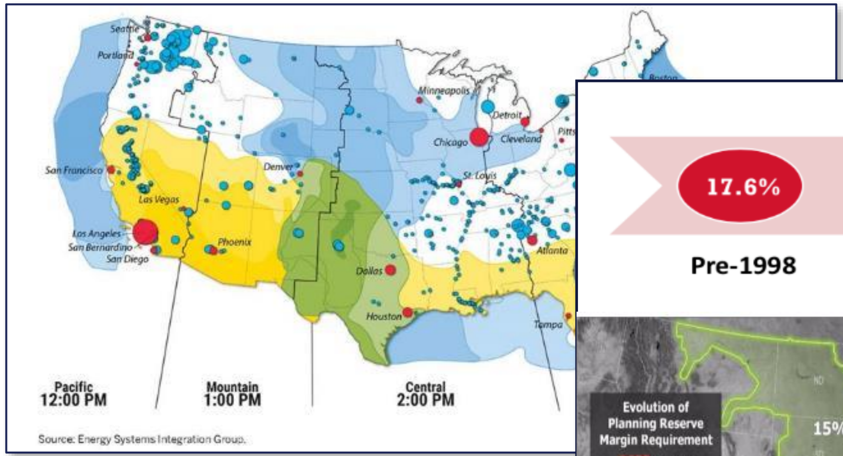
We need transmission to…

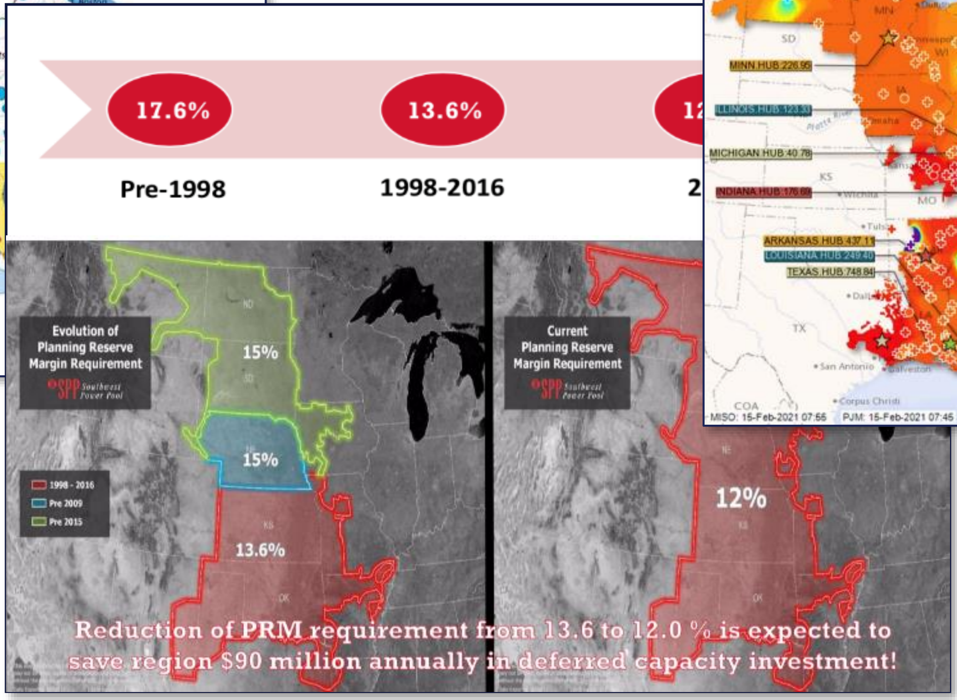
Deliver resources to loads

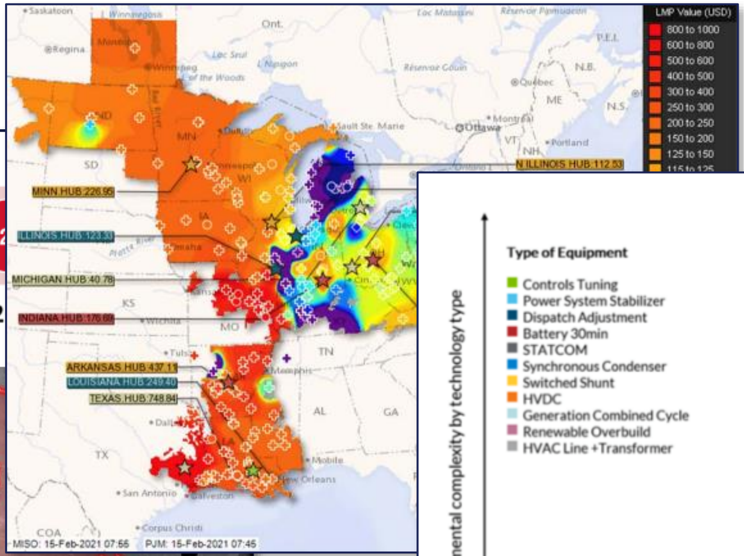
Contribute to resource adequacy

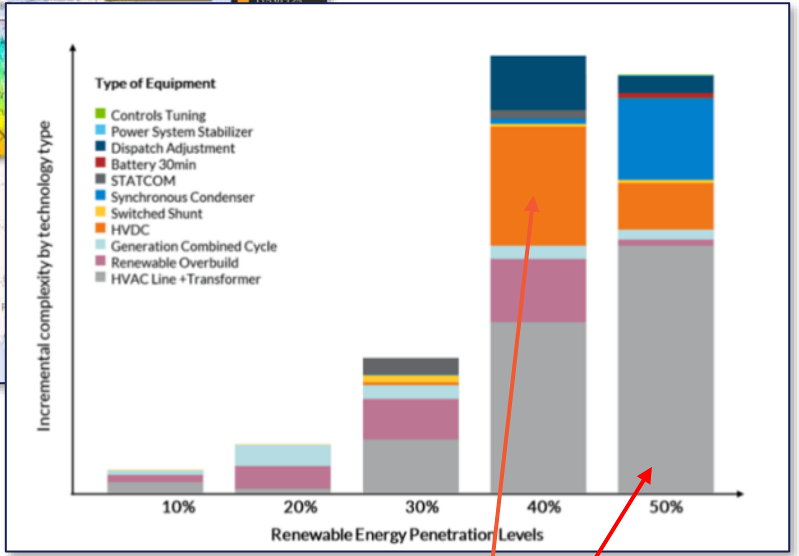
Provide resilience

For a host of other reliability benefits







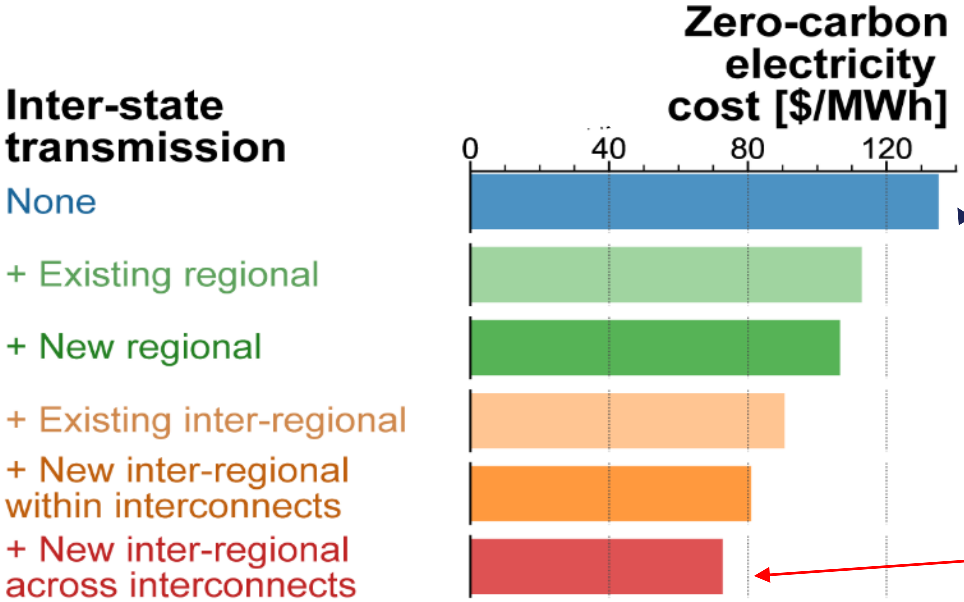


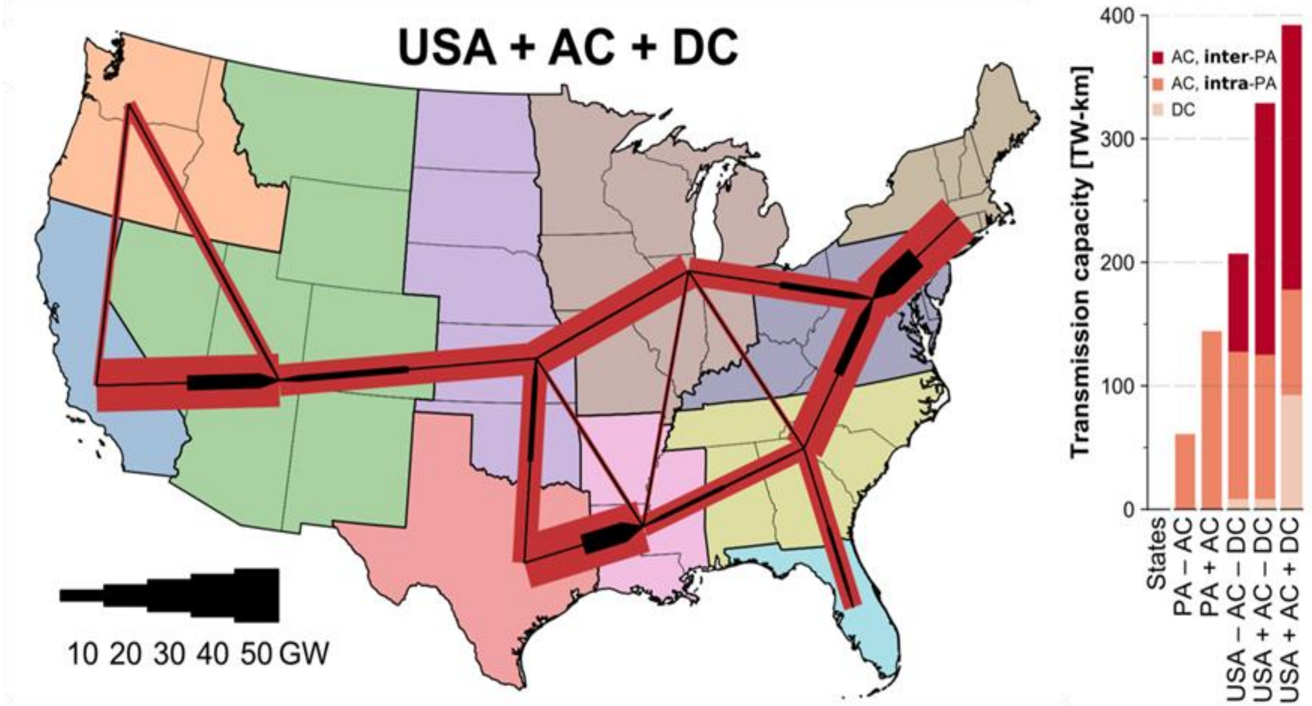
DC TRANSMISSION
AC TRANSMISSION

Nickell, SPP, WIEB CREPC Spring meeting, 2017; Joint and Common Market contour map, see Goggin, Transmission Makes the Power System Resilient to Extreme Weather, July 2021; MISO, Renewable Integration Impact Assessment, Feb 2021

National transmission planning is needed

This study examines 100% clean electricity in the US under scenarios with increasing geographic levels of transmission expansion and operations



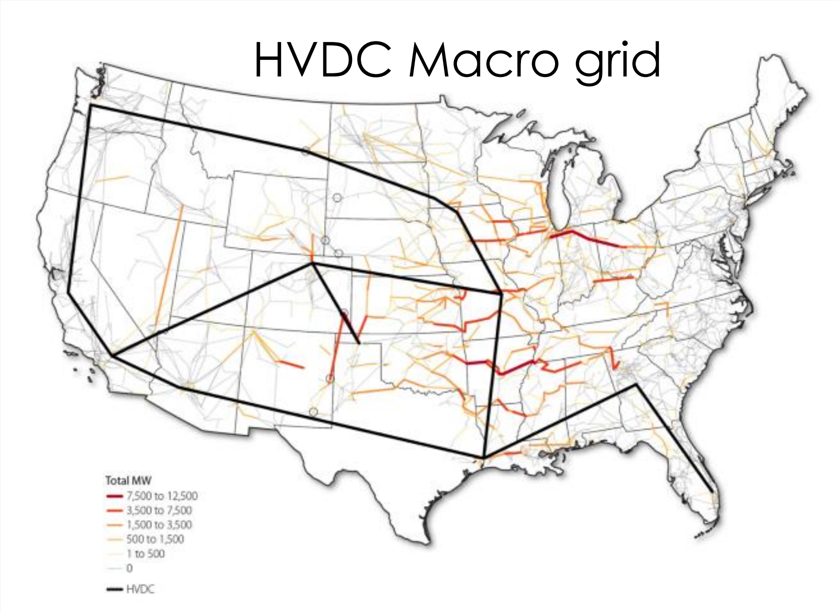


"Every state for itself" costs twice as much ($135/MWh) as the nationally optimized and coordinated approach ($73/MWh)

Brown and Botterud, "The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System," Joule 5, 1-20, Jan 20, 2021

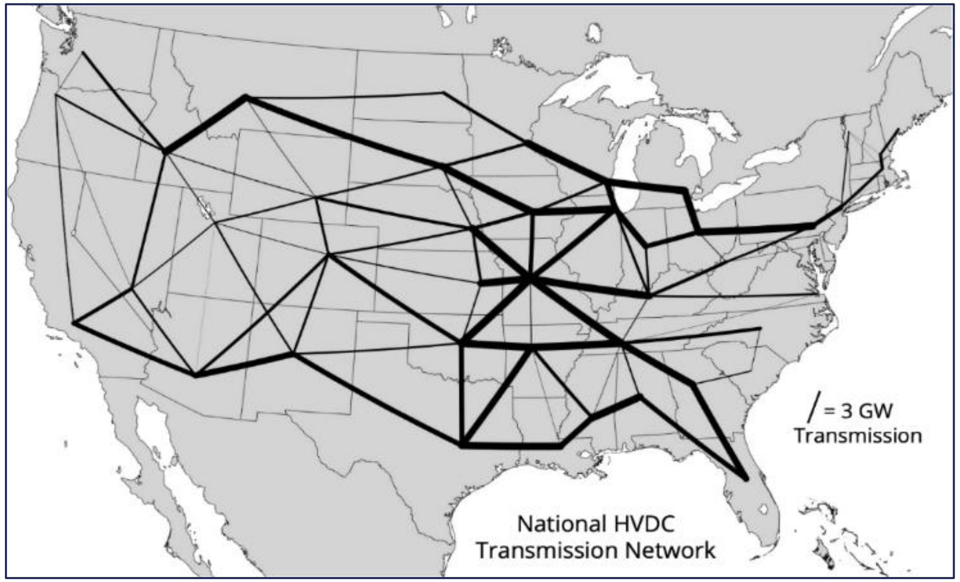
A macrogrid saves money – especially with decarbonization

NREL Interconnection Seams Study



- With a 50% renewables goal, this HVDC macro grid has a benefit-to-cost ratio of 2.5
- With a 85% renewables goal, this HVDC macro grid has a benefit-to-cost ratio of 2.9

Vibrant Clean Energy ZeroByFifty



- Transmission expansion costs are $200B and $350B for 100% clean electricity and 100% clean energy, respectively
- If a macrogrid is not built, it costs $1T more to get to 100% clean energy by 2050

Figueroa Acevedo, et al, *Design and Valuation of High-Capacity HVDC Macrogrid Transmission for the Continental US*, IEEE Transactions on Power Systems, Vol 36, no 4, July 2021; VCE, see Lew, et al, *Transmission Planning for 100% Clean Electricity*, IEEE PES Magazine, Nov/Dec 2021

Transmission costs are *tiny* compared to other resource/infrastructure costs

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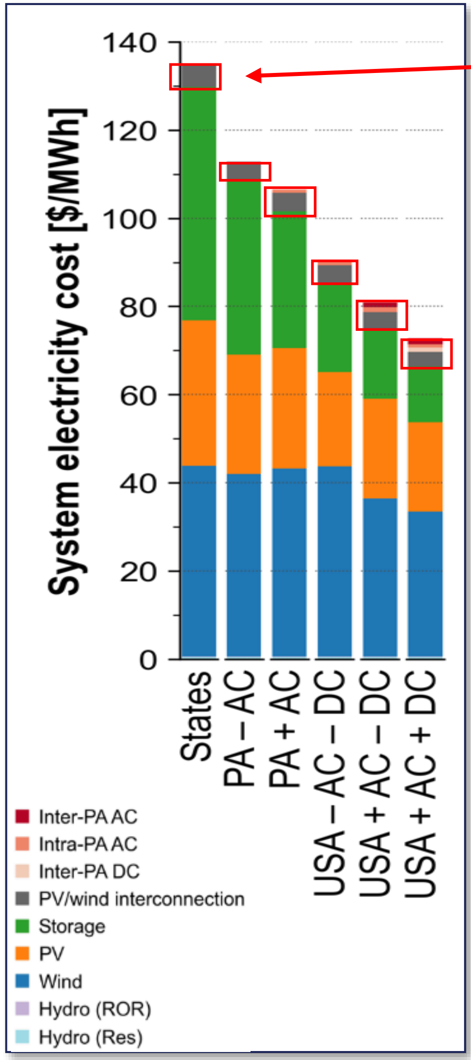
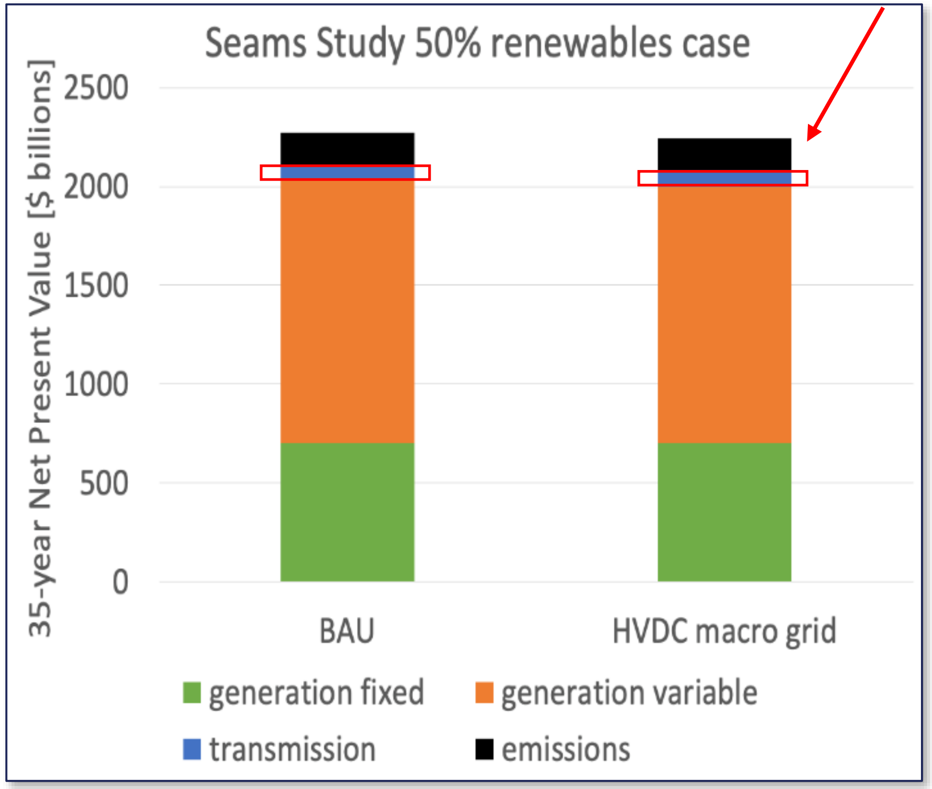
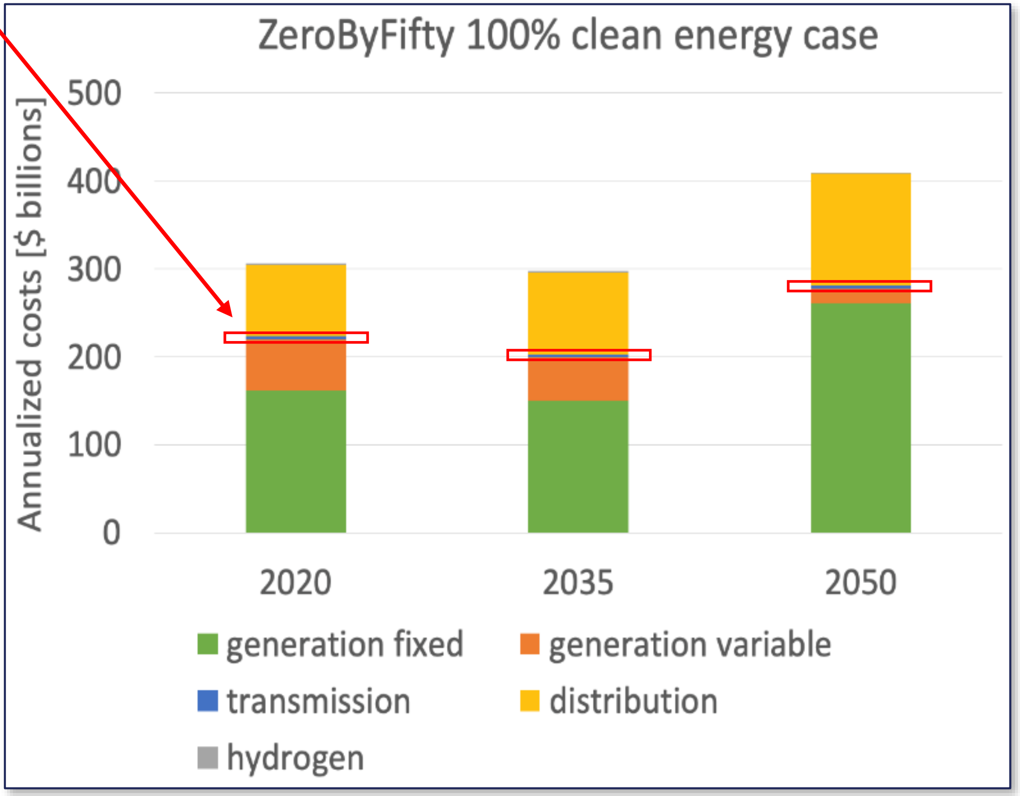
TRANSMISSION COSTS

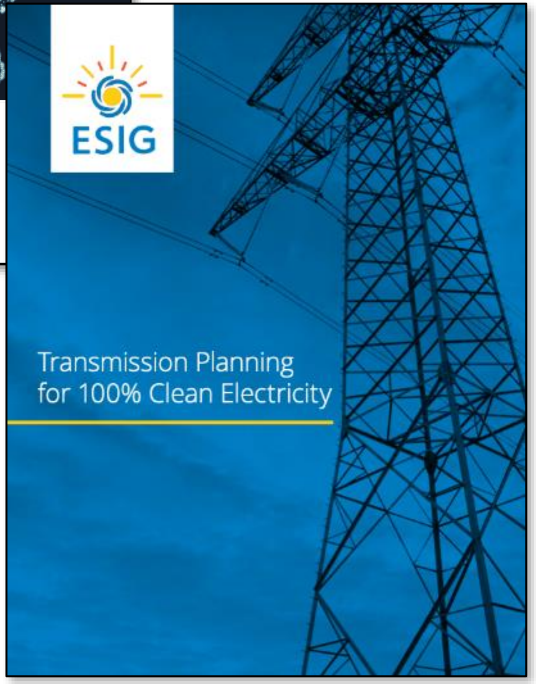






Brown and Botterud, "[The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System](#)," Joule 5, 1-20, Jan 20, 2021; data from NREL Interconnection Seams Study; data from VCE's ZeroByFifty Study

ESIG Recommendations



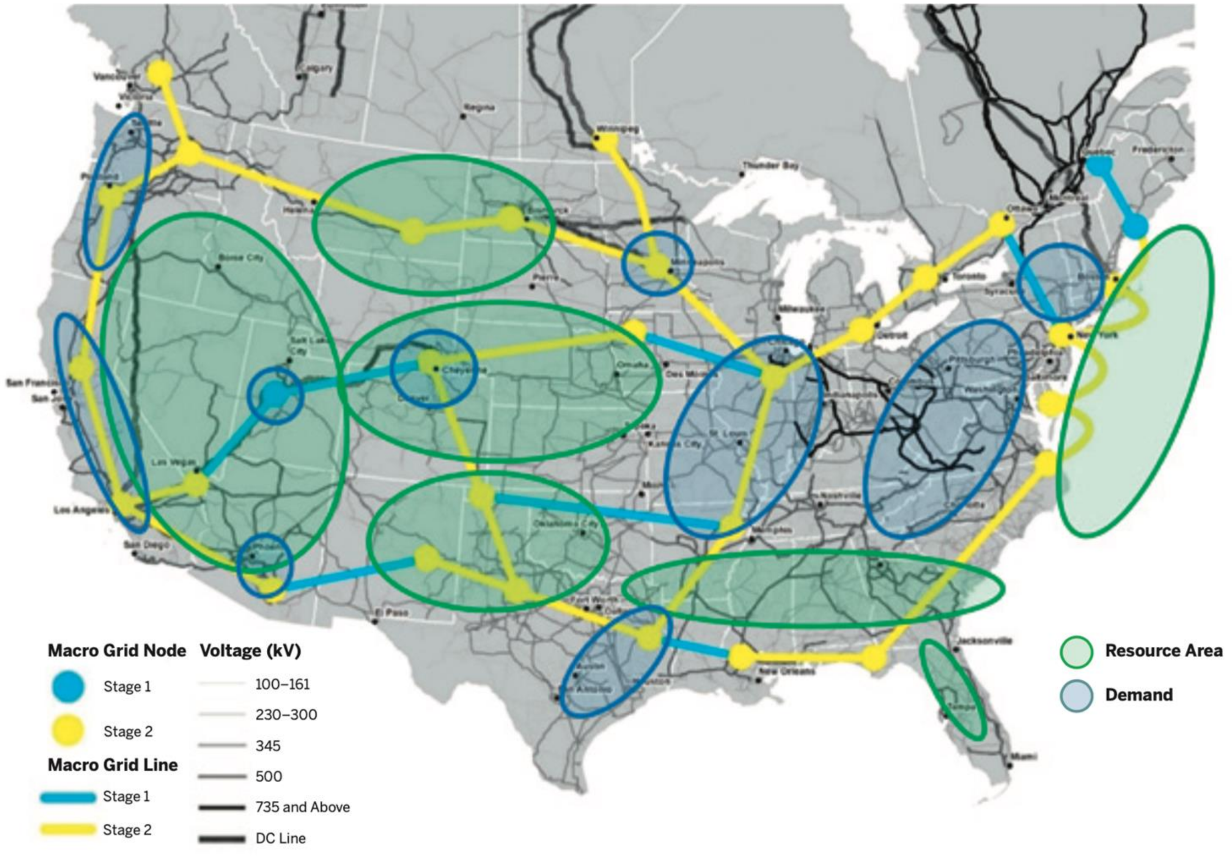
- **We need ongoing national transmission planning, not just a one-off study**
- **We need to proactively plan and build transmission to high quality clean energy zones**
- **We need to design and evaluate performance of a national macro grid for reliability, resilience, operations and economics**

https://www.esig.energy/design-study-requirements-for-a-u-s-macrogrid/
https://www.esig.energy/transmission-planning-for-100-clean-electricity/

Why Not Conventional Transmission Expansion?

- Transmission fills three buckets of needs:
  - Connecting resource zones to loads to provide energy and ancillary services
  - Connecting diversity for resource adequacy and resilience benefits
  - Reliability for steady-state and dynamic stability

- A fundamental transformation of the grid for the fundamental transformation of the resource mix.
  - Incrementalism won't achieve this.
  - Top-down 'optimizations' can show us the end game and improve bottom-up efforts.
  - Macrogrid design would be based on sound transmission planning principles but may require some new approaches.
  - HVDC allows for controllability to coordinate across regional system operators
  - HVDC allows for long distances transfers at low cost with limited right-of-way use
  - VSC-HVDC supports stability with high levels of inverter-based resources



Source: Energy Systems Integration Group.

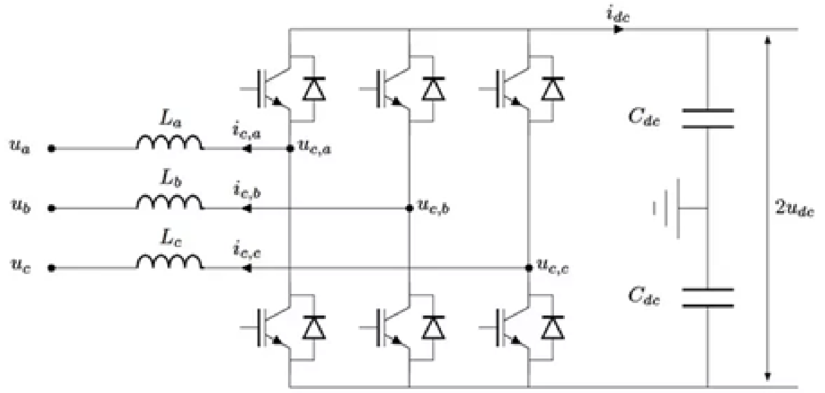
You can't get there if you don't know where you're going

Macrogrid Design

Elements of Macrogrid Design

- The Macrogrid expansion represents the **Innovative design**
  - A self-redundant, multi-terminal VSC HVDC;
  - Voltage source converter (VSC) is mature - TRL9;

    Multi-terminal DC is TRL4-6 and increasing quickly
  - Couples with HVAC expansion for collection and local/regional delivery of clean electricity



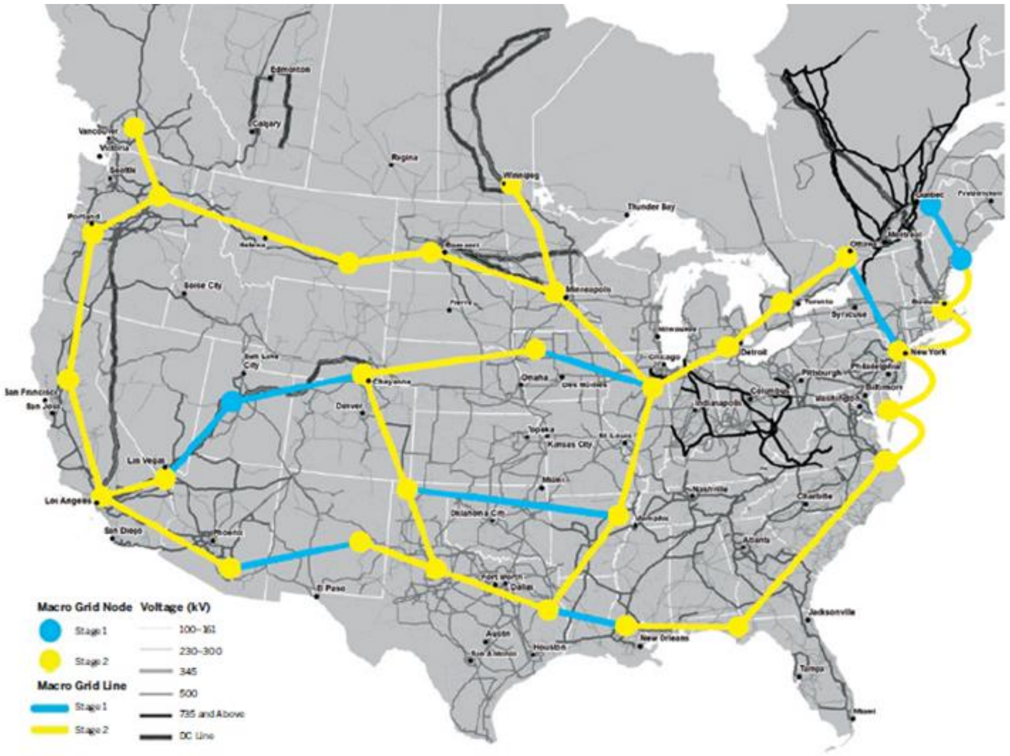
- Focus on developing a final and complete design to support high CO2 reduction; identifying development stages & design refinements are important, but subsequent steps.
- Design Macrogrid to perform well (least regrets) under multiple targeted scenarios in terms of electrification, technology costs, DR growth, offshore growth, gas prices….
- Compare to other transmission expansions under the same scenarios

- The Macrogrid is a largescale and fundamental change to the North American power system; its planning, design, and operations will require developing new procedures, approaches, and tools.

Initial Macrogrid Design: Objective

Start with a proposed design; use tools to enhance architecture, topology, capacities, so as to maximize known benefits and effects:

- **Reducing cost of decarbonization**
  - Enabling access to and deliverability for the most attractive wind and solar resources
- **Reducing delivered costs of energy and services**
  - Sharing daily energy and services across time zones
- **Reducing investment of new planning reserves**
  - Sharing reserves during regional peaks
- **Increasing reliability**
  - Offloading underlying AC system
  - Utilizing additional control capabilities
- **Improving resilience to extreme events and enhancing optionality/adaptability to unexpected futures**
  - Increasing deliverability between regions

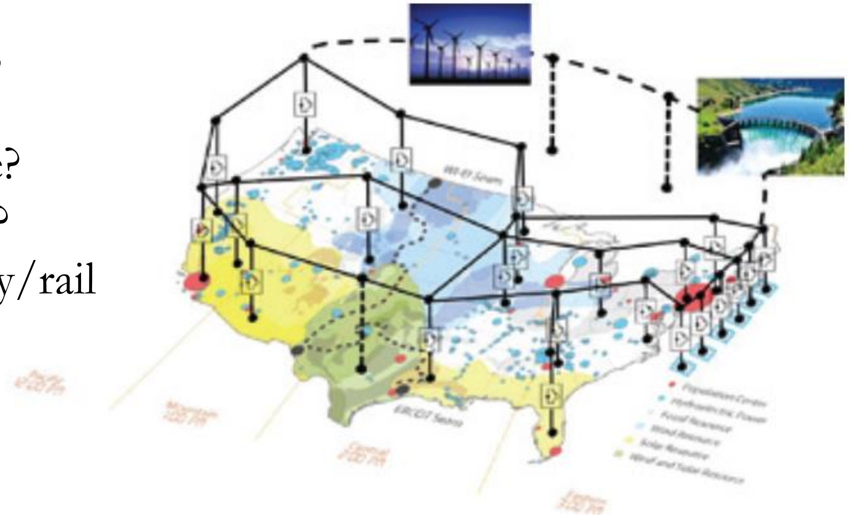


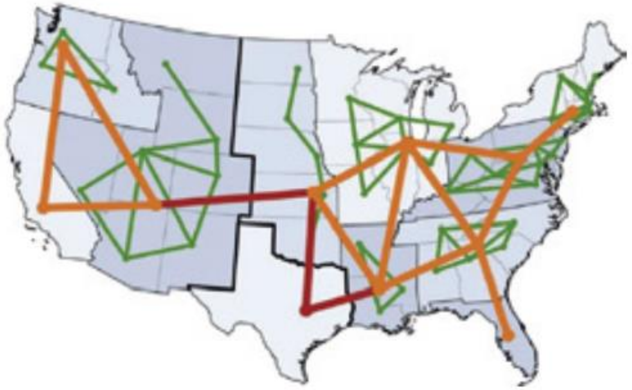
Source: Energy Systems Integration Group.

Initial Macrogrid Design: Proposed to-date

High-level design issues:

- Geographic scope: Canada; ERCOT; offshore.
- Terminal density: One terminal/state?
- Collection: Entirely AC or some DC?
- Routing: Existing AC, Co-locate Hwy/rail
- Facilitate EV/rail electrification





Several top-down designs have been proposed in recent research.

Sources, clockwise from upper-left: Figueroa-Acevedo et al (2021), Clack (2021), Energy Systems Integration Group (2021), Brown and Botterud (2020), McCalley and Zhang (2020)

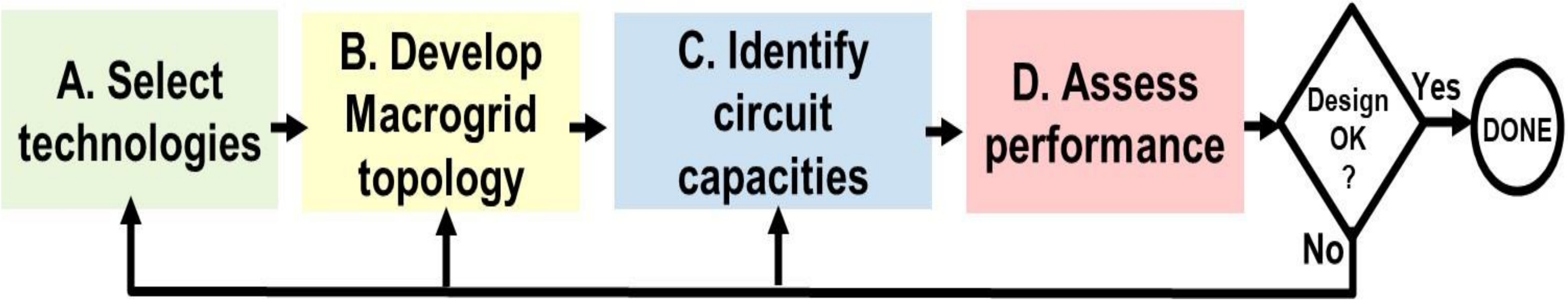
Initial Macrogrid Design: Process

Info: HVDC MT Network VSC Grid-Forming Converters
Tools: Electromag. Transient (EMT)/dynamics co-simulation

Info: Resources/load-center locations
Existing transmission weaknesses
Differences between regions;
Routing data.
Tools: Iterative graph-search

Info: Future scenarios; network; resource & load profiles; economic data
for future conditions.
Tools: Large model reduction; fast expansion planning optimization; resource/energy adequacy;

Info: Operations & markets; Power flow/voltage response; Dynamic analysis & control design;
Tools: Decomposed prod.cost sim for zero-marg cost; EMT/dynamics co-simulation; Hierarchical control design for very large systems.



- All macrogrid topologies proposed to-date are notional; i.e., Step B has not yet been performed systematically/quantitatively.
- Iteration between steps is essential, especially from Step D to others.

Incorporates Important Transmission Planning Principles

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The process of moving from concept to preliminary design involves more than just sizing elements to transport energy. Because this effort is focused on the Macrogrid as it would exist after many years of development, we have the opportunity to develop new engineering principles and approaches for design and operation of an advanced transmission system:

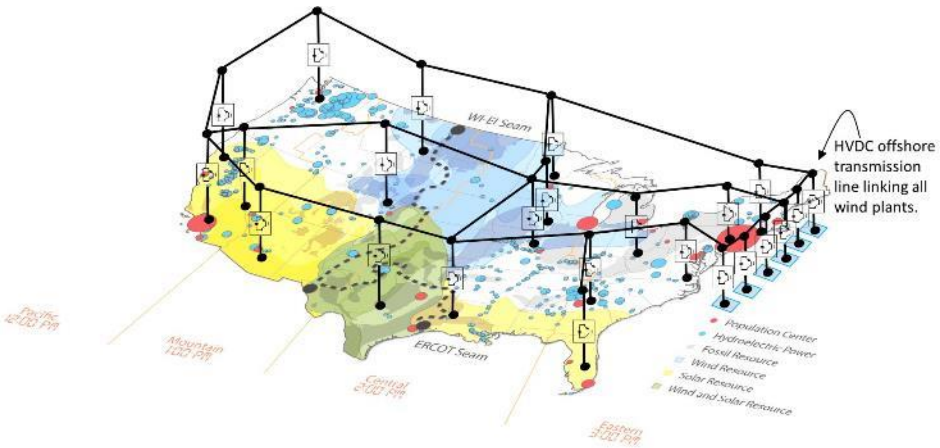
- **The "old" general principles still apply:** Coordination, openness, transparency, participation, regional, scenario-based.
- **But new ones are in play:** Multiregional and proactive, to support policy while enhancing reliability, resilience, and optionality.
- **New concepts for appropriate mixes of technologies**: line-commutated converter HVDC (LCC-HVDC), voltage source converter HVDC (VSC-HVDC), AC and DC collector systems, and HVAC grid reinforcement.
- **Enhanced control opportunities**: Issues of low-inertia power systems, grid-forming capabilities via VSC-HVDC terminals, utilization of multi-terminal HVDC control, black start, improved frequency, voltage, transient control, local/regional/continental control
- **New engineering design considerations**: Modularity, equipment ratings, circuit configurations (e.g., rule of 3), expandability, embedded VSC-HVDC considerations, HVDC system protection, HVDC to HVAC system interactions.
- **Assessing robustness and optionality**: Macrogrid increases deliverability and increases robustness and optionality – how to assess this in the face of uncertainty in future resource and load development paths due to: (1) evolving electricity supply and storage technology and cost options, (2) varying levels of electricity demand associated with end use efficiencies, (3) demand response, energy efficiency and electrification paths, and (4) policies and costs associated with distributed energy resources.
- **Interactions with other sectors**: Electrified transportation requires DC; can the Macrogrid be designed to facilitate this need?

The rule of 3 guideline

➔High-capacity inter-regional transmission is (i) self-contingent & (ii) economically attractive; if it is built using at least 3 parallel circuits.

Total Max Flow Before N-1 Outage ≤ Total Capacity After N-1 Outage

n (minimum number of new lines to satisfy inequality at p)	p (derating factor - fraction of total transmission capacity that can be used without overloading remaining circuits during loss of one new circuit)	nC (capacity added, MW)	pnC (total available capacity added, MW)
1	0.37	3600	1323
2	0.73	7200	5276
3	0.88	10,800	9549
4	0.97	14,440	13,925



Multi-terminal HVDC Should be the Foundation of the Macrogrid

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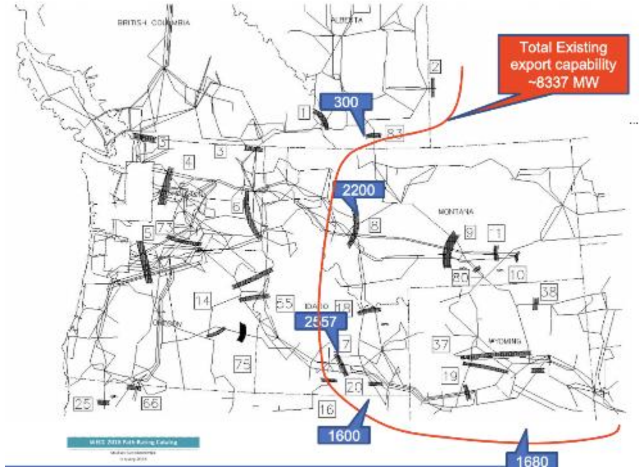
What Difference Could a Macrogrid Make?

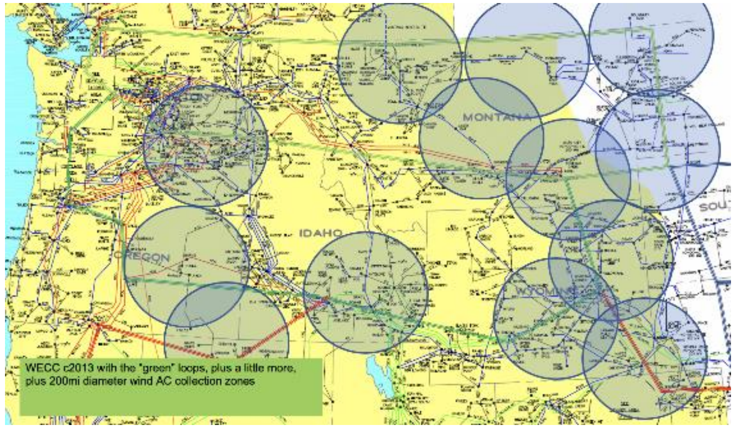
Consider the Pacific Northwest. Current HVAC infrastructure delivers 8,337 MW. The region shown has probably 10x that amount of developable clean energy potential.

- Additional interregional HVAC – maybe with additional interregional and local HVAC lines -- could deliver a portion of this capacity, but could take decades to build and be very complex with respect BPS security
- But building new interregional HVDC lines supported by local interconnection lines could deliver more economically, developed more quickly with fewer lines and land use.

Current Pacific Northwest Transmission



Potential Pacific Northwest Macrogrid



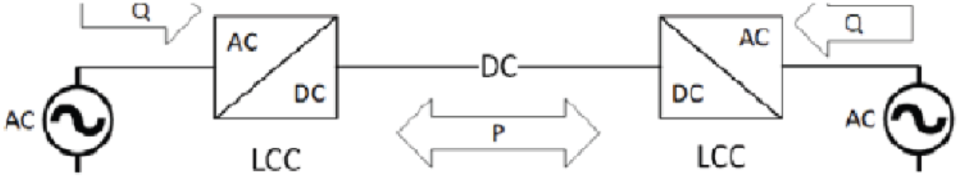
Blue circle = gen collector zone
Black line = HVDC

Some Macrogrid Attributes

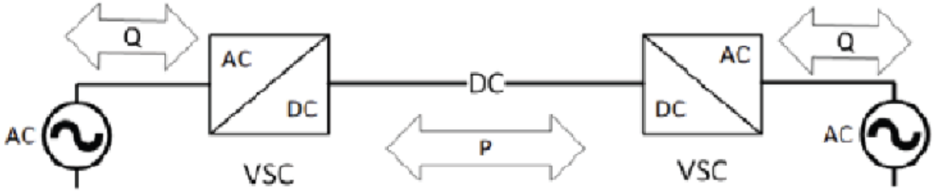
- Not just "bigger pipes" for moving clean electricity, but an overlay of HVAC and HVDC lines and terminals that connects clean energy-producing and consuming regions across the entire nation (perhaps serving most of the continent)
- Leverages diversity in demand and clean energy production over maximum geographic scales – beyond neighbor-to-neighbor
- The entire Macrogrid would be self-redundant, with limited interactions with the underlying bulk AC transmission system
- Mixture of conventional and new technologies – e.g., **multi-terminal HVDC with shunt-connected VSC converter stations**
- Can be leveraged to improve or enhance operation of the existing and future bulk AC grid
- Operates in coordination with underlying bulk AC system, and ways that maximize reliability and economic benefits

Not Just Any HVDC…

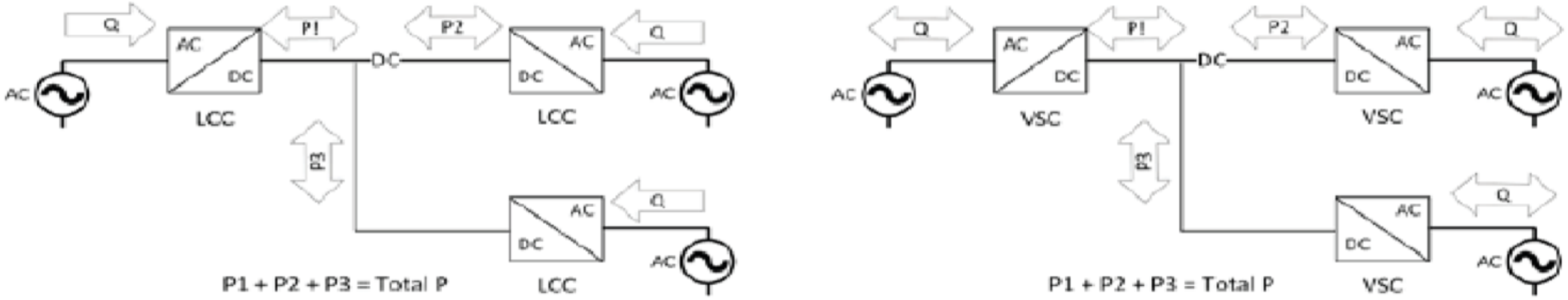
- Substantial global experience with HVDC (especially LCC)
- Limited mostly to point-to-point connections (asynchronous grids or long-distance energy transfer)
- VSC-based HVDC maturing quickly. Offers significant new opportunities for controllability and integration with AC systems. Is the “go-to” advanced solution for transmission of offshore wind generation



Conventional LCC HVDC - many installations globally, “point-to-point” connections



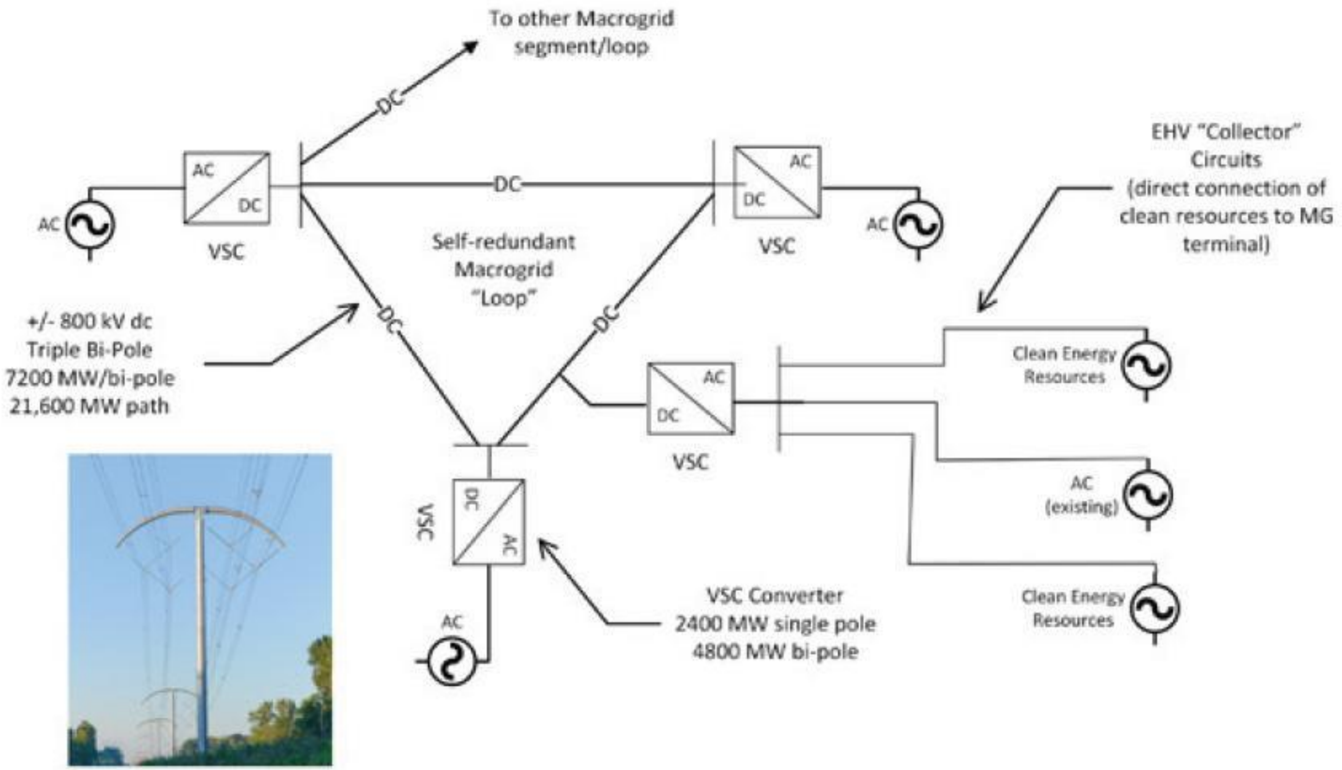
VSC HVDC (some global projects, offspring of “HVDC lite”, but now with higher capacity ratings available



Multi-terminal (i.e., more than 2 terminals) implementations of LCC or VSC HVDC. Some projects globally, but interest growing quickly

Extending the Concept

- Macrogrid overlay comprised of networked HVDC with multiple, modular VSC terminals
- Designed to be self-redundant – i.e, contingency on HVDC grid does not impact underlying HVAC system
- Would need DC breakers for circuit protection, but these should be available commercially



AEP "Bold" TL design for triple bi-pole circuits

Sources: Energy Systems Integration Group (graphic); American Electric Power (photograph).

Reliability and Resilience Analysis Will Have Some Radically Different Aspects

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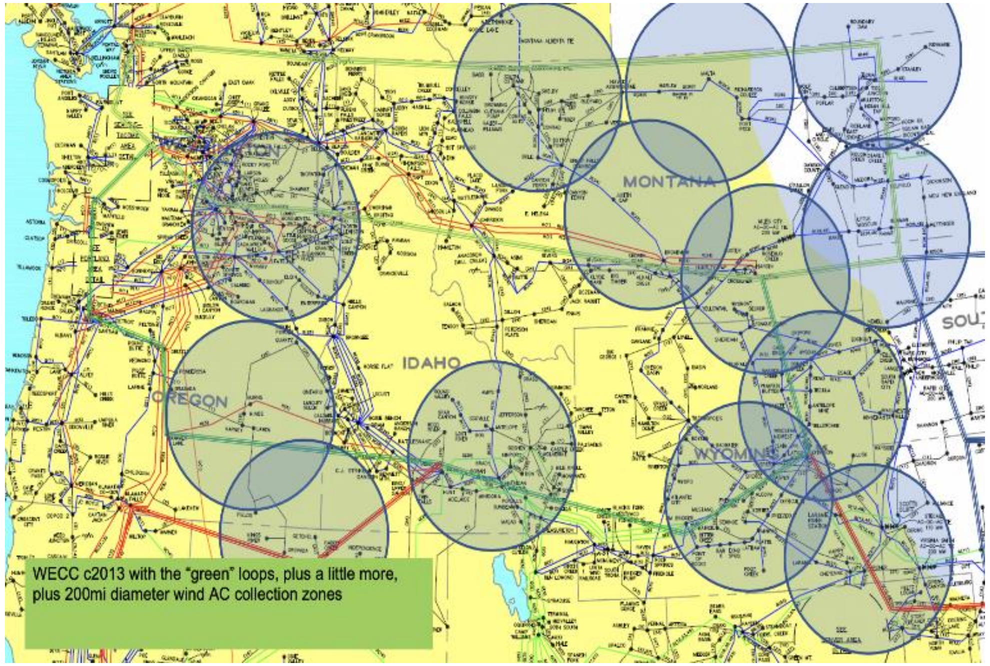
Getting the Macrogrid Right Will Create Local Benefits

- Beyond the self-contingent behavior, the Macrogrid will also provide a solid "anchor" against which existing and new local/regional AC systems can lean. This will provide performance (and economic) benefits beyond the transfers on the macrogrid
- The reliability investigation must design tests and demonstrations to explore these opportunities.
- For example:
  - Macrogrid response to disturbances on the supporting AC grid, should relieve (some) performance constraints (e.g. increase path limits); increasing utilization, saving costs, reducing the need for more ROW for supporting AC circuits.



Blue circle = gen collector zone
Black line - HVDC

Sharing Services: Frequency Response, Reserves and Inertia

- These issues will tend to be geographically broader or systemic, compared to transient and voltage stability.
- The Macrogrid will tie regions together in ways that should facilitate better overall performance, and economic sharing of resources - including essential reliability services.
- Security performance, particularly the response to events that unbalance the system – causing frequency and intertie violations, will be altered.
- The security investigation must design experiments to test existing and new types of systemic stress, and make demonstrations of possible benefits from the Macrogrid.
  - For example, the Macrogrid should allow for sharing of primary frequency response, delivery of FFR, and more economic compliance with FROs. Novel controls may be needed to fully realize some potential benefits.

Technology Opportunities for Energy Systems Integration

- The entire system, including the balance of the AC grid, and the mix of resources, such as massive IBRs buildout, new energy storage resources, electrification of new sectors, will be different and should leverage new technology opportunities.
- Reliability performance demonstrations should start with an assumption of best available and appropriate grid-enhancing technologies (GETs) such as high functionality inverter-based resources (IBRs) with grid-forming inverters (GFM), best practice protection, high function reactive compensation, dynamic line ratings, VSC HVDC, etc.
- Investigation must be designed to incorporate refinement and addition of new (but reasonably well established) technologies.
  - These can be used to mitigate problems or improve performance. Focus on expected technology growth: large-scale energy storage (with reliability centric controls), active EV infrastructure, distributed generation and newly electrified industrial segments.

Implications for Reliability & Resilience

Higher risk to grid and society from climate change and human threats

- Historic ("normal") weather conditions not a relevant guide for current & future conditions
- Extreme weather no longer HILF events but High Impact Medium Frequency events
- Higher risk = (higher frequency of extreme weather events) x (worse weather events causing more grid and societal damage)

Challenge for current grid assets

- Lesser ability to withstand harsher extreme weather conditions (asset destruction, condition deterioration, overloading)
- Lower performance capability and Limited ability to replace, upgrade or expand
- Restoration challenges – wider damages require more time, eqpt, crews, $$$

Different character of reliability and resilience challenges

- Macrogrid will be self-contingent for "normal" events; implications and response for extreme/HI events needs new thinking
- Effective strategies will likely drive both Macrogrid design details (e.g "hardening"), but resource (and resource adequacy) decisions.

Operability of a Macrogrid Overlay Will Require System Developments to Optimize/ Interface With System Operators

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Operations & Operability

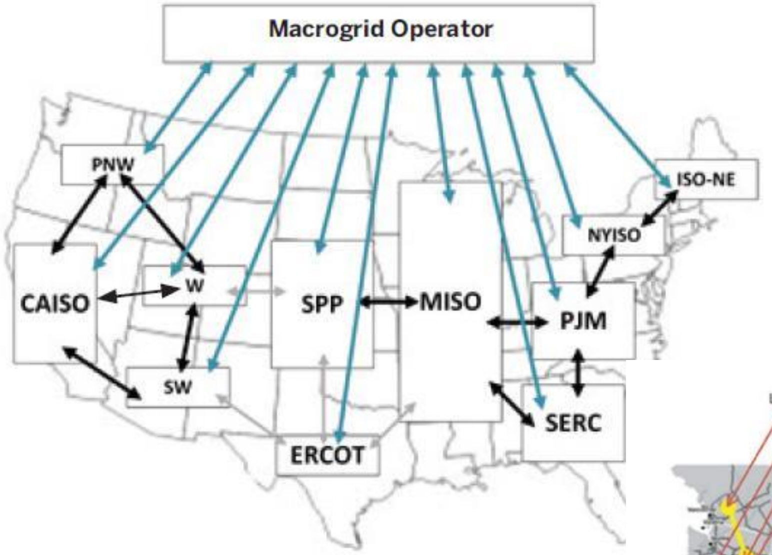
Analysis of the operational needs associated with a future Macrogrid (HVDC overlay) across North America, outlining the steps needed to ensure that future operation of the Macrogrid is studied and coordinated with existing operational structures and organizations.

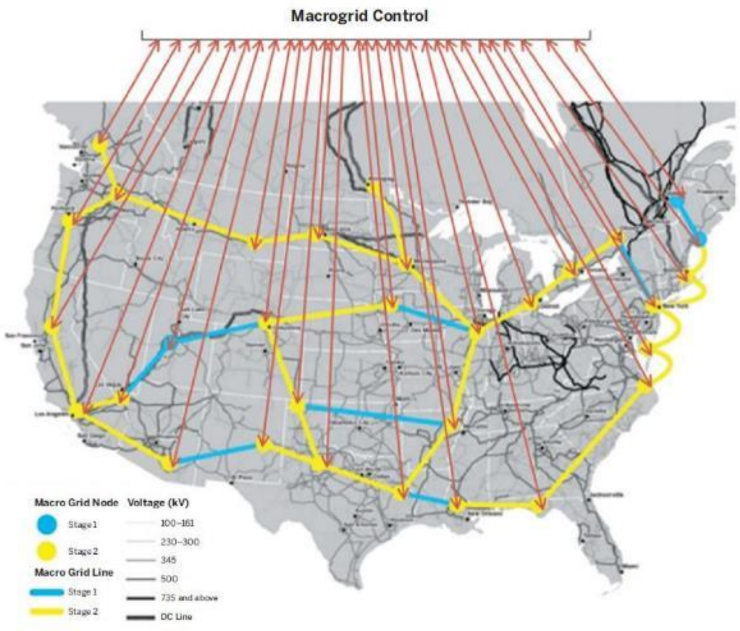
Objectives

- Posit options for workable organizational structures and responsibilities for operation of Macrogrid overlay
- Assess operational requirements for the Macrogrid and how it integrates with and affects the underlying transmission network
- Determine how operations could be coordinated with regional markets and entities
- Identify new tools and approaches that may be required to fulfill national operational mission (e.g., simultaneous transport of energy with reliability constraints)

Operations & Operability: General

- A national Macrogrid would offer a degree of control over the flow of energy from sources to loads. Those flows will be orders of magnitude greater than present power system flows.
- To leverage such control, however, new architectures and methods for grid control may have to be developed.
- Current control structures are based on cooperation mostly between neighbors and within interconnections.
- With a Macrogrid, operational concepts and opportunities will extend across interconnections and to neighbors' neighbors and beyond
- New governance and operating institutions may be needed as well





The dispatch and flow of energy on the macrogrid would be the responsibility of the macrogrid operator and effectuated by the real-time control of all macrogrid nodes.

Source: Energy Systems Integration Group.

Coordinating Macrogrid Operation

- Select or create an entity that operates the Macrogrid to meet reliability/resilience needs and facilitate economic operation of the U.S. electrical infrastructure.
- Determine appropriate mechanisms for technical control and operation of the Macrogrid and underlying networks to:
  - Maintain bulk system security
  - Balance generation and load
  - Manage congestion
  - Coordinate between regional and national entities for system operations
  - Conduct long-term resource assessments and planning
- Identify appropriate options to manage power, economic and market transactions, including:
  - Coordinating renewable energy procurement nationally, both day-ahead and in real time
  - Coordination between regional and national entities regarding commitment and dispatch of all electricity sources, demand response and storage, and market operations
  - Ancillary services management
  - Cost allocation of ancillary services and uplift costs
- Macrogrid economic and operations studies would likely use large-scale production simulations to illustrate both higher-level coordination concepts and issues such as balancing and congestion management.

Economic Analysis Must Evaluate All Costs and Benefits

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Economic & Financial Considerations

- Apply meaningful and consistent economic analytical and evaluation techniques for all of the Macrogrid studies and analyses
  - Macrogrid costs
  - Macrogrid benefits - how are benefits distributed by region, customer type, across services, and over time? Note that unlike local transmission, the Macrogrid will deliver benefits continent-wide over multiple generations
  - Cost-effectiveness should compare between alternate Macrogrid cases and against Business as Usual (BAU) case designed to achieve 100% clean energy by 2035 (if possible)
  - Cost allocation should reflect extensive scope and duration of benefits, not just traditional cost allocation methods. It should also explicitly call out equity as well as economic impacts
  - Summarize metrics for comparison of Macrogrid and BAU cases, including timing and speed of each

Costs of Macrogrid Construction

- Capital costs and ongoing fixed costs for new transmission
- Opportunity costs of not building Macrogrid, including likely slower development of clean renewables, slower decarbonization, higher delivered energy costs and reduced reliability and resilience relative to Business-as-Usual option.
- Time and speed to build. Lines that can be built fast with minimal community and landowner opposition – even if higher nominal capital cost due to longer mileage or more expensive structures and building for future expansion – are preferable to lines that take longer but cost less, because they could avoid litigation and enable faster realization of economic, reliability and resilience benefits.

Options to reduce costs for Macrogrid lines and converter stations include routing along existing transmission, pipeline and highway ROWs, siting converter stations at existing and retired power plants and mines, using limited selective undergrounding, maximize capability on initial build (ROW width, structure capability, terminal capacity) to enable future expansion, and using longer routes and bigger payments to get around hostile landowners.

Benefits Methodology

- As long as the scenarios and relevant costs and benefits are consistently defined and evaluated, it is appropriate to calculate the differences in costs and benefits between different scenarios and factors
- For most benefits to be studied, the total benefit from a given scenario should be credited to the goal (e.g., 100% clean electricity)
- Look at multiple scales of impact (local/state, regional, national) without restricting benefits to the immediate geographic area around the Macrogrid lines.
- Benefits for every scenario should be compared to the impacts of the BAU (no Macrogrid) scenario to identify the opportunity costs of not building the MacrogridG.

Optionality & Insurance Value

Consider how transmission enhances optionality

- There is increasing uncertainty in our future. We don't know how load will evolve, what fuel will cost, what resources will cost, which resources and technologies will see commercial and economic breakthroughs
- Sensitivity studies can help evaluate the robustness of a Macrogrid against many different futures and its ability to provide optionality across these futures

Quantify the insurance value of the Macrogrid for mitigating high impact grid events

- Grid Strategies finds that the Southern Cross project would have paid for itself during Winter Storm Uri.
- "Dunkelflaute" events
- Increased extreme weather due to climate change

Goggin and Gramlich, *Transmission Makes the Power System Resilient to Extreme Weather*, July 2021

TABLE 1. *Value of 1 GW of additional transmission by region for each event*

Receiving region – delivering region	Savings per GW of additional transmission capacity (millions of $)
WINTER STORM URI, FEBRUARY 2021	
ERCOT – TVA	$993
SPP South – PJM	$129
SPP South – MISO IL	$122
SPP South – TVA	$120
SPP S – MISO S (Entergy Texas)	$110
MISO S-N (Entergy Texas - IL)	$85
MISO S (Entergy Texas) – TVA	$82
TEXAS HEAT WAVE, AUGUST 2019	
ERCOT – TVA	$75
NORTHEAST BOMB CYCLONE, DECEMBER 2017 – JANUARY 2018	
Eastern PJM (VA) – Western PJM (Northern IL)	$43
NYISO – PJM	$41
PJM – MISO	$38
NYISO – ISONE	$29
NORTHEAST POLAR VORTEX EVENT, JANUARY 2014	
PJM – MISO	$17
NYISO – PJM	$9
NYISO – MISO	$21
MIDWEST POLAR VORTEX EVENT, JANUARY 2019	
MISO – PJM	$2

Conclusions

- Transmission is a necessary facilitator for clean electricity/energy futures
- The scope and scale of the transmission need for high renewables and decarbonization is far beyond what is or has been considered in existing planning processes
- It is unclear that incremental expansion of the HVAC bulk system could eventually lead to what would be needed – but HVDC has a clear role in this ambitious future
- Advanced HVDC, with multi-terminal VSC converters (grid-forming), redundant high-capacity and high-density DC lines forming a true DC grid, with appropriate integration with the underlying AC bulk system, is now at the leading edges of commercial technology and has many potential long-term benefits
- Advanced, innovative HVDC solutions should be evaluated in detail as an alternative to conventional expansion of the HVAC grid
- A transparent industry collaborative process is critical

THANK YOU

Parking Lot

Why a "Macrogrid"?

- Previous studies referred (explicity or implicitly) to a "Macrogrid" that **overlays** the existing AC bulk system
- Would help overcome challenges with incremental expansion of bulk AC transmission systems and with current transmission planning processes
  - Difficult to fundamentally change the capabilities of AC system with incremental expansion – Large single EHV AC lines don't buy much
  - Current planning processes use shorter time horizons and are bound by benefit-cost methodologies that do not consider all future benefits
  - A Macrogrid moves energy, but equally important, it moves capacity and services, and it moves all three (***energy, capacity, services***) both ***near and far***.
- Value of "top-down" vs. "bottom-up"
  - A thorough top-down examination of the desired bulk power system long-term ***end-point*** could redirect and improve bottom-up system planning efforts
  - Effectively a single-step system expansion from present to Clean Electricity or Clean Energy
  - Macrogrid design would be based on sound transmission planning principles, but likely require developing some new approaches because of its novelty.

How Could the Macrogrid Change the BPS?

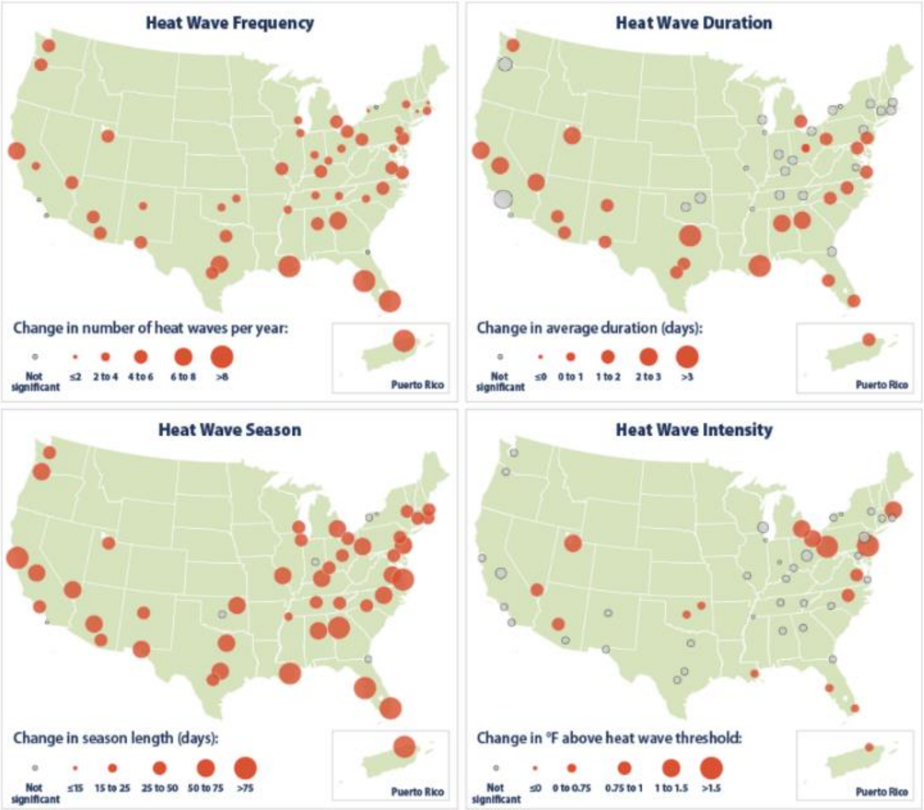
ESIG

1. The most economically attractive resources (bulk generation and storage, for energy and ancillary services) can be dispatched to cover energy demand across 4 time zones to serve all regions & customers.
2. Energy, capacity, and ancillary services are deliverable from any region of the country to any other region, not just between neighbors.
3. A system of diverse resources significantly improves reliability and resilience on a continental scale.
4. Macrogrid terminals offer very large control opportunities for grid management and enhancing system security during routine and high-consequence climate-induced and other severe events.
5. A central operator sees the nation's entire grid and coordinates with regional grid operators.
6. A macrogrid is the only approach that has the SCALE necessary to meet societal decarbonization objectives. It's not that incremental approaches (local build-outs, packing more onto existing lines & ROW, use of advanced technology, DER, energy efficiency, etc.) are wrong – they are necessary, but insufficient.
7. This isn't just once-in-a-generation opportunity, this is a once-in-a-century opportunity that must be started immediately to transform the industry and to combat climate change.

Extreme Weather Changes

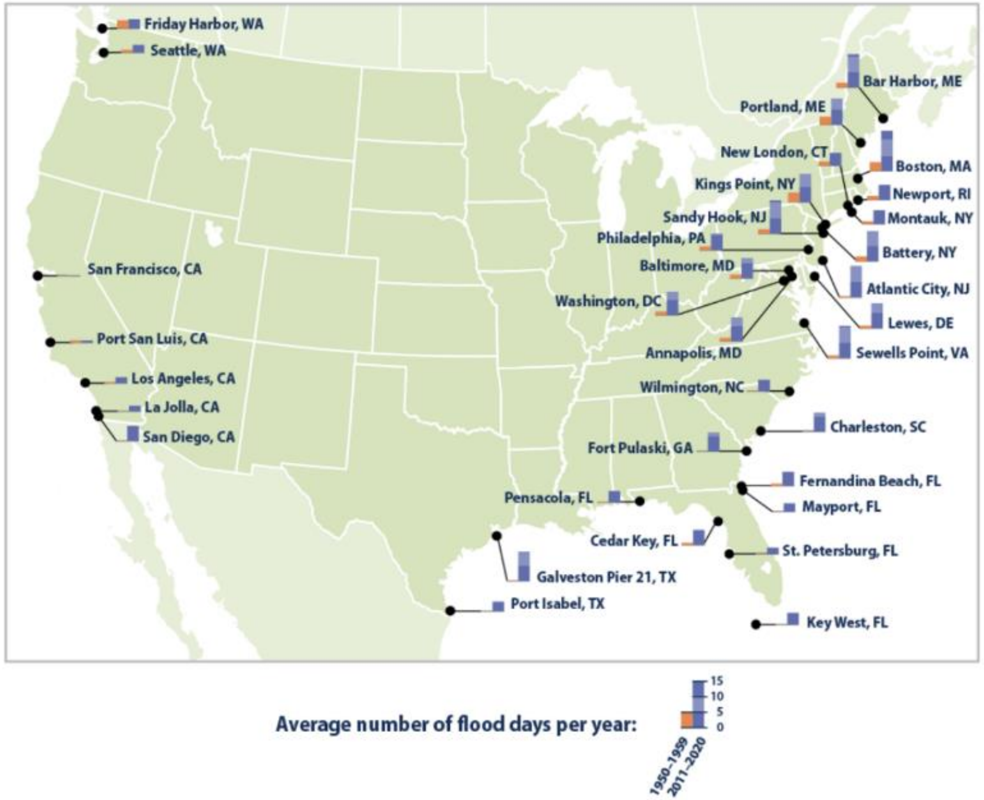
Heat waves worsening

Figure 2. Heat Wave Characteristics in 50 Large U.S. Cities, 1961–2019



Coastal flooding accelerating

Figure 1. Frequency of Flooding Along U.S. Coasts, 2011–2020 Versus 1950–1959



Also:
Hurricanes
Precipitation
Inland floods
Wildfires
Droughts

Source: https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature

Resiliency Evaluation

Goal -- Macrogrid proposals should be evaluated to determine whether they improve resilience as well as reliability

Context – Extreme weather events have historically been the most frequent causes of widespread electric distribution, transmission and generation failures. Looking ahead, threats are expected to increase due to climate change (becoming High Impact, Medium Frequency (HIMF) events) and potential attacks.

- Extreme weather situations and event recovery issues fit within NERC's legal obligations and responsibilities for reliability, even though the word "resilience" does not appear in the Federal Power Act legislation that gives FERC and NERC their powers.
- But recent atypical extreme weather events and reasonably possible HIMF and HILF events require a different analytical approach; they must be addressed through credible scenarios because extensive historic data and past system performance are not yet available.
- Assume standard reliability using historical data on load and generation patterns (as defined and operationalized in NERC-FERC context) will be built into and frame the Macrogrid engineering design framework.
- Design and construction of Macrogrid must reflect future extreme weather threats and be hardened to ensure system ability to operate under extreme conditions when it is most needed for human safety and national security.