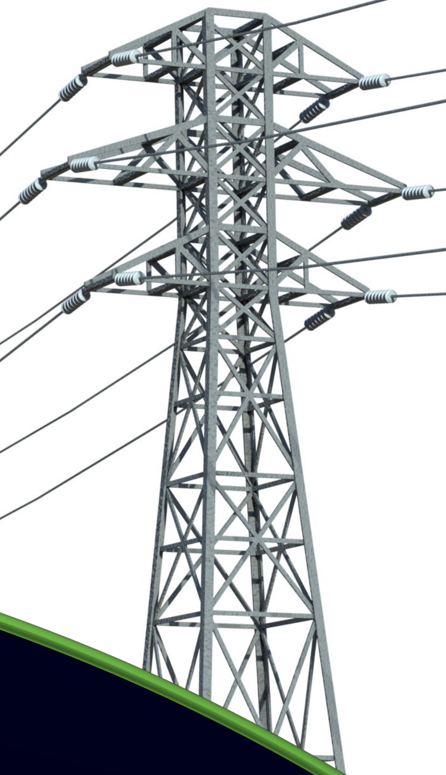
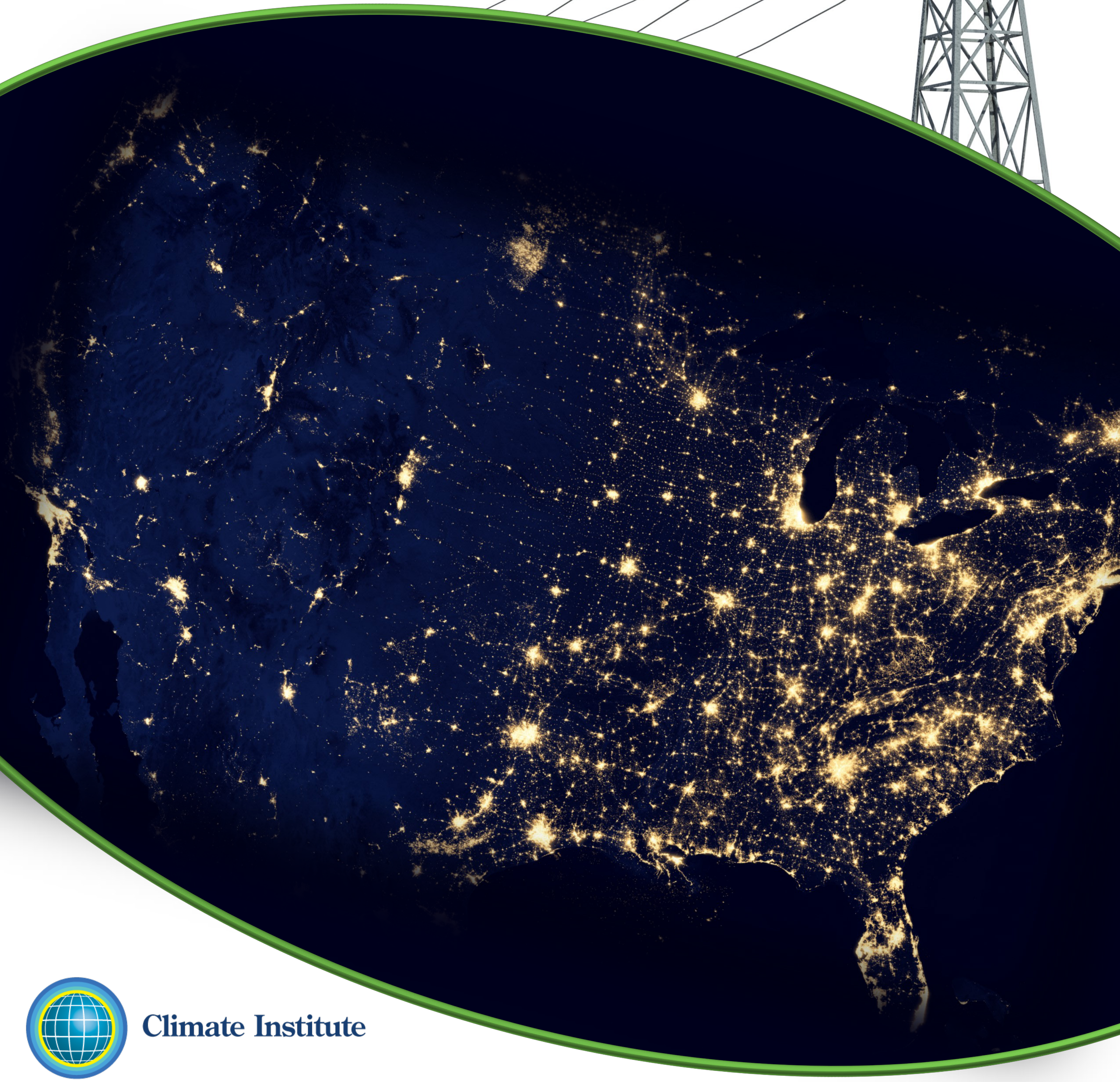
North American Supergrid

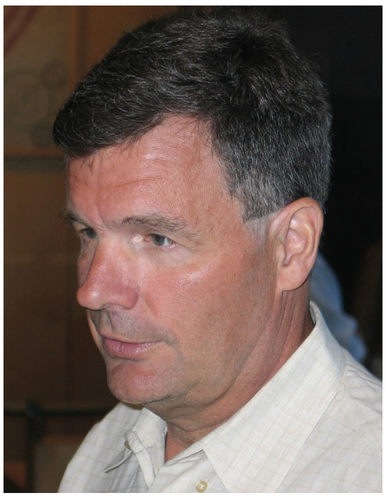
Transforming Electricity Transmission





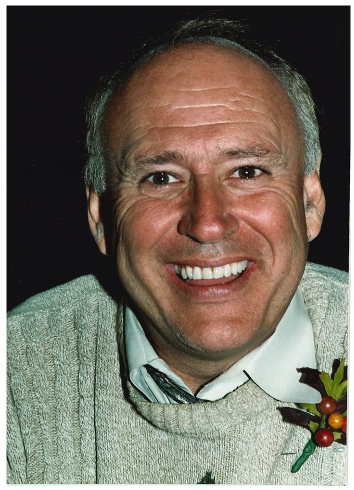
Climate Institute

In loving memory of David Burwell, Michael Garvin, and Bob Gough, without whom this project would not have been possible.



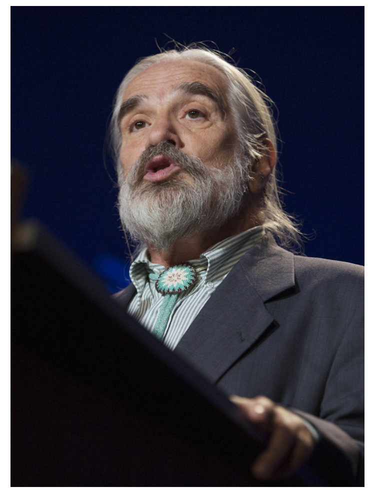
About David

David Burwell, the late founder of Rails-to-Trails Conservancy, was a leading expert in the legal nuances surrounding the repurposing of underused rights-of-way for innovative purposes. His legacy not only lives on in the many miles of converted bike paths present throughout the United States, but also though the invaluable counsel he provided to the North American Supergrid team in the early stages of this project. David's imagination and drive continue to influence every member of our team.



About Michael

Michael Garvin's long years of service to the environmental movement are marked by his innovative spirit. Michael's counsel contributed to much of the preliminary technical and economic work for this project, and pushed this team to continuously evolve and improve our analyses. His determination to make a lasting contribution to climate change mitigation and adaptation causes never faltered, and to us, he certainly succeeded. It was truly a pleasure to work with him.

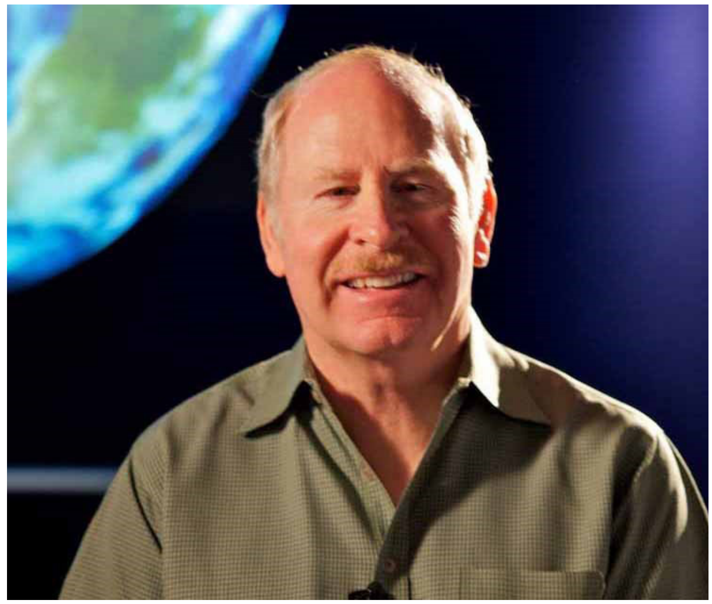


About Bob

Robert 'Bob' Gough was the Secretary of the Intertribal Council on Utility Policy, and dedicated his life to championing clean energy development and economic opportunities for Great Plains tribes. He was a leading expert on tribal energy law and policy, and was instrumental in spearheading this team's research on the inclusion of sovereign lands in the North American Supergrid's feasibility research. His memory will live on in the upholding of his values by this team.

This initiative would not have been possible without the groundbreaking, foundational work of the National Oceanic and Atmospheric Administration funded study that generated the *Nature Climate Change* publication entitled *Future Cost-Competitive Electricity Systems and their Impact on US CO_2 Emissions*. This academically acclaimed work was completed by a six-member team over the course of six years, and work in conjunction with the Climate Institute has continued since. Namely, Dr. Alexander E. ('Sandy') MacDonald has spearheaded this effort.

About Sandy



Dr. Alexander E. ('Sandy') MacDonald retired from over 40 years of federal service in the National Oceanic and Atmospheric Administration, on January 3, 2016. He was a Senior Executive since 1990 and President of the American Meteorological Society in 2015. He retired after 10 years as Director of NOAA's largest research laboratory, the Earth System Research Lab in Boulder, Colorado. He was Chief Science Advisor for NOAA's research line, and it Deputy Assistant Administrator from 2006 to 2012. He was Director of NOAAs Forecast Systems Laboratory from 1988 to 2005. He is the inventor of NOAA's 'Science On a Sphere', an educational exhibit now in over 130 museums worldwide. He worked with Vice President Al Gore to start the GLOBE Program in 1994. He is the recipient of four Presidential Rank Awards.

Dr. MacDonald's recently published (January 25, 2016) entitled "**Future cost-competitive electricity systems and their impact on US CO_2 emissions**" was ranked in the 99th percentile of impact by *Altimetric*. The article presents a solution to greenhouse gas emissions that could be implemented now with existing technology, and would be also be feasible in other major economies such as Europe, China and India.

On April 4, 2016 he joined Spire Global, where he is leading a group that is developing global weather models and advanced energy solutions.

Foreword

In the short time span of 100 years, reliable electric energy has gone from a rare luxury to a primary, life-sustaining requirement. This system, on which our society is increasingly reliant, is plagued by inefficiency and fragility in the face of modern threats. We must build a secure electric system to ensure that our populated areas do not rapidly descend rapidly into chaotic conditions if electric energy ceases to be available over a large area for an extended period. The United States remains vulnerable to terrorist attacks, solar storms, cyber-attacks, extreme weather events, and "electromagnetic pulse" nuclear bombs, all of which could deliver these catastrophic outages at any time.

Until recently, the energy market has been plagued by transmission inefficiency and intermittency, limiting the economic viability of cheap electricity sources. High voltage direct current transmission technology significantly decreases inefficiency by reducing line losses during electricity transmission, allowing the creation of a national electricity market that can serve load centers with electricity derived from distant generation centers. This new market structure would allow for greater penetration of renewables into the electric grid, resulting in up to a 78% reduction in power sector carbon emissions.

As we discuss in this policy paper, this potentially low-carbon solution is now available with existing technology – a "supergrid" that makes wind and solar energy less expensive and contributes to the reliability of our grid. The North American Supergrid is a high voltage direct current electric transmission overlay system that would solve the variability problem of wind and solar generation, leveling the playing field to allow consumers to access the cheapest energy source available at any given time. Such an outcome can be achieved without traditional "command and control" regulatory based strategies, while still maintaining a high level of environmental stewardship.

A modern, secure, largely underground North American Supergrid could protect us, and could likely be paid for by private commercial entities without an increase in electric rates using existing and proven technology. We must remedy our vulnerable and unsustainable electric grid for the good of our country and its people.

John Topping
President
Climate Institute
Washington DC
October 29, 2017

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Acronyms, chemical compounds and scientific units

ABB – ASEA Brown Boveri
AC – Alternating Current
AEMC – Arnoux, Enerdis, Metrix, Pyro Control Group
AIS – Automatic Identification System
ALJ – Administrative Law Judge
APT – Advance Persistent Threat
BIA – Bureau of Indian Affairs
BLM – Bureau of Land Management
BOEM – Bureau of Ocean Energy Management
CAP – Cross-Agency Priority
CAPEX – Capital Expenditures
CAISO – California ISO
CREZ – Competitive Renewable Energy Zone
DC – Direct Current
DFC – Device Fence Control
DHS – United States Department of Homeland Security
DNP3 – Distributed Network Protocol Version 3.3
DOE – United States Department of Energy
DOT – United States Department of Transportation
DOTs – Departments of Transportation
DPRK – Democratic People's Republic of Korea (North Korea)
EFH – Essential Fish Habitats
EGUs – Electric Generating Units
EHV – Extra High Voltage
EIA – United States Energy Information Administration
EMP – Electromagnetic Pulse
EMS – Energy Management Systems
EPA – United States Environmental Protection Agency
Epact 2005 – Energy Policy Act of 2005
ERCOT – Electric Reliability Council of Texas
FERC – Federal Energy Regulatory Commission
FGROW – Federally Granted Rights of Way
FLPMA – Federal Land Policy and Management Act
FPA – Federal Power Act
FRCC – Florida Reliability Coordinating Council
FWC – Florida Fish and Wildlife Conservation Commission
FWRI – Fish and Wildlife Research Institute
GAP – National Gap Analysis Program
GHG – Greenhouse Gases
GIC – Geomagnetically Induced Currents
GIS – Geographic Information System
GMD – Geomagnetic Disturbances
GW – Gigawatt
HAPC(s) – Habitat Area(s) of Particular Concern
HEARTH Act – Homeless Emergency Assistance and Rapid Transition to Housing Act
HEMP – High Altitude Electromagnetic Pulse
HMS – High Migratory Species
HPEM – High-Power Electro Magnetic
HPM – High-Power Microwave
HVDC – High Voltage Direct Current
IC – Intelligence Community
ICS – Industrial Control Systems
IEA – International Energy Agency
IEMI – International Electromagnetic Interference
IRS – International Revenue Service
ISO(s) – Independent System Operator(s)
ITP – Integrated Transmission Planning
JEDI – Jobs and Economic Development Impact
Km/W – Kelvin-meter/Watt
kV – Kilovolt
LCOE – Lazard Levelized Cost of Electricity
LPO – Loan Program Office
MIP – Mixed-integer Linear Programming
MMBtu – Million British Thermal Units

MTEP – MISO Transmission Expansion Plan

NAAQS – National Ambient Air Quality Standards

NARUC – National Association of Regulatory Utility Commissioners

NAS – North American Supergrid

NCIC – National Center for Interstate Compacts

NEPA – National Environmental Policy Act

NERC CIP – North American Electric Reliability Corporation's Critical Infrastructure Protection

NEWS – National Energy from Weather Systems

NIETC(s) – National Interest Electric Transmission Corridors

NNEMP – Non-nuclear Electromagnetic Pulse

NOAA – National Oceanic and Atmospheric Administration

NOM – Natural Organic Matter

NOPR – Notice of Proposal Rulemaking

NO_x – Nitrous Oxides

NPV – Net Present Value

NREL – National Renewable Energy Laboratory

NYISO – New York ISO

ONCC – Overnight Capital Costs

OSPAR – Oslo/Paris Convention

OT – Operational Technology

PABs – Private Activity Bonds

PIER – Public Interest Energy Research Group

ppm – Parts Per Million

PPP – Public-Private Partnership

PUC – Public Utilities Commission

RFW – Radio Frequency Weapons

ROI – Return on Investment

ROW(s) – Right(s)-of-way

RTEP – Regional Transmission Expansion Plan

RTO – Regional Transmission Organization

SAFMC – South Atlantic Fishery Management Council

SCADA – Supervisory Control and Data Acquisition

SERC – Southern Electric Reliability Council

SEZ – Solar Energy Zones

SO_2 – Sulfur Dioxides

SPP – Southwest Power Pool

SSC – Sudden Storm Commencement

STB – Surface Transportation Board

SVP – Special Purpose Vehicle

TERA – Tribal Energy Resources Agreement

TNC – The Nature Conservancy

TNT – Trinitrotoluene

T-SCADA – Transmission Supervisory Control and Data Acquisition

UAPs – Utility Accommodation Plans

UNEP-WCMC – The United Nations Environment Programme's World Conservation Monitoring Centre

USDA – United Statesd Department of Agriculture

USGS – United States Geological Survey

WECC – Western Electricity Coordinating Council

WEIM – Western Energy Imbalance Market

WPP – Western Pilot Project

WSR leases – Wind and Solar Resources leases

µT – Microteslas

Ωm – Ohm-meter

Executive Summary

The North American Supergrid (NAS or Supergrid) would make electricity infrastructure more resilient and greatly reduce power sector carbon emissions.

The North American Supergrid is a proposed nodal high voltage direct current (HVDC), largely underground transmission network that would extend across the lower 48 states, thus creating a national electricity market. The Supergrid would create a resilient backbone to the existing system and make clean renewable energy competitive with fossil fuel-generated energy in open markets. Adding the Supergrid atop the existing regional alternating current distribution system would provide the flexibility and reliability that would enable expanded use of electricity across the economy, without altering how electricity is currently used in homes or businesses. This would also afford electromagnetic pulse (EMP) and geomagnetic disturbance (GMD) protection not garnered from the current system, as well as much needed fortification against increasingly common natural disasters.

The NAS concept is based on research summarized in the MacDonald et al. publication released in 2016 in *Nature Climate Change*. Through extensive temporal and spatial modelling of the variable weather patterns present in the continental United States, the MacDonald et al. publication surmised that solar and wind power penetration into the electric grid could be achieved through the construction of an integrated national electricity market, without raising electricity costs or sacrificing the reliability of power delivery to consumers. MacDonald et al. idealized that a single national market (built from low-loss, high-capacity direct current cabling) would allow the instantaneous transmission of excess power (often generated in areas with little immediate demand) to large load areas where it can be utilized, better integrating both large scale utilities as well as distributed systems in a non-preferential market based solely on cost. The optimization technique is unbiased towards any one energy source and is mainly dependent on forecasted technology costs. The authors estimated that the evolution in the electricity market that such a grid would prompt could result in nearly an 80% reduction in power-sector carbon emissions, as low-cost wind and solar generated power would displace more expensive fossil fuel based electricity generation in a competitive market.

Preliminary analyses by the Climate Institute confirm both feasibility and cost-effectiveness.

While MacDonald et al.'s article explored the potential benefits and implications of a North American Supergrid, quite a number of other practical aspects were left for additional investigation. The Climate Institute, a Washington-based non-governmental organization that has a three-decade record of bringing innovative approaches to wider attention, has conducted a number of feasibility analyses to assess the practical challenges associated with the creation of a mostly underground HVDC transmission overlay system, considering practical aspects such as how best to meet the need for rights of way, compatibility of soils and HVDC cabling, natural-disaster and national-security co-benefits from undergrounding, and the projected costs for a few representative network lines. As explained briefly below and more fully in the associated chapters, our studies indicate that the NAS would: (a) improve national security by strengthening cybersecurity, structural integrity, and EMP deterrents; (b) be feasible at modest cost and would contribute to mitigation of climate change by allowing a much higher penetration by renewables than is projected to be possible with the present grid system; and (c) be a cost-effective addition to the electric grid, even in the absence of a price placed on carbon and assuming there is not a sustained drop in average natural gas prices persisting over the next three decades. The technical sections of this policy brief document the environmental and electrical engineering challenges associated with the implementation of an underground HVDC overlay system and our main conclusions, as summarized in the following paragraphs

The installation of the North American Supergrid comes with inherent feasibility challenges, and its operation might result in environmental consequences that range from minimally adverse to highly beneficial.

- Approximately two-thirds of the HVDC cable links in the proposed system can feasibly be placed underground along existing rights of way, greatly reducing the time and effort needed to move forward with permitting and construction. Where a link cannot be aligned to be buried and blasting through bedrock is required, construction of traditional aboveground transmission lines may be required. Offshore submarine lines may be utilized to circumvent the usage of this alternative configuration solution if the surrounding environment allows.
- By enabling a diversification of energy sources, the Su-

pergrid will reduce the power sector consumption of water by ~400 billion gallons per year and reduce the power sector withdrawal of water for power generation by ~1.4 trillion gallons per year, resulting in a 65% reduction overall in total fresh-water usage across the power sector.
• The increased use of renewable sources of energy as opposed to traditional fossil fuels would reduce projected 2040 power-sector emissions of SO2 (sulfur dioxide) and particulate matter by a factor of ~7, (measured in weight of metric tons) compared to 'business as usual' emissions levels based on current expected 2040 generation contributions to energy production.
• The magnetic fields emitted by properly functioning HVDC cables present a minimal, but not negligible, level of risk to surrounding animal species which utilize the natural magnetic field of the Earth for orientation.

The installation and operation of the Supergrid would result in significant improvements in security and reliability.

• Undergrounding the NAS would greatly reduce the vulnerability of the present grid to physical assaults and intrusions.
• Undergrounding would reduce the vulnerability to naturally occurring GMD and manmade EMP, including particularly to an EMP attack originating from the Democratic People's Republic of Korea (a threat currently being considered by the U.S. Department of Energy, U.S. Department of Homeland Security, and Congress).
• Undergrounding would reduce vulnerability to natural disasters, including fires, high winds, floods, and other extreme storms.

The installation and operation of the Supergrid appear to be financially viable via funding mechanisms that range from private to public.

• Possible avenues for funding the Supergrid include: private, user-based fees that require no public funding; public-private partnerships (in some states); the Department of Energy Loan Guarantee Program (if certain requirements are met); and U.S. Department of Defense allocation for additional hardening of grid security aspects.
• Direct and indirect estimates of job creation over the 30-year time frame due to construction and operation, including increased employment for generation of energy from renewables, range from ~650,000 to ~950,000 (particularly in construction, operation, and maintenance jobs associated with transmission and equivalent new renewable generation).
• Exclusive of right of way costs and complications, our estimated cost for aboveground installation is ~$580 ($/MW-mile), which is about 20% less than the ~$723 ($/MW-mile) estimated by MacDonald et al. Our estimate is that underground installation costs would be about three times as much, but with lower cost and time for right of way acquisition. Whether above or below ground, we estimate substation costs at ~$250K ($/MW), while MacDonald et al. estimated ~$188K ($/MW). Station costs would remain about the same for aboveground and underground scenarios. The total estimated cost for constructing the proposed NAS is under $500 billion.
• The economic feasibility of the NAS is partially contingent on the future price of natural gas as well as the additional incremental cost of constructing HVDC lines in an underground configuration.

Regulatory reform for the Supergrid can be accomplished by a Regional Transmission Organization (RTO)/Independent System Operator (ISO)-centered framework for effective operation of the Supergrid and measures streamlining the routing and permitting processes.

• A nationally integrated approach that grants siting authority to RTOs and ISOs would be the most preferable regulatory reform for the Supergrid, given the cost and complexity of going through state and local siting authorities.
• Using existing federal and cooperating states' rights of way for routing cables would greatly expedite build-time, requiring cooperation from key bureaus such as the Bureau of Land Management and the Federal Highway Administration (FHWA). Notably, the FHWA is authorized to grant ROWs for what it considers to be for the public good.
• Streamlining the permitting process involves mitigating barriers to using land for renewable energy transmission. This can be done using three strategies: (1) encouraging states to consider regional and in-state benefits; (2) expanding the legal definition of "public use" to include merchant transmission lines; and (3) incorporating the western and southeastern regions of the country into RTOs or ISOs.
• Routing cables through tribal lands involves further legal complications where the federal government does not have eminent domain authority.

Introduction

The United States has vast resources of renewable energy: wind energy on the Great Plains and in the Midwest, solar energy in the Southwest, geothermal energy in the Rocky Mountains and Great Basin, and hydropower in the Northwest and Southeast. Unfortunately, the variability and dispersed nature of renewable energy resources has made it difficult to optimally utilize them, given that the existing electrical grid was not originally set up to transmit electricity over long distances from renewable energy supply centers to major load centers. As a result, renewable energy resources remain significantly underutilized in the U.S., even as the cost of electricity generated from wind and solar sources has declined sharply in recent years. However, recent research indicates that both geographic dispersity and intermittency can become optimized with a comprehensive transmission infrastructure plan that connects the supply of renewable energy to load centers.

The North American Supergrid (NAS or Supergrid) is a proposed 52-nodenodal, high voltage direct current (HVDC), largely underground transmission network that would extend across the lower 48 states, thus creating a national electricity market. The Supergrid would create a resilient backbone to the existing system, making clean renewable energy competitive with fossil fuel-generated energy in open markets, creating hundreds of thousands of jobs for several decades, increasing U.S. domestic energy generation, and securing the nation's electrical transmission infrastructure against modern threats.

The NAS concept is based on research summarized in the MacDonald et al. publication released last year in Nature Climate Change. Through extensive temporal and spatial modelling of the variable weather patterns present in the continental United States, the MacDonald et al. publication surmised that solar and wind power penetration into the electric grid could be achieved through the construction of an integrated national electricity market, without raising electricity costs or sacrificing the reliability of power delivery to consumers. MacDonald et al. idealized that a single national market (built from low-loss, high-capacity direct current cabling) would allow the instantaneous transmission of excess power (often generated in centers with little immediate demand) to large load centers where it can be utilized, better integrating both large scale utilities as well as distributed systems in a non-preferential market based solely on cost. The optimization technique is unbiased towards any one energy source, and mainly dependent on forecasted technology costs.

The existing electric power system is comprised of two basic network components – transmission for higher voltage, and distribution for lower-voltage power delivery. The National Electricity with Weather System (NEWS) results indicate that the creation of a third layer HVDC backbone network, or Supergrid, built from low-loss, high-capacity direct current cabling is feasible. This Supergrid would effectively create a national market in which all types of generators, from opposite corners of the country, could fairly compete. Thus, increased transmission capacity would turn the enormous size of the country into an advantage by enabling efficient production and delivery of a large amount of electric power across the country rather than relying on the existing patchwork of generating centers with local or regional scale transmission capabilities. The more optimistic cost forecasts for the year 2030 resulted in an optimal system which utilized a large proportion of wind and solar, and decreased U.S. power sector carbon emissions by 80% compared to 1990 levels.

The NAS would also help secure the U.S. electrical grid against both natural and human-caused threats. Modern conveniences and life sustaining infrastructure depend more than ever on the reliability and availability of electricity. If power were to be disrupted for an extended period of time, modern civilization simply could not function. Yet, our electrical transmission infrastructure is troublingly unprepared for modern threats and natural hazards. If a terrorist organization or rogue state, for example, obtained and detonated a nuclear weapon high above the United States, it would send a powerful electromagnetic pulse (EMP) that would overload transmission infrastructure, taking the grid down for years. A similar effect would occur in the event of a solar storm like the famous Carrington event of 1859, a completely unavoidable and unpredictable event. A lone wolf attack or extreme weather event could also carry out structural damages, which can leave municipalities or entire regions without power for days or weeks. The NAS would make significant strides in safeguarding our nation's transmission system through its configuration and hardware.

The proposed HVDC cables contain a metallic sheath surrounding the conductor (which would be grounded with an Earth-return) and would be placed in an underground configuration whenever possible. Additionally, above ground elements will be encased in shielded structures. These elements will work together to not only prevent against malicious tampering, but also provide a crucial defense against EMP attacks and unpredictable solar storms. The network configuration of the system will provide resilient pathways to maintain the delivery of electricity, even in the case of a line fault. Even if one line were to go down, the Supergrid could reroute power through an alternative pathway and still deliver electricity to where it needs to go.

Even though the costs of building the needed transmission capacity would be roughly under $500 billion, analysts have concluded that this proposal can be overwhelmingly privately financed and paid for through consumer bills and that consumer electricity prices would be about the same as the national average. While the costs of electricity infrastructure would increase and be passed to the consumer, the costs of electricity generation would decrease enough to make up for the costs of additional infrastructure.

Over an estimated timeframe of 30 years, roughly 650,000 to 950,000 jobs would be required to build the necessary infrastructure. These jobs would be impossible to outsource to other countries and would likely be located in rural areas since renewable energy capacity is mostly in sparsely populated areas that are typically disadvantaged economically.

Since the MacDonald et al. study, both wind and solar costs have decreased significantly faster than expected and, in high quality, locations are already lower than the other available options including nuclear, coal, or natural gas. This means that the MacDonald et al. study is even more cost advantageous than originally indicated.

Expanding energy transmission infrastructure is the most practical way to improve grid resiliency to modern threats and to reduce power sector greenhouse gas emissions. The need to protect transmission infrastructure against EMP and to reduce greenhouse gas emissions are both key national interests. The NAS would build electricity transmission in a way that addresses both of these issues without overwhelming the national budget. It is a market solution to power sector carbon emissions that enhances national security, provides jobs, and enhances domestic energy use. Initial contacts conducted by our team to various Congressional offices and think tanks suggests that the NAS has high potential for bipartisan backing.

Our studies, as detailed in the upcoming chapters, indicate that the installation and operation of an undergrounded HVDC linked into the existing grid would: (a) be feasible at modest cost and would contribute to mitigation of climate change by allowing a much higher penetration by renewables than is projected to be possible with the present grid system; (b) improve national security by strengthening cybersecurity, structural integrity, and EMP deterrents; and (c) be a cost-effective addition to the electric grid, even in the absence of a price placed on carbon and assuming there is not a sustained drop in average natural gas prices persisting over the next three decades. The technical sections of this document describe the environmental and electrical engineering challenges associated with the implementation of an underground HVDC overlay system.

1 Technical feasibility and environmental challenges

Lead author: Rachel Levine **Co-authors:** José Alfredo Durand Cárdenas, Xie He
Dwight Macomber, Eliana Lins Morandi

Summary

This chapter details the scientific and engineering challenges associated with implementing the North American Supergrid concept.

Many site attributes dictate terrestrial underground HVDC cable placement, as some settings are not conducive to proper cable functioning. We mainly examined the topographical, geological, physical, and chemical components of the landscape, especially soils, in order to gain insight into the most advantageous places cables may be placed underground. We also kept ease of permitting in mind, as we visualized areas held sovereignly or have protected status. Our study reached several conclusions regarding the relative positive and negative impacts of the NAS's construction and operation:

- By diversifying energy sources, the NAS has the potential to save over 400 billion gallons of water per year based on current electricity demand, and may reduce the emission of several criteria pollutants.
- Should the NAS share right-of-way (ROW)space with fiber optic cables, it is imperative that HVDC cables be placed parallel to fiber optic cables. In the instance of a single existing fiber optic cable, HVDC cables should be located below *and* parallel to the fiber optic line.
- The magnetic field output from properly functioning cables could affect the migratory capabilities of land animals, as well as the directional orientation of compasses, to a limited extent. We do not anticipate any negative impacts on human health.
- The regulation of both heat dissipation characteristics and the relative electrical resistivity of the ambient environment are crucial to efficient HVDC cable functioning.

Additionally, we analyzed two hypothetical case studies to demonstrate potentially important siting variables in both onshore and offshore cable placement. For onshore cables, we conducted a feasibility analysis for a preliminary route for a 'Western Pilot Project' by analyzing several variables relating to soil composition and natural formations. For offshore cables, we mapped environmental and technical realities that may impact siting on the Atlantic Cost, allowing a determination to be made regarding the placement of onshore-offshore substations linking a potential offshore wing of the NAS to the onshore nodal network. Several environmental characteristics overlapped in their importance to both onshore and offshore cable configurations in this combined feasibility effort:

- Depth to bedrock
- The presence of protected species/land areas that house protected species
- The presence of existing oil and gas infrastructure

Overall, this feasibility analysis concluded that the positive environmental impacts of the NAS system will enable far outweighs any minimally negative externalities.

1.1 Introduction

Variations in the natural landscape have a clear effect on the hypothetical construction of the national grid. Soil properties are perhaps the greatest limitation that grid designers and construction teams face. Should designers use native soils to surround cable and backfill trenches, the soil must maintain critical moisture values to ensure proper heat dissipation. Similarly, natural hydraulic systems (namely water migration patterns) must be maintained despite soil changes. Variations in the depth to bedrock can also affect costs and construction time. Taking these and other similar considerations into account, this section outlines crucial feasibility considerations regarding the NAS's environmental impacts and technical challenges.

The proposed underground HVDC grid would be best implemented by building a nodal bidirectional system. This configuration enables maximum resilience and flexibility in the bi-directional transportation of electricity with minimal environmental and mechanical interferences. Because the electric and magnetic fields from transmission cables are static, any negative effects on human or animal health originating from either field type can be considered minimal. It is possible that the NAS would have minor impacts on the migratory capabilities of flightless land mammals and/or insects in the immediate vicinity of a cable right-of-way stretch due to weak magnetic fields originating from the transmission line. Magnetic directional compasses may also become slightly disoriented from this effect. While the underground system configuration does not directly reduce the impact of such fields, cables themselves would be less susceptible to an electromagnetic pulse (EMP) attack or extreme weather event (a valuable safeguard not afforded by unshielded above-ground lines). We conclude that, while surveyors must use caution to minimize environmental impacts, the negative impacts associated with the implementation of an underground HVDC grid are insignificant compared to the benefits that it would achieve regarding national security and carbon reduction.

We begin with examining how soil properties impact cable placement, which would ultimately ensure proper functioning of underground cables in the host environment. Further, the environmental risks and benefits of implementing a nationwide HVDC system were examined, with conclusions drawn regarding the relative impact the system would have on the surrounding environment and living beings. Lastly, we examined two case studies to determine the viability of the NAS in varying environments, with promising results.

1.2 Siting in the Context of Soil Properties

Since the NAS will be constructed in a [mostly] underground configuration, the soil conditions of the host environment will be pertinent to proper system functioning. While surveying must be completed to confirm proper cable placement, information about a soil's categorization (coupled with knowledge of the field of soil mechanics) can provide a strong indication of which soils should be considered *suitable* for underground cable placement. Soils deemed *unsuitable* require "amendment" before use; that is, native soils must be removed and replaced with manmade fill. The physical and chemical properties of soil will also influence its interaction with foreign materials. For the purposes of this analysis, a "physical" property will be defined as a trait that does not require manipulation of the soil's natural state of matter to be expressed or measured;[1] physical properties include electromagnetic properties, texture, water content, and electrical and thermal resistivity (among others).[2] Additionally, "chemical" properties are those that may be evident only after or during a chemical reaction of some kind (common examples include oxidized trace metal content, salinity, pH, and natural organic matter (NOM) content.[3] The inherent soil properties displayed in various soil samples may give strong indications as to the functioning of underground cables.

1.2.1 Siting Based on Soil Orders

To identify and classify the bulk-physical and chemical properties present in soils in the contiguous United States, soils are sorted into several hierarchical categories based on their properties; there are soil Orders, Suborders, Great Groups, Subgroups, Families, and Series.[4] As the levels progress, categorization becomes more detailed and specific, with "orders" serving as the most general classification. Globally, there are twelve soil orders: Alfisols, Andisols, Aridisols, Entisols, Gelisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols.[5] Each order possesses general properties that have the potential to interact negatively or positively with multiple electrical components of the underground network. Therefore, each must be carefully analyzed and assessed for risk potential. Keeping in mind the extent to which the physical and chemical properties described above will influence system functioning, the twelve United States Department of Agriculture (USDA) soil orders were determined to be either suitable (potentially without amendment) or unsuitable without amendment. Classifications should be taken as tentative until surveying is completed, as soils within a right-of-way may be disturbed or mixed, altering their properties from the ideal case.

1.2.1.a Alfisol (Suitable)

Alfisols are a clay based soil usually derived from vegetation found in forests and/or savannahs in temperate environments. They contain a modest level of organics which gives them enough agricultural potential that they could support a shorter growing season. Moisture content fluctuates strongly based on the season, allowing for the potential moisture levels to be high. Additionally, sublayers of this soil have the potential to contain oxidized iron or aluminum (that can attach to the clay itself), or other minerals such as quartz. This sublayer's depth will dictate any resistive potential, as clay base itself has low resistivity; the more clay that is present, the lower the resistivity will be.[6]

1.2.1.b Andisol (Unsuitable)

Andisol is a very specific soil order denoted by a primary composition that is made up of volcanic ash. It has the potential to have an extremely high mineral content, yet these minerals are usually non-crystalline (which is glass based and not metallic in nature). Andisol can retain massive amounts of moisture because it is not very densely packed; its organic concentration varies based on location. Alloys (i.e. amorphous metals) can also be present in high quantities and act as excellent conductors (potentially interacting unpredictably with an HVDC system).[7]

1.2.1.c Aridisol (Suitable)

Aridisols are often found in dry desert regions, and can best be described as sand-based with poor moisture content and little to no organics. Sublayers usually contain silica, salt, gypsum, or calcium carbonates (all of which are generally poor conductors when compared to metals). Potentially high temperatures, coupled with the potential for very little moisture recharge, are concerns when the prospect of a thermal runaway is considered. Built-in protections against this phenomenon around the HVDC cable itself must be evaluated further to utilize this soil order without amendment.[8]

1.2.1.d Entisol (Suitable)

Entisols are relatively under-developed soils that lack fully formed horizontal layers. Formations of this order are usually due to some form of disturbance, such as erosion, and are further formed by either a very dry or very wet environment. This soil type is predominantly clay and sand, yet has no clear or predictable composition. Furthermore, a variety of materials can contribute to formation including dense rock, highly compacted soils, or even toxic waste. Moisture content can also vary widely, compounding resistivity issues already present due to the formation material. Locations must be surveyed carefully before non-amendment use if they contain Entisol soil.[9]

1.2.1.e Gelisol (Unsuitable)

Gelisols contain glaciated deposits which are characterized by thick impenetrable permafrost layers (such as those found in tundra environments). They are well-known stores of organics, yet are only formed in very cold environments and therefore, do not support the growth of most plants. This frost layer introduces resistivity concerns. Additionally, the permafrost layer will most certainly hamper or halt trenching efforts and therefore should not be considered usable ground without extreme amendment.[10]

1.2.1.f Histosol (Unsuitable)

Histosols are primarily composed of organics and are commonly found in peat rich bogs or swamp environments. The organics in the soil have a strong potential to oxidize other soil constituents, allowing for decomposition to occur rapidly due to the anaerobic conditions present when soil is completely immersed in liquid. Logistical construction problems could arise due to the potential for the soil's texture to be inconsistent. Having a high concentration of organics, that act as heat insulation material, these soils should not be considered suitable for cable undergrounding without amendment.[11]

1.2.1.g Inceptisol (Suitable)

Inceptisols form in a multitude of environments (like Entisol soils). Ultimately, Inceptisols typically contain a larger than usual quantity of organics and moderate moisture retention ability. Minimal accumulation of oxidized metals, clay, and organics can occur, but rarely in the amounts that would exceed present detection limits. This order is usually present within mountainous areas, but contains low erosion potential. Ultimate usage is dependent on the depth bedrock level in these mountainous areas.[12]

1.2.1.h Mollisol (Suitable)

Mollisols are characterized by a layer of grassy vegetation followed by a layer of dark organically rich humus soil. They often have high moisture levels, leading to saturation during some seasons. However, the lack of toxic or troublesome compounds mitigates this concern. Mollisols must be surveyed before use without amendment to determine the depth of the organically rich layer directly below the topsoil.[13]

1.2.1.i Oxisol (Unsuitable)

Oxisols are characterized by their low nutrient/organic levels, low concentration of electrolytes, and high concentrations of oxidized metals. This is due to the fact that oxisols are usually located in humid environments with a very acidic pH levels, which leads to favorable oxidation conditions. They usually contain moisture but do not readily retain it. The extreme acidity of these environments could prove to be unfavorable for the outer sheath of the HVDC cable.[14]

1.2.1.j Spodosol (Unsuitable)

Spodosol soils contain three distinct layers; a rich organic surface topsoil, an ash-based sublayer, and a reddish horizon layer (due to high iron content). Generally, subsoils in this order have both a low organic content and a low clay content. Organics in the top layer have a strong potential to oxidize metals within the soil, which can flow down into the sublayers since the base soil usually has a sandy texture with favorable permeability characteristics. Moisture content can vary, but tends to be high when rainfall exceeds evapotranspiration removal rates. The relatively uninhibited transference of problematic materials throughout the layers could pose issues for grounding equipment present along the length of the HVDC cable. Therefore, Spodosols should be amended before hosting cables.[15]

1.2.1.k Ultisol (Suitable)

Ultisols are mineral rich clay based soils (which sometimes contain oxidized iron, namely due to the low pH conditions) and quartz. The moisture content of Ultisols varies widely depending on where they are formed. Nevertheless, soil fertility is low due to a lack of organics and electrolytes, which leads to a texture that promotes mineral leaching throughout the soil horizons. Surface soils tend to be more hospitable, yet can still contain these troublesome minerals. Due to the shallow depth of cable trenches, it is reasonable to assume that the cables will most likely be laid in this more hospitable area.[16]

1.2.1.l Vertisol (Unsuitable)

Vertisols are clay based soils, rich in calcium, magnesium, and lime, that respond dramatically to changes in water content by shrinking and swelling. Such activity can cause deep cracks within the soil layers during times of low moisture. In high moisture periods, water tends to settle in the topsoil of this order, and can even collect standing water. This unpredictability will not only be troublesome during the construction period, but also could cause issues with the thermal regulation of cables (particularly regarding heat dissipation), and should be avoided without extreme amendment.[17]

Should soils contain favorable properties as described above, it would be possible to bury cables in native soils directly, thus eliminating the use of cable sand entirely in certain line stretches (as long as no large boulders or stones are present). The possibility of utilizing native soils as fill materials must be evaluated on a case-by-case basis once cable routes are established, usually by means of surveying and moisture testing. The properties of native soils in such areas (described by soil orders) could possibly be used as a guide to pinpoint optimal sampling locations during the initial construction phase of the NAS.

If native soils are unsuitable, amendment by way of “backfilling” may be employed as a cost effective and simple construction technique, during which existing soils are replaced with artificial fills before in-ground cables are placed. The area immediately surrounding the cable and its electrode may require an engineered soil fill to both regulate and stabilize the thermal properties (even when the material itself is dry),[18] a crucial component to the proper function of HVDC cables. Engineered soil parent material can vary based on the geographical source of the materials relative to the construction site. However, modern engineered fills, such as Fluidized Thermal Backfill, typically include sand, cement, and aggregated minerals.[19] When compared to native soils, engineered soils not only consistently achieve proper moisture levels, but also allow for proper compaction (without the possibility of soil contamination during the process).[20] Trenches housing cables are often refilled with a maximum of 50% existing soil as an economical technique to prevent lasting ecological disturbance.[21]

It is also vital to note that not all existing engineered soils can be utilized in an HVDC system. For instance, typical highway construction methods require the presence of several engineered layers that are not conducive to grid construction. These are the two layers that are usually present underneath a paved road, the “base course” and the “subbase.”[22] While the thickness of these layers is dependent on the quality of the native soil, both of these layers typically contain aggregates of high resistivity, such as granite, and are heavily compacted to form a single layer.[23,24] However, the use of highway right-of-way could still take place next to a paved surface in native soil, or along the highway median.[25] This presents a considerable advantage, considering all locations containing major highways are typically tested for soil quality before construction, much like an HVDC grid. In contrast to the highway support materials, a railroad subgrade is not as densely packed at the surface. This is due to the “ballasts” that are made up of loose stones, which are compacted (and not cemented in place) to form a single layer on rail tracks.[26] If necessary, it could be easier to possibly insert HVDC lines directly underneath railway lines in the natural soils below, (depending on their overall depth). This alternative must be explored further by installation contractors throughout the initial surveying process.

1.2.2 Siting Based on Soil Resistivity Trends

Soil science is influenced by two distinct types of resistivity: thermal resistivity and electrical resistivity. Thermal resistance is the ability of a material to resist heat dissipation (or, the movement of heat away from a source),[27] whereas electrical resistance is a measure of a sample's potential electrical conductivity.[28] Furthermore, there is no direct mathematical method to compare one value to another in the realm of soil science (this can be done only if one is interested in comparing electrical and thermal resistance in metals).[29] Electrical resistivity is expressed in terms of Ωm (Ohm- meter) whereas thermal resistivity is expressed as Km/W (Kelvin-meter/Watt, where "Kelvin" is a unit of temperature). Therefore, electrical and thermal resistivity will need to be analyzed separately for the same area of soil using different techniques. Despite this fact, there is a direct and simple relationship between resistivity and conductivity that can be applied to both electrical and thermal calculations. Conductivity can be expressed as the inverse of resistivity, and vice versa. This implies that one value can be transformed into the reciprocal to get its corresponding resistivity or conductivity quantity. While an exclusive study of soil properties (without field surveying thereafter) is, at best, a tentative approximation for resistivity, such an analysis is nevertheless a promising guide as formal surveying begins.

Both resistance phenomena will separately affect a HVDC grid, with an increase in either thermal or electrical resistivity resulting in similar negative results for both the cable's current rating (i.e. the ability of the electricity to flow through the cable while staying within optimal temperature limits, based on manufacturer specifications) and its subsequent wattage. If thermal resistivity is high, heat becomes trapped close to the cable's surface. As the cable's temperature increases, its electrical resistance also increases, resulting in higher power losses (denoted by the formula: I2R); these losses then further increase the temperature, causing a cyclic trend referred to as "thermal runaway." If the thermal resistance value is unfavorable, the current may still flow, but the actual current rating may decrease to prevent cable overheating. In more extreme cases of a very high thermal resistance value, the same trend will initially occur, but eventually the process of heat production, entrapment, and increasing power losses will cause the entire system to overheat and collapse.

Thermal and electrical resistivity are strongly influenced by three indicators: salt content, moisture levels, and temperature. These indicators are often dictated by soil composition and the concentration of chemical constituents, if present. Thermal probing of field sites is often required to properly determine if the host soil contains favorable moisture properties. This information is necessary to determine how soil moisture relates to its relative thermal resistivity value, a relationship depicted in a "soil thermal dry-out" curve. If the critical moisture value is not met or exceeded, the lack of moisture will be further exacerbated by way of cable heat, driving away what little moisture that is present.[30] A lack of heat transfer between the HVDC cable and its surroundings can cause a dramatic increase in the temperature of the cable itself, ultimately causing thermal runaway. The soil thermal dry-out curve can also yield clues as to the behavior of a system during times of surplus moisture. The asymptotic behavior of the curve signifies that the critical moisture point has been reached and exceeded. Thereafter, the thermal resistivity will most likely not reach zero, but simply trail along the asymptote as moisture continues to increase. This implies that excessive moisture does not cause any additional significant reduction in thermal resistivity after the critical moisture point is reached. When this information is coupled with the possible negative consequences of excess moisture outlined below, it is reasonable to conclude that excess moisture situations must be avoided, as they add no positive attributes to the system. Field testing should be completed to gather data for an accurate dry-out curve representation prior to grid installation.

As moisture content increases, a soil sample's thermal conductivity value tends to increase because air has a significantly lower thermal conductivity rating when compared to water. Water aids in increasing contact between the individual soil particles, allowing for heat to easily flow away from the source.[31] Electrical resistivity of the soil tends to decrease with higher moisture values as chemical constituents, such as electrolytes, become activated around conductors. For the purposes of HVDC application, the moisture content of the cable's direct surroundings should be a minimum of 10%, as resistivity increases significantly when moisture content falls below this level.[32] Similarly, it is generally accepted that electrical resistivity is high when the moisture content of soil falls below 10%.[33] Indeed, field-derived sensitivity tests focusing on the relationship between soil salinity and moisture, conducted by *AEMC Instruments*, were not even conducted at conditions below 15% moisture.[34] While moisture is clearly a critical component of suitable soils, it must be noted that excessive moisture can also cause two kinds of problems. First, moisture can cause corrosion over time due to its potential to interact with other soil constituents around the cable, stimulating chemical reactions. Second, waterlogged soils are more likely to cause the formation of a frost layer, which can dramatically increase both types of resistance, even if the host soil order is favorable during warmer seasons.[36]

Typically, soils that are low in moisture and electrolyte (free ion) concentrations introduce the most electrical resistance;

solid stone and volcanically derived soils are prime examples of this phenomenon.[37] The depth to bedrock (discussed subsequently in the section entitled "Siting in the Context of Geology, Topography, and Contamination") and presence of solid rock fragments present within the immediate area must be accounted for during surveying to accommodate this trend. Generally, electrical resistivity decreases as salt content in soil increases.[38] This is because sodium chloride (along with many other salts) is a strong electrolyte,[39] meaning that it will completely ionize in water by breaking into the charged elemental components of its molecular structure. These ions then become mobile in solution and improve conductivity by shuttling electrons.[40] It should be noted that ionization does not imply dissolution. Every particle does not have to break into its positive and negative elemental components for improved conductivity to occur. Being a "strong electrolyte" simply implies that when the molecular compound does break down, it completely ionizes.[41] Ionization must first occur for salts to lower levels of electrical resistance. Therefore, the moisture content is an intertwined soil component that is often measured concurrently with salinity.

When wet, naturally occurring sand deposits possess high relative thermal conductivity compared to conventionally favorable soils, such as clay.[42] Soils rich in clay and sand tend to possess higher thermal conductivity values compared to soils rich in NOM, which tends to insulate cables and prevent heat transfer to the ambient environment.[43] Salt content is usually measured as its percent weight in moisture, as the ability of a soil to retain moisture will often drive its concentration of electrolytes. Well-graded soils, with multiple granular sizes, or porous sandy soils that are notorious for low moisture values should similarly be expected to have low naturally occurring electrolyte values, even if salts are present. Even if soils do not have naturally occurring salts, electrical resistivity may still be low if enough moisture is present. As shown in an analysis of electrical resistivity in terms of moisture content, *AEMC Instruments* found that moisture contents below 20% were much more susceptible to disproportionally large increases in resistivity, compared to more saturated soils found at a constant above-freezing temperature.[44]

Temperature, the final indicator of thermal and electrical resistivity, is influenced by both moisture levels and salinity. Generally, soils with very low temperatures tend to have high electrical resistivity values, especially at temperatures which allow the moisture present within soils to freeze. Similarly, soils with higher levels of moisture tend to lower, or maintain lower, temperatures over time.[45] An important deterrent to the obstacle of soil moisture freezing is the presence of salts (which may possess varied elemental make-ups in nature). While salts do not totally prevent increases in electrical resistivity associated with temperature drops, they tend to lessen the severity of these fluctuations. Ultimately, soil temperatures appear to be the overarching condition which determines soil fitness in both quantitative and qualitative approaches. Not only does temperature influence moisture levels, and vice versa, but it can also heighten, or lessen, the impact of soil thermal resistivity on current ratings. Most common soil types tend to require 15% - 30% moisture content in temperate environments to maximize cable functioning, according to our own calculations.

1.2.3 Siting in the Context of Geology, Topography, and Contamination

The natural surface characteristics of the earth can greatly influence construction of the NAS. Geological bedrock formations, as well as surface characteristics, which can be both natural and anthropogenic, have the greatest potential to slow down or halt construction. To construct the NAS efficiently, as much preliminary siting as possible should be completed to prove project feasibility in conditions where land restrictions and non-project related manmade infrastructure are present. This section surveys how landscapes, geology, and manmade environmental interferences impact soil siting.

HVDC cables should be laid at a minimum depth of 1.2 meters below the topsoil whenever possible. This 1.2 meter depth is both deep enough to maximize protection against accidental tampering, while allowing for ease of access during cable maintenance. When deciding where to lay cable, it is especially important to note the presence of shallow bedrock layers, as the process of cutting through such a layer is time consuming, costly, and potentially environmentally hazardous. Bedrock is often removed by blasting, which "fractures" the formation, and can potentially cause temporary groundwater contamination.[46] We used high-resolution nationwide data banks to visualize areas which require further investigation due to the complexity of bedrock formations. Since the NAS will ideally be built upon existing rights-of-way, such geologic features will be crucial to identify, and avoid if possible, near highways and rail lines.

Foreign objects, either natural or artificial, can complicate underground cable placement. To ensure cables consistently function properly, they must not encounter any foreign objects in soil, and several measures must be taken to prevent such interaction. First, the removal of trees directly on top of and immediately near a given right-of-way stretch is essential. This ensures that roots do not become entangled in cable trenches or around cables. We do not anticipate that tree removal will be a large factor during cable installation, as this process has likely already been completed along highway medians or in highly developed areas. In virgin (or, previously undeveloped) lands, tree removal must be conducted with caution to ensure that the local biosphere traits are maintained. Ultimately, the usage of virgin lands should be avoided when possible. If left in place, nearby trees or larger plant developments must be monitored to ensure that no roots encroach on the HVDC trench over time. Manmade infrastructure in the form of oil/gas transportation pipelines must also be circumvented. Should a HVDC line failure occur, free electricity will often jump to and charge metallic objects nearby, including oil and gas infrastructure; this in turn may create dangerous conditions that could damage both the conductor itself and any other manmade infrastructure nearby. To avoid this, we mapped oil and gas infrastructure in the continental United States and compared these routes to proposed cable routes. HVDC cables may also compete for underground space with fiber optic cables, which are often used in the telecommunications industry. (We discuss the possibility of co-placement and/or usage of fiber optic cables in the NAS system below in the subsection entitled “Potential System Interferences”).

In addition to the presence of possible physical obstructions to HVDC cable placement, some land areas may be restricted due to government regulations or miscellaneous soil-related environmental hazards. Throughout the contiguous United States, the designation of a certain land area as a “protected area” restricts development in National Parks, biodiversity conservation areas, and some federally owned lands (such as military bases). While dozens of “protected” designations were analyzed to ensure that the NAS avoids passage through such areas, the most critical restrictions placed on siting for the new grid were the avoidance of GAP (National Gap Analysis Program) 1 and 2 status lands. GAP Status 1 is defined as “an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) [can] proceed without interference or are mimicked through management”.[47] These are areas with strict rules against construction of any kind to protect biodiversity and/or endangered species. In GAP Status 4 areas there are “no known public/private institutional mandates/legally recognized easements.”[48] Areas with GAP Status 3 can be subject to extraction uses, such as mining and logging. Data pertaining to the presence of Native American sovereign lands was also collected from public sources.[49] While this analysis allowed for the potential placement of cables in sovereign areas, future collaboration must occur if the final cable route passes through these lands to ensure that the opinions of tribal leaders are considered, particularly regarding sacred areas (which should not be infringed upon).

Lastly, hazardous environmental disturbances must be accounted for and avoided during cable placement to ensure proper cable functioning and, more importantly, to protect the outer protective casing of the cables themselves. We have mapped out land areas of known contamination, namely Superfund and Brownfield locations, that should be avoided as route siting continues. Similarly, we eliminated conditions which could cause the corrosion of concrete conduits surrounding the cables. Such corrosive conditions can stem from either anthropogenic interference or natural causes. Concrete corrosion potential was rated to indicate “low”, “medium”, or “high” risk by considering variables such as soil acidity.

1.3 Environmental Risks and Benefits

The North American Supergrid will enable the avoidance of the majority of power sector carbon dioxide emissions if implemented as outlined by the foundational MacDonald et al. publication (described previously). However, the scale of the NAS means that numerous geographical regions will be impacted by its construction. So far, few immediate environmental or health risks stemming from NAS implementation have been identified, given that proper installation procedures are used and extensive environmental impact assessments are completed. This section presents what we know about these risks at present. It should be noted that this technical analysis is the most representative of any possible effects of the development of virgin land. Presumably, burying cables along existing transportation avenues would not drastically change the ecologically disruptive tendencies of existing infrastructure.

1.3.1 Avoidance of Terrestrial Ecological Risks

The magnetic field output from cable operation could affect the migratory capabilities of land animals to a limited extent. Animals in contact with ground surfaces and residing up to 1.5 meters above the surface will most likely be the most susceptible to field output along the length of any overhead or underground direct current (DC) line (likewise for compasses used at such locations). The presence of highways has most likely already caused some form of ecological disturbance in the area, especially if the land surrounding the roadway has already been developed.[50] In the very rare case that virgin lands, or remote railway rights-of-way, must be used to accommodate cables, the ecological impacts of magnetic field contact at the specific setting should be evaluated and resolved if possible. In any area of high animal activity, fencing or other physical deterrents may be used to further prevent ecological risks and structural damage.

1.3.2 Avoidance of Marine Ecological Risks

The prospect of placing cables in marine environments presents unique environmental challenges. Cables must be able to withstand extreme pressure and saline conditions, while the surrounding environment must be able to rebound and thrive after cable installation is complete. In this section, we discuss two crucial considerations linked with marine cable placement, chlorine gas emission and magnetic field interference. The section entitled "Case Study 2 – Atlantic Coast Submarine Project", paints a more detailed picture of chemo-physical, biodiversity, and anthropogenic siting considerations along the Atlantic Coast of the United States.

Chlorine gas is produced in HVDC submarine cables at the anode of a monopolar system, where the electrical current interacts the surrounding water through the process of electrolysis.[51] During ocean electrolysis, salt dissolves into positively charged sodium ions and negatively charged chloride ions. These ions then combine with the electrons originating from the anode to form gaseous chlorine.[52] While chlorine gas is highly toxic and corrosive, especially in aqueous environments,[53] it can only be produced in a monopolar HVDC configuration. The literature has noted that the use of bipolar systems, as is proposed for usage in the NAS system, virtually eliminates the risk of chlorine gas production in underwater HVDC systems.[54]

There is concern about the potential disorientation of aquatic organisms that rely on Earth's magnetic field to migrate near HVDC cables. This issue of magnetic interference originating from underwater cables has been studied extensively. Yet, the literature has not reached a consensus as to the effects on migrating marine life, in part due to the mystery surrounding the mechanism whereby various land and aquatic organisms orient themselves.[55] During the installation of the SwePol HVDC link, an underwater monopolar HVDC link between Sweden and Poland, researchers concluded that the usage of a bipolar configuration significantly lowers magnetic field interference when compared to monopolar systems due to the partial cancelling of fields in opposing directions.[56] Furthermore, shallow buried cables often only emit a strong magnetic field directly above the cable location, with some systems indicating a significant drop in magnetic field distortion at a horizontal distance greater than 5 meters from the cable.[57]

While these considerations suggest that cables are generally safe for the surrounding oceanic environment, it is still prudent to take basic safeguards to further protect aquatic species. Cables should be buried in the deepest seabed possible, preferably in the oceans' dysphotic zone (at least 200 meters below the water surface). In this zone, photosynthesis cannot occur and sunlight diminishes rapidly as depth increases.[58] This may minimize the risk posed to many endangered species and commonly consumed fish, which usually reside closer to the surface. In addition, any protected coral reef formations must be mapped beforehand and carefully avoided during the installation process. Although marine environments have been proven to successfully rebound after disturbances by cables, the fragility of many reef ecosystems makes such resilience an unlikely trait.[59] Analysis of potential species interactions and any disturbances to fishery activities must be accounted for during the installation and operation submarine HVDC cables.

1.3.3 Possible Public Health Concerns

To date, the majority of studies attempting to quantify the health impacts of HVDC lines have been conducted using above-ground configurations. Even so, we can learn quite a bit about the potential of underground HVDC lines to interact with humans, animals, and inanimate objects in their immediate surroundings from these studies. Ultimately, the literature suggests that magnetic fields associated with HVDC outputs do not have the potential to impact cell growth or reproduction capabilities.[60] Impacts on the migratory abilities of land-bound animals positioned very close to cable beds are the main health-based consequence of HVDC line operation.

Magnetic fields produced by HVDC line operation may have the potential to affect biological migration systems. As such, it is crucial to put into context the magnetic field strength associated with overhead and, by extension, underground cables. Magnetic fields of 2000 microteslas (μT) are required to impact the health of nearby animals or humans.[61] Comparatively, the magnetic field of Earth is less than 100μT at the surface. To explore the possibility of exceeding this value, we calculated the magnitude of the *B*-field resulting from the superposition of the magnetic fields for the two conductors when they were carrying 3000 amps in opposing directions to determine its relative strength compared to Earth's magnetic field. If final magnetic field strength was determined to be equal to or less than that of Earth, negative health impacts were assumed minimal or negligible. The graphical representation (Figure 1.1) illustrates the increasing weakness of the field as it moves outwards and away from the source (3GW bipolar HVDC cable pairing with 3000 amps flowing in each direction on a single circuit), resulting in a magnetic field of negligible strength at 10 meters away from the cables on either side. The dashed line on Figure 1.1 represents the residual B-field of Earth, which was maintained at 40μT. It is clear that a HVDC line of significant capacity will produce a magnetic field much stronger than that of the ambient surroundings directly above and near the cable pair.

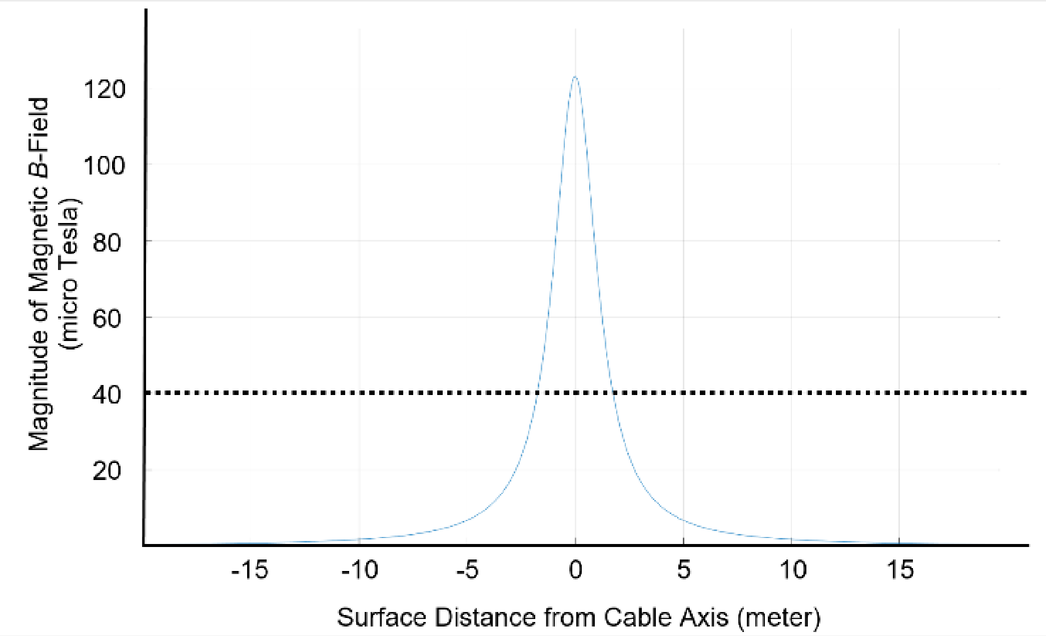


Fig 1.1 | Magnetic field for cable pair spaced 0.3 meters apart at a depth of 1.5 meters

As noted above, the strength of a given magnetic field must be at least twenty times Earth's magnetic field to impose negative health effects on humans and animals. While Figure 1.1 proves that this value is not broached for a 3GW line, the field produced could impact the directional capabilities of nearby mammals who utilize Earth's magnetic field to orient themselves in their environment. However, two factors limited our ability to draw more specific conclusions about the impacts artificial magnetic fields have on migratory mammals. First, the variance between magnetic field responses of different species makes it impossible to apply a single conclusion to all affected animals. Second, in many cases, the literature lacks a firm consensus as to the mechanism that controls magnetic field responses in animals, thus making it unclear how this phenomenon even emerges. For these reasons, it should be assumed that animals in very close horizontal proximity to a buried HVDC cable and known to utilize the Earth's magnetic field will most likely be affected by the HVDC system. This conclusion highlights the importance of utilizing existing rights-of-way whenever possible. By placing cables in previously developed land, fewer land-bound species may be impacted when compared to the same placement on virgin land.

The electrostatic fields created by above ground HVDC transmission lines have been known to produce air ions via conductor operation, in the form of charged particles.[62] There is very little research on such particles in relation to human health. Therefore, there is no set limit for maximum recommended air ion exposure for humans or animals. Similarly, several studies involving air ion output from above ground HVDC transmission lines determined that there were no conclusive changes in blood pressure, pulse, respiratory function, and body temperature due to air ion exposure. Indeed, typical car exhaust emits more air ions than an HVDC transmission line.[63] The electrostatic field, although present, also does not have the capability to "penetrate an organism," and therefore should not be considered a harmful component of this system.[64]

Generally, the electric and magnetic fields emitted by properly functioning underground cables pose a minimal risk to surrounding lifeforms. While the migration mechanisms of many species are still not well understood, limited interference with this capability by HVDC cables is the main concern found by our analysis.

1.3.4 Potential System Interferences

As we have already indicated, electric fields do not produce major mechanical interferences in other systems. When HVDC lines are operated properly, both the resulting electric and magnetic fields remain static in nature,[65] meaning that they are constant with changes in time.[66] In such cases, the harmonic energy content and electric radio-frequency interference (RFI) that is shot into the HVDC side of station converters may radiate and impair nearby radio and telephone communications. However, grounding the metallic screens of the buried cables greatly suppresses this interference. The capacitance between the center conductor and the metallic screen wrapping serves to filter and suppress much of this high-frequency energy. Grounding the screen shields shunts these time-varying electric fields to ground.[67] The grounding of the outer metallic screen of buried HVDC cables also serves to significantly suppress the radial voltage field of the high voltage current-carrying center conductor. With the outer metallic screen held very near ground potential, the entire voltage drop, or rise in some situations, between the operating voltage of each cable and the local ground is constrained to occur within the insulating layer within the cable. Therefore, no significant external DC voltage fields exist.

There is, however, some risk that HVDC-produced magnetic fields could interact with unrelated man-made systems. Aside from reduced physical vulnerabilities of the network hardware, the proximity of two buried cables results in a significant reduction in the net magnetic field at moderate distances from the pair. The opposing currents in the two conductors produce opposing magnetic fields. This in turn could combine additively in the ground area between and above the cables, but oppose each other to partially cancel out either side of the burial trench. At a distance ten times the inter-cable spacing on either side of the trench, the static magnetic field is reduced to less than one-eleventh of that of a single cable.

Careful configuration of HVDC cables within highly utilized rights-of-way is essential to proper system functioning, particularly regarding the potential interactions between telecommunications and electric cables alike. Most often, HVDC technology competes for right-of-way space with existing fiber optic telecommunication cables. Fiber optic cables are a common type of telecommunication cable, and are designed for long distance, high performance data transmission. Additionally, the proper usage of fiber optic technology to transmit valuable operational information is essential to the application of software to deter cyberattacks. The center of each glass strand is called the core, which is surrounded by a layer of glass called cladding. The external optical fiber jacket and buffer tubes protect glass optical fiber from environmental conditions that can affect the fiber's performance and long-term durability.

The NAS will require a communications system (to transmit real-time system diagnostic data) by means of a *single mode* fiber optic cable, which is designed to carry light directly down the fiber. This can be accomplished with existing fiber optic cables due to the ability of such technology to simultaneously transmit different signals within one optical fiber; signals can be sent with different frequencies and will not intermix in transit. It should be noted that the same result cannot be accomplished with existing multi-mode fibers because the large diametric core that allows multiple light reflections within the optical cable, will in turn, generate an attenuated/unreliable data signal.

In shared rights-of-way, the potential for DC links to generate a magnetic field which interacts with charged particles or objects nearby (such as a fiber optic cable) is great. Depending on the magnetic field strength generated by power transmission cables and the outer electric field, the refractive index of the optical fiber material may change. This process, known as the Kerr Effect, occurs when the intensity of the light beam in the optical fiber affects the refractive index,[68] ultimately limiting high-speed (more than 10Gbps) data transmission. The Faraday effect is another phenomenon that relates the light propagated through the optical fiber and the field generated by the HVDC cables, potentially producing errors in data transmission.

The closer HVDC transmission cables are to existing fiber optic structures, the larger the electromagnetic effect over the fiber is. Therefore, determination of correct configuration for both types of cables (within a given right-of-way) is essential. NAS HVDC transmission cables should be buried at a minimum depth of 1.2 meters. Each bipolar pair is based on two parallel cables with their centers separated by a distance of 0.30 meters. Buried fiber optic cables must be located in a neutral area, far enough away from the electromagnetic source to be unaffected by it. Additionally, fiber optic cables should not cross transmission cables, since the magnetic field generated would be parallel to the propagation of light in the fiber.* In the case that two optical fibers were located above the HVDC cables, the value of the magnetic field would be much higher than the Earth's magnetic field. Therefore, a fiber optic cable should be parallel to HVDC cables. In the instance of a single fiber optic cable, it should be located above and parallel HVDC cables, according to the design in Fig. 1.2

In the scenario in Figure 1.2, transmission cables and the optical cable must have a 0.3 to 0.61 meter soil separation,[69] implying that the fiber optic cable depth must extend from 0.61 meters to 0.91 meters. After various simulations, and considering the fact that the fiber optic cable cannot be close to the soil surface, we determined that the horizontal distance of the fiber optic cable from the center of the HVDC transmission cable should be at least 1.5 meters (at a burial depth of 0.64 meters for the fiber optic cable). In this configuration, the magnetic field generated around the fiber optic cable is approximately 17μT, a lower value than Earth's magnetic field. Additionally, to avoid coupling effects between groups of bipolar 2-GW transmission lines, a minimum horizontal distance between groupings is essential for proper configuration. Results showed that a distance of 2 meters between bipolar HVDC pairs is needed to get a magnetic field of 31μT, a value comparable to the Earth's magnetic field. By applying these configuration suggestions, the NAS system can potentially work with existing infrastructure in a fortified configuration to protect against both manmade and natural disturbances.

* HVDC cables will only generate static magnetic fields; therefore, induction does not impact calculations for the general design analysis.

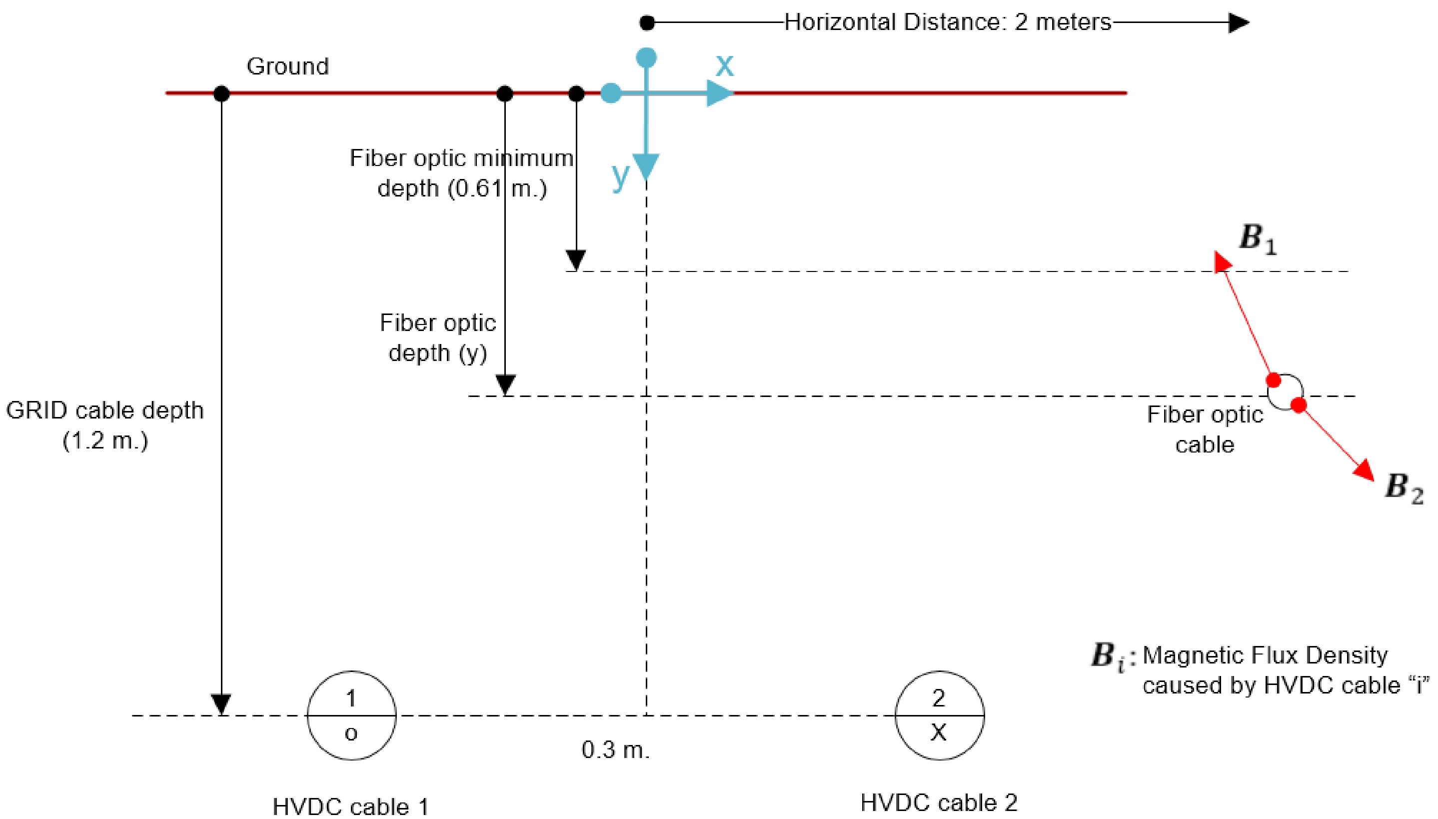


FIG 1.2 | Design configuration for the HVDC transmission cables and the fiber optic cable

1.3.5 Water Quality Impacts and Usage Modelling

The presence of groundwater and aquifer stores must be accounted for when designing and constructing an underground HVDC system. Not only does the construction of such a system have potential negative consequences for groundwater quality, such as temporary turbidity; it could also permanently alter water flow through natural systems. The cable sand surrounding HVDC cables and the heat the cables produce are the system components most likely to cause problems, since they have the greatest potential to interact with aquifers and subsequent groundwater stores.

The contiguous 48 states are home to thousands of freshwater aquifers of varying degrees of drinkability. The geological and topographical characteristics of a location determine the thickness of an aquifer, the depth to the water table, and the ease of access to the water supply. The distinction between confined and unconfined aquifers complicates the collection of data regarding groundwater depth and flow patterns. The depth to groundwater must be considered when building an HVDC system, as shallow, unconfined water reserves may be unnecessarily disturbed by cable trenches. An analysis not incorporating these factors could possibly cause standing water and/or well contamination. It is accordingly vital that we distinguish between the components of a groundwater system to accurately describe mapped data. The various components of a given water system are illustrated in Figure 1.3.

A system's "water table" designates the top of an aquifer (otherwise known as "depth-to-water"). Its depth is relative to the corresponding topsoil layer and can change based on variations in topography, even within a relatively small area. An aquifer is deemed unconfined if there is no presence of a bedrock/impenetrable layer above the water table. In such a case, a permeable soil layer is the aquifer's only protection from its surrounding environment. To determine the characteristics of major aquifers in the United States, the United States Geological Survey (USGS) has classified several major aquifer systems as "principal aquifers," which are

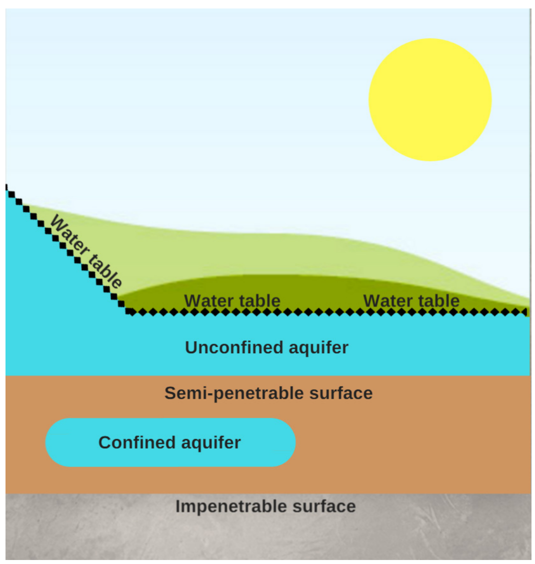


FIG 1.3 | Design configuration for the HVDC transmission cables and the fiber optic cable

considered extensive sources of drinkable freshwater. However, wide variation in depth-to-water values in groundwater monitoring wells in such aquifers (provided through the national Advisory Committee on Water Information, a USGS subsidiary) implies that generalized conclusions regarding aquifer water table depth may be too simplistic. Therefore, NAS research has focused on visualizing all nationally available monitoring well data to inform later system refinement.

It is possible for the depth of the water table and the type of aquifer formation to impact the properties of the native soil, which in turn can affect cable function. Soils present above the groundwater table are more resistant to current flow and exhibit higher water evaporation rates,[70] because soils are typically dryer there. This exacerbates the importance of the critical water level in the surface layers of native soil. While cable or thermal sands may not directly interact with groundwater formations, they can greatly influence the groundwater flow. This is particularly important when right-of-way routes are present near highly graded, or sloped, land. In these specific cases, "trench plugs" placed at the bottom of slopes can alleviate the possibility of water flow through cable sands preferentially causing disturbance of natural groundwater movement.[71] In such high-risk areas, the possibility of eliminating the usage of cable sand entirely, if native soil is favorable, is the cheapest and arguably most effective protection against plausible hydraulic disturbances.

Furthermore, changes associated with water usage due to NAS implementation must also be estimated. Water demands from the power sector, mostly due to power generation methods, heighten competition for freshwater resources and thereby increase prices for various sectors of the economy. Changes to both withdrawal and consumption influence the stock of freshwater available. All freshwater resources removed from a water source are known as "withdrawal," while "consumed" water is the total volume of water not returned to the original source after electricity has been generated. Consumed water is not available for future withdrawal. Comparatively, producing energy with fossil fuel or nuclear material withdraws and consumes more water per megawatt-hour than equivalent renewable generation. Therefore, most of the water savings achieved by the NAS are the result of increased renewable penetration in the electric grid.

We constructed a model to gain insight into the changes in national water consumption and withdrawal patterns due to NAS implementation. This required us to analyze current contributions to electricity generation by heavily utilized sources (such as coal, natural gas, wind, and solar), estimate likely future contributions by these sources in 2030, and calculate consumption and withdrawal values for all generators to utilize many different figures and achieve a weighted average. We concluded that, if electricity demand remains constant, the NAS has the potential to produce consumptive water savings of over 405 billion gallons yearly and withdrawal savings totaling over 14 trillion gallons yearly (if electricity demand in 2030 is equal to that of present day); these reductions equate to a 65% reduction in total freshwater usage, both withdrawn and consumed. Even if electricity demand doubles by 2030, the NAS can still potentially ensure sizable water savings compared to current usage levels.

1.3.6 Air Pollution Impacts and Emissions Modelling

Air pollutants such as ozone and nitrogen oxides will undoubtedly be released into the atmosphere during the construction of HVDC transmission systems. The resulting pollution pales in comparison to the enormous reductions in atmospheric carbon and criteria pollutants that will result from the increased penetration of renewables the NAS makes possible.

Ozone pollution from the NAS is not a significant concern. In terrestrial HVDC transmission systems, most research concerning ozone output has been conducted using data from above ground configurations. Nevertheless, the results of this research still yield important clues about the behavior of underground systems. In all HVDC systems, ozone is generated from the system conductors along the transmission line, which can produce ozone and its precursors, such as nitrogen oxides.[72] This phenomenon, referred to as the Corona Effect, influences how the transmission system interacts with its surrounding environment at many interfaces. Both the Corona Effect and subsequent pollutant discharge is dependent mainly on the environmental conditions the cable is exposed to. Hence, contact with moisture through precipitation or fog is a driving factor to determine the strength of the Corona Effect in overhead HVDC lines.[73] Scientific literature has proven that ozone concentrations specifically derived from overhead HVDC transmissions lines, with total voltages comparable to those proposed for the NAS, are consistently below detection levels during times of favorable weather when compared to ambient ozone concentrations.[74] Heavy precipitation events, which are assumed to be the worst case scenario for producing ozone emissions due to a subsequent inflammation of the Corona Effect only produced ozone cloud concentrations totaling 0.01 ppm.[75] Comparatively, 0.07 ppm is the maximum allowable daily limit of ozone exposure set by the United States National Ambient Air Quality Standards (NAAQS).[76] In American megacities, such as Los Angeles, ozone levels are frequently recorded at 0.15 – 0.5 ppm levels,[77] double the NAAQS value and a maximum of 50 times higher than ozone levels produced by HVDC technology.

We determined that implementing the NAS would have positive effects through modelling of EPA-sanctioned Criteria air pollutants associated with current and expected electricity mixes. We chose criteria pollutants as an air quality indicator due to their widely-accepted impact on human and environmental health. Of the six pollutants in the class, three were analyzed: Nitrogen Oxides (NO_x), Sulfur Dioxides (SO_2), and Particulate Matter. According to the EPA, Lead and Carbon Monoxide usually do not arise from utility scale fossil fuel combustion in significant levels, and are therefore considered negligible in the subsequent model. Additionally, ozone levels were not studied. Ozone is not *emitted* through combustion technology; it is instead produced in highly complex and variable post-emission reactions. The only life cycle stages measured in this analysis were production (i.e. emissions from the fuel source itself due to mining and drilling disturbances) and usage (i.e. combustion). Wind and solar power were assumed to emit negligible amounts of criteria pollutants, and emissions from transportation machinery, manufacturing, and end-of-life/disposal were not considered.[†]

The analysis indicated that the emission of these criteria pollutants followed the same downward trend with the introduction of the NAS. While NOx pollutants were emitted or created in larger volumes than SO_2 and Particulate Matter, percentage changes in weight for both conditions were relatively consistent across all compounds studied. With the NAS, the weights, expressed in metric tons, of SO_2 and Particulate Matter emitted were reduced by a factor of 7, while NO_x was minimally reduced in the year 2040 when compared to 2015 levels. Conversely, the business-as-usual electricity generation case in 2040 (no HVDC grid, with no implementation of the Clean Power Plan) showed an increase in the emission of NO_x and marginal decreases in the emission of SO_2 and Particulate Matter compared to the 2015 base scenario. Reductions in coal usage associated with NAS implementation undoubtedly contributed significantly to these reductions. It should also be noted that the business-as-usual case did evidence a slight decreasing trend in pollutant emissions beginning in 2030, due to the replacement of fossil fuel generators with a modest increase in the number of renewable generators. However, such additions are minimal compared to the potential renewable capacity afforded by the NAS system within the same time span. Therefore, the NAS can generally by expected to improve air quality through an expected reduction in the usage of fossil fuel combustion technology.

† The air quality model described is proprietary, and therefore not described in its entirety. All results are simulated estimations and should be taken as a finite descriptor of system effects; further refinement may be required before results can be considered in design and system planning. Please contact authors if you would like to request more information about the source data used or calculation steps.

After conducting general research, we turned to examine two specific case studies located in the Western United States and the Atlantic Ocean. Siting analyses with public data determined obstacles to cable placement and optimal routes.

1.4 Case Study 1: Western Pilot Project

The Western Pilot Project (WPP), a subset of the NAS, was conceptualized to demonstrate the viability of a large, highly resilient HVDC grid overlay to efficiently transmit all forms of energy. California's ambitious carbon-neutral energy policy would ideally anchor support for the system in the region, while allowing for the expansion of renewable energy generation and usage. Most of the 13 western-most states included in the WPP have proven to possess large potential capacities for wind and/or solar power, which cannot be used to full capacity without an efficient means to transmit the energy to large distant markets. To prove the effectiveness of the system, it is imperative that it accomplish what the current electricity transmission cannot: the resilient and efficient transport of electricity over long distances, regardless of the source location. The portion of this system that is most likely to be underway first lies along interstate 10, stretching from Phoenix to Los Angeles. This HVDC line is the product of a project proposed by the partners of the Central Arizona Project, which aims to cover the Central Arizona Canal with solar panels. Excess solar energy from this structure will most likely be purchased by a Southern California power entity and transported along the HVDC line, which will ultimately be connected to the remainder of the system. The core of the WPP will theoretically be centered to the West of the Plains states and will ideally follow existing highway rights-of-way. It is important to note that this route is a proposed pathway optimized solely with respect to environmental and security concerns, and will ultimately depend on the costs and stakeholders associated with its construction.

Below is an explanation of the Geographic Information System (GIS) layers which were combined to form the environmentally optimized WPP route. Although only one state, Arizona, is shown below as an example of the mapping methodology used, eleven states were ultimately included in the WPP: California, Oregon, Washington, Idaho, Montana, Utah, Wyoming, Colorado, Arizona, Nevada, and New Mexico. Several variables were combined to form two main layers showing "avoid" areas (denoted by unfavorable conditions) and "amend" areas (which can be utilized for cable burial grounds, but may require amendment with artificial fill before construction). All data displayed below was obtained from public sources, and was modified using a working knowledge of soil sciences and transmission requirements (articulated previously). Any white or grey areas in subsequent maps denote areas with a lack of sampling data. All raw data sources can be found in the GIS bibliography in the back of this publication.

1.4.1 "Avoid Burial" Map Layer

We analyzed soil areas to determine if they were of suitable composition to support the proper function of undergrounded cables. We concentrated on four potential obstacles: the presence of shallow bedrock/impenetrable surface below the topsoil,[78] the presence of "protected" land areas,[79,80] the presence of manmade oil/gas infrastructure (including underground gas storage and pipelines of both above and below ground configuration),[81,82] the presence of Superfund/Brownfield sites,[83] and the presence of shallow groundwater (qualified by measurements in government-monitored test wells).[84] Any soil area in which any one of these obstacles was present was eliminated as a potential location for undergrounding cables. If a given right-of-way traversed such areas, cables were automatically placed in an above ground configuration. In this analysis, fossil fuel infrastructure includes transportation pipelines for crude oil, petrol products, and natural gas, as well as underground natural gas storage facilities. Available pipeline data was unclear about pipeline configuration (whether the lines were above or below ground configuration), and are assumed to be avoided by building transmission cables above ground regardless of the pipeline configuration. Additionally, protected areas were also visualized and added to the avoid layer for completeness, yet major rights of way were found to not pass through those areas.

As noted previously, depth to bedrock is a critical indicator of the ease of cable installation, and the environmental impacts of the installation itself. Therefore, any soils with a bedrock layer at a starting depth shallower than 1.2 meters from the land surface were excluded as potential locations for undergrounding, as shown in the example in Figure 1.4.

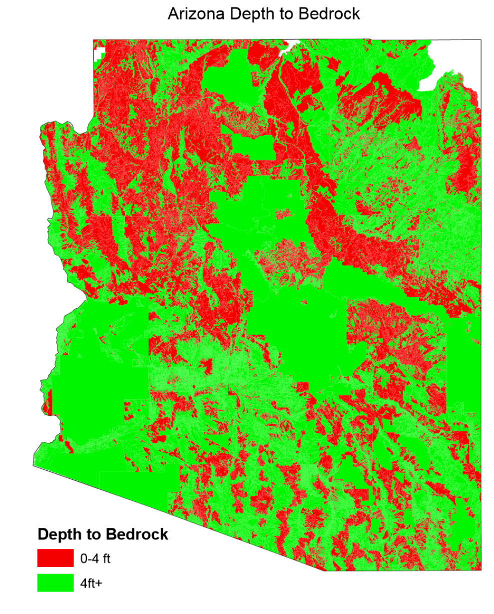
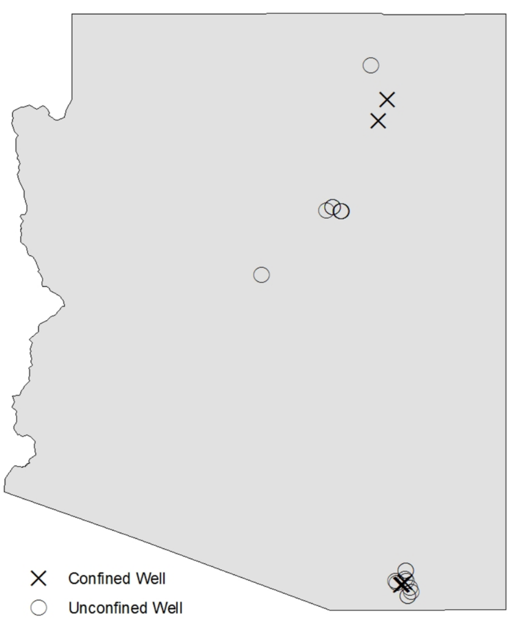


Fig 1.4 | Depth to bedrock layer in Arizona

Shallow freshwater aquifers may present challenges for cable placement, and must be safeguarded carefully to avoid contamination or changes to water table hydraulic properties. Potential groundwater levels were surmised from data taken from government operated test wells located throughout the contiguous US. While the average depth of most aquifers is at least 11.6 meters from the surface in this dataset, depth levels have the potential to change within small geospatial areas and fluctuate with season. To obtain data on a manageable scale, depth-to-water in all govern-



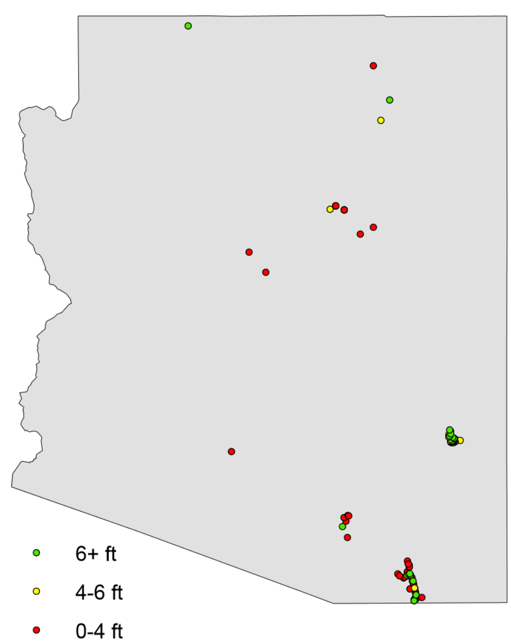


Fig 1.5 | Groundwater conditions in Arizona

ment wells (2000 in total in the contiguous 48 states) was averaged and plotted. The structure of the aquifer (confined vs unconfined) was also collected for later usage during design phases. This as well as depth data must be further scrutinized as system design evolves. An example of both datasets is present in Figure 1.6.

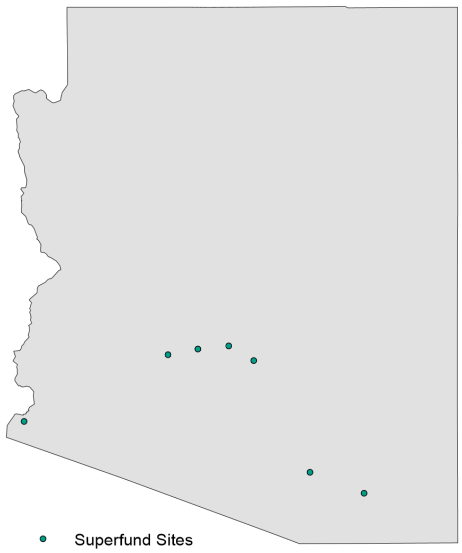


FIG 1.6 | Superfund and Brownfield sites

Existing Superfund and Brownfield sites were also tracked, regardless of contamination type, and should be avoided.

Finally, the location of manmade oil and gas infrastructure is displayed in Figure 1.7.

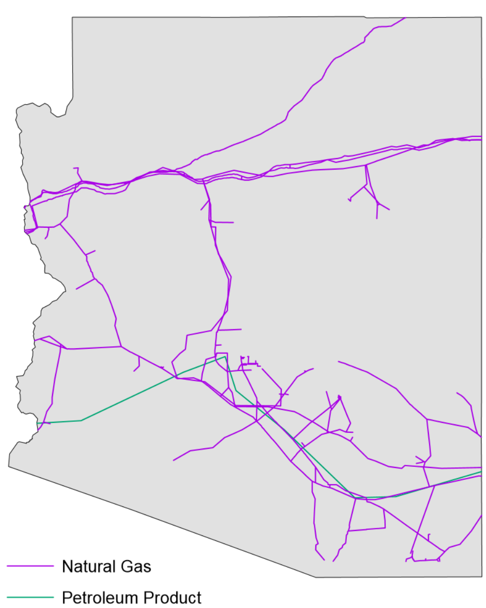


FIG 1.7 | Oil and gas infrastructure in Arizona

These layers were then combined to form a single "avoid undergrounding" layer (Figure 1.8), which will subsequently be combined with other soil characteristics to complete a final route map for the state of Arizona.

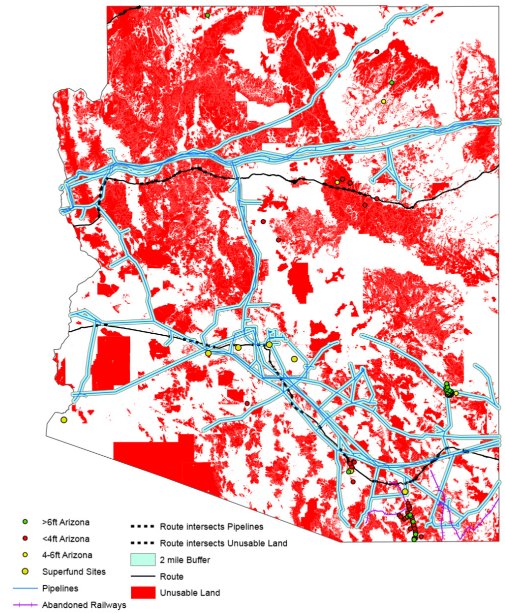


FIG 1.8 | Final areas to avoid when undergrounding cables

1.4.2 "Amend Before Burial" Map Layer

While some soil properties are difficult to correct, others may be readily altered to receive undergrounded cables without imposing unnecessary operational challenges. In other cases, no amendment/alteration is necessary at all, lowering costs and build time. For a soil to be considered amendable, it must not fall into the same area as a highlighted "avoid undergrounding" space when the two final maps are merged. For areas where this condition was met, we analyzed soil organic concentration,[85] potential concrete corrosion capability,[86] and soil order properties[87] to determine if the soil sample needs amendment. Amendment of soils usually occurs through usage of engineered silica fill to surround cables in trenches. Electrical and thermal properties of soils may also play a large role in the determination of potential amendments, yet due to their complexity, they are discussed elsewhere in this publication (in the section entitled *Siting Based on Soil Resistivity Trends*).

A comprehensive qualitative analysis of soil order properties can be found in the "Siting in the Context of Soil Mechanics" section. From this information, the extent of unsuitable soil types varied widely on a state-by-state basis. All soil orders previously deemed *suitable* were merged into a single green layer, erasing the colored distinction between orders.

Furthermore, organic content plays an important role in the extent of heat dissipation for undergrounded cables.

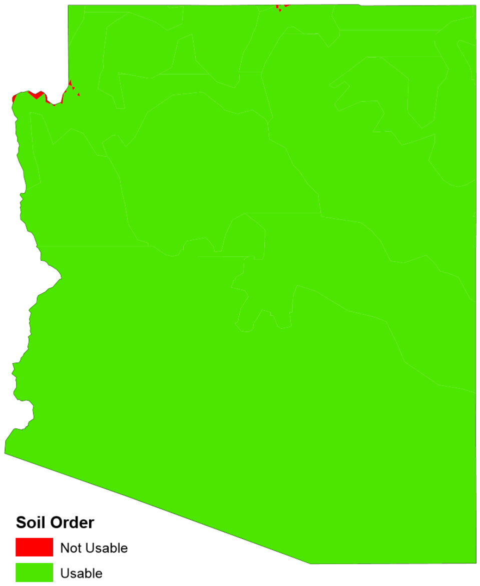


FIG 1.9 | Characterization of soil orders

According to the literature, normal soils usually contain a composition of 5% organic matter.[88] Any soil that contains more organics than this baseline percentage is more likely to trap heat around operating cables. In this analysis, any soil samples containing more than 5% organics (Figure 1.10) were accordingly marked as requiring amendment before cable burial.

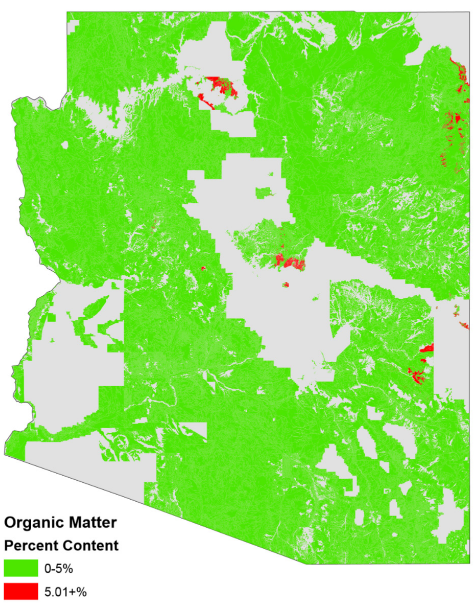


FIG 1.10 | Organic soil content

Qualitatively, we estimated concrete corrosion potential by combining the impact of salinity, acidity, sulfates, and other potentially harsh environmental components. Finally, we estimated corrosion potential, classifying areas either low, moderate, or high risk. Of these three distinctions, only areas which constituted a moderate or high risk were in need of amendment for the purposes of this analysis. Such areas are visualized in Figure 1.11.

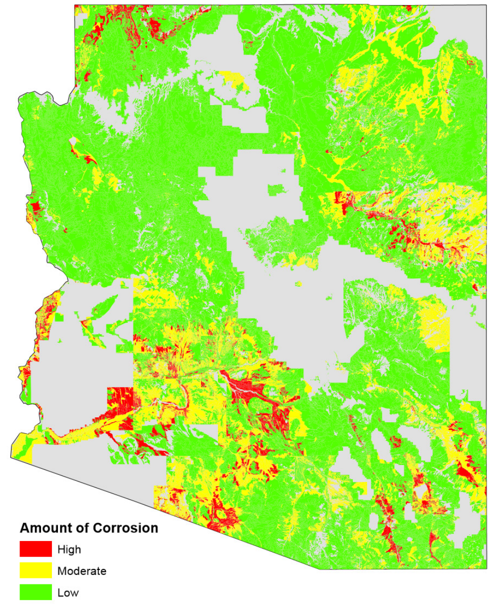


FIG 1.11 | Concrete corrosion potential

The final combination of these amend maps can be found in Figure 1.12. Pipeline infrastructure identical to that present in the final "avoid undergrounding" map was also represented at this stage, before the final combination of layers was executed.

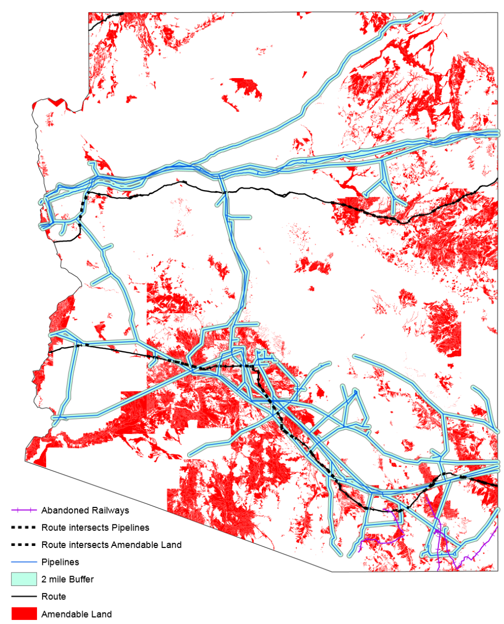


FIG 1.12 | Final areas in need of amendment when undergrounding cables

1.4.3 Final Cable Route

The combination of the "avoid" and "amend" map layers produced Figure 1.13. Although not explicitly shown, all information obtained from the previously described layers is contained in this figure. Areas that did not intersect any unfavorable avoid or amend conditions were assumed to be appropriate for underground burial without soil amend-

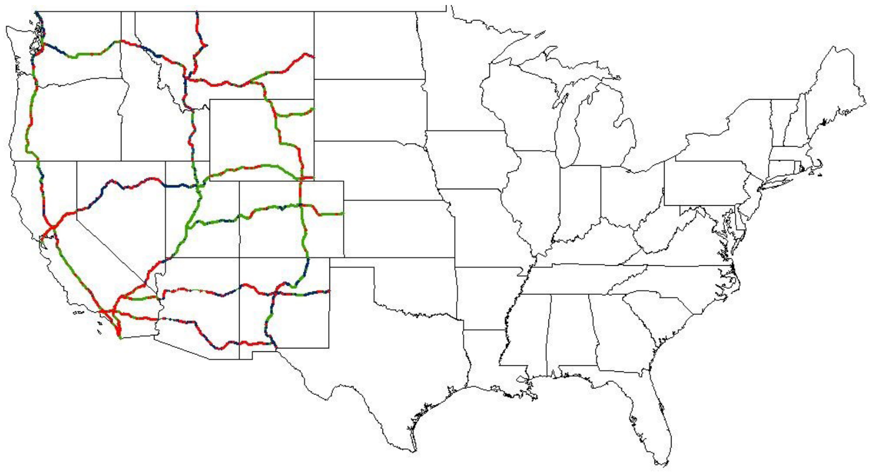


Fig 1.13 | Final Western Pilot Project route (red line stretches denote above ground lines, blue line stretches denote underground lines requiring amendment before burial, and green line stretches denote underground lines requiring no amendment before burial.)‡

ment. Nodal areas (which often center around large city centers) have the largest concentration of above ground cable configurations. Ultimately, 36% of mapped cable lines were placed above ground, with the remainder of lines remaining in an underground configuration. This percentage will most likely evolve as cable routes are mapped Eastward in the continental United States.

1.5 Case Study 2: Atlantic Coast Submarine Project

An offshore grid link may be a desirable method to connect the Northeastern and Southeastern coastal states. This feasibility study is a first investigation regarding this possibility and has considered biodiversity, chemo-physical, and anthropological concerns, which were classified as primary, secondary and supplemental concerns. Variables that were publicly available and considered relevant were gathered and overlapped using GIS tools. We present possible locations for the cable in three distinct scenarios.§

1.5.1 Chemo-physical Analysis

Chemo-physical analysis refers to data concerning the physical and chemical aspects of the offshore environment in the East Coast of the contiguous United States. To better understand this topic area, we studied sediment thickness, bathymetry, and seabed soil composition. Knowledge of sediment thickness was needed to identify sections of shallow soil that were inadequate for HVDC cable burial.[89] Although no mention was made within the metadata regarding the unit adopted in this dataset, it is reasonable to assume that "meters" was the intended unit. This dataset was compared to another showing the existence of communications cables in areas proximate to where HVDC cables might be buried, perhaps indicating the existence of appropriate conditions in the area.¶

Bathymetry is the depth, measured in meters, from the water surface to the seabed floor. Bathymetric differences can be represented graphically by isobath contours (lines which show the terrain present on the seabed) of equal relative depth.[90] Data referring to bathymetry was collected from USGS in the form of two different GIS datasets.[91,92] Both were combined to provide a high-resolution view of seabed depth. The isobaths contained in similar bathymetric intervals were colored with the same shade of green. As presented by an OSPAR Commission Report, "telecommunication cables installed over the last decade have been buried as [deep] as technically feasible, but not in areas with a water depth of more than 3,000 meters."[93] According to the same report, cables have already been placed in depths up to 1,000 and 1,200 meters.

Finally, the last dataset applied in this analysis was called "usSEABED facies data for the entire U.S. East Coast," and was also collected from USGS datasets.[94] This data is a set of points for which a soil sample of known composition was collected; the data was first published in 2005, two years after data collection period occurred. This layer represented information such as the components and genesis of the sea-

‡ This representation of the Western Pilot project should not be regarded as a final design for the system, it is subject to change and evolve as data is further collected and analyzed.

§ This case study is meant to provide an extremely comprehensive view of the potential issues that may be associated with cable placement, using public data outlets as the main information source. Actual construction plans may necessitate the gathering of additional data or disregard certain datasets mentioned in this work.

¶ This dataset will be presented later in this report. Although, other reliable sources must be consulted before the installation of the offshore cable.

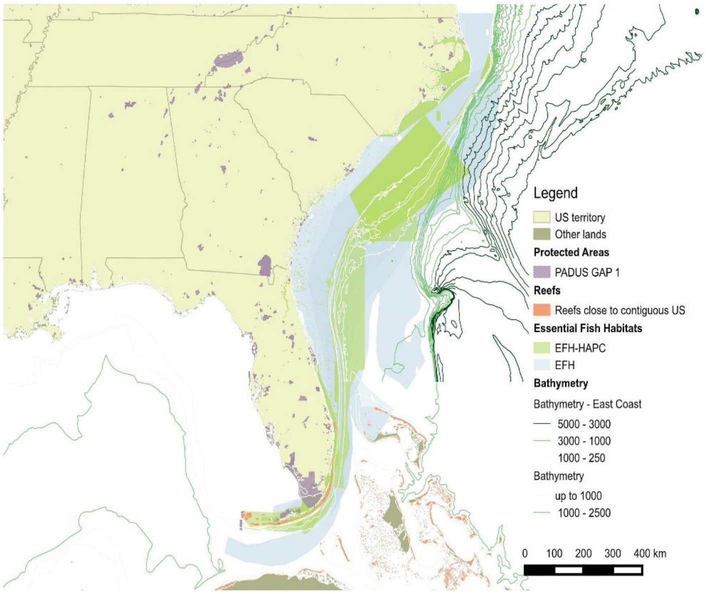


Fig 1.14 | Bathymetry, reefs, protected areas, and essential fish habitats - North Carolina to Florida

floor, and was compiled from different sources that applied various methods in the collection. From the usSEABED data-set, points signaling the presence of carbon, volcanic rock, coral and/or another geochemical signal were highlighted, meaning some percentage of the component(s) was present in each sample (the presence of metamorphic rock and hard plant percentages were highlighted separately). While the conclusions drawn from this dataset are only approximations, such information may help to inform formal surveying efforts.**

1.5.2 Biodiversity Analysis

An additional aspect to consider when implementing a new electric grid is the impact it might have on localized biodiversity, particularly considering protected areas and habitats of marine species/coral. In order to predict and mitigate negative impacts associated with offshore HVDC cables, the following variables were included in the analysis: protected areas according to GAP statuses; Essential Fish Habitats (EFH) and Habitat Area(s) of Particular Concern (HAPC(s)), with data generated by the Florida Fish and Wildlife Conservation Commission (FWC), and the Fish and Wildlife Research Institute (FWRI) in association with the South Atlantic Fishery Management Council (SAFMC); Migratory Behavior - EFH Highly Migratory Species (HMS), with data generated by National Oceanic and Atmospheric Administration (NOAA); and Global Distribution of Coral Reefs, with data generated by the United Nations Environment Program's World Conservation Monitoring Centre (UNEP-WCMC), the WorldFish Centre, World Resources Institute (WRI), and The Nature Conservancy (TNC).

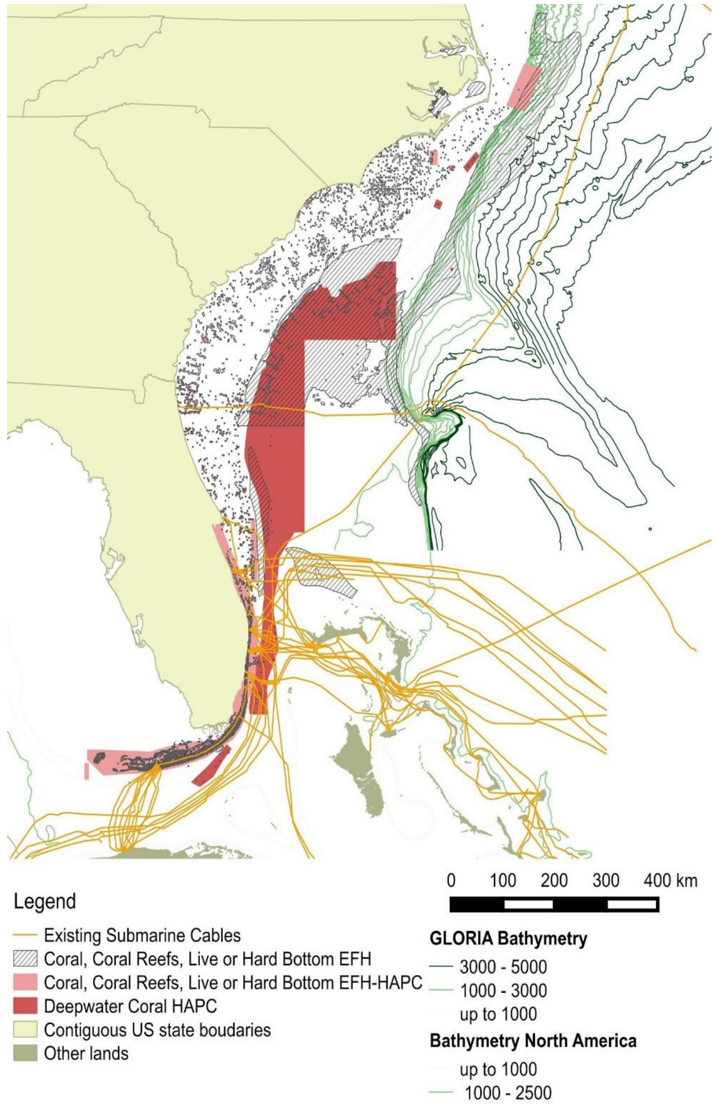


Fig 1.15 | Coral EFH, EFH-HAEC and submarine cables

As described in the WPP analysis, protected areas within the United States are classified in four categories (GAP Status 1 to 4) that are applicable in both marine and land environments. GAP Status 1 aquatic environments were avoided during the mapping process to maintain natural interaction between biotic and abiotic elements of these ecosystems. In addition to respecting designated GAP 1 lands, mapping of EFHs is also crucial to ensure that commercial fishing enterprises are protected during cable construction and operation. According to NOAA, EFHs are "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity."[95] Among the EFHs, some are also

** The sediment thickness and bathymetric information presented appear to be accurate and consistent. The information regarding soil composition, however, should be further verified applying other sources such as private firms, scholars, or government agencies who have worked directly in these offshore areas. Despite the broad visualization of soil composition this USGS dataset has enabled, the data collection dates do vary from 1840 to 2003, meaning that there is the possibility that some of the information has significantly changed. In addition, the absence of data from some of the points does not necessarily imply the absence of a mineral/organic soil component in the sample (this can occur due to unavailable data), which could also undermine conclusive statements regarding soil composition.

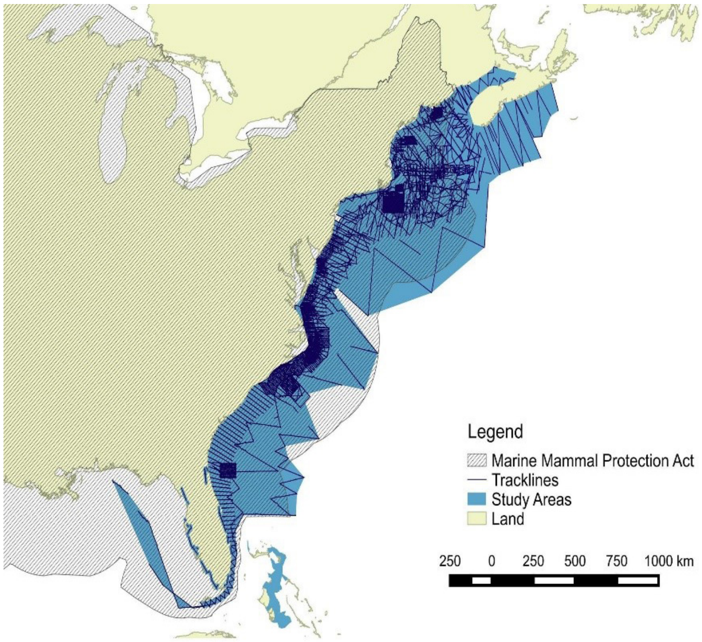


FIG 1.16 | Marine mammals study areas and tracklines

classified as HAPC(s). This special category is considered a conservation priority, and is denoted as a "habitat type and/or geographic area identified by the eight regional fishery management councils and NOAA Fisheries as priorities for habitat conservation, management, and research."[96] A table of the species for which EFHs and/or HAPCs which were mapped is shown in Table 1.1 below.[††]

Figure 1.14 shows the areas where EFH, EFH-HAPC, and Coral Reefs were identified by the aforementioned sources (previously mentioned depth data is visualized in green contours on the same figure). The reef database plotted in orange was compiled by UNEP-WCM, the WorldFish Centre, WRI and TNC. It represents the global distribution of coral reefs (data collection was held from 1999 and 2002), with emphasis on warm-water coral reefs.[‡‡] Coral reefs in orange show that reefs in close proximity to the U.S. are concentrated in and around Florida's South and Southeast Coast and near other islands South of the U.S.

As is true with coral reef locations, HAPCs are areas in which "the use of all bottom damaging gear is prohibited including bottom longline, trawl (bottom and mid-water), dredge, pot or trap, or the use of an anchor, anchor and chain, or grapple and chain by all fishing vessels."[110] Therefore, it is important to distinguish these areas from general HAPCs as well as Deepwater Coral HAPCs, which are a separate category defined after the establishment of HAPC areas. Scientific research points to the existence of high relief and hard bottom habitat areas that had not been included in the Coral HAPC boundaries. Figure 1.15 highlights both of these categories. It is crucial to note that various submarine cables intersect the three coral layers in the map.[111,112,113] This suggests that there is a method to burying submarine cables in Coral Habitat Areas. Nevertheless, guaranteeing the continuity of the natural lifecycle without great interferences will certainly require a deeper analysis by experts in localized marine biodiversity.

Essential fish habitats	Habitat areas of particular concerns
Dolphin[97]	Dolphin[98]
Wahoo[99]	Wahoo[100]
Golden Crab[101]	Shrimp[102]
Shrimp[103]	Spiny Lobster[104]
Spiny Lobster[105]	Coastal Migratory Pelagics[106]
Coastal Migratory Pelagics[107]	Snapper Grouper[108]
Snapper Grouper[109]	Tilefish[§§]

TABLE 1.1 | EFHs and HAPCs for prevalent species

The habitat of some mammals was also considered as a variable to minimize the environmental impacts of an offshore HVDC cable.[114] Their distribution through the U.S. Atlantic Zone is presented below (Figure 1.16).[115] All three layers cover the entire East Coast of the United States, which means that the cable will necessarily intercept those areas, if installed. This implies that the submarine cables presented in Figure 1.15 also cross those areas.

Similarly, we mapped animal migration, which highlighted the existent EFHs of Highly Migratory Species in the East Coast of the United States (according to data available from NOAA) previously. Most of these species are sharks[¶¶] and tunas;[***] we included all other species in a third group

†† A Snapper Grouper EFH layer could not be visualized and is not included in the corresponding map

‡‡ "Approximately 85% of this dataset originates from the Millennium Coral Reef Mapping Project, of which 35% was validated (by IMaRS-USF and IRD-Noumea) and 50% remains unvalidated (but was interpreted by UNEP-WCMC). Millennium Coral Reef Mapping Project products (validated or not) are at a consistent 30 m resolution." (Quotes contained in the "Global Distribution of Coral Reefs (2010)" GIS data documentation).

§§ Website currently under construction, originally used metadata not available. Original link to data available upon request.

¶¶ The species of sharks included in this report are those available in NOAA GIS dataset on Highly Migratory Species: Caribbean Reef Shark, Common Thresher Shark, Dusky Shark, Finetooth Shark, Great Hammerhead Shark, Lemon Shark, Longfin Mako Shark, Oceanic Whitetip Shark, Night Shark, Nurse Shark, Porbeagle Shark, Sandbar Shark, Sand Tiger Shark, Scalloped Hammerhead Shark, Shortfin Mako Shark, Silky Shark, Spin Shark, Tiger Shark, Whale Shark, White Shark, Atlantic Sharpnose Shark, Bigeye Thresher Shark, Basking Shark, Bignose Shark, Blacknose Shark, Blacktip Shark, Angel Shark, Blue Shark, Bull Shark and Bonnethead Shark.

*** The species of tuna included in this report are those available in NOAA GIS dataset on Highly Migratory Species: Skipjack Tuna, Yellowfin Tuna, Bluefin Tuna, Albacore Tuna and Bigeye Tuna.

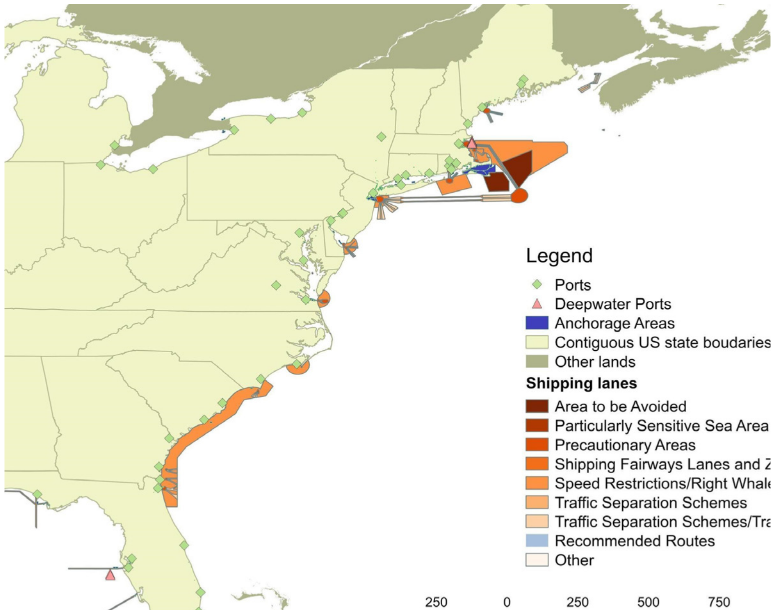


FIG 1.17 | Shipping lanes, ports, and deepwater ports and anchorage sites

termed "other species."[†††] All areas considered ideal for the cable burial, in terms of the chemo-physical conditions, are traversed by Highly Migratory Species EFH (especially by sharks).[‡‡‡] Overlaying the Bathymetry and the information presented above, it was possible to clearly identify which species were present in the potential cable path.

The aforementioned shark population only circulate through the Gulf of Mexico or very close to the coast and in shallow waters. All other species inhabit or migrate through the area where the cable may be buried.[§§§] However, the circulation of those species throughout the entire East Coast of the United States did not impede the development of other offshore energy and infrastructure projects, positively impacting the feasibility assessment of this project. Nevertheless, the planning of any new marine infrastructure should still take place in a careful manner, considering the seasonal routes commonly traced by those species.

1.5.3 Anthropogenic Analysis

Aside from Biodiversity and Chemo-physical aspects, it is important to observe the anthropologic structures and activities that are present in the proposed placement area. To ensure that cables do not disrupt shipping channels, route planners must identify areas of high shipping traffic. While cables are usually buried at a safe depth in marine environments, seabed erosion and movements in the water can gradually expose the formerly buried cable. Human activity can further accelerate this process using anchors and because of trawling, processes that could expose cables and bring about life-threatening situations, for instance, a nautical vessel could capsize if its anchor were to catch on the exposed cable. In our attempts to identify risks for sea traffic, we considered several variables: shipping lanes,[116] locations of ports, anchorage areas, and localized vessel density.

Shipping lanes are defined as routes regularly adopted by ships and are classified in the following seven categories:

1. *Precautionary Areas*, or those in which it is important to navigate with caution
2. *Speed Restriction Areas*, or those in which the speed is seasonally reduced because of endangered species
3. *Particular Sensitive Areas*, or those endangered by international maritime traffic
4. *Shipping Safety Fairways*, or areas in which artificial structures are prohibited
5. *Areas to be Avoided*, or areas that are hazardous for ships
6. *Recommended Routes*, or those that should be chosen by ships for safety reasons
7. *Traffic Separation Schemes/Traffic Lanes*, where marine traffic is directed into designated routes

Recommended Routes are only found close to Long Island, NY and along the coast of Maine. Speed Restriction Areas are the predominant shipping lane category used in the Eastern Atlantic. States in this category include: Georgia, South Carolina, North Carolina, Florida, New York, Virginia, Delaware, New Jersey, Connecticut, and Massachusetts. All shipping lanes should be avoided if possible.

††† "Other species" include: Longbill Spearfish, White Marlin, Sailfish, Swordfish and Blue Marlin.
‡‡‡ Few species of sharks have essential habitats outside of the desired bathymetric clarification: Caribbean Reef Shark, Finetooth Shark, Lemon Shark, Nurse Shark, Whale Shark, Sandbar Shark, Spinner Shark, White Shark, Atlantic Sharpnose Shark, Blacknose Shark, Blacktip Shark, Bull Shark, and Bonnethread Shark.
§§§ A complete set of maps for each of the affected species available upon request.

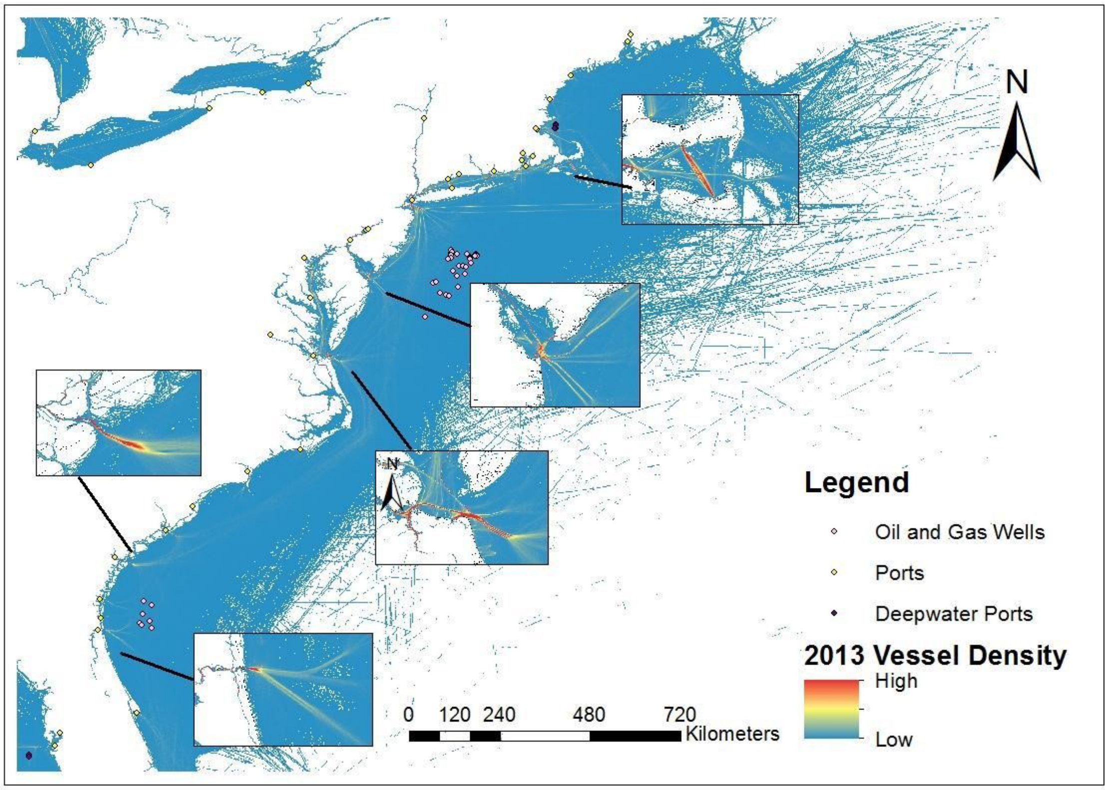


FIG 1.18 | Vessel density for the year 2013

Ports were georeferenced using newly created methodology, while similar information for deep-water ports (those located farther from the shoreline than traditional ports, which are used to load and unload large ships) was found in a premade public GIS dataset.[117,118,119] All ports are spread in a non-equidistant manner along the East Coast, while deep-water ports can only be found off the coasts of California and Massachusetts. Consequently, deep-water ports should also be avoided by the cable burial path, which might be located a significant distance from the coastline. We recommend that conventional ports should be avoided by the offshore-onshore connections that will join the offshore cable with the underground grid in the continent, thus avoiding unnecessary disturbances to traffic during construction. According to a NOAA description, "an anchorage area is a place where boats and ships can safely drop anchor."[120] Such areas are created if required to improve safe and responsible navigation. Oftentimes there is high potential for ship crowding in areas specifically created for anchorages. Such areas should be avoided by any offshore grid cables and associated connections to prevent further overcrowding of such areas especially during the construction phase. Figure 1.17 represents the information described above, and proves that the areas and structures described above are very close to the coast, with the exception of the region between New Jersey and Massachusetts, where they might represent an obstacle for cable burial.

We also considered vessel density along the East Coast and mapped it separately from other concerns because of the difficulty of visualizing the associated data. This dataset in Figure 1.18 represents 2013 annual vessel traffic density for the contiguous United States offshore waters based on Automatic Identification System (AIS) monitoring.[121] This is a comprehensive density map that includes many types of vessels (cargo, fishing, passenger, etc.) and includes high to low density scaling that shows traffic concentration, not literal vessel counts. High vessel density is likely to occur around ports and narrow channels, based on data observation. Cable placement should purposely avoid high vessel density areas to prevent external vessel damage and ensure safe installation.

In addition to mapping of shipping-associated obstacles, we also considered marine based oil and gas infrastructure.[¶¶¶] Data regarding petroleum product pipelines, product terminals, refineries, power plants, and points of underground storage were collected by U.S. Energy Information Administration (EIA).[122] Coastal Energy Facilities (data collected from NOAA's Bureau of Ocean Energy Management (BOEM) and preexisting submarine cables were also accounted for in this sub-section. Figure 1.19 presents these components in the same map and were considered in the final suggested route for cable burial. The most obvious component of this figure is that cable intersections are common, implying that this is a possible configuration, given the cable function and op-

¶¶¶ Utilized data was published in 2015, with collection occurring from 1975 to 1984.

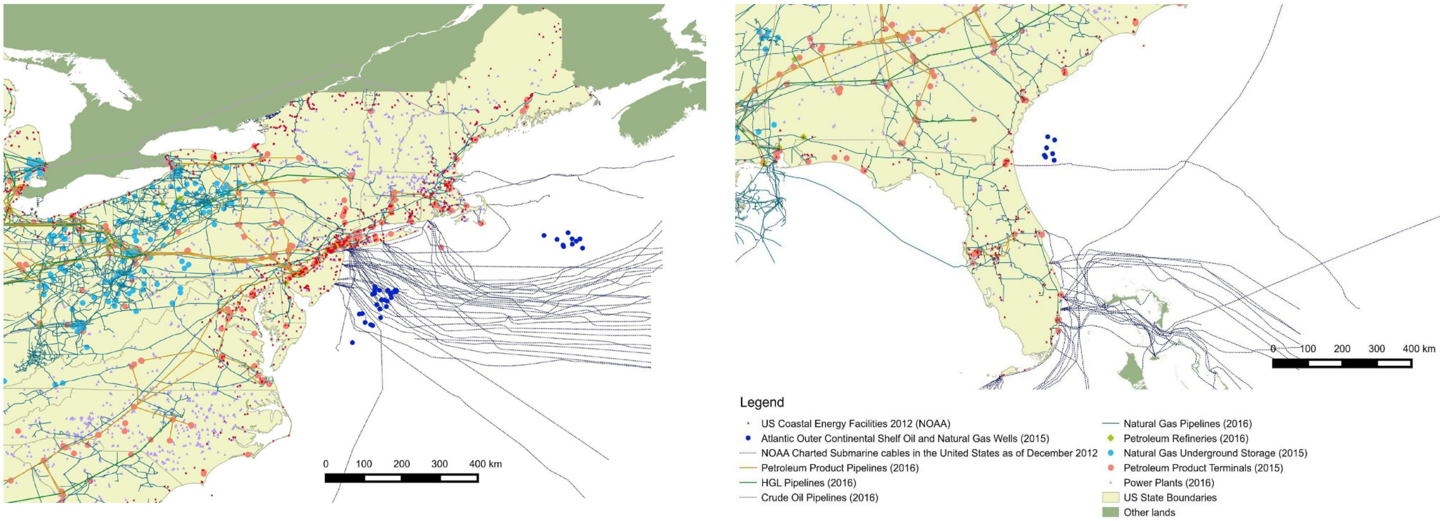


Fig 1.19 | Coastal energy facilities, oil and gas wells, pipelines, power plants, petroleum product terminals and petroleum refineries, and natural gas underground storage

erating party is known. We also considered fossil fuel well locations, power plant locations, and coastal energy facilities, particularly renewable-based facilities. Offshore wind planning zones and renewable energy leases, published by BOEM, were mapped;[123,124] the leasing areas included the current leases and grants regarding renewable sources.[125] Finally, we analyzed disposal sites, military installations, unexploded ordinates[126] and wreckage sites[127] regarding the scenarios presented in the following section. Although these areas were not visualized in their own respective maps, it is important to state that many of them are already crossed by existing submarine cables, which decreases the relevance of those elements as a real concern for the cable burial.

1.5.4 Offshore Grid Placement

Information pictured and/or described above was compiled into final maps displaying potential zones for cable placement. We classified chemo-physical, biodiversity, and anthropologic considerations into three categories: primary concerns, secondary concerns, and supplementary concerns (listed in Table 1.2 and visualized in Figure 1.20). Primary concerns are defined as factors that the cable

Primary concerns	
Bathymetry	Optimal water depth to place is between 1000-3000 meters
Sedimentary thickness	Optimal seabed depth to bury is at least 1m
Deepwater ports	Must avoid existing structures
Military installations	Must avoid existing structures
Oil and gas wells	Must avoid existing structures
Coastal energy facilities	Must avoid existing structures
GAP status 1	Permanent protection from land cover conversion
Secondary concerns	
Seabed type	Avoid hard seabed bottom if possible
Vessel type	Avoid high vessel density area if possible
Wind planning zone	Avoid planning zone if possible
Renewable energy lease	Avoid lease zone if possible
Coral	Avoid deep-water HAPC coral zone if possible
Supplementary concerns	
Expanded coral	Choose to avoid coral EFH and EFH HAPC
Anchorage area	Choose to avoid anchorage area
Disposal sites	Choose to avoid disposal sites
Unexploded ordnance	Choose to avoid unexploded ordnance

Table 1.2 | Primary, secondary, and supplemental concerns for cable placement

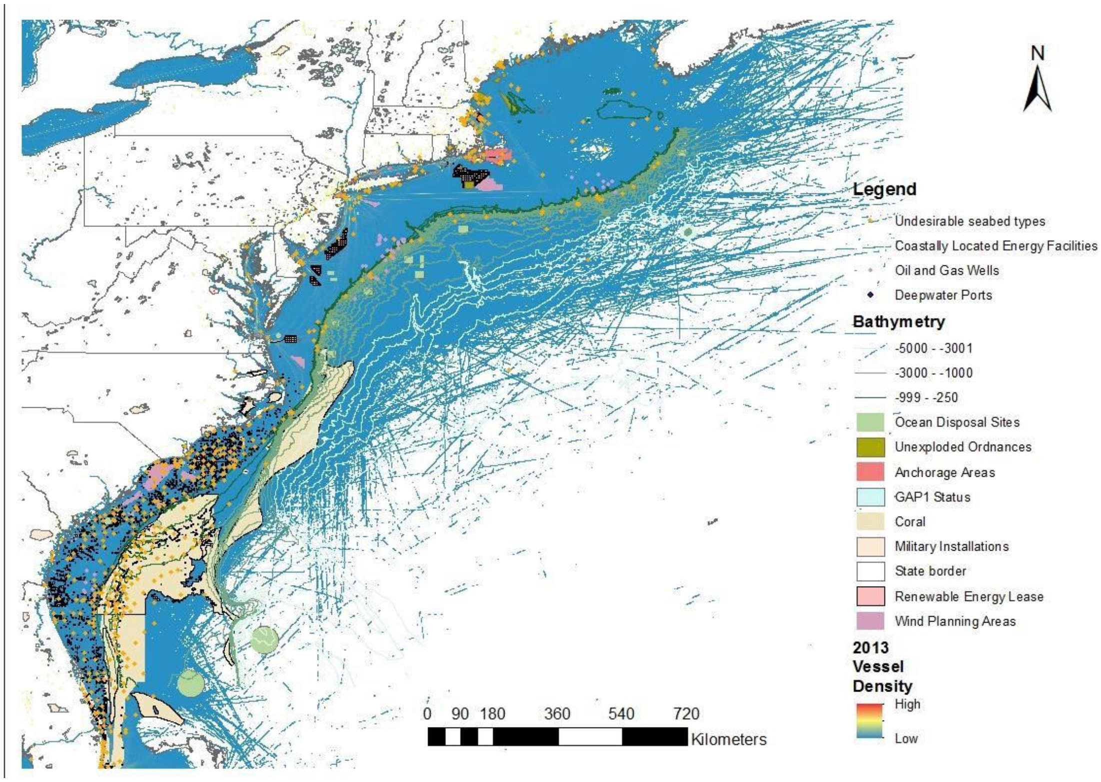


Fig 1.20 | Coastal energy facilities, oil and gas wells, pipelines, power plants, petroleum product terminals and petroleum refineries, and natural gas underground storage

placement must comply with without exception. Secondary concerns are factors that the cable placement should avoid if possible. Supplementary concerns are factors that the project developer can choose to adhere to (in order to lower risk) or ignore for the sake of cost. Subsequently, these scenarios were built based on these classifications. The final decision on the cable placement will likely be a compromise between results from this feasibility analysis, a financial evaluation, and a developer-driven analysis. The classification of primary, secondary, and supplemental concerns may evolve over time with more detailed feasibility and design efforts.

Having set out the possible cable routes, we also needed to demonstrate the feasibility of building connections between the offshore cable and the onshore underground grid. In assessing the environmental conditions, we avoided military installations, coastal energy facilities, oil and gas wells, ports and deep-water ports, high vessel density, as well as GAP status 1 protected areas. We considered areas with suitable soils and at least a 2.2 meter depth to the bedrock most favorable for offshore-onshore connections. Based on that, we have suggested three potential locations for onshore-offshore connection points in Delaware, New Jersey, and Georgia.

1.6 Conclusion

This section aimed to give concreteness to the ambitious vision of the creation of a HVDC underground network in the contiguous United States. By collecting publicly available data and analyzing the distribution of those variables in a geo-referred manner, this study was able to pinpoint what seems to be an optimistic scenario for the construction of an HVDC cable network with both onshore and offshore components. Considering the way existing cables interact with relevant variables, it seems to be quite feasible to build the system without causing serious and long-lasting impacts on the surrounding environment, humans, or wildlife.

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2 Security and the North American Supergrid

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Summary

Electric grid security has moved to the forefront of policy discussions at nearly all levels of government. At present, the U.S. electrical grid is outdated and prone to damage from sources as varied as squirrels nibbling on power lines to threats from terrorist organizations and rogue states. The North Korean (DPRK) regime's testing of multiple missiles and testimony that the DRPK possesses electromagnetic pulse weapons, which could bring down portions of our electric grid, should rightfully alarm policy makers. Naturally occurring threats such as geomagnetic disturbances can also bring down large portions of the grid in a similar manner as EMP attacks. Additionally, physical attacks on electrical infrastructure have been increasing in severity, with the 2013 Metcalf incident being a particularly alarming example. Lastly, cyber threats on electrical infrastructure evolve every day, with assaults on grid systems becoming increasingly effective. Societal recovery times from any of these threats could be very long considering the extensive lead time needed to replace larger transformers and power equipment, causing widespread loss of life and economic damage.

The North American Supergrid could play a strong role in solving these problems. The following report outlines various avenues for improving the security and resiliency of the grid:

- **Electromagnetic Pulse Attacks and Naturally Occurring Threats:** The NAS would feature a fault detection system as well as protective shielding around the cables that enclose the system's wires. The fault detection system ensures that if one portion of the grid goes down it would not affect the entire system. A failure in one section of the grid would be detected as a "fault," and the system would compensate by rerouting power away from the affected components and, subsequently, retaining system stability. This system would be effective against both EMP and naturally occurring threats such as geomagnetic disturbances. Protective shielding would ensure that the cables protecting the wires are safeguarded against physical tampering and extreme temperatures.
- **Threats to Structural Integrity:** The NAS makes use of underground cables to counteract purposeful tampering by threat actors and to prevent animals from destroying the wires. These improvements strengthen the structure of the grid system.
- **Threats Originating from Weaknesses in Cyber Defense:** The NAS would possess measures that protect against the hacking of the Supervisory Control and Data Acquisition systems (SCADA), Distributed Network Protocol Version 3.3 (DNP3) systems, and attacks on the Industrial Control Systems (ICS) of the grid. Some protections against these types of assaults come in the form of better employee vetting/monitoring, daily password randomization, limiting access to important areas of substations to a small set of individuals, and better segmenting of grid network systems.

This chapter also discusses the role of federal oversight for the initial building of the grid overlay and the role of federal oversight in creating the NAS more broadly. The security upgrades presented in this chapter would aid in protecting our nation against attacks on the electrical grid. It is our opinion that the NAS is perhaps our country's best option for updating and hardening our aging and vulnerable electrical grid infrastructure.

2.1 Introduction

The grid's importance to our nation's economy and way of life cannot be overstated; the grid is the common denominator that underlies all other critical infrastructure--water, food, transportation, homeland defense, and more, yet it is also the weakest component of our infrastructure. This report will summarize solutions to the four major security challenges confronting our grid: manmade electromagnetic disturbances, natural electromagnetic disturbances, structural integrity, and cybersecurity. The much-needed improvements laid out in the North American Supergrid Initiative would enable us to meet these challenges.

2.2 Manmade Electromagnetic Threats

The electrical power transmission grid in the United States is largely made up of a series of many long and highly conductive metallic cables. These cables have the potential to be impacted by electromagnetic waves. A commonly referenced potential source of such disturbances is an EMP attack (brought about by high altitude detonation of a nuclear device). This form of attack is becoming an increasingly likely threat to modern civilization given the current security climate. The EMP electric field waveform has three components referred to as E1, E2, and E3 waves.[1] The short, high-intensity E1 wave couples large currents to disrupt operational power and communication lines.[2] The E2 wave is much lower in energy than E1, with the E3 wave having the lowest energy of the three waves, and possessing characteristics similar to solar geomagnetic disturbances (GMD).[3] The E3 wave can produce significant currents on long electrical lines.[4] E1 waves can damage both smaller electrical devices, and distribution transformers.[5] E3 waves have the potential to destroy larger transformers causing damage requiring replacement.6

The High Altitude Electromagnetic Pulse (HEMP) threat is a type of EMP that is intensified by being detonated over a large geographic coverage area, exceeding the capability of conventional grid protection equipment to isolate the disturbance to a single region.[7] In either scenario of solar storm or HEMP, the combined strength of the three waves could shut down the electrical grid for months to years, causing unprecedented economic disruptions and loss of life.[8] The duration of the outage can also be greatly increased based on the availability of replacement transformers, and the especially long lead times needed for installation and start-up of these transformers.[9]

Threats from a HEMP are likely to come from North Korea or any other actors with hostile intent towards the United States. However, it should be noted that any nation with hostile intent that possesses nuclear weapons with EMP enhancement capabilities poses a threat to all other nation states. In a *Washington Times* article on North Korea's rumored development of EMP weapons, a Chinese military commentator is quoted as saying that the North Koreans possess EMP weapons.[10] North Korean motives are uncertain, but they appear prepared to attack the United States with an EMP style weapon, whether by satellite or by nuclear missile. North Korea tested an intercontinental ballistic missile in early July 2017[11] and has continued to ramp up these tests in recent months.[12] The threat posed by North Korea as a potential perpetrator of a HEMP attack has also been confirmed by former Director of Central Intelligence, R. James Woolsey. In a report from the *National Review*, he pleads with Congress to seriously consider the threat from EMP.[13]

Whether this attack occurs likely depends on the delicate political situation within and outside North Korea, and the success of potential target states to "harden" their electric grids and other key infrastructures against EMP attack hazards. China, though acting as a moderating force, may be unable to stop North Korea from initiating an attack. Economic hardships in North Korea may keep the DPRK focused on domestic issues, but this is unlikely considering the leadership's bellicose maneuvers in the last few months.

A new and more resilient grid could bolster our defenses against a nationwide blackout caused by a HEMP attack. HEMP attacks can be executed using various means depending on a country's level of technological sophistication. Delivery platforms for these devices can include unguided missiles and balloons. The usage of balloons to transport airborne weaponry was utilized by the Japanese during World War II.[14] During the war, the Imperial Army launched balloons carrying bombs across the Pacific and into U.S. territory.[15] Today, delivery means have evolved. In a February 2017 article from the *Washington Times*, James Oberg, a distinguished astronaut and space expert who visited the DPRK's satellite launch facility, stated that satellites armed with small nuclear warheads may very well have become a major part of North Korea's space program and that they seek to use it as a threat against the United States.[16] As the options to deliver these types of weapons continue to increase, it has become increasingly imperative that the United States arm itself against these types of attacks.

Non-nuclear EMP (NNEMP) attacks are also causes for concern, especially when considering non-state actors. Individuals, terrorists, or criminal groups wishing to interrupt or destroy communication systems can execute intentional electromagnetic interference (IEMI) attacks. However, these effects are generally limited to smaller areas since the energy from IEMI emitters diminishes with distance.[17] For this reason, the non-nuclear EMP threat is not as serious for entire critical infrastructures as the hazards posed by high-altitude nuclear EMP. However, NNEMP devices can be used to take down segments of the electrical grid. They can be utilized by both the military and criminal or terrorist groups for their own purposes. During a Congressional hearing with the Subcommittee on Cybersecurity, Infrastructure Protection and Security Technologies on May 8 2014, it was said that a malicious individual armed with what is called an “EMP suitcase” could disable the grid of a major city if the perpetrator knew the location of a main plant or transformer farm that routes electricity to the area.[18] The EMP suitcase is a type of NNEMP and can be effective if the individual or team of individuals using these devices are skilled operators.

Threat actors (especially non-state actors such as ISIS) seeking to execute this sort of attack can create their own IEMI devices.[19] The relevant components are inexpensive, and such devices are easy to build. According to the Congressional Research Service’s final deliverable in 2008, a short range, small scale device could be created for less than $2,000.[20] The material to create the device is also easily found and is commercially available.[21] Although the device has a much smaller range than a HEMP, if one were to be used in Times Square in New York City, the results could be deadly and the psychological effects would be profound. Such an attack is very possible as demonstrated by the recent explosion of a handmade bomb in New York City on 17 September 2016.[22] As terrorists become more resourceful, the threat from a small scale IEMI device has become a major cause for concern.

The effects of large-scale man-made electromagnetic disturbances have previously been demonstrated by nuclear weapons testing on Johnston Island in the Pacific Ocean. The Starfish Prime nuclear tests occurred on the unincorporated U.S. territory of Johnston Island. The tests, conducted on 9 July 1962, were part of a series of “high-altitude nuclear bomb tests” used to gather information about EMP effects by the United States.[23] The nuclear warhead used at the time was equivalent to “1.4 million tons of TNT exploding”.[24] Following a blast of this magnitude, electrons quickly move away from the area of the blast, and are deflected by the Earth’s magnetic field, creating an electromagnetic pulse.[25] The effects of the explosion were immediate and led to effects from the EMP being felt hundreds of kilometers away in Hawaii, where it caused the blackout of “…hundreds of streetlights, and caused widespread telephone outages…other effects included electrical surges on airplanes and radio blackouts.”[26] The radiation’s effects in the atmosphere were long-lasting and damaged several space satellites.[27] A weapon of similar size to the Johnston Island tester could cause even more damage if detonated above populated areas like New York City or Washington DC.

2.3 Naturally-Occurring Electromagnetic Threats

The grid faces not just manmade, but also natural threats. Random solar flares, can lead to rapid and drastic changes in the Earth’s magnetic field through the ejection of solar coronal mass, and these geomagnetic storms can induce impulsive currents in bulk power systems around the globe; the sequence of events caused by geomagnetic storms has been thoroughly documented and studied. These currents, referred to as geo-magnetically induced currents (GICs), can be large enough to disrupt normal operation and possibly damage or destroy portions of bulk power systems.

We will consider three types of geomagnetic solar storms in this section: auroral electrojets, coronal hole disturbances, and sudden storm commencement (SSC) events. Each can impact different portions of the globe, as well as different components of the nation’s electric grid.

Auroral Electrojets originate in the Earth’s ionosphere, which is an electrically conductive atmospheric layer situated in altitudes from 40 miles above the Earth’s surface.[28] More specifically, auroral electrojets originate in the two lowest of the three regions of the ionosphere: D and E.[29] Most activity in the D region (in the form of radio wave absorption) occurs during the day, with the region disappearing during evening hours.[30] The E region follows the same temporal pattern, yet absorbs x-rays.[31] In the D and E regions, electrojets are produced by horizontal electric fields, which can be extremely destructive.[32] Importantly, it should be noted that these electric fields and the associated conductivity of the ionosphere are strongest and most prevalent at higher latitudes,[33] making the Northern Hemisphere particularly susceptible to this type of solar storm. One effect of such storms is visible to the naked eye in the form of the Aurora northern lights. The storms can last several hours to several days; the Carrington events of 1859, for example, impacted telegraphic systems over a period of 12 days.[34] Pipelines and similar infrastructure may also be affected.[35]

The Sun’s corona (as with other stars) is a layer of plasma material that surrounds the Sun.[36] Coronal Hole disturbances form when movement of low density sun plasma creates gaps in the coronal layer.[37] Unlike the rest of the sun, magnetic fields originating from coronal holes leave the Sun’s surface in a “high speed solar wind stream”[38] and extend into outer space, where they may come into contact with Earth and create fairly severe geomagnetic solar storms.[39]

Lastly, perhaps the least understood type of geomagnetic disturbance is referred to as a Sudden Storm Commencement. There is some debate in the scientific community regarding the classification of these events. Some believe that SSCs are merely the beginning phase of a larger geomagnetic event, while others believe SSCs should be denoted separately, as they are not always followed by a larger solar storm.[40] Currently, the accepted classification of SSCs dictates that a SSC solar event occurs due to a sharp change in the vertical component of the Sun's magnetic field,[41] due to "a sudden increase of ... solar wind dynamic pressure."[42] Such storms do not affect any single portion of the Earth; instead, every part of the globe is susceptible to SSCs.[43] SSCs, even of brief durations, have been suggested to cause transformer failures.[44]

The most widely regarded modern example of a natural geomagnetic disturbance was one that caused a shutdown of a Quebec Hydro Plant. It involved a moderate amplitude GMD that caused the regional grid to shut down within 2 minutes, resulting in power outages to 6 million customers for approximately 9 hours.[45] Another less well-known incident in 2012 involved a massive solar storm that missed the earth by a week.[46] The storm would have created electronic disruption effects similar to or perhaps even larger than the Carrington Event of 1859, causing blackouts on a large scale.[47]

2.4 Threats to Structural Integrity

Power and utility companies spend a great deal of their time on guard against any and all cyber intrusions to the electrical grid. This is an important task, but it also may divert their attention away from attacks on the physical structure of the grid itself that can result in power outages of a similar duration.[48] Recent attacks on transmission stations and other parts of the electrical infrastructure make it imperative that our grid be updated to withstand attacks from physical destruction. At present, the grid and its structures are outmoded and so prone to damage that even squirrels can take down an entire electrical line by nibbling the wires. Due to the fact that many of the cables are above ground, they are highly susceptible to damage from extreme weather conditions, threat actors (who need little technical know-how to inflict damage), and animals, creating a high risk of power disruption. Physical destruction of substations, especially those containing large transformers, can result in electricity outages over wide areas lasting from one month to over a year.[49]

Security at electrical substations tends to be very limited and unsophisticated. A coordinated attack on multiple substations could accordingly cause a large-scale blackout. An article from the *Wall Street Journal* regarding the coordinated assault on Metcalf substation discusses the incredibly limited security measures that many electrical substations tend to possess. Indeed, most stations have little beyond cameras (which may not be consistently monitored) and barriers as basic as a chain link fence.[50] Such limited monitoring and security makes the need to upgrade the grid even more imperative.

The most notable past incident involving an attack on physical grid infrastructure was the Metcalf substation attack on April 16th 2013.[51] This incident was executed by a small group of individuals armed with long range rifles and an impressive degree of advanced preparation. The operation began at 1AM when the attackers cut telephone cables to prevent raising an alarm.[52] The attackers appeared to have done a great deal of preparation before conducting the attack. A small pile of rocks left near certain areas of the substation seemed to serve as indicators of where fellow attackers should take their shots in order to effectively cause a shut down.[53] The attackers then started to fire on these locations, causing significant damage.[54] The individuals responsible for the attack have never been caught.

The Metcalf incident was referred to by former Chairman of the Federal Energy Regulatory Commission Jon Wellinghoff as "the most significant incident of domestic terrorism involving the grid that has ever occurred".[55] There is reason to believe that an attack on the components targeted in this incident could have resulted in prolonged blackouts ranging from months to years; again, due to the difficulty to replace and build more transformers.[56] The attack, aimed at a station that routes power to Silicon Valley, also makes clear how realistic the possibility is of a mass blackout in one of the nation's economic powerhouses, something that could do massive economic damage to the nation.[57] The location of the Metcalf substation (in San Jose, California near the South Valley Freeway)[58] is also significant, and illustrates the all too common practice of placing substations in areas with low foot traffic and relatively little security (making them even more vulnerable to attack by cover of night).

In addition to domestic threat actors, foreign terrorists are interested in attacking electrical grids. According to the *Wall Street Journal* the Electric Power Research Institute found that, "overseas, terrorist organizations were linked to 2,500 attacks on transmission lines or towers and at least 500 on substations from 1996 to 2006."[59] Alarmingly, terrorists are very much aware of grid vulnerabilities in target nations and considering the low-level of skill required to carry out an attack similar to the Metcalf incident, there is reason for concern. Analysis by the *Wall Street Journal* found that there had been 274 incidents of intentional damage done to the grid by individuals in the three years prior to 2014.[60] Threats to the structural integrity of the grid are very real and require little beyond preliminary surveillance and planning. A threat actor need not be incredibly sophisticated or affiliated with any specific nation or non-state group; threats may emanate from disgruntled employees, eco-terrorists, or even simply bored hunters.[61] The extent of the threat and the simplicity in which to execute it make upgrades to the grid imperative and well overdue.

2.5 Cybersecurity

The current grid possesses minimal cybersecurity measures against hacking, and the system is still quite vulnerable to attacks. These types of attacks may vary, and in the grid's current manifestation, are executable through a variety of different means. Indeed, there have been many cyber-attacks on grid infrastructure in recent years; the three major threat actors of note in this arena being Russia, North Korea, and Iran. All three countries have either committed acts of sabotage against the United States, or have shown that they have the capacity and intent to carry out these attacks. Non-state actors like ISIS and other terrorist groups, while not as immediate a threat as conventional state actors, have still shown that they intend to carry out attacks on the grid through cyber sabotage.[62] At present, conventional state actors are likely the most probable culprits for attacks on the U.S. electrical grid. However, given the long lead time required to secure and upgrade the U.S. grid, there is ample time for independent threat actors to develop--or hire or purchase--sophisticated cyber capability.[63]

Electrical companies are inundated with new and evolving cyber threats every day. Indeed, according to *U.S. News and World Report*, there has been a major spike in cyber-attacks on energy and electrical utility companies in recent years.[64] In fact, of the 150 employees at various companies surveyed, more than 75 percent said that there had been at least one "successful attack", meaning that hackers were able to breach at least one of the company's firewalls.[65] Although, few, if any have been able to affect the actual Operational Technology (OT) network of the respective systems, the number of attacks is still substantial and could eventually breach the OT network, leading to attacks that could affect both monitoring and control systems of the electric grid.[66] Attacks can be executed in a variety of ways. For example, attacks can come in the form of the insertion of new code into an existing system to cause a disturbance, or as manipulation attacks.[67] Other common examples include denial of service, rerouting of power, and tampering with temperature controls.[68] All could possibly lead to a brownout or blackout situation.[69]

Russia appears to have the capability to use cyber-attacks on electrical systems as a means of political leverage and tactical advantage. The Russian annexation of Crimea and its rather aggressive dealings with Ukraine have been a focal point of U.S. and Russian foreign policy. Particularly noteworthy is Russia's likely involvement in the hacking of the Ukrainian electrical grid in December 2015 and again in December 2016.[70] The hacks shut down portions of Ukrainian electrical infrastructure and left hundreds of thousands without power.[71] The Ukrainian attacks were possibly used to gain tactical advantage over the country by Russia.

North Korea illustrated its ability to execute cyber-attacks during the Sony Pictures hack of 2014. Although the North Koreans did not fully admit to being behind the hacking, there is evidence suggesting that the DPRK's Unit 121 was the force that led the attack.[72] Unit 121 is the cyber warfare component of the Korean People's Army.[73] Mr. Kim Heung-Gwang, a professor at North Korea's Hamhung University of Computer Technology, told the *Washington Times* that "North Korean hackers are targeting nuclear power plants, transportation networks, electrical utilities and all major government organizations abroad…".[74] Mr. Heung-Gwang's remarks show that the North Koreans appear to be actively interested in sabotaging electrical utilities and by extension, the grid. It should be noted that North Korea's closest allies are fellow rogue states Iran and Syria, who they regard as confidants due to their mutual opposition to the United States.[75]

Iranian and U.S. relations have rested on very fragile foundations for some time. Both states have actively used cyber sabotage against one another and diplomatic relations are still strained following the Iran Nuclear Deal carried out during the Obama Administration. A cyber intrusion of particular importance occurred in 2013, when Iranian hackers gained access to the back-office systems of the Bowman Avenue Dam, 30 miles north of New York City.[76] Although, the intrusion was not substantial, it illustrated the ability of external actors to gain access to critical infrastructure, an issue of growing concern to policy makers. Earlier in 2013 and 2014, the hackers in question also executed denial-of-service attacks against major U.S. banks such as J.P. Morgan and Wells Fargo.[77] Cyber-attacks such as this can cause major economic interruptions and loss of money. A grand jury in the Southern District of New York ruled that both intrusions were committed by Iranian nationals who were "…manager[s] or employee[s] of ITSecTeam or Mersad, private security computer companies based in the Islamic Republic of Iran that performed work on behalf of the Iranian Government, including the Islamic Revolutionary Guard Corps."[78] This shows that not only are these attacks essentially state sanctioned, but that they can do immediate damage to the U.S. economy and its people.

Modern cyber-attacks can be inflicted on the SCADA systems which are the Industrial Control Systems (ICS) that operate the grid. For our purposes, there are three main security concerns that are associated with SCADA systems. One problem is policy and procedure vulnerabilities (holes in security that can be exploited by an external source). According to the Public Interest Energy Research Group (PIER), these usually are caused by a "lack of security audits, disaster recovery plan etc".[79] Another concern is platform configuration vulnerabilities (involving inadequate upkeep of effective password policies and ineffective security patch policies).[80] Yet another is platform software vulnerabilities (i.e. the lack of intrusion detection and prevention software as well as an absence of malware protection software).[81]

Other notable types of vulnerabilities can allow the hacker to take large-scale control over many different components within the SCADA system. Network configuration vulnerabilities, for example, are weaknesses in the security of the system's network architecture (in other words, effective data control is not applied).[82] Network perimeter vulnerabilities, or weaknesses in network security architecture in the form of a lack of firewalls or segmented architecture, can lead to insecure connections with outside sources that can exacerbate or lead to more system problems.[83] Finally, network communication vulnerabilities are the broad holes that exist in the communication architecture of a SCADA system, allowing an attacker access to sensitive components.[84]

Attacks that impact grid network architecture itself are also of concern. According to PIER, "network architecture design is critical in offering the appropriate amount of segmentation between the Internet, the company's corporate network, and the SCADA network".[85] In the context of the NAS, the "company's corporate network" is the utility company, providing electricity through the Supergrid. When discussing network configuration vulnerabilities, the primary concern is that server connections may not be protected by firewalls when contacting corporate partners and other outside sources. This connection can then become insecure, leaving a backdoor open for potential adversaries to take advantage of when given the chance. Moreover, a lack of firewalls within a company's segmented network architecture can lead to openings that can be exploited as well. Such issues can lead to concern regarding network perimeter vulnerabilities. Without protective mechanisms like firewalls and proper network configuration, SCADA systems can be left open to attacks from worms, viruses, and hackers.[86] Indeed, network connections provided over wireless system architecture are especially vulnerable to attack. Despite this, many control systems (and many SCADA systems) make use of WIFI, exacerbating security and system recovery issues.[87] Network communication vulnerabilities primarily involve threats to the system's security protocols.[88] For our purposes, inter-connected systems such as the Distributed Network Protocol Version 3.3 (DNP3) are of the most importance for evaluation.[89]

DNP3 systems are designed to make it easier for macro system architecture to communicate with smaller units like Regional Transmission Units. However, interoperability at this level comes with risk. Threat actors can initiate cyber-attacks in the form of "Length Overflow and DFC [(Device Fence Control)] Flag Attacks", "Reset and Unavailable" function attacks, and "Outstation Data Resets".[90] Length Overflow and DFC Flag Attacks insert data into the length field, which can cause outstations to receive a false message that causes it to shut down.[91] The "Reset and Unavailable" function allow an attacker to take control of an outstation, allowing them to reset it or deactivate it for an extended period.[92] An "Outstation Data Reset" falls under the same category, and can cause an outstation to suddenly become inactive and inoperable.[93]

The last major type of attack that the NAS should be defended against is an Advanced Persistent Threat (APT) attack, a method of cyber-attack where the threat actors (which could be a nation-state or other nefarious individual) monitor and target a component of the transmission architecture over an extended period.[94] The attack on Ukraine's electric grid could be categorized as an APT, considering that the initial infiltration occurred 9 months before the grid system blackout.[95] But APTs are executable through any system equipped with network capabilities. This type of attack is typically used for intelligence gathering rather than for outright exploitation and sabotage.[96] However, it could serve as a prelude to a larger cyber assault. Hackers could theoretically use APT methods to monitor the operations side of the system, keeping a low profile as they search for ways to breach security protocols in the Operations Technology area of the grid system.[97] Strategies for mitigating the threat from APT do exist (such as daily password randomization), and measures for preventing these types of attacks will be put in place in the new grid.

Coordinated assaults where actors attack both the physical and cyber components of the grid are becoming a major cause for concern.[98] An intelligent attack of this sort could cause devastating damage to the grid, especially if inflicted on multiple major transmission sources at once. The updates proposed in this brief should help in alleviating these concerns. However, cyber threats evolve every day and utility operators and policy makers must remain vigilant in their surveillance of these systems.

2.6 Mitigation of Threats by HVDC Cable Construction

The North American Supergrid will utilize shielded HVDC cables, which contain a metallic sheath between insulation layers that acts as an absorbent for excess charge that may come into contact with a cable during an EMP or GMD event.[99] Since currents and voltages from electromagnetic disturbances can be extreme and destructive, the outer screen of shielded cables in the proposed system could be physically "broken" at regular intervals to limit the induced currents. At these break points, one end of the electrically isolated cable screen section is grounded to the soil to provide an alternate path away from the center conductor for the EMP-induced current. The impulsive nature of EMP causes currents induced on the outer screen to couple energy into the center utility load-bearing conductor of the HVDC cable.[100] How much energy of the EMP wave is coupled into the center conductor is a complicated function of the EMP wave-shape and its angle of arrival, soil conductivity and burial depth, cable geometry and the length of the section of outer screen.[101,102] The interval placement of the grounding arrangements is dependent on the soil conductivity and the effectiveness of the EMP suppression that is desired. Since these grounds are only effective during an extraordinary EMP event, they would not need to be on the scale of those designed for continuous use in a unipolar ground-return type system. Ultimately, rolling blackouts due to cable malfunction or transformer explosions can be avoided or lessened if these steps are followed.

Similarly, some cross-linked polyethylene (XLPE) HVDC cables, such as those which will be utilized in this system, can also contain a tamper resistant outer shell, which can prevent accidental or malicious tampering incidents with little upkeep.[103] This thermoset resin can withstand abrasions as well as contact with extreme temperatures, moisture, and most chemical compounds without losing rigidity.[104] Since cables will be placed underground, this casing will provide a crucial first line of defense against tampering or naturally caused abrasions. This will be installed along with the cable itself for no additional cost.

2.7 Mitigation of Threats by Federal Oversight and Software Monitoring Systems

The North American Supergrid will require cooperation between federal, state, private, and likely local entities if it is to be effective. Regional counterparts would continue to monitor the various sections of the existing grid. However, a group within the Federal Energy Regulatory Commission (FERC) should play a role in overseeing the bulk monitoring of the NAS overlay. As illustrated by the Defense Science Board's 2017 paper concerning the Task Force on Cyber Deterrence, mitigation of cyber threats at the federal level is already occurring.[105] However, the Department of Homeland Security (DHS), Department of Energy (DOE), and utilities should increase their information sharing between one another so as to ensure an effective and unified response to any and all attacks on the NAS.[106] Moreover "…data definitions, databases, and communication protocols…" need to be standardized within the entirety of the grid system to prevent confusion.[107] Currently, the grid is too disconnected to effectively manage its many components. The North American Supergrid would allow for a coordinated cyber security partnership that would be resilient against manipulation attacks as well as other types of cyber threats.

On the most basic level, the cornerstone of effective cybersecurity is the proper conduct of the employees who directly interact with the system. Employees in charge of monitoring the electricity transmission process must be thoroughly vetted to ensure that they are not a security liability. This process should include thorough background checks for all employees, with strict punishments in place should an employee knowingly allow a hacker into the system. Leaders of regional teams should also be well-versed in cyber security threats and the measures currently in place to guard against said threats. Employees should also have specialized training with a focus on pertinent threats and be encouraged to think creatively. Finally, access to the physical control center of the transmission substations should be limited to one or few employees to decrease the likelihood of a security incident.[108]

The intelligence community (IC) should also play a vital role in the development of the North American Supergrid security mechanisms. It is imperative that the IC remains well connected with like-minded professionals and seeks help from cyber security experts and companies in monitoring threats to the grid.[109] Utility companies are ill-equipped to deal with cyber threats as they increase in seriousness because of differences in the utility ICS architecture across companies.[110] As such, utilities cannot be expected to handle the problem on their own.[111] The IC should help the DOE and DHS in standardizing data definitions, databases, and communication protocols so as to enable an effective response to evolving cyber threats.[112] Standards derived from the North American Electric Reliability Corporation's Critical Infrastructure Protection (or NERC CIP) plan should continue to be used, and continuously updated to remain in line with the newest security advancements. However, as underlined in the National Association of Regulatory Utility Commissioners (NARUC) report on cybersecurity issues concerning the grid, utilities must also continuously take part in "risk assessment" to effectively combat cybersecurity threats.[113] Moreover, there should be a sustained recruitment campaign to procure exceptional talent in the field of cyber security into the IC.[114] Furthermore, red team scenarios involving the creation of novel ways to attack the grid using hacking should be designed and undertaken on a regular basis (perhaps even more so than the GridEx exercise that is currently only held every two years). Cybersecurity experts should be used continuously as the members of the red team. This activity will ensure that the grid is up to date and prepared for attacks. However, regardless of preparations we cannot possibly account for every single vulnerability. The IC should remain diligent in keeping information concerning grid vulnerabilities confidential and limited to people immediately involved in its upkeep.

The North American Supergrid will also feature secure firewalls to protect against attacks within the network system infrastructure itself. Moreover, utility companies in each of the Regional Transmisson Organizations (RTOs) must have experts on hand to monitor the system at all times in order to make certain that the system is monitored for any of the above attacks against inter-connected systems like the DNP3 protocol system. Connections to outside sources should require that the other entities or individuals make use of a password to engage in the trade of information. Internet used for major SCADA networks and systems should be provided via wired connection only to avoid security issues associated with WIFI. Indeed, WIFI security issues are serious, especially if the network employs a simple password or none at all. Researchers at Kaspersky Labs and elsewhere have found that, without such safeguards, a hacker can disguise himself as the WIFI hotspot, giving access to all information that is being sent over the network.[115]

A secured gateway to the electrical system to protect the grid from malware should also be ensured to further aid the utilities in proper monitoring of the system. The gateway is the parameter through which messages are given to and received by the control room of the utility company.[116] If attackers were to exploit this flaw they would "…have the ability to directly manipulate all communications to and from the substation."[117] This would allow attackers to have direct control over any Transmission SCADA (T-SCADA)/Energy Management Systems (EMS) systems the substation is connected to at the time. This is a substantial vulnerability that must be removed,[118] since T-SCADA/EMS systems regulate energy transmission for utilization in substations and lines[119] and are in charge of preventing load overload and other electrical line problems.[120] To protect against this threat, the grid must be monitored 24/7 and staffed by alternating individuals to reduce the chance of any employee being susceptible to coercion or threats.

To be applied in conjunction with improvements to the SCADA and ICS system, a fault detection system should also be implemented. Faults, or electrical-flow failures that occur within the grid, may arise from a variety of causes throughout the system. The detection and clearance of faults is important for safe and optimal operation of any HVDC system. If a power line goes down or short circuits, the new grid system will be able to detect these faults before they can affect the macro system. This would reduce or eliminate the chance of a power outage by notifying a utility that a fault has occurred and, consequently, would allow for an affected substation to be isolated before it can affect the rest of the system. There are three main techniques for identifying and detecting potential system faults in so-called "hybrid" HVDC systems (in which AC distribution is linked with DC transmission). The fuzzy logic method is the strongest detection system of the three, as it is based on human reasoning. This means that the variables used in this case are words rather than numbers. The fuzzy logic method does not require an iteration process, and studies have proven that either AC and DC faults can be detected in a HVDC system. It is a rule-based approach where a set of rules represent decision making, making it the most comprehensive fault detection choice for the NAS. The model used in this report[121] considers two AC voltage sources with the same specifications are interconnected by a HVDC cable. Following this structure, different faults can be produced in the two AC sides of the HVDC system, and in the DC link itself. When analyzing only one side, five faults can be considered. However, for mathematical purposes, the normal operation of the HVDC system is considered a sixth fault.

This survey of the different faults that can occur in the HVDC systems makes clear that multiple lines of the same configuration can be affected by the same type of fault. It is accordingly necessary to implement a detection system which considers this and other issues. In total, ten faults in the AC left side of the system can be found, and another ten in the AC right side. Along with the DC fault, the whole HVDC system presents 21 types of faults.[122] Unlike the analysis performed for 6 electrical faults, a twenty-one-fault detection system will require data from both AC sides of the HVDC system, since a fault can occur at any point. The healthy condition for the system occurs when all the output values are null. All the outputs will be zero except for the DC output in the case of a DC fault. By implementing a detection system that will not produce a rigid binary output, a wider net can be cast to detect and eliminate more types of faults that may be present in the NAS's hybrid electric system. Regardless of where a fault originates, having the tools to quarantine problem areas will contribute to both reliability and resilience.

2.8 Conclusion

The North American Supergrid presents a new and innovative way of securing our nation's future. While ambitious, the security updates contained in this report are not without precedent. Federal Agencies such as the DOE and DHS have already conducted substantial amounts of research on the updates being proposed, and Congress has also shown great interest in updating the grid to withstand threats from outside hostile actors. Additionally, the Trump Administration has stated its intent to overhaul electrical infrastructure, and the North American Supergrid Initiative offers an affordable and effective proposal for doing so.

The innovations suggested in this report allow the U.S. to lower electrical costs, increase penetration of multiple types of electrical sources (including renewable electric sources), and strengthen national security. In this way, the North American Supergrid will help the U.S. elevate itself as the leader and torchbearer for grid security.

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3 Economic advantages and financial feasability

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Summary

The purpose of this chapter is twofold: to get more detailed accounts of the benefits of the NAS and to analyze financing mechanisms for construction.

We project numerous economic benefits to building the Supergrid:

- Since the data for the MacDonald publication was gathered in 2009, the price of energy generation, particularly from solar and wind (onshore and offshore), has dramatically decreased, making the NAS even more advantageous than previously projected.
- We project the price of the infrastructure to be under $500 billion. Yet, the savings in electricity generation (the cost of generating electricity from wind and solar sources is much less than traditional sources) offset the cost of building the supergrid under most reasonable scenarios of the price of undergrounding transmission lines and the price of natural gas. Therefore, the total annualized cost of generating and transmitting electricity would be likely be lower because of the NAS.
- We estimated that between 650,000 to 950,000 constant jobs would be needed for construction of the transmission and generation capacity over a 30-year build time.

We analyzed financing options and make conjectures as to how the Supergrid would be financed in each region of the country accounting for projected cost and precedent of how other transmission projects were financed in each region.

We do not recommend new taxes or government sponsored financing programs to build the Supergrid.

Private financing would fund most of the lines in a majority of regions. We also encourage participation from energy developers that stand to benefit from the Supergrid. Further, the Rural Utilities Services could make loan capital available to developers for the less lucrative lines that may be less attractive to private financiers.
In addition, these financing mechanisms could be used:

- Public-Private Partnerships.
- DOE loan guarantee programs.
- State clean energy funds.
- Private activity bonds.
- Federal infrastructure spending.

To make the NAS more attractive to investors, policymakers must make progress in several areas of development:

- Secure backing of federal/state governments, DOE, RTO/ISOs.
- Reduce permitting and regulation burden.
- Ensure stakeholder interests are aligned in each region.
- Encourage regional and national collaboration.
- Engage in thorough planning.

3.1 Economic Research, Methods, and Results

The primary objectives of this analysis were to explore in more detail the economic benefits of the proposed national overlay HVDC electric grid, and to develop a framework that could be used to update and repeat economic benefit calculations as new cost projections associated with energy generation and transmission technologies become available. This analysis provides a methodology to compute total project cost and create an updated line construction cost estimate. We used the publicly accessible Jobs and Economic Development Impact (JEDI) models provided by the National Renewable Energy Laboratory (NREL) to estimate the NAS's effect on job creation and regional economies at the national and state levels. Further, we used the results to conduct more detailed analysis with higher resolution data to estimate the economic impact of the NAS at state levels. The model includes a database of cost assumptions for varying types of transmission lines and power plants.

3.1.1 Cost Structure and Calculation

Due to major changes (unanticipated steep downward trend in costs of wind and solar energy generation over the last several years), it became necessary to update the input cost assumptions of the NAS compared to those used in the MacDonald et al. study. The total capital cost for the transmission system was estimated by summing the Overnight Capital Cost (ONCC), new HVDC transmission cost, and variable natural gas costs. The renewable generation ONCC figures from 2013 MacDonald et al. figures were compared to 2016 Lazard Levelized Costs of Electricity figures (referred to as LCOE or Lazard figures).[1] The more recent study showed a dramatic decrease in ONCC for building the various renewable generation capacities. Such current LCOE are very close to the most optimistic MacDonald et al. estimates of future costs (projected for 2030, shown in Table 1), leading to an even more favorable forecast for the HVDC supergrid system.

Updated vs old generation costs /kWh		
	MacDonald et al. 2009	Updated Lazard 2016
Solar PV commercial		
Low	$1.19	$1.30
Mid	$2.57	$1.38
High	$3.94	$1.45
Onshore wind		
Low	$2.16	$1.65
Mid	$2.26	$1.68
High	$2.36	$1.70
Offshore wind		
Low	$3.41	$2.75
Mid	$5.53	$3.63
High	$7.64	$4.50
Natural gas		
Low	$1.24	$0.65
Mid	$1.24	$0.88
High	$1.24	$1.10

Table 3.1 | Updated vs forecasted renewable generation costs

	MacDonald et al. study costs	JEDI model costs
Station ($/MW)	188,389.34	$250,160.38
Lines ($/MW-Mile)	722.58	$529.52

Table 3.2 | Line and station cost comparison

Next, total transmission system cost was estimated. Transmission cost is a function of Line Cost ($/MW-mile) and Station Cost ($/MW). A line and station cost comparison of MacDonald et al. figures against JEDI Model figures is shown below in Table 2. While the figures for both categories were comparable, the MacDonald et al. paper used data that indicated lower station costs and higher line costs. Due to unforeseen favorable generating costs, these differences were mitigated, rendering the results very comparable.

We then combined the MacDonald et al. system design with the results from the JEDI Model (i.e. front-end stations cost) and the updated cost figures to arrive at a final comparison for the cost of the NAS system (both above and below ground) versus the system cost of the current AC grid. In the first two scenarios, a simulation of a single integrated system that could send electricity across the lower 48 states was used, as prescribed by the NAS. In the last scenario, the lower 48 states were split into district regions where energy generated in those boundaries must be used within the same boundaries (shown in Table 3). The single system was much more efficient since the scenario with the divisions requires natural gas to fill in the gaps that wind and energy cannot supply. Some regions, in the system divided in distinct regions, overproduced renewable energy while others underproduce renewable energy.

Simulations of the cost of generation sources with and without the NAS were completed, where the new system favored only the least expensive forms of electricity generation amongst offshore wind, onshore wind, solar PV, and natural gas. Coal and oil were omitted since they are more

	Annualized HVDC transmission grid cost	Annualized total system cost
Single national system (overhead lines) using JEDI line & station costs and Lazard generation costs	$12,655,601,55	$224,259,771,183
Single national system (buried lines) using JEDI line & station costs (using three times multiplier and Lazard generation costs)	$23,357,370,796	$234,961,540,424
128 Node system using Lazard Generation costs without a national grid	$0	$267,124,313,548

Table 3.3 | Comparison of the NAS to current AC system cost

expensive electricity generators in either scenario.[2] Our results showed that the onshore wind generation capacity, which has gone down in price recently, will drive changes in nameplate capacity more than anything else under the NAS scenario. Costs would favor solar PV generation and natural gas generation much less, while offshore wind energy generation would remain stable.

While both overhead and underground line configurations come at a cost advantage under most natural gas price scenarios, the advantage diminishes as the cost of natural gas lowers since natural gas generation facilities can be built anywhere and would require less transmission cost since they would be located closer to load centers. The breakeven point, where the advantage goes away for the underground HVDC scenario, is $4.43/MMBtu. The breakeven point for overhead lines is $2.50/MMBtu. This is assuming that the "multiplier" for the increased cost of underground lines (assuming siting and capacity are equal to that of an above ground line in the same configuration) is three times that of overhead lines. Breakeven points for other multipliers are shown in Table 4 below.

3.1.2 Natural Gas Impact

Since the usage of underground lines is not common enough to determine a commonly accepted multiplier, we performed a sensitivity analysis to find out how the breakeven point moves depending on both natural gas prices and the aforementioned multiplier. The results show that the breakeven comes at a higher price of natural gas as the multiplier increases. As mentioned before, the most likely scenario for the multiplier is approximately three, at which point the breakeven is $4.43/MMBtu. When the multiplier is two, the breakeven point of natural gas is well below $4.00/MMBtu. At a multiplier of four, the breakeven point is closer to $6.00/MMBtu. Long-term projections of the cost of natural gas are variable as many influences affect both the demand and supply of fuel costs. Expert analysts, however, predict that the cost of natural gas will be well over the 4.00/MMBtu threshold, meaning that at a three times multiplier, the NAS is projected to be economically viable in the long-term at the aggregate level.[3]

	High cost gas ($11.44/MMBtu)	Mid cost gas ($7.00/MMBtu)	Low cost gas ($2.50/MMBtu)
Annualized total system cost for 128 node system (Lazard)	$267,124,313,548	$223,492,775,758	$179,230,610,307
Annualized total system cost of national system (JEDI model, overhead lines)	$224,259,771,183	$200,985,337,226	$177,374,505,650
Difference between 128 node system and national system	$42,864,542,366	$22,507,438,532	$1,856,103,657
Capital cost already included in national system to build grid	$12,665,601,555	$12,655,601,555	$12,655,601,555
Breakeven for annualized total grid cost	$55,520,143,921	$35,163,040,087	$188,463,704,056
Breakeven for total grid cost	$721,040,830,138	$456,662,858,272	$188,463,704,056
Breakeven for overhead lines to buried lines multiplier	9.01	5.21	1.35

Table 3.4 | Breakeven points for system economic feasability based on natural gas prices and underground system multipliers

3.1.3 Job Creation Estimation

Job creation values were estimated with data obtained from the NREL's JEDI Model for transmission and generation. While these models are highly regarded, they do have limitations that should be noted before data interpretation:

- Does not project future and different values of LCOE, does not consider alternative investment avenues
- Transmission specific limitations and comments
- Must independently obtain transmission recovery rates that are crucial for Return on Investment (ROI) and Net Present Value (NPV) calculations
- Inter-state lines must be broken up into separate model runs and then recombined
- Lines transiting through rural/urban/etc. areas also require separate model runs
- Only one HVDC option: 500kV with overhead lines
- No capacity input, assumes 3GW
- Outputs from model runs using New Mexico as the state had anomalies

Table 5 shows the total projected costs of building the NAS. After consulting with multiple industry experts, a three times multiplier was agreed upon to estimate the costs of transmission lines per mile. JEDI figures were also used to determine the cost of converters and substations per mile with the estimation of total mileage of transmission cables needed to construct the NAS. No consideration was given to price impacts of technology adoption.

Jobs created from installing transmission infrastructure are listed above, but only contribute a small amount of jobs compared to the jobs needed for the energy generation. Using the results from the NEWS model, developed by MacDonald et al. in the foundational paper, combined with the JEDI model, we calculated the job generation due to renewable energy infrastructure development (from transmission and generation) for each of the lower 48 states. After we combine the jobs estimates of all states with the jobs from installing the thousands of transmission facilities, we estimate that the NAS would produce the equivalent of 649,010 to 936,111 total constant jobs per year over 30 years.

Anualized total system costs						
Station cost = $250,160.38						
Line Cost ($/MW Mile)	$529.52	$1,059.05	$1,588.57	$2,118.10	$2,647.62	
Multiplier	1x	2x	3x	4x	5x	
Fuel Cost ($/MMBtu)						Annualized cost of system without grid
$2.00	$(438,489,106.59)	$(5,789,373,727.04)	$(11,140,258,347.50)	$(16,491,142,967.95)	$(21,842,027,588.40)	$174,312,591,923.39
$4.00	$8,739,881,948.79	$3,388,997,328.34	$(1,961,887,292.12)	$(7,312,771,912.57)	$(12,663,656,533.02)	$193,984,665,457.35
$6.00	$17,918,253,004.17	$12,567,368,383.72	$7,216,483,763.26	$1,865,599,142.81	$(3,485,285,477.64)	$213,656,738,991.30
$8.00	$27,096,624,059.55	$21,745,739,439.10	$16,394,854,818.64	$11,043,970,198.19	$5,693,085,577.74	$233,328,812,525.26
$10.00	$36,274,995,114.93	$30,924,110,424.48	$25,573,255,874.02	$20,222,341,253.57	$14,871,456,633.12	$253,000,886,059.21
Figures in parentheses denote negative values						

Anualized total system costs						
Station cost = $250,160.38						
Line Cost ($/MW Mile)	$529.52	$1,059.05	$1,588.57	$2,118.10	$2,647.62	
Multiplier	1x	2x	3x	4x	5x	
Fuel Cost ($/MMBtu)						Annualized cost of system without grid
$2.00	-0.3%	-3.3%	-6.4%	-9.5%	-12.5%	$174,312,591,923.39
$4.00	4.5%	1.7%	.1.0%	-3.8%	-6.5%	$193,984,665,457.35
$6.00	8.4%	5.9%	3.4%	0.9%	-1.6%	$213,656,738,991.30
$8.00	11.6%	9.3%	7.0%	4.7%	2.4%	$233,328,812,525.26
$10.00	14.3%	12.2%	10.1%	8.0%	5.9%	$253,000,886,059.21

Table 3.5 | Sensitivity analysis to cost of natural gas and multiplier effect for undergrounding

Jobs & economic impacts during new construction							
	Total project cost	Transmission lines	Transmission line cost/ Megawatt mile	Converter hall & sub-station	Hall/substa-tion cost/ Megawatt mile	Jobs	Economic impacts
Overhead lines	$169.8 B	$70 B	526.57	$95.5 B	248,765	231,503	$25.4 B
Buried lines	$309.7 B	$209.9 B	1579.71				

Table 3.6 | CAPEX & jobs & economic impacts during new construction

3.2 Potential Financing Methods

3.2.1 Private Financing

The majority of energy infrastructure projects are developed by private companies that secure financing from financial institutions, institutional investors, and the capital markets. Privately financed transmission projects typically have both a debt and equity component. Projects can be structured to have either corporate financing or project financing. Corporate financing uses existing funds from a company's operating budget to fund a project which could use revenue from existing assets or funds from a corporate bond issue. In corporate financing, the lenders and investors have recourse to the entire corporation, not just the specific asset. Project financing involves the creation of a special purpose vehicle (SPV) whose only assets and debt are related to the specific project. In project financing, the lenders or investors only have recourse to the assets of the project.[4] Much of the NAS construction would likely involve project financing because it is conducive to multiple entities collaborating on a development.

Investment by private investors has been increasing as governments struggle to keep up with the demand for new infrastructure projects, including transmission projects. The International Energy Agency (IEA) projects $260 billion invested globally in new transmission and distribution lines through 2035.[5] There is private capital available in the market ready to invest in quality infrastructure projects. In the first half of 2016, it was estimated there was $75 billion of capital waiting to be invested in infrastructure.[6] The capital comes from insurance companies, pension funds, private equity, infrastructure funds, and sovereign wealth funds.

There are multiple reasons why investing in transmission lines can be attractive to investors. Cost recovery for transmission projects is regulated by the Federal Energy Regulatory Commission (FERC) creating an almost certain guaranteed rate of return. Cash flows from the project are typically stable and independent of energy prices or line utilization. Established transmission lines utilize proven technology and require minimal ongoing maintenance. Additionally, transmission investment is often resistant to competing investment along the same corridors. A competing investment would have difficulty obtaining financing unless there was significant load growth driving increased demand. These characteristics allow investors to accurately predict investment performance and help make transmission investment more attractive than other types of infrastructure.[7]

3.2.1.a Debt Financing

Debt typically comprises 70-90% of infrastructure project financing. The primary forms of debt financing are through commercial banks, institutional private placements, and the corporate bond market. Traditional bank financing has long been a key component of infrastructure financing. Bank loans typically have lower interest rates than other types of debt financing. However, due to regulatory changes following the 2008 recession, banks are now required to secure long-term bonds to back longer-term loans and therefore banks prefer shorter loans (typically 7 years or less) due to the lower cost.[8] This can create refinancing risk for borrowers. Bank financing is most likely to be used in the early stages of planning and construction. After completion, bank loans are refinanced by a long-term security which has lower cost as much of the construction, permitting risk, etc. has been removed. Banks tend to be more flexible in the event of unforeseen events during construction and can negotiate loan restructuring or adjust the timeframe of disbursements.

Institutional private placements are another form of debt financing that can be arranged by an investment bank. Capital would be secured from select institutional clients through a negotiation process led by a bank acting in an agency capacity. The disclosure and paperwork required is similar to issuing a public bond, but there can be more room for flexibility when creating the contract. Insurance companies, pension funds, and sovereign wealth funds are types of investors that could participate in a private placement due to their need for long-term investments.

A third form of debt financing for transmission developers is the corporate bond market. Private companies can issue bonds to support general operations or specific projects and that money can be allocated to pay for development costs. Bonds are typically more common in the later operational stages of a project when the asset is producing a steady cash flow. Bonds can be a mechanism used when refinancing bank loans at the conclusion of the construction phase.

With all types of debt financing, the credit rating of the borrower is important to secure lower cost financing. Pension funds and insurance companies often have guidelines dictating the required credit quality of their investments. Transmission developers constructing the NAS will likely rely on multiple types of debt financing. Construction of many segments of the NAS will likely be financed by traditional bank loans. Once construction is completed, corporate bonds or private placements could be used to refinance the debt. This structure would align the risks and cash flows of the project with investor expectations for each type of debt. The types of debt ultimately used for each segment will be dependent on the developer that wins the contract and their preferred financing mechanisms.

3.2.1.b Equity Financing

Debt holders usually require an infrastructure project to have an equity component to reduce risk and help protect debt holders from loss. Equity typically only comprises 10-30% of infrastructure financing. Equity holders take on the most risk in the project and therefore demand a higher return. Enlisting quality equity holders is often key to being able to secure debt financing at the lowest cost. Transmission developers often provide a portion of the equity in projects they construct. Aside from having a stake in the project, developers benefit from the tax savings of the depreciation generated. Additionally, private equity funds, insurance companies, infrastructure funds, and sovereign wealth funds can also be a source of equity.[9]

In the current low interest rate environment, long-term investors such as insurance companies and pension funds are eager to invest in infrastructure projects that offer a higher return than traditional investments. However, currently only 0.8% of the approximately $50 trillion in investable assets from insurance companies and pension funds are invested in infrastructure.[10] The lack of quality projects is the primary reason investment is not higher. Similarly, private equity funds are currently raising $30.5 billion for 43 new funds to invest in quality North American infrastructure projects in addition to the $68 billion in funds they hold, but have not yet invested.[11] This is evidence that there are willing investors looking for superior projects like the NAS to invest in. The key for the NAS will be securing the backing of stakeholders and making the project attractive to new investors.

3.2.2 Public-Private Partnerships

A new financing model has developed over the past two decades that could be used for some segments of the NAS. The Public-Private Partnership (PPP) model can take on many forms, but it involves the collaboration of government and private parties. The PPP model is particularly useful for projects where there is not sufficient private capital financing because it can use government investment to leverage additional private capital. It has become a popular model to finance transmission projects in emerging markets and is beginning to be used more in the United States. The main benefit to the PPP model is spreading risks associated with a large infrastructure project. It is important to structure the deal so that no one party takes on exorbitant amounts of risk. Spreading risk can attract investors that might not otherwise participate in a project. Private firms can provide project expertise and are often able to push projects along faster than the government. The PPP model works best when there is a stream of revenue to ensure an adequate return to investors.[12] FERC regulations allow each Regional Transmission Organization (RTO) and Independent System Operator (ISO) to use an allocation process to dictate how costs are recovered from ratepayers for transmission developments creating a steady revenue stream once the project is complete.

There are some challenges in implementing the PPP model for transmission projects. As of January 2017, only 37 states have legislation that allow public-private partnerships.[13] This could prevent using this model for some segments that cross multiple states if not all states allow public-private partnerships. The high regulatory burden of developing transmission projects can slow the process and discourage private investors from joining into a partnership. Projects financed with this model often work best if they have a political champion (governor, senator, etc.) helping to build support for the project. They can also help the project navigate the various federal and state agencies during the permitting process.

Historically, the PPP model has been used in the United States for transportation infrastructure projects. But there are some examples of transmission projects using a PPP financing model. The Path 15 project used a public-private partnership structure to finance and build an 83-mile transmission line connecting northern and southern California, helping to eliminate a bottleneck in the grid system. The Western Area Power Administration built and operates the line. The private company Trans-Elect assembled a majority of the project financing. In return, they were granted long-term transmission rights that will help them pay off banks and investors. As a high priority project in California, federal and state agencies expedited environmental studies and the project permitting process.[14] This was one of the first successful PPP projects for a transmission line and it shows the cooperation involved between governments and public and private companies.

The PPP model will be used for segments of the NAS that are less lucrative and do not have as much private financing available. As with all segments of the grid, collaboration and support from federal and local governments will be important to successfully structuring PPP deals that are beneficial to all parties. This financing model will be a vital mechanism to construct the less lucrative segments allowing the entire national grid to be completed.

Private financing will likely be the primary source of funds for constructing the NAS. It will be crucial to partner with transmission developers that have a wealth of experience in securing financing and successfully completing projects. The high cost of the NAS will necessitate using a variety of debt and equity financing mechanisms for each segment of the national grid.

3.2.3 Federal Infrastructure Spending

Traditionally transmission projects have been privately financed with little assistance from the federal government. However, infrastructure spending has come to the forefront of the national discussion so it is worth examining how a potential infrastructure spending bill at the federal level may impact the NAS. As of July 2017, no infrastructure bill has been proposed in either house of Congress, and it is likely they will focus on other issues before infrastructure. However, the presidential administration has released a framework for what their proposed policy might look like. Their policy would reduce regulations and the time needed to receive federal permits. They also propose using government investment to leverage private sector investment. This could indicate public-private partnerships will be much more common in the future. The policy also hopes to focus federal infrastructure investment on transformative projects that change the way infrastructure is designed, built, and maintained.[15]

Many of the proposals from the presidential administration could benefit the NAS. Fewer regulations and a shorter permitting time would help expedite the project and help attract private investment. The NAS could qualify as a transformative project since it is different from the structure of the current electrical grid and promises to have both environmental and national security benefits. Lower direct federal investment in infrastructure likely means the NAS would have trouble securing federal money for construction. Nonetheless, a PPP model used for some segments of the grid could receive federal money to leverage private investment.

The uncertainty regarding federal government support for infrastructure development will make private financing a crucial component of funding the NAS. However, there are some government programs available to supplement private financing for the less lucrative grid segments.

3.2.4 Department of Energy Loan Guarantee Program

The U.S. Department of Energy (DOE) issues loan guarantees to promote growth of new clean energy technology through the Loan Program Office (LPO). Title XVII of the Energy Policy Act of 2005 authorized the loan guarantees. The program applies to a wide range of technologies, including renewable energy and transmission projects. As of June 2017, there is up to $4.5 billion in funding available for projects in renewable and efficient energy. The NAS project appears to meet many of the criteria for acceptance into this program. Projects "that will have a catalytic effect on the commercial deployment of future Renewable Energy Projects" will be looked at favorably in the review process.[16] The NAS is likely to promote additional investment in wind and solar generation because more electricity will be able to be transported over long distances to population centers. The program specifies that for transmission projects to be considered efficient, they must lower electricity losses when compared to current commercial processes in the U.S. over an equivalent distance. The HVDC technology used in the NAS would limit losses of electricity through transmission, making the technology more efficient for long distance transmission.

However, there are factors that could limit the eligibility for the loan program for certain parts of the national grid. Projects that could be fully financed by commercial banks are viewed unfavorably in the review process. Projects that receive any other assistance from the federal government (grants, loans) may not be eligible. The loan guarantee program is designed to help new technologies prove their financial worthiness so that future investment can be financed by the capital markets. This program will most likely be useful for sections of the NAS that are projected to be less profitable and therefore need government assistance to secure financing. A section of the grid constructed early in the process may also have a better chance of acceptance into the program. Financial, technical, legal, and environmental factors are reviewed in the approval process along with a review of how well the project fits the policy of the program. The DOE is accepting applications through at least September 2019, although additional submission dates may be announced in the future.

The One Nevada Line is an example of the loan program being used for a transmission project. The project received a $343 million loan guarantee to finance a 235-mile 500 kV line through Nevada. The use of a new transmission tower design that has a smaller environmental impact was the technological innovation in this project. The new line is also expected to bring wind and solar generated power from Wyoming and Idaho into Nevada.[17] The NAS project has many of the same benefits as the One Nevada Line. This gives confidence to the idea that the loan guarantee program would be a possible financing mechanism for the NAS.

3.2.5 Additional Funding Sources

3.2.5.a State Clean Energy Funds

More than 20 states have created Clean Energy Funds using state government funds as a way to promote growth in renewable energy.[18] While each state's fund has their own design, these funds often are used to attract private investment to renewable energy projects. These funds have primarily been used to provide funding for individual renewable generation projects, but there may be potential to access state funding for the NAS because an improved transmission grid will drive private investment in renewable generation. These funds would likely not provide direct investment to build the NAS but would instead help attract and guarantee financing for private capital investors. This would involve collaboration between private investors, utility companies, and state government agencies.

3.2.5.b Rural Utilities Service

The Rural Utilities Service is a program under the U.S. Department of Agriculture that provides needed infrastructure development and improvement to rural communities. The program provides direct loans, loan guarantees, and grants to electric projects in transmission, distribution, and generation. The loans are primarily made to state and local government entities and cooperative utilities, although for-profit companies are also eligible.[19] The program made $3.4 billion in loans and loan guarantees in 2015 and the amounts are expected to continue increasing. Most loans are between $20 million and $200 million. General guidelines indicate projects should benefit populations of 20,000 or fewer, although there is some flexibility.[20]

Segments of the NAS through rural areas or segments that would improve service to rural areas are likely to be eligible for financing through this program. While this program is not likely to be a large piece of grid financing, it could help secure funding for less lucrative segments in rural areas. This program can be used in partnership with other financing to help attract private investment. It would also provide a source of public investment in a public-private partnership.

3.2.5.c Private Activity Bonds

A potential source of financing for private companies investing in transmission infrastructure are Private Activity Bonds (PABs). These bonds are federally tax exempt and therefore allow borrowing at a lower interest rate. They do require a private company to partner with a government agency that acts as the issuer of the bond. However, the private company pays the debt service on the bond under a contractual agreement. Section 142 of the IRS tax code allows PABs for surface transportation projects.[21] They have not been used for transmission projects in the past and it would take new legislation to allow PABs for electric developments. Allowing these types of bonds to be used for the NAS would incentivize private companies to invest in the project because borrowing would be cheaper for transmission projects using PABs than investing in other types of infrastructure.

3.3 Regional Overview

Historically, the energy sector in the United States had been dominated by vertically integrated organizations that owned and operated the generation, transmission, and distribution services within a geographic area. Beginning in 1978, deregulation allowed some utilities to create power pools to facilitate wholesale transactions over larger geographic areas. By the 1990's there was a need to have open access to transmission services for all utility companies to create competition among generators. FERC issued orders to encourage the creation of regional organizations that would control the transmission of energy and allow open access to transmission lines.

Today there are six RTO or ISO regulated by FERC: ISO New England, New York ISO, PJM, Midcontinent ISO, Southwest Power Pool, and California ISO. The Electric Reliability Council of Texas is regulated by state regulators because it is located entirely in the state of Texas. Much of the southeastern and western United States are not currently covered by ISOs. In analyzing the financing options for the NAS, we look at a financing strategy for each ISO region. We will also look at the Southeast U.S. and Western U.S. as separate regions despite not having an organized ISO.

One of the primary responsibilities of each RTO is managing the transmission planning process to ensure the grid continues to meet expected future electrical demand. We reviewed the planning process in each region because the NAS will first need to secure the support of RTOs through

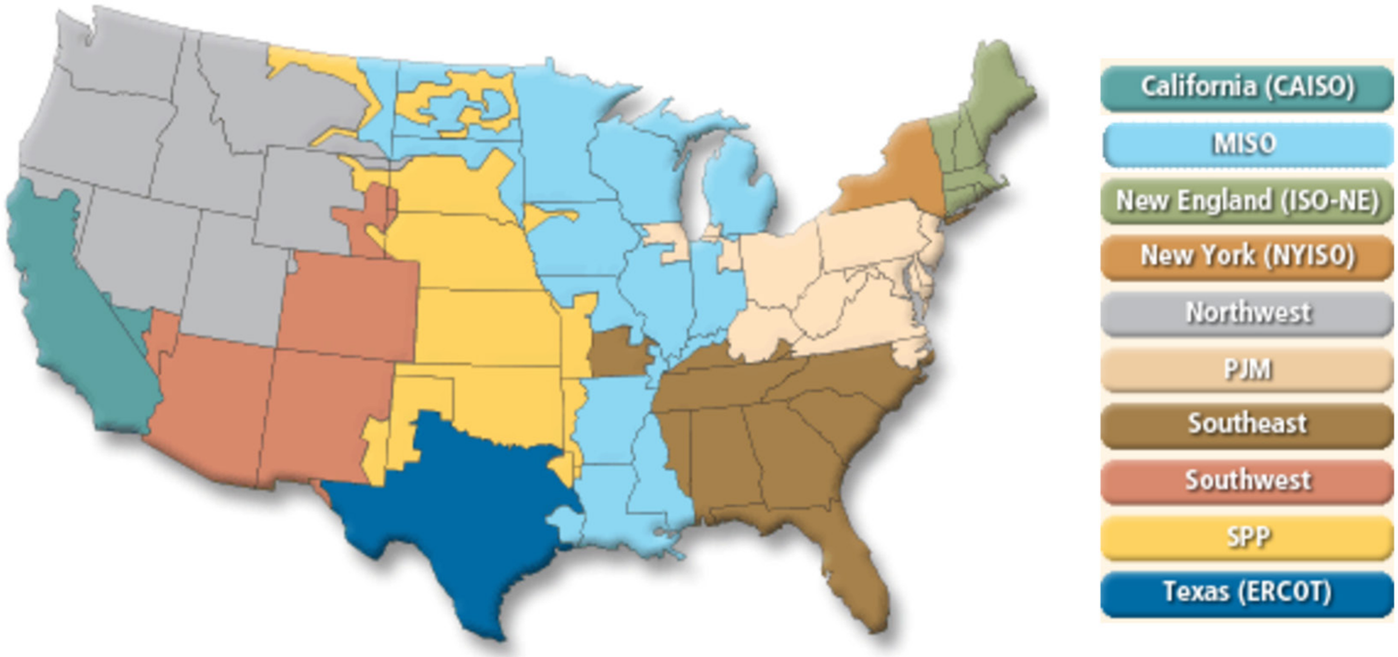

Fig 3.1 | National electric markets. Source: Federal Energy Regulatory Commission[22]

each individual planning process. We also look at recent regional transmission projects. We review the financing an- project details for recent developments to help guide our recommendations for possible financing strategies in each region.

3.3.1 ISO New England

Geographic Region:	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Transmission Miles:	9,000
Generating Capacity:	3,0500 MW
Proposed NAS Miles:	1,167
Proposed NAS Cost:	$7,927,385,532

3.3.1.a Transmission Planning and Approval Process

The transmission planning process for ISO New England develops a regional plan for future system needs over a ten-year time horizon. The process begins by conducting a Needs Assessment to determine the grid's adequacy. Where it is determined upgrades to the grid are necessary, either a Solutions Study or a Competitive Solution process will be undertaken to find the most economical upgrade project. A Competitive Solution process will be the most likely entry point for the NAS. In this process, project sponsors submit proposals for projects to address the identified need. Projects are then selected based on the cost, electrical performance, feasibility, and future system expandability.[23]

3.3.1.b Recommended Financing Mechanism

The proposed routing through the New England region is the smallest segment of the NAS with an estimated cost of approximately $7.9 billion. The grid in this section will likely be privately financed. Every state in this region does have a Clean Energy Fund indicating there is government support for renewable energy projects. The Clean Energy Funds also open up the possibility of using state financing to help attract private investors. This funding could be used to leverage private investment through a public-private partnership. Vermont is the only state in the region that does not currently allow the PPP model.

3.3.2 New York ISO (NYISO)

Geographic Region:	New York
Transmission Miles:	11,124
Generating Capacity:	38,576 MW
Proposed NAS Miles:	1,267
Proposed NAS Cost:	$8,607,906,983

3.3.2.a Transmission Planning and Approval Process

NYISO engages in planning for reliability, economic, and public policy upgrades to the transmission grid. The reliability plan is a two-year process that assesses the needs over the next ten years. The economic planning process identifies areas of congestion in the grid and determines specific projects that have a positive benefit to cost ratio. The public policy planning identifies needs driven by new public policy requirements and solicits solutions from member firms.[24]

Upgrading transmission infrastructure could be part of either the economic or public policy planning process and could solve congestion problems within the state's grid identified in the economic planning studies. It could also help the state meet renewable energy goals and would be an appropriate public policy solution. Exceeding the benefit to cost expectations will be the greatest hurdle for the NAS to gain approval in New York.

3.3.2.b Current and Proposed Projects

A proposed 80-mile HVDC transmission line buried under the Hudson River provides insight into a financing model that could work for portions of the NAS. The $1 billion West Point Transmission project is very similar in structure to the NAS. The project was proposed as part of the state's Energy Highway Blueprint in 2012 and is still in the development phase securing permitting. It is similar to two other completed projects by PowerBridge, Neptune and Hudson. The proposed financing plan includes equity financers Energy Investors Funds, Starwood Energy Group, and NRG Energy. Debt financing would also be secured from either commercial banks or institutional private placements. The developer would enter into a long-term transmission capacity purchase agreement to recover the costs of construction.[25]

3.3.2.c Recommended Financing Mechanism

The NYISO has a history of supporting high voltage transmission projects similar to the NAS and there are development companies that have experience securing the private financing required. The estimated cost of the NAS in the NYISO is $8.6 billion. This cost is reasonable when compared to the $1 billion for the 80-mile West Point Transmission project. A national grid would help upstate New York connect with the large population center in New York City. This connection would allow renewable hydro electricity generated in the northern part of the state to benefit all rate payers in the region. The Energy Highway Blueprint approved in 2012 also shows there is support for transmission projects from the state government. The state's regulatory bodies have approved similar projects in the past and should be receptive to new proposals as part of a national system. Due to the large population base and government support, it is likely that the NAS will be lucrative to private investment.

3.3.3 PJM Interconnection

Geographic Region:	Delaware, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, Virginia, Washington D.C., West Virginia
Transmission Miles:	82,540
Generating Capacity:	176,560 MW
Proposed NAS Miles:	5,265
Proposed NAS Cost:	$35,755,649,493

3.3.3.a Transmission Planning and Approval Process

PJM conducts an annual planning process resulting in the Regional Transmission Expansion Plan (RTEP). A 15-year time horizon allows the planning to look at how reliability upgrades and expansion will impact the grid in the future. The planning process includes input from all stakeholders as well as changes in public policy. The PJM board ultimately approves recommended system improvements and they are added to the RTEP. Since 1999, the board has approved $29.3 billion of transmission system improvements.[26]

3.3.3.b Current and Proposed Projects

A 150-mile 500 kV transmission line upgrade between Pennsylvania and New Jersey was completed in 2015. The $1.4 billion project was a joint venture between two public utility companies, PPL Electric Utilities and PSEG. PPL Electric built 101 miles of the line for $630 million and PSEG built 45 miles for $775 million. The project was intended to improve reliability and reduce congestion. This project was fast-tracked by the Obama administration allowing better coordination of government permitting. However, there was pushback from environmental groups because the line passed through federal park lands. State regulators approved the project in 2010, but the National Park Service did not approve the project until 2012.[27] Despite having backing from the presidential administration, the environmental concerns still caused a delay in permitting. The Susquehanna-Roseland project is an example of two public companies collaborating to complete a needed high voltage transmission expansion. Government support allowed the project to proceed more quickly and successfully satisfy all stakeholders, which illustrates the importance of gaining support from all public and private stakeholders.

3.3.3.c Recommended Financing Mechanism

The NAS in the PJM region is likely to be privately financed. This segment of the grid goes through highly populated regions, and will therefore be lucrative to private investors. The estimated cost of the NAS in this region is approximately $35.7 billion. Each state in this region also has legislation allowing public-private partnerships. The Susquehanna-Roseland Reliability Upgrade shows how two companies can collaborate to complete a large scale project. Encouraging partnerships between public and private parties is a strategy that should be successful in this region.

3.3.4 Midcontinent ISO (MISO)

Geographic Region:	Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Montana, North Dakota, South Dakota, Texas, Wisconsin
Transmission Miles:[28]	65,800
Generating Capacity:	174,724 MW
Proposed NAS Miles:	8,276
Proposed NAS Cost:	$56,204,593,784

3.3.4.a Transmission Planning and Approval Process

The MISO develops the MISO Transmission Expansion Plan (MTEP) annually. The plan addresses reliability of the grid as well as ensuring compliance with state and federal energy policy requirements. The planning process begins with stakeholders submitting proposed projects for review. MISO's Board of Directors facilitates the evaluation of projects to determine if they are appropriate for inclusion in the MTEP. The 18-month planning process includes model building, reliability and economic analysis, and resource assessments. There are three types of projects included in the MTEP: Bottom-Up projects, Top-Down projects, and Externally Driven projects. The NAS would likely be considered an interregional Top-Down project because it would have a regional and national impact. These projects have costs shared among beneficiaries.[29]

3.3.4.b Current and Proposed Projects

The CapX2020 is a series of five transmission expansion projects across North Dakota, South Dakota, Minnesota, and Wisconsin. The development of 345 kV and 230 kV lines spans 725 miles and will cost $2.1 billion. It is a joint initiative between 11 transmission-owning utilities in the states.[30] The project was designed to bring wind energy to population centers. Lack of transmission capability has been a roadblock to additional development of wind generation facilities in South Dakota and North Dakota. This project will not satisfy all the transmission needs of the region and more development will be necessary to reach the full potential of wind generation development.[31] This expansion illustrates the need for a robust transmission grid to ensure the growth of renewable energy generation, a problem the NAS will help solve.

3.3.4.c Recommended Financing Mechanism

The CapX2020 development shows that companies in this region are willing to collaborate to build a transmission network to benefit the entire region. Most of the financing for that project and for the NAS will come from companies securing private financing. The estimate cost for the NAS in the Midcontinent ISO is $56.2 billion. This is one of the largest section of the NAS with over 8,000 miles of proposed transmission lines. There is potential in this region for collaborations between transmission developers and renewable energy developers. A lack of transmission capacity has delayed some wind energy projects, while transmission developers are hesitant to build transmission until generation plants are built. Partnerships between transmission and generation developers will ensure both get built and could attract investment to the NAS.

3.3.5 Southwest Power Pool (SPP)

Geographic Region:	Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Wyoming
Transmission Miles:	65,755
Generating Capacity:	83,945 MW
Proposed NAS Miles:	4,786
Proposed NAS Cost:	$32,505,907,344

3.3.5.a Transmission Planning and Approval Process

The Southwest Power Pool conducts an iterative three-year planning process that includes a 20-Year, 10-Year, and Near-Term Assessment in a process they call Integrated Transmission Planning (ITP). These reports identify transmission projects that are needed within both short and long-term time horizons while also identifying potential costs and benefits of each project. The Near-Term Assessment focuses on reliability issues within the grid at current usage levels. The 20-Year and 10-Year Assessments focus on identifying larger transmission projects to benefit the region using a number of different usage scenarios. These scenarios account for growing demand and potential changing regulations requiring more energy to come from renewable sources. The

20-Year Assessment is intended to create a transmission structure of high voltage (300 kV and above) lines that will be able to serve the region in the long-term.[32] Additionally, entities can request a Sponsored Upgrade or perform a high priority study in accordance with the region's Open Access Transmission Tariff that can lead to a transmission project being approved. The NAS could either request a Sponsored Upgrade study or be included in one of the longer term assessments.

3.3.5.b Current and Proposed Projects

The Midwest Transmission Project was a 180-mile 345 kV transmission line between Sibley, Missouri and Nebraska City, Nebraska completed in 2017. The development was a joint venture between Kansas City Power & Light and the Omaha Public Power District. The new line is an additional connection between the east and west sections of the RTO and aims to deliver more renewable energy to the eastern half of the region. The venture cost approximately $400 million and was financed by the participating companies. The project was one of SPP's Priority Projects, so cost recovery will come from the entire region's rate payers.[33]

3.3.5.c Recommended Financing Mechanism

Financing in the SPP will likely be similar to MISO. Most of the NAS will be financed by private capital secured by the developing companies. Rural areas may be able to use loans from the Rural Utilities Service. The estimated cost for the NAS in the SPP is $32.5 billion. There is a lot of wind generation in this region so there is also the potential for collaboration with wind energy developers. Renewable energy developers in this region will benefit greatly from the NAS because the energy generated in the SPP will be transmitted to population centers outside of the region. This should entice private developers and government bodies to support the NAS to help drive economic development in these regions.

3.3.6 California ISO (CAISO)

Geographic Region:	California, Nevada
Transmission Miles:	26,000
Generating Capacity:[34]	71,417 MW
Proposed NAS Miles:	2,220
Proposed NAS Cost:	$15,078,438,727

3.3.6.a Transmission Planning and Approval Process

CAISO conducts an annual transmission planning assessment. The plan identifies reliability, public policy, and economic needs of the transmission grid. The reliability planning performs a 10-year analysis of grid performance during projected peak usage. The public policy planning cycle largely attempts to determine needed grid upgrades to meet the state's renewable energy goal of 50% by 2030. Economic planning determines projects that would provide economic benefits to customers. The NAS could satisfy all three of the planning mechanisms by increasing reliability and reducing grid congestion lowering costs for customers. The grid also would help the state meet the renewable energy goal. The ISO also conducts "special studies" on issues impacted by transformational change in the way electricity is consumed.[35] It might make sense for the NAS to be part of a special study due to its wide ranging interregional impacts.

3.3.6.b Recommended Financing Mechanism

California has one of the most ambitious renewable energy standards, requiring 50% of the state's electricity to be supplied by renewable sources by 2030.[36] The state's aggressive approach indicates there is government support for growing renewable energy production. The estimated cost of the NAS in the California ISO is approximately $15.1 billion. Because of the state's high population, extensive renewable energy generation, and public policy support for renewable energy it is likely that private investment will be lucrative in California. The state also has legislation allowing public-private partnerships, which could be another avenue to attract private investors.

3.3.7 Electric Reliability Council of Texas (ERCOT)

Geographic Region:	Texas
Transmission Miles:	45,600
Generating Capacity:	78,000 MW
Proposed NAS Miles:	2,525
Proposed NAS Cost:	$17,150,753,074

3.3.7.a Transmission Planning and Approval Process

ERCOT develops a Regional Transmission Plan annually with their Regional Planning Group and Transmission Service Providers in the region. The plan assesses reliability and economic transmission grid needs within six years. The ISO also conducts a Long-Term System Assessment every two years. This assessment uses scenario analysis to determine the strength of existing projects when considering the long-term transmission needs of the region.[37] Stakeholders can submit projects for evaluation by the Regional Planning Group. A project will be included in the Regional Transmission Plan if the ERCOT Board of Directors determines the project would be a solution to identified grid needs.

3.3.7.b Current and Proposed Projects

The Competitive Renewable Energy Zone (CREZ) is a $6.8 billion project born out of legislation from the Texas Legislature in 2005 that designated geographical areas for potential renewable energy generation. The Public Utility Commission of Texas established a transmission development plan and assigned construction of the proposed lines to transmission service providers. The total development had approximately 3,600 miles of 345 kV transmission lines connecting renewable resources in West Texas to population centers in the eastern part of the state. This project is an example of a government sponsored transmission project that was constructed, developed, and financed primarily by private companies. Because the initiative was backed by government entities there was more collaboration in permitting allowing efficient regulatory approval.[38]

3.3.7.c Recommended Financing Mechanism

The ERCOT region is the most independent of all RTOs because it operates its own interconnection and most transmission lines are within the state. The independence has allowed them to complete projects, such as the CREZ, much more efficiently than other regions. Their state government has shown support for transmission projects similar to the NAS and there are transmission service providers with experience in developing and financing transmission lines. The estimated cost of the NAS in the ERCOT region is $17.1 billion. The cost would likely be financed by private capital. A wealth of renewable wind and solar resources in the western part of the state and large population centers in the eastern part of the state make transmission projects lucrative to private investment.

3.3.8 Southeast Region

Geographic Region:	Alabama, Florida, Georgia, Kentucky, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, Virginia
Transmission Miles:	55,000
Generating Capacity:	238,000 MW
Proposed NAS Miles:	6,116
Proposed NAS Cost:	$41,536,690,357

3.3.8.a Transmission Planning and Approval Process

The electric grid in the southeastern United States is not controlled by a RTO and thus the planning and approval process is less formalized than other regions. The Florida Reliability Coordinating Council (FRCC) and the Southeastern Electric Reliability Council (SERC) are the primary bodies that oversee the bulk power system in the region. The planning process for the FRCC includes an Annual Transmission Planning Process coordinating local utility's expansion plans into a regional development plan and a Biennial Transmission Planning Process that determines projects to make the grid more efficient.[39] The planning process for SERC involves the collaboration of many transmission providers in the region. Because planning in this region is driven by transmission providers and not a RTO, the NAS will need to gain support from the transmission providers in the region that will ultimately advocate for construction.

3.3.8.b Recommended Financing Mechanism

Gaining support from private transmission providers will be crucial to get the NAS approved for construction, so private financing is likely to be the primary financing mechanism in this region. The estimated cost of the NAS in the southeast United States is approximately $41.5 billion. Each state in this region has legislation allowing public-private partnerships. Along with gaining support from private transmission providers, there is potential for collaboration with government entities.

3.3.9 Southwest and Northwest Region

Geographic Region:	Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, Wyoming
Transmission Miles:	-
Generating Capacity:	125,964 MW
Proposed NAS Miles:	10,218
Proposed NAS Cost:	$69,396,436,656

3.3.9.a Transmission Planning and Approval Process

The Western Electricity Coordinating Council (WECC) is charged with promoting the reliability of the bulk power system throughout the Western Interconnection. The territory includes the southwest and northwest regions along with California, Alberta and British Columbia. WECC represents a wide spectrum of organizations. WECC coordinates an adequacy planning process to determine transmission needs in the next 10 to 20 years. WECC studies are made available to stakeholders in the region who can then propose projects as solutions to identified needs.

3.3.9.b Recommended Financing Mechanism

The Southwest and Northwest regions have the largest estimated cost for the NAS at approximately $69.4 billion due to covering the largest geographical area. Portions of the grid in this region will be privately financed, but government support will likely be needed for other sections due to the high cost. The Rural Utilities Service loan programs could be a viable option in this region since much of it is comprised of rural areas and the grid will improve service reliability to those regions.

Land use and siting for the NAS will be especially important in the western United States because the federal government owns so much of the land. There are likely to be greater environmental issues to clear when determining the exact grid route. Collaboration and support from the federal government will be crucial to approve segments of the grid in this region so they can attract private investment. A possible strategy is creating a structure where proceeds from the more lucrative sections of the grid in highly populated regions can help pay for less lucrative segments. This might involve bidding highly lucrative segments with less lucrative projects as a single project that would still be financially beneficial for transmission providers. This will likely be the most challenging section of the NAS to approve and finance, but it is crucial to creating the national network and allow renewable energy generated in the western United States to reach population centers in the southern and eastern regions of the country.

3.4 National Overview

Private investment will be the primary funder for this project, just as private capital currently funds most energy infrastructure projects. The key to successfully financing the NAS is ensuring the project is attractive to private investors. There is private capital available in the marketplace, but that capital can only be accessed if the interests of all stakeholders are properly aligned making the NAS an attractive investment. In addition to private capital, strategic partnerships should be explored with the federal government, state and local governments, and government agencies. Due to the national security and environmental benefits, there should be government interest in this project.

Key areas of project development that will make the project more attractive to investors:

- **Secure backing of federal/state governments, DOE, RTOs/ISOs:** Support from the federal government and RTOs in each region will give credence to the importance of this project. This support will help increase the likelihood of getting the NAS approved and included in each RTO planning process opening the door for transmission providers to begin construction.

- **Reduce permitting and regulation burden:** The high regulatory environment adds to the cost and time to begin construction. This can make it challenging to secure financing at a rate acceptable to both investors and transmission providers. Legislative action can ensure that permitting for the NAS grid does not get held up by any one stakeholder. A reduced regulatory burden also reduces the overall cost of the grid.
- **Ensure stakeholder interests are aligned in each region:** The nation's electric grid is a large system with a diverse set of stakeholders. Ensuring that the interests of all stakeholders are aligned will make getting approval and support for the NAS easier. Utilizing existing ROWs will reduce the number of local stakeholders and make gaining national support more practical. Wide spread support will help attract private investors and making financing the project feasible.
- **Encourage regional and national collaboration:** Historically, transmission development was completed on a state level. This has led states to have differing regulations and processes governing transmission project construction. More collaboration between states and direction from the federal government would reduce the time and cost to comply with multiple agencies in interregional transmission developments.
- **Planning is crucial:** Environmental studies, transmission line siting, permitting, and eminent domain are all potential hurdles for companies constructing the NAS. The proposal to use existing rights-of-way somewhat reduces this concern.

Transmission projects today are focused on increasing grid reliability and efficiency and less on load growth. Improved efficiency of electronics has stabilized the growth of energy demand across the country. Additionally, grid improvements must enable the future transmission grid to be adaptable to changes in load patterns and generation sources.

There is wide spread agreement about the need for more investment in transmission. Improved reliability will likely lower costs to rate payers due to fewer congestion charges. The NAS will allow more flexibility for RTOs to manage where electricity is generated, allowing greater access to cheaper energy. Rate payers will ultimately pay for the NAS through transmission charges, but costs for construction will likely be offset by the cheaper cost of energy and reduced congestion fees.

3.4.1 Cost Allocation

Cost allocation often becomes an important issue for interregional transmission projects. FERC mandates that cost allocation procedures for transmission projects must be developed by each RTO and uniformly applied. However, each RTO has slightly different procedures. In general, RTOs have shifted to a regional cost allocation system for large transmission projects. Every rate payer in the region pays for a portion because everyone benefits from a regional transmission project that improves reliability and makes the grid more efficient. Costs are generally allocated based on load usage.

If there is wide spread support for constructing the NAS, cost allocation should not create major issues. The NAS has benefits to all ratepayers so it makes sense to use a regional or even national cost allocation system. Due to the increased reliability and efficiency the NAS would create, the overall electric costs to rate payers would remain relatively constant because they will pay less congestion charges and have access to cheaper renewably generated electricity.

3.5 Conclusion

Our investigation suggests that the NAS is feasible without requiring new public funding schemes or new taxes to garner capital. Instead, rate payers will produce returns through electric bill fees. Moreover, investment in the NAS will enable the creation of millions of jobs nationwide that will not only be generated from the construction of the transmission system, but will also originate from the construction and operation of new (mostly renewable) electricity generation facilities throughout the United States. Overall, this infrastructure package will cost between $303 billion and $442 billion dollars to build the transmission system (depending on the cost of cable burial), as well as an additional $2.2 trillion dollars to construct additional electricity generation facilities. Despite these costs, the average consumer electric bill will not increase as a result. Additionally, although configuring HVDC lines underground often costs three to five times that of above ground lines, this study indicates that this costlier configuration is still an economically viable solution; an underground HVDC system (that is three times more expensive than above ground lines) will cost less than continuing the operation of the nation's current grid system given that the cost of natural gas remains above $4.43/MMBtu. According to the EIA, the cost of natural gas is set to increase to at least $5/MMBtu by 2030, meaning that the NAS is forecasted to be a viable economic solution by its time of completion.

There is a need for new investment in our nation's transmission infrastructure. The NAS will benefit all rate payers by allowing greater access to cheaper renewable energy while also increasing national security. The estimated $500 billion cost for an underground HVDC system will require a number of different financing mechanisms over a number of years. Private sector interest in infrastructure projects is growing and capital is available in the marketplace. The NAS must build partnerships with experienced transmission developers and gain support from federal and state governments, government agencies, and RTOs to successfully secure financing for this landmark energy transmission project.

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4 North American Supergrid permitting and regulatoin

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Summary

We analyze regulatory reform advocacy for a RTO/ISO-centered framework for effective operation of the Supergrid as well as routing and permitting processes.

The NAS may need to utilize private land, public land, or tribal land. For private land, the NAS may require negotiations with affected landowners regarding easement and, if necessary, exercise eminent domain. Additionally, the NAS will have to obtain approvals from the necessary federal, state and local government agencies (particularly the Bureau of Land Management and Bureau of Indian Affairs). Tribal lands involve complications with the federal trust relationship.

Streamlining the permitting process involves reducing barriers to using the land for renewable energy transmission. Three potential state-based strategies have been identified to facilitate the streamlining of the permit process: (a) allow states, in determining whether a project is "necessary," to consider regional and out-of- state benefits, which would allow for construction of the NAS in pass-through states while also considering in-state and local concerns; (b) expand the definition of "public use" to include specific application for installation of merchant transmission lines and allow state and local government to consider general economic benefits; (c) create new RTOs/ISOs in those areas of the western and southeastern United States that are not presently incorporated into an existing RTO/ISO.

Rights-of-way through tribal lands add another level of complexity. Tribal lands are governed mainly for the benefit of the tribes and are held in trust by the Federal Government. While the Federal Government does not maintain eminent domain authority over tribal lands, there is a provision that allotted lands can be commandeered for public purposes, if needed. The Supergrid might significantly improve connectivity to the national energy market for renewable energy developments on tribal land.

Our analysis indicates that the most feasible routing for inter-connected Supergrid links could be mainly along existing rights-of –way, specifically federal and state highways as well as abandoned rail lines. Accomplishing this would require working with the Federal Highway Administration (FHWA) and other federal authorities which retain authority over such routes. The FHWA is authorized to consider whether proposed transmission projects are within the public interest and to grant right-of-way permission.

As evidenced by the complexity in achieving line siting authority across the lower 48 contiguous states, this path would be an approach both costly and vulnerable to roadblocks from state and local regulatory bodies. A nationwide approach with regional decision-making authority would provide the Supergrid with an opportunity to go nationwide, while safeguarding regional considerations of geography, available resources and market conditions. Under the Energy Policy Act of 2005, a group of three or more contiguous states can enter an interstate compact establishing regional siting authority. Alternatively, we recommend that Congress grant siting authority through legislation to RTOs and ISOs. Such a shift in the regulatory structure is supported by the ever-evolving nature of the nationwide electricity market as well as the physical nature of the grid itself. With Congressional involvement, the NAS can alleviate the modern problems posed to the current grid, and strike a balance between local area concerns and centralized federal authority.

4.1 Introduction

The current regulatory and permitting landscape for interstate electric transmission projects is an impediment to implementing the NAS. While it is important to engage with all stakeholders, including state and local authorities, placing primary siting and eminent domain authority at the state and local level makes it difficult to properly value the regional and national benefits of the NAS. As a result, Congressional action transferring siting and eminent domain authority to a federal or regional permitting entity would streamline the process and more fully consider the federal and regional costs and benefits in addition to state and local costs and benefits. This chapter evaluates the flaw in the current permitting system and proposes some solutions with regard to portions of the NAS on private lands, federal public lands, tribal lands, and highway and railroad rights of way.

Part 4.2 details the local, state, and federal laws governing siting and eminent domain authority for interstate electric transmission line projects like the NAS. State statutes regarding siting vary across the United States. It is important for state and local entities to address their individual needs, but it often results in delaying or completely preventing the transmission projects needed to integrate more renewable energy into the grid.

Part 4.3 of this chapter discusses the challenges of siting a transmission line on federal land. When using federal land, a project must deal with both the federal government and state governments. A transmission project must comply with strict federal standards when crossing federal land.[1] The Bureau of Land Management (BLM) within the U.S. Department of Interior has set aside land aimed at developing renewable energy projects on federal land.[2] Federal land use may be an important asset, particularly for projects in the western United States.

Part 4.4 discusses the responsibilities of a transmission operator when the project crosses tribal lands that are unique, because such land is held in trust by the United States government.[3] Projects on such lands may be expedited by giving the tribes a more central role in allowing siting of renewable energy projects over their land and creating concrete benefits for tribes associated with the NAS projects.

Part 4.5 explores potential issues with transportation rights of way. The U.S. Department of Transportation works in conjunction with the BLM and state transportation departments for siting along highway corridors. Different regulatory requirements in multiple state departments of transportation can impede progress and delay build time. Railroad rights of way may also be an option for NAS projects so long as the projects can create mutual benefits for the railroads. Part 4.6 recommends Congressional action to transfer some state siting and eminent domain authority for interstate electric transmission line projects in general or the NAS in particular to either the FERC or RTOs.

4.2 Public Use, Public Need, Siting Authority, and Eminent Domain

4.2.1 Siting of Interstate Transmission Lines

In order to construct a transmission line, the transmission line operator must generally comply with a siting process in each state through which the line will pass by obtaining a certificate of need or certificate public convenience and necessity from the state public utilities commission or public service commission. Generally, the transmission operator obtains a certificate of need by establishing "the 'need' for the line, the effect of the line on reliability, alternatives to the proposed line, and potential environmental impacts of the line."[4] In most states, the certificate of need allows the operator to exercise eminent domain authority to assemble the necessary property easements to build the line if voluntary contracts with landowners cannot be obtained. In some states, the operator must make a separate application to the commission for eminent domain authority beyond the certificate of need. In many states, the relevant state law does not allow companies other than public utilities to seek a certificate of need or exercise eminent domain and in other states the law is unclear.

The determination of need differs across states, but many states "have some concept of 'need' pertaining to the state's own citizens... ."[5] For example, in Florida, the Public Utilities Commission (PUC) considers the "need for electric system reliability and integrity, the need for abundant, low-cost electrical energy to assure economic well-being of the residents of the state, the…starting and ending point of the line, and other matters…deemed relevant."[6] On the other hand, Arizona statute urges the state PUC to balance, "in the broad public interest, the need for an adequate, economical and reliable supply of electric power with the desire to minimize the effect…on the environmental and ecology of this state."[7]

Some states, such as New York, provide detailed regulatory requirements for obtaining a certificate. Title 16, Part 86 of the New York Compilation of Codes, Rules, and Regulations outlines the several requirements for an interstate transmission line. An application is required to "submit detailed maps…[that] shall include" the location of a right-of-way and possible damage to the environment as well as historical areas.[8] Further, the applicant must "submit a statement explaining what consideration, if any, was given to: (1) any alternative route; (2) the expansion of any existing right-of-way…[and] (3) any alternate method which would fulfill the energy requirements with comparable costs" where the applicant may compare the benefits and drawbacks of the alternative.[9] The applicant is also required to "submit a statement describing" economic effects on the "residential, commercial or industrial land-use patterns of any area adjacent to any portion of the proposed facility."[10]

Other states have arguably limited the ability of transmission lines to obtain a certificate of need by limiting the definition of a public utility. In 2012, Illinois replaced their previous Public Utilities Act with new legislation.[11] The act defines a public utility to include:

> every corporation, company, limited liability company, association, joint stock company or association, firm, partnership or individual, their lessees, trustees, or receivers appointed by any court whatsoever that owns, controls, operates or manages, within this State, directly or indirectly, for public use, any plant, equipment or property used or to be used for or in connection with, or owns or controls any franchise, license, permit or right to engage in:
>
> (1) the production, storage, transmission, sale, delivery, or furnishing of…electricity… .[12]

The new bill was interpreted as providing a more restrictive definition of public utility in *Illinois Landowners Alliance v. Illinois Commerce Commission*. In the case, the Illinois Landowners Alliance challenged an Illinois Commerce Commission order "granting a certificate of public convenience and necessity to Rock Island Clean Line…for construction of a high voltage electric transmission line… ."[13] Rock Island is a merchant transmission project that planned to "construct and manage" the line, but did not "yet own, control, operate, or manage any plants, equipment, property in Illinois…."[14] The Illinois Landowner's Alliance argued that Rock Island could not qualify as a public utility since "it did not already have in place the transmission infrastructure that would qualify it as a public utility… ."[15] The Illinois Supreme Court, in holding that Rock Island did not qualify as a public utility, focused on the specific language of the Illinois Public Utilities Act. The court noted that section 2-105 requires a company to "own, control, operate or manage…a plant, equipment, or property" for the transmission of electricity.[16] A company that simply sells electricity "does not, in itself, make the enterprise a public utility" since that company could sell the electricity to "a select group of industrial customers" without being a public utility.[17] The Illinois Supreme Court reasoned that Rock Island only held "an option to acquire a parcel of real property," and "having an option to buy something is not the same as owning or even controlling it."[18] The court noted that the previous Public Utilities Act's definition of a public utility contained the language "now or hereafter…may" in regard to controlling or owning transmission infrastructure.[19] The court interpreted the removal of this language as requiring potential projects to own or control "utility-related property or equipment."[20] The court also challenged an administrative law judge's (ALJ) argument that "imposing such a requirement would… create an unworkable 'Catch-22'" in requiring an entity to only apply for a certificate of need until that entity "already owned public utility infrastructure.[21] In other words, such an interpretation would only allow previously established public utilities to qualify as public utilities. The Illinois Supreme Court countered that the statute would allow Rock Island to develop the line "as a purely private project," and "[o]nce [the] projects are further underway" and own, control, or manage the "utility-related property," Rock Island could "then seek certification" to operate as a public utility.[22]

The Illinois Supreme Court seems to understate the impact of the statutory interpretation on merchant transmission lines. While it is true that a line could operate a purely private basis, it would not be able to find a customer base to sell to and it may not be able to acquire land through eminent domain. The court also did not specify what stage a transmission infrastructure needs to be in for a merchant transmission line to quality as a public utility. While the Catch-22 is not technically unworkable, it does create significant barriers to any merchant transmission line looking to enter the market. This decision, and any similar decisions, could have significant impact on the NAS. The NAS would have to build transmission infrastructure before knowing whether it would qualify as a public utility. Forcing companies to sink costs into a project without knowing how those costs can be recovered could create a chilling effect on merchant transmission lines hoping to enter the market.

While states differ in their "need" requirements for certificates, each one has some concept of weighing potential benefits against economic or environmental costs. There has been some debate as to how broadly these benefits may be construed. At one extreme, one could consider national benefits to the grid as whole. At the other extreme, one could only consider the in-state benefits. The *Illinois Landowners Alliance* decision also seems to suggest that a project must significantly invest in a state before the state grants a project with the benefit of being a public utility. The debate focuses on whether a state should sacrifice economic and environmental resource for the benefit of the region or the nation.

4.2.2 Federal Siting Authority

Federal siting authority could consider national or regional benefits as opposed to only in-state benefits.[23] A federal approach would streamline permitting, creating a more efficient approach for interstate transmission projects. There has been an effort to expand federal siting authority, but it has been unsuccessful.

In 2005, Congress passed the Energy Policy Act of 2005 ("EPAct 2005"), which amended the Federal Power Act ("FPA") by adding § 216.[24] The amendment granted FERC authority to override state siting authority under certain circumstances. The law directed the U.S. Department of Energy to evaluate and identify national interest electric transmission corridors (NIETCs).[25] An NIETC is an "area experiencing electric energy transmission capacity constraints or congestion.[26] Once DOE identifies a NIETC, FERC may issue a permit for a project to relieve congestion if it finds that the potential line (1) is "used for interstate commerce," (2) is "consistent with the public interest," (3) will "significantly reduce transmission congestion in interstate commerce," (4) is also "consistent with national energy policy," (5) and will "[m]aximize the use of existing towers and structures."[27]

In order for FERC to grant a siting permit under these circumstances (often called "backstop-siting authority") the project must also meet one of the following conditions.[28] First, the state must lack authority to site the transmission line or it is unable to "consider the interstate benefits" of the potential line.[29] Second, "the applicant" is unable to obtain a permit, "because the applicant does not serve end-users in the State."[30] Third, the state has "withheld approval for more than 1 year after the filing of an application."[31] Fourth, the state has approved the permit, but has "conditioned its approval" in a way that the line will not "significantly reduce transmission congestion in interstate commerce or is not economically feasible.[32] After Congress enacted EPAct 2005, FERC enacted a rule interpreting its authority to allow it to exercise backstop-siting authority after a state denied a siting permit within a NIETC.[33]

In *Piedmont Environmental Council v. FERC*, some state utility commissions filed suit against FERC's interpretation of § 216(b)(1)(C)(i) of the FPA.[34] FERC construed "withheld approval for more than 1 year…to include a state's *denial* of a permit within the one-year statutory time frame."[35] The U.S. Court of Appeals for the Fourth Circuit ruled in favor of the plaintiffs and against FERC.

The court noted that § 216(b)(1) contains a "list of five circumstances when FERC may preempt a state and issue a permit."[36] Since an outright denial of a permit was not a part of the five circumstances, the court found that FERC's interpretation did not make sense. The court added that, if FERC's interpretation prevailed, the federal government could overrule any state siting decision.[37] Circuit Judge Michael compared the difference between a state siting authority withholding approval or granting approval "with project-killing conditions," and a state siting authority that "denies an application outright."[38] The former "misuses its authority," while the latter "acts with transparency and engages in a legitimate use of its traditional powers."[39] The dissenting judge, however, argued that § 216 was intended to override state authority in the interest of national grid security" and would have upheld FERC's interpretation of its statutory authority.[40]

The *Piedmont* decision severely limited federal backstop siting authority.[41] As of today, FERC has not exercised its backstop siting authority."[42] An attempt to pass new legislation on the matter was made in 2009, but it was unsuccessful.[43] Creating more federal siting authority will require enacting new federal legislation, a difficult task in recent decades. Furthermore, federalizing the permitting process would come at the cost of local control. If the federal government is leading the process, there may be some concerns as to where the line is built and which communities bear the cost. It is important to keep a decentralized process while providing some uniform standards for the implementation of the NAS through federal legislation.

4.2.3 Eminent Domain Authority

If negotiations are unsuccessful, a common technique for acquiring land is the power of eminent domain. The Fifth Amendment to the U.S Constitution allows private property to be taken for a "public use upon payment of just compensation."[44] Most states have similar provisions in their own state constitutions. State constitutions, however, have varying requirement before granting eminent domain authority.

Eminent authority is particularly important because it allows a transmission project to use land if there is a landowner who chooses not to sell or an agreement cannot be reached.[45] While some entities can afford to invest without eminent domain, "siting costs, litigation and construction delays" may increase due to landowner expectations.[46] On the other hand, under a national interstate transmission project, such as the NAS, private buyouts could add up rather quickly.[47]

However, there are problems regarding eminent domain for interstate transmission due to the varying definition of "public use" among the states.[48] Most states include transmission lines as a public use by statute, so long as the operator has received a certificate of need. But, the question has arisen in many states whether a merchant transmission line designed to carry electricity to customers several states away is a public use with regard to a state where the line passes through but does not provide electricity.[49]

Some states extend eminent domain authority only for projects that are of "use by the public" and provide "electricity immediately to [the] in-state residents."[50] Some states define "public use" quite literally in that the project must be used by the residents of that state. These states are very restrictive in how they define public use. For example, Article 1, section 16 of the North Dakota Constitution states, "a public use or public purpose does not include public benefits of economic development including…general economic health."[51] The section also states that private property may not be taken by "any private individual, or entity, unless that property is necessary for conducting a…utility business."[52] The North Dakota constitution suggests that, while eminent domain may be used to transfer property between private entities in the context of transmission, general public benefits cannot be used as means of proving a public use. Additionally, the Idaho Constitution defines "public use" as, "[the] necessary use of lands for the constructions of reservoirs…, for the purpose of irrigation, or for the rights-of-ways for the construction of canals…to convey water to the place of use for any useful purpose…, or any other use necessary to the complete development of the material resources of the state … ."[53] Other states can expand or restrict the definition of public use through statute. California statute states that when the legislatures provides that when the power of eminent domain may be exercise, "such action is deemed to be a declaration…that such use…is a public use."[54] Additionally, the California Constitution allows for government taking and conveyance to a private person when it is done "for the purpose of protecting public health and safety… ."[55] California, unlike North Dakota and Idaho, is more permissive in regard to public use and potential exceptions for conveyances made to private entities.

The varying definitions of "public use" can be particularly problematic for merchant transmission lines since in some states they are considered to be for private gain only and not a public use.[56] Merchant transmission lines "are distinguished from traditional public utilities in that the developers of merchant projects assume all of the market risk of a project and have no captive pool from which to recoup the cost of the project."[57] Merchant transmission projects can be allowed to "charge for transmission service at negotiated rates, unencumbered by traditional cost of service ratemaking principles."[58] Negotiated rates, as opposed to cost-based rates, could provide a transmission operator with more flexibility when it comes to cost recovery. The ability to charge higher rates could attract investors. As a result, it has been difficult in many states for merchant lines to seek a siting permit or establish that the line is a public use for purposes of exercising eminent domain. Generally, merchant transmission lines may be hard pressed to prove their use is a public use beyond general economic benefits, especially in states where a line would be passing through.

The varying definitions of public use and differing values among states could pose a significant obstacle to the NAS. It could be difficult for the NAS to meet the requirements of North Dakota in proving more than general economic benefits while also developing the natural resources in Idaho and providing in-state benefits. The NAS could benefit from state legislatures revising their eminent domain statutes to include merchant transmission lines as a public use or allow for legislative-made exceptions.

Legislatures will have to consider how expanding the definition of public use under eminent domain statutes to include merchant transmission projects could affect their state. Perhaps instead of focusing on whether the line provides electricity to citizens of the state, the legislature could focus on the overall economic benefits in the form of jobs. A state receiving energy could find a way to trade benefits with pass-through state. It is clear that for the NAS to work legislatures need to think about benefits beyond the form of energy delivery. States could be creative with how they trade benefits to each other.

An interstate transmission line often provides regional or national benefits in addition to state and local benefits. This may not be considered a public use since it does not directly benefit the people of that state. This is of the most concern in cases where the line merely runs through the state without providing any direct benefits such as allowing exports of renewable energy or reduction in electricity prices through imports of renewable energy. Those states are asked to sacrifice their environmental resources for the benefit of the generation-state and the end-user state. There may be states where the transmission line passes through without providing any power to that state. It is important to find ways to instill benefits on "pass-through" states. It would be prudent for the NAS to focus on the broader economic impact of the line in these states.

4.3. Interstate Transmission Projects on Federal Land

An interstate transmission project is likely to cross some federal land. Federal land use brings new challenges that the NAS must meet. Much of the federal land ownership is located in the West.[59] There are five "source of access" problems for interstate transmission projects hoping to use federal lands.[60] First, there are fragmented parcels of land owned by private and state entities within federal lands.[61] Second, there are many "alleged rights by use, prescription, or ancient statute."[62] Third, surface and subsurface rights are severed in areas of "known or suspected mineral occurrence."[63] Fourth, people are often informally allowed to wander onto unsettled lands and this may interfere with land-use projects.[64] Fifth, there are "partial…property interests" held by many users that may get in the way of an interstate transmission project.[65]

4.3.1 Federal Land Policy and Management Act

If an interstate transmission project passes through federal land, then the BLM is generally the permitting authority acting pursuant to the Federal Land Policy and Management Act (FLPMA).[66] The relevant sections of the FLPMA are sections 1761 to 1171 which "provide comprehensive guidelines for nearly all rights of way on BLM public lands and national forests… ."[67] Section 1761(a)(4) of the FLPMA grants the Secretary of the Interior "with respect to public lands… are authorized to grant, issue, or renew rights of way over, upon, under, or through such lands for—[4] systems for generation, transmission, and distribution of electric energy."[68] The act also grants power to the Secretary of Agriculture "with respect to lands within the National Forest System (except for public lands designated as wilderness)."[69] Subsection 4 also requires applicants to "comply with all applicable requirements of the Federal Energy Regulatory Commission under the Federal Power Act."[70]

An interstate transmission project must then submit the appropriate paper work for a federal right-of-way.[71] If the project is unable to "submit all requisite information," BLM could "reject…[the] ROW application."[72] Additionally, the applicant is encouraged "to make an appointment for a preapplication meeting[.]"[73] The meeting is important because "BLM can: (1) Identify potential routing and other constraints; (2) Determine whether the lands are located inside a designated or existing right-of-way corridor or a designated leasing area; (3) Tentatively schedule the processing of your proposed application; (4) Inform [the applicant] of…financial obligations, such as processing and monitoring costs and rents."[74] Being apprised of the process and maintaining regular contact with BLM can make the process more efficient. The BLM processes the project application in several ways. First, BLM holds "public meetings" if there is "sufficient public interest…to warrant their time and expense."[75] BLM has established "17 Solar Energy Zones (SEZ) in Arizona, California, Nevada, New Mexico, and Utah."[76] SEZ "are deemed priority areas for commercial-scale solar development."[77] Further, BLM "authorizes commercial solar projects using a FLPMA [ROW] that authorizes…electrical and transmission facilities … ."[78] BLM also allows for transmission lines for wind energy that "may be authorized with a…linear [ROW] authorization."[79] A solar or wind project must (1) hold a meeting for people "affected by the potential right-of-way," (2) go through a screening process where applications with "lesser resource conflicts" are prioritized, and (3) the application is evaluated "based on…input from other parties, such as Federal, State, and local government agencies, and tribes, as well as comment received in preliminary application review meetings…and the public meeting[s]."[80] Furthermore, the project must comply with the National Environmental Policy Act (NEPA).[81] The NAS could take advantage of these specialized provisions to help the project move forward. The FLPMA provides special areas for renewable energy development that fit the NAS goals. It would be in the best interest of the NAS to work with BLM using the specialized provisions of the FLPMA. BLM rules show that the agency has had an eye toward renewable energy development on federal land. If the NAS can get through the stakeholder meeting and screening process, it could use public lands as a way to develop renewable energy transmission.

4.3.2 Bureau of Land Management Segregated Land

43 C.F.R. § 2804.25(f)(1) authorizes the BLM to segregate federal land in a "right-of-way application…for the generation of electrical energy from wind or solar sources."[82] BLM is also authorized to segregate public lands for potential ROWs for wind or solar energy generation "when initiating a competitive process for solar or wind development on particular lands."[83] Segregation would be important to the NAS, because it allows BLM to only use the land for renewable energy development.[84] The NAS, however, has to keep in mind the purpose of the public land. If the potential use is contrary to the purpose of the public land, BLM may deny the application.[85] BLM may also deny the application if the potential use is not in the public interest.[86] The NAS would also have to ensure they are qualified to receive the grant for the ROW.[87] To qualify for a grant, an operator must be a business entity "authorized to do business in the state where the right-of-way" is located as well as be able to "[t]echnically and financially [be] able to construct, operate, maintain, and terminate the use of public lands" in the application.[88] The NAS must also make sure that the grant is not contrary with the FLPMA or any other laws or rules. BLM may also deny an application if the project cannot prove technical or financial feasibility.[89] In particular, the application "must… demonstrate technical and financial capability to construct, operate, maintain, and terminate a project throughout the application process and authorization period."[90] If an applicant is unable to "demonstrate and sustain technical and financial capability," the application may be denied.[91] Additionally, the project may be denied under 43 C.F.R. § 2804.25(e)(2).[92] If the NAS is unable to meet any of the requirements, the project may ask for a variance.[93] In order to receive the variance, the project must show good reason for not meeting the original requirement, bring forth an appropriate alternative requirement, and send the alternative requirement in writing to BLM.[94] The NAS is allowed to appeal an application denial from BLM.[95] It is not clear if the segregated land would apply to transmission, as opposed to

generation, facilities. There needs to be more inquiries as to whether the rule applies to transmission construction. The NAS could ask for a variance for transmission as it advances the goal of renewable energy development

4.3.3 Effect of the Executive Order Establishing Discipline and Accountability in the Environmental Review and Permitting Process for Infrastructure on Federal Lands

On August 15th, 2017 the Trump administration issued an Executive Order outlining processes for improving environmental review and permitting for infrastructure projects on federal lands. The order aims to "develop infrastructure in an environmentally sensitive manner" and "provide transparency and accountability to the public regarding environmental review and authorization decisions."[96] The order also calls for conducting environmental reviews and authorizing permits "in a coordinated, consistent, predictable, and timely manner… ."[97]

The Executive Order discusses "Performance Priority Goals" and how the federal government should meet them.[98] "Performance Priority Goals" are met using Cross-Agency Priority (CAP) Goals. CAP Goals are used to accelerate progress "in priority areas that require active collaboration among multiple agencies… ."[99] The Trump administration creates a time table of not more than an average of two years "from the date of the publication of a notice of intent to prepare an environmental impact statement or other benchmark…."[100] The administration also implements the One Federal Decision principle where "[e]ach major infrastructure…have a lead [f]ederal agency" to be responsible for getting a project through the federal environmental review and permitting process.[101] The principle allows for one federal agency to be the lead agency of a project while coordinating with other agencies. The idea is that all of the agencies cannot work against each other. The order also authorizes the Department of the Interior and Agriculture to designate "energy [ROW] corridors on [f]ederal lands for [g]overnment-wide expedited environmental review for the development of energy infrastructure projects.[102]

The Executive Order could potentially affect the NAS, if it plans to work with multiple agencies. Working with multiple federal agencies on several fronts could make matters complicated. For example, if the NAS planned had to deal with multiple agencies, there may be some confusion as to which one is in charge. It is also not yet known what is meant by an expedited environmental review for energy ROW corridors. The manner in which the permitting process is accelerated could be beneficial to the NAS, but it may prevent stakeholders from adequately participating in the process. If the expedited review keeps stakeholders from fully participating in the process, there may be delay from stakeholder backlash, possibly in the form of lawsuits. It remains to be seen if the Trump administration can expedite infrastructure projects while also providing transparency and accountability. It will be important to see how the Trump administration implements the Executive Order.

4.4 Rights-of-Way and Tribal Land

Tribal ROWs add another layer of complexity because the NAS would be dealing with a sovereign entity in a trust relationship with the federal government. The Department of the Interior is charged with granting ROWs on tribal lands held in trust by the federal government.[103] In *United States v. Navajo Nation*, the Court examined the trust relationship in light of a specific statute.[104] The Court explained that "a general trust relationship between the United States and the Indian people…is insufficient to support jurisdiction under the Indian Tucker Act."[105] The Court held that a statute must create a "duty-imposing" prescription that would allow a tribe to sue to the federal government. The NAS will have to examine the specific statute under which the land is being used to learn of a particular trust relationship and potential recourse on the part of tribes. While the federal trust relationship is well established, it can also lead to inefficiencies in the transmission ROW process.[106] It is important for an interstate transmission project to understand the tribal legal landscape and possible routes for streamlining the process.

4.4.1 Allotted Land and Federal Trust Land

There are several different types of tribal land but among the most basic are allotted lands and federal trust lands. It is important for an interstate transmission project to know the difference because it drastically changes the procedure for acquiring an ROW. Tribal trust lands are for the benefit of the tribe but are held in trust by the federal government.[107] Federal trust lands are the most common among types of tribal land, so an interstate transmission project is likely to run a line across these lands.[108] The distinction between tribal trust land and allotted land is that the federal government has not granted the authority of eminent domain over tribal trust lands.[109] Congress, however, has the power to abrogate treaties and allow condemnation of tribal lands.[110] For example, FERC, under the FPA, is authorized to issue a license for transmission lines on tribal lands subject to federal jurisdiction and sometimes that license will include the power of eminent domain.[111] Before issuing a license, FERC is required to show that the license is consistent with the purpose of the reservation and contains protections for the tribe.[112] On the other hand, allotted lands can be condemned for a public purpose.[113] Federal statute authorizes condemnation of allotted lands under state law.[114] While condemnation is an option, a transmission project is usually required to make an attempt negotiate and purchase the right first.[115]

A significant inefficiency in tribal transmission siting is "the requirement that the Secretary of the Interior (and the Bureau of Indian Affairs (BIA)) approve leases of Indian lands."[116] Fortunately, there are several avenues to make the process more efficient. Many of the current solutions involve tribes petitioning for a more central role in the decision-making process.

4.4.2 The HEARTH Act

Allowing tribes to exercise central authority in land development could open the door to renewable energy development on tribal lands.[117] The Homeless Emergency Assistance and Rapid Transition to Housing (HEARTH) Act aims to reduce the amount of time it takes to obtain a lease on tribal lands. A tribe hoping to benefit from the HEARTH Act must petition the Secretary of the Interior and prove that "the tribe's leasing regulations meet the enumerated requirements of the HEARTH Act."[118]

Allowing tribes to play a more pivotal role in the permitting could streamline the process for the NAS. Apart from the tribes playing a more central role, there are other ways for the NAS to gain access to tribal land without a statutory ROW.[119]

The HEARTH Act could be a potential revenue source. Removing obstacles for private entities to obtain a lease on tribal land could incentivize tribal land development as well as partnerships between the tribes and renewable energy developers.

4.4.3 Indian Tribal Energy Development and Self-Determination Act of 2005

The Indian Tribal Energy Development and Self-Determination Act of 2005 authorizes tribes to enter into an agreement with the Secretary of the Interior known as a tribal energy resource agreement (TERA).[120] The Secretary must consider the "best interests of the tribe and the Federal policy of promoting tribal self-determination."[121] Additionally, the Secretary examines several factors to determine if the tribe has proven "sufficient capacity" to use a transmission line.[122] If the Secretary of the Interior approves the TERA, then tribe will be able to grant ROWs without approval from the Secretary.[123] The TERA must specify the procedure for the administration of ROWs for the tribe.[124] There are, however, some limitations to the TERA.[125] The ROW under the TERA may not exceed 30 years.[126] Additionally, the transmission line must serve "an electric generation transmission, or distribution facility located on tribal land or a facility located on tribal land that processes or refines energy resources developed on tribal land."[127] As of 2014, the Indian Tribal Energy Development and Self-Determination Act of 2005 has not been fully utilized.[128] The Act allows tribes to play a more central role in the siting process. The NAS could partner with a tribe to be one of the first to administer a TERA. This route could help the NAS build a transmission line more efficiently while paving the path for other renewable energy projects. Energy development on tribal land could be a "method to achieve economic diversification, promote tribal sovereignty..., and provide employment and other economic assistance to tribal members."[129] Former Senator Ben Nighthorse Campbell explained that "[m]ost tribes do not have the financial resources to fund extensive energy projects..., and so must partner with private industry, or other outside entities, by leasing out their energy resources...in return for royalty payments."[130]

4.4.4 Renewable Energy Lease

An interstate transmission project does not necessarily have to obtain a ROW to build a line on tribal lands. Wind and Solar Resource leases ("WSR leases") are a means of using tribal trust lands for wind and solar energy development.[131] Among the uses allowed under a WSR lease is the transmission of electricity.[132] A WSR lease does not exactly shift the central authority to the tribes, but it does serve as an adequate alternative. BIA must approve a WSR lease before construction can begin.[133] Additionally a potential transmission project must seek authorization from the tribe.[134] The regulation notes other requirements for WSR leases on tribal lands including alternative payments for lease based on income.[135]

4.5 Highways and Renewable Energy

Along with BLM lands, state and federal highways are a source of public lands that can be helpful to the NAS. A potential obstacle to the NAS is the amount of involvement from state departments of transportation (DOTs). The federal government and State DOTs have been developing ways for utilities to access ROWs with renewable energy.[136] Since the NAS is likely to be a merchant transmission line, it will have to obtain a ROW use agreement.[137] ROW use agreements involve "[a]ny non-highway use of real property interests."[138] A party seeking such an agreement must obtain approval from the FHWA,[139] authorized to consider whether the proposed project "is in the public interest, is consistent with the continued use, operations, maintenance, and safety of the facility and such use does not impair the highway or interfere with the free and safe flow of traffic ... ."[140]

4.5.1 Variance of State DOT Statutes and Rules

State DOTs statutes and rules, on the other hand, impose a wider variety of requirements on entities that may wish to construct projects on highway ROWs. A utility must obtain a use and occupancy agreement from state DOTs.[141] The agreement must refer to state DOT standards, which are likely to vary.[142] As of 2012, most states "indicated that their utility accommodation plans (UAPs) do not characterize renewable energy facilities as utilities in regarding to accommodating them in highway ROW."[143] Other states "do not make distinction between renewable and non-renewable energy facilities" while some states are silent on the matter.[144] Efforts to create uniform state laws can assist interstate transmission projects in streamlining the process. Interstate transmission projects may also find success in looking at routes other than state highways.

4.5.2 Railroads

Use of railway ROWs to construct interstate transmission lines might be important where the highway system does not cover certain important geographic areas and to avoid certain state statutes that vary regarding parts of the highway system. The NAS project has done a large amount of research regarding areas of the country where use of railway ROWs could help complete the NAS.

The federal government has broad authority to preempt state and local governments when it comes to railroads.[145] Federal preemption was created to ensure that state and local entities did not halt the railroad through varying statutes and rules.[146] The Surface Transportation Board has authority over railroad, including intrastate tracks.[147] There have been many unsuccessful challenges to federal authority of railway from state and local entities.[148] The NAS could use federal preemption of railroads as a way to bypass a highway system that is subject to more state and local control.

However, at present, federal law says nothing about what railroads should do with property it owns, including the granting of easements or rights of way to other private parties. Thus, there must be a reason and incentive for a railroad to permit an existing railway right-of-way to be used as part of the NAS.

Solutionary Rail is a proposal from a team of "rail experts, economists, and public interest advocates" that advances the idea of transmitting electricity through rail lines.[149] Railroads have been linked to energy sources. When the national highway system was built, coal distribution kept railroads afloat.[150] With coal gradually being phased out, it may be time to supplant the railroad industry with renewable energy transportation.[151]

The cost of building a transmission line on a railway right-of-way may be an obstacle. Solutionary Rail has proposed the Steel Interstate Development Authorities as a means to finance its project. The Authorities would be comprised of several government agencies that could collectively fund the project along with the federal government. Perhaps the NAS could partner with Solutionary Rail for transmitting renewable energy.

However, it is unknown whether a railroad would want to be involved in an interstate transmission project. There is the question of how the benefits would go to the railroads. It might be necessary for the designation of the NAS as a national project with incentives to achieve that goal. Thus it might be seen as a follow-on to the Inter-Continental Railway of the 19th century for which so much federal land was originally given to railroads.

Another possibility is to explore the use of abandoned railway corridors for the NAS. Where the railroad received federal granted rights of way (FGROW), there are long established rules regarding the nature of the interest granted and the disposition of FGROW upon cessation of railroad use.[152] In addition, there are special rules for rail banking under Surface Transportation Board (STB) jurisdiction for abandonment under more recent legislation. These rules have been primarily used for the rails to trails program established by the non-profit Rails to Trails Conservancy. These latter rules for actions immediately upon abandonment by a railway do not appear to fit the necessities of the NAS as discussed below but might be adjusted as part of a legislative package for the implementation of the NAS. We plan to work with the Rails to Trails Conservancy to explore this possibility as part of the next stage of this Project.

Regarding FGROW, 43 U.S.C. section 912 provides that such a right-of-way continues to exist as a railway right-of-way usable for railroad or other public highway purposes until either Congress adopts a statute transferring title or until there is a judicial declaration of abandonment, whichever comes first. As a necessary precondition to that judicial declaration, STB must "authorize an abandonment," thus that the line is no longer required for interstate commerce.

If there is judicial declaration of abandonment, then, section 912 states that the title vests in the person or entity owning the legal subdivision traversed by the FGROW. Thus to the municipality concerned or to a state or local government if a public highway is established on that parcel within one year of the judicial declaration of abandonment.

Later, in the National Trails System Act Amendments of 1988, 16 U.S.C. section 1248(c), it was provided that unless a public highway was set within the one year time limit then the federal interest in the FGROW "shall remain in the United States." This latter requirement was set to assist the rails to trails movement but could conceivably be used also for a transfer to the NAS as another type of envisioned public use.

Recent federal court decisions have, however, challenged that remaining federal FGROW interest based on Takings Clause under the Fifth Amendment to the United States Constitution. The Federal Tucker Acts designate the U.S. Court of Claims to resolve takings claims against the United States.[153] The "Little Tucker Act" permits claimants seeking compensation from the federal government under $10,000 to be heard by the relevant federal district court.[154]

The question of a taking turns on what ownership interest was originally acquired by the railroad. This applies not only to rights on federal land but also to other rights not acquired by rail-banking procedures as below. It is the important element also in deciding quieting of title to the land concerned under state law by judicial declaration that resolves adverse claims of ownership and rights in property so it can be used for trails or other public uses as under rail banking below.

The important factors include the method by which the railroad interest was acquired (private grant, condemnation, federal grant or adverse possession) and the property interest acquired (fee simple absolute, determinable or subject to condition subsequent, general or limited easement, or license). A railroad deed may not clearly state the right granted and whether the right-of-way is included. Grant of a conditional (defeasible) fee may mean its extinguishment upon the occurrence of a specified event, such as cessation of rail service. Where the railroad acquired an easement, non-use alone may not be sufficient for abandonment but may have to be coupled with affirmative actions such as piecemeal sales of the corridor or removal of tracks and ties.[155] Thus the acquiring of rights in abandoned railway rights of way in federal land are complex and must be dealt with on a case-by-case and state-by-state basis. The preparation of initial case studies will put these issues in more concrete focus.

Finally, the second possibility is to explore the abandoned railways legislation enacted to protect the railway system for future use following the increasing number of abandonments and railway bankruptcies starting in the 1970s. These rules are difficult to apply for use by the NAS but indicate what is now being done to use such railways for public uses such as trails.

The STB has jurisdiction over interstate railway service, and thus exclusive authority to issue a certificate of public convenience and necessity authorizing abandonment. STB authority preempts any conflicting state or local law.

The Railway Revitalization and Regulatory Reform Act of 1976 (4-R Act) provides authorization for the STB to impose a Public Use Condition as part of an abandonment authorization. That Condition defers the disposition of railroad rights of way for 180 days to allow for possible transfers for public use.[156]

The restrictions on railway abandonments were then loosened in 1980 under the Staggers Act. Railways that had been out of service for two or more years could abandon their lines under an abbreviated notice process.[157] However, this led to sale offs of underlying property or allowing claims of adjacent landowners that risked making the rail system very fragmented.

Then in 1983, Section 8(d) of the National Trails System Amendments Act set up a national policy to preserve established rights of way for future re-activation of rail service, to protect rail transportation corridors, and to encourage energy efficient transport use.[158] This Law established a rail banking process under the STB by which a railway could free itself from an unprofitable rail line by transferring it to a qualified private party or public authority for interim use as a trail until the line is needed again for rail service.[159]

The rail banking procedures are complex and have a number of problems that make them difficult to use for the NAS. The railroad concerned must agree to enter negotiations with the interested party and reach a voluntary agreement within the 180-day period set under the 4-R Act for the transfer by sale, lease or donation. What is issued by the STB is a Notice or Certificate of Interim Trail Use. Thus the agreement must provide that the corridor remains available for future restoration of rail service. A rail banking order will not be issued by STB if the railroad has already sold sections of a corridor for non-transportation uses. STB loses its jurisdiction if the railroad "consummates" its abandonment authority prior to the issuance of the above notice. Also, once STB loses jurisdiction over the corridor, then state law principles would apply. Some states have no clear answer as to who owns a railway corridor. Many states give priority to the rights of nearby landowners according to ownership principles discussed above.

In some cases, abandonment of a railway easement may be inferred when the corridor is put to uses outside the scope of the easement. Trail use has been considered as within the easement as a broader public use (shifting public use policy). This rule might apply to an NAS right-of-way as well, but different states have different policies.

Finally, the federal definition of abandonment under these laws is where STB grants the railway permission to terminate its common carrier obligation to provide rail service and liquidate its property interest in the rail corridor. However, that authorization is permissive only. Abandonment under state law generally requires actions of implementation, such as removal of tracks and ties and transfer of the line for non-railroad use.

There are many general problems with the use of abandoned railway rights of way that must be considered on a case-by-case basis. There is a strong policy reason that the NAS has a strong public use justification for such use. The next step will be a review of the rails to trails program to see whether legislation can be provided to fulfill that public use. Railroad rights of way, in general, can be an important supplement to highway rights of way for the creation of the NAS that avoids where possible the purchase of private land rights.

4.6 Regional Approach: The Argument for a Regional Transmission Organization or Independent Service Operator Centered Regulatory Structure for the North American Supergrid

Incorporating the NAS into the existing regulatory framework for transmission line projects would not be impossible; however, it would be costly and possibly temporally prohibitive. A nation-wide electricity transmission project within the existing regulatory scheme would require coordinated compliance with regulatory siting bodies across the lower 48 states. Siting authority across states results in multiple decision-makers applying multiple legal standards. A new regulatory framework with a consistent, nation-wide structure for interstate transmission projects like the NAS would best be provided through Congressional legislation. Thus, Congress should pass legislation which transfers authority from the individual states to create a new regulatory framework to accommodate the NAS, and contribute to its overall goal of a national energy market with increased capacity for renewable technology connectivity. This section will address this topic, and proposes a RTO or ISO centered framework in order to retain regional power, in a cooperate form, without surrendering siting authority to the FERC.

This proposal draws heavily from the writings of University of Minnesota Law School Professor Alexandra Klass, who has served as a member of the NAS Steering Committee.

4.6.1 The Need for Change

4.6.1.a Barriers to the NAS

Advancing the NAS in the current regulatory state is theoretically possible—but could prove to be functionally impossible once the siting process begins across the lower 48 states. Specifically speaking, the circumstances justifying a regulatory shift in authority include:

1) the physical nature of the grid which long ago grew from local and state based origins to a regional, multi-state network that facilitates interstate, wholesale electricity market transactions;

2) the growth of renewable energy, particularly wind energy which is often located far from population centers and can only be transported by interstate transmission lines, in contrast to fossil fuels which can be transported by train, pipeline, truck, or ship throughout the country;

3) the growth of RTOs—federally-approved nonprofit entities that manage the transmission of electricity within multi-state regions in many parts of the country, operate wholesale market transactions for electricity, and oversee the planning of transmission grid expansions within their foot prints; and

4) developing state and federal clean energy policies such as state renewable portfolio standards and the U.S. Environmental Protection Agency's (EPA's) 2014 proposed greenhouse gas (GHG) rule for existing power plants, which has the potential to fundamentally shift the dominant electric energy sources throughout the country in future years toward increased renewable energy."[160] However, it is very uncertain whether these rules will be implemented under the Trump administration. Since the time of writing, the Trump Administration's EPA Director Scott Pruitt has proposed a new rule to repeal the Clean Power Plan's emission guidelines for existing Electric Generating Units (EGUs).[*]

5) lastly, the current grid as is is ill equipped for three main security challenges: EMPs, structural integrity, and cybersecurity.

A starting point for regulatory analysis regarding the NAS is the WPP, a connection between Arizona and California created by installing the wire overlay technology along the path of the I-10 freeway. The WPP specifically highlights the large number of different regulatory authorities for just two states individually. This is representative of the multiple permitting agencies and stakeholders involved in each stage of siting a transmission line.

While the need for an updated regulatory framework is evidenced by the changing nature of the electric grid, what to change and where to start can be a daunting task for developers of projects like the NAS. It is useful to consider

* Repeal of Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Generating Units, 82 Fed. Reg. 48035 (proposed Oct. 16, 2017)(to be codified at 40 C.F.R. pt. 60).

the process for previously developed nationwide energy infrastructure projects and compare those circumstances to those implicated in the proposal for the NAS.

4.6.1.b Parallels from the Natural Gas Pipeline System

The development of the natural gas pipeline system is a comparable illustration with regard to the regulatory considerations for an interstate system. Congress granted federal siting and eminent domain authority for interstate natural gas pipelines under the Natural Gas Act of 1938, with amendments in 1947.[161] For a developer to begin construction, it must first apply to obtain a Certificate of Public Convenience and Necessity from FERC (states have their own respective certificates for intrastate projects). In its evaluation, FERC determines whether the applicant is willing and able to perform the operation, sale, service, construction, extension or acquisition while in compliance with any rules or regulations of the Commission, and that the action "is required by the present or future public convenience and necessity."[162] If the applicant is unable to meet this statutory criteria, the application will be denied.

Once a pipeline receives a Certificate of Public Convenience and Necessity from FERC's predecessor (the Federal Power Commission), the pipeline operator is granted nationwide eminent domain authority along the path of the pipeline if they cannot not first enter into voluntary easements with implicated landowners.[163] Such a structure is beneficial for pipeline developers because it offers a centralized authority and, in many cases, greater certainty and lower costs of implementation by eliminating roadblocks created by multiple state permitting and eminent domain requirements.

In comparison to current circumstances, using a federal regulatory approach in implementing the NAS would require a major shift in regulatory structure. Even though grid connectivity implicates both interstate commerce and nationwide security, electricity transmission line siting and permitting is a power held primarily by the individual states.[164] This allows states to have final authority on the lines which run through them, requiring consideration of local market interests, as well as geographic and aesthetic concerns. Shifting such a power to FERC would federalize the line siting process and has the potential to be not just politically unpopular amongst states, but could produce economically inefficient results for localized interests not taken into account.

On the other hand, increased transmission capacity is necessary for the inclusion of renewable energy resources, specifically wind and solar, as well as natural gas, as the transmission lines are the sole option of transport for such resources. This is in contrast to other modes of energy generation, such as oil, which is easily (and sometimes dangerously) transported by pipeline and rail.[165]

While the regulatory framework for the natural gas pipeline system is useful as guidance in the development of regulatory reform considerations for the NAS, it should not be followed for this project. The rise and resulting success of regional organizations like RTOs and ISOs offer a less federally-centralized option—a benefit to states and local regions, whose diverse energy resource portfolios would be benefitted by localized focus.

What is also apparent from this history is that it "shows that Congress is able to move beyond state authority in the energy law context when there is a drive to turn what has historically been a locally constrained energy resource into a national one."[166] The reality is that the modern electric grid's potential for capacity and technological progress is stymied by the slow pace of achieving the regulatory go-ahead state by state. Therefore, a regionally-centered approach, like placing the decision-making authority in the hands of a regional body, can streamline the line siting process while safeguarding local control.

4.6.2 Proposed Modified Framework

4.6.2.a Introduction and Politics of RTOs/ISOs

Regional bodies like RTOs and ISOs are "FERC-approved nongovernmental agencies that manage portions of the transmission grid and regional markets for wholesale power for much of the country."[167] RTOs/ISOs provide three key functions: 1) while utilities maintain ownership of their lines, RTOs/ISOs handle day-to-day operations like running the transmission grid, 2) operating and setting prices for wholesale electricity markets within each jurisdiction, and 3) planning for grid expansions.[168] The EPAct of 2005 preserved the status of the organizations "as central to the wholesale markets."[169] The structure of RTOs and ISOs allow the bodies to provide significant benefits, specifically lowering prices for end consumers.[170] We provide describe the geographic layout of all the RTOs and ISOs in 3.3.

In the FERC Notice of Proposed Rulemaking (NOPR) first authorizing RTOs in 1999, the Commission found RTOs could improve efficiencies in grid management, improve grid reliability, remove opportunities for discriminatory transmission practices, improve market performance and "facilitate lighter-handed governmental regulation."[171]

It is important to consider why RTO membership is not already mandatory, and the circumstances surrounding that decision. Initially, FERC considered mandating RTO membership, though "it eventually instead required that public utilities either join a FERC-approved RTO or report on their progress toward joining one."[172] Through FERC Order No. 2000, codified in 1999, the Commission encouraged utility participation in RTOs in order to shift to a regional approach. Order No. 2000 requires that "each public utility that owns, operates, or controls facilities for the transmission of electric energy in interstate commerce make certain filings with respect to forming and participating in an RTO."[173]

While RTOs and ISOs already cover roughly two-third of the U.S. population, a main contributor to the lack of nationwide participation has been political opposition centered in the Southeast and the West.[174] Oregon Representative Greg Walden commented in a 2017 congressional hearing that there have been failed attempts for RTO formation in Oregon and Washington—a failure fueled by opposition which is still present today.[175] While FERC Order No. 2000, which was a compromise of sorts, was released in 1999, the regional politics of forming an RTO or ISO might not have changed enough over that time to make nationalized participation a reality. This only highlights the need for government participation to incentivize unassociated regions. In light of this, the proposed regulatory reform should not be squashed as a political impossibility as the movement toward cleaner energy has gained momentum nationwide. RTOs and ISOs have been leaders to including more renewable resources onto local grids, and implementing the NAS only increases the amount of accessible renewable energy sources with connectivity capability.

Many states have already passed legislation declaring a commitment to grid modernization technology and are in the developing stages of their own respective plans. The North Carolina Clean Energy Technology Center—out of North Carolina State University—tracks grid modernization strategies in all 50 states and published a report[176] with some existing regulatory considerations. The largest commitments so far come from both Illinois and Ohio. Illinois' project *NextGrid* is described as a "utility of the future study."[177] The state's Commerce Commission just ended the public comment period for proposals on both technology and utility and regulatory models to modernize the energy grid and benefit end use consumers. Ohio's *Power Forward* is an initiative of the state's Public Utility Commission to examine technologies, ratemaking and regulation recommendations from stakeholders.[178] In addition, in the wake of withdrawal from the Paris Climate Accord, states and cities across the country have publicly asserted their individual leadership in achieving the goal of a more sustainable energy future.

In the time since their creation, RTOs and ISOs have proven to have the expertise when it comes to "setting wholesale electricity rates, planning new transmission lines, and acting as a forum where multiple stakeholders, including regulated entities, consumer interests, and state can collaborate on these issues."[179] Existing RTO and ISO bodies act as an example for how such regional structures can bring together all relevant stakeholders and craft workable solutions for providing electricity. Next it is important to look at how RTOs function, and then how they can serve as a model for a nationalized regional solution.

4.6.2.b Mechanics of RTOs

To be considered an RTO sanctioned by the Commission, Order No. 2000 sets out minimum characteristics, which are "1) independence from market participants; 2) appropriate scope and regional configuration; 3) possession of operational authority for all transmission facilities under the RTO's control; and 4) exclusive authority to maintain short-term reliability."[180]

The gaps in RTO/ISO coverage leave an opportunity for unassociated utilities to form their own RTOs or ISOs, or join existing ones to work collaboratively on transmission line siting. States choosing to form their own regional bodies can look within their own public utilities for guidance. Western states have begun to organize in an impressive regional wholesale market in the form of the Western Energy Imbalance Market (WEIM). WEIM formed out of CAISO and is a bulk power market with utility membership spanning across 8 states – Washington, Oregon, California, Arizona, Nevada, Utah, Wyoming and Idaho. Regional leadership such as WEIM could be beneficial for implementing the NAS across the West.

4.6.3 Paths to Achieving the Regional Approach

In order to meet the goal of an RTO-centered regulatory structure, there are two promising paths; the first centered on states themselves and the latter requiring Congressional action—though there is room for Congressional participation along both paths.

First, EPAct 2005 "allows three or more contiguous states to enter into interstate compacts to establish regional siting authorities to determine the need for future transmission facilities within those states and carry out the transmission siting responsibilities of those states."[181] Such authorities could then review, certify and permit the siting lines for transmission facilities.[182] The National Center for Interstate Compacts (NCIC) has proposed a model compact for this option, including:

1. A state project review panel within each member state to coordinate the views of different agencies and interests in the state.

2. A combined multi-state siting authority, consisting of states affected by the project authorized to make siting decisions for the project.

3. Interstate Compact Commission to provide administrative support and rulemaking capability.[183]

This would provide the structure for states to have representation, meaning each state's local concerns can be voiced, while the ultimate decision will likely weigh what is best for the region as a whole. Such a democratic system could avoid the problem of individual state holdouts blocking interstate transmission projects which would be regionally beneficial. As an example, Southwest Power Pool President and CEO Nick Brown recently testified before Congress that the RTO formed a Commission with representation from each member state to invest in $10 billion into transmission across the RTOs 14 state footprint.[184] Brown also testified that but for transmission growth in the region such as this, the rise of wind energy would not have been possible.[185]

One problem with this interstate compact approach is that there is no incentive for states to engage with partners to form regional authorities. A possible solution would be to stipulate in the delegating legislation that absent an interstate compact, transmission line siting authority would default to FERC or offer additional funds for participating states.[186] In order to retain authority over transmission line siting, states would be incentivized to form compact agreements rather than lose representation.

A second option would be for Congress to pass legislation delegating line siting authority to RTOs and ISOs within their footprint.[187] It's useful to consider federal precedent of support for RTO planning in analyzing the likelihood of federal legislation. FERC has supported RTO planning efforts in both Order No. 1000, which mandated "a regional transmission planning process for the first time with RTOs playing a central role in the process in the areas where they exist, and places regional planning process requirements on all public utility transmission providers regardless of whether they are part of an RTO."[188] Such an exercise of FERC authority was upheld in subsequent legal challenges[189] and the 2013 decision in *Illinois Commerce Commission*.[190] In addition, both RTOs and ISOs have a history and reputation of successfully creating a forum for implicated stakeholders—including utilities, consumer advocates and local governments.

Any discussion of encouraging of congressional legislation requires a subsequent discussion on the likelihood of political success. However, rather than a general discussion on the politics of including increased renewable resources onto the nation's grid, the scope of political discussion here will be limited to the specific legislative requests of the NAS, i.e. a legislative grant of line siting authority with incentives for nationwide RTO/ISO participation.

4.6.4 Political Hurdles

The overall likelihood of Congressional legislation granting line siting authority to regional bodies is quite uncertain. As previously mentioned, regional politics has been a main contributor to the lack of national RTO/ISO participation and could translate to national politics as well. However, there are some members of Congress who recognize the role of regional organizations in the national wholesale electricity market and are open to hearing if any federal action is needed. In July of 2017, the House Energy and Commerce Committee held a hearing on just that, including witnesses from the leadership of various RTOs and ISOs.[191] While the focus of that hearing was the broad role of RTO/ISO participation in wholesale electricity markets, the discussion of the hearing here will be limited to the scope of this policy document—which is how RTO/ISO-centered authority for transmission line siting is preferable for implementing the NAS.

NYISO Chairman and CEO Bradley Jones told the story of how the New York power grid was "a tale of two grids"—upstate the grid is fueled by nuclear, hydro, wind and solar energy, whereas the southern portion of the state is powered with 75% fossil fuel generation.[192] This highlights the importance of transmission lines in remedying grid disparities amongst regions. Jones testified that focusing on transmission projects would help the state meet its goal of 50% energy from renewables by the year 2030.[193]

Representative Jerry McNerney posed an open question to all witnesses in the hearing asking what federal policies could encourage investment needed to address the changing circumstances on the grid.[194] While the responses varied amongst region, the most occurring answers covered grid resiliency, and regulatory certainty and stability.[195] If legislation granting RTO/ISO transmission line siting authority succeeded, the NAS initiative would best be equipped to address these organizational goals.

4.7 Conclusion

Constructing and obtaining the necessary permits for the NAS will be an arduous and lengthy task. Fortunately, there are several pathways to success. The NAS can use private lands and can petition state and local governments for expanded uses of eminent domain. By participating with local state Public Utility Commissions, the NAS developers can apply for eminent domain authority to serve regional goals. Expanding federal authority may also streamline the permitting process but could also ignore state and local concerns. On the other hand, a state-based approach could meet those concerns but may become tedious. An RTO could provide a balance between both approaches as long as states are willing to work with each other.

If private lands are inaccessible, the NAS could use BLM segregated lands and take advantage of the competitive process or use highway corridors. The problem, however, with highway corridors is varying state statutes and regulations. Using railroads as potential ROWs could sometimes be simpler.

The NAS could also obtain a ROW through tribal lands held in trust by the federal government, so the NAS would have to work the tribes and BIA. Finding ways to allow the tribe to play a more central role in granting ROWs could be key to streamlining the process.

While planning a process for implementing such a wide scale initiative, the NAS must consider the existing regulatory framework and must offer concrete changes to existing regulatory policy to best accommodate the project. In the case of the NAS, the HVDC wire overlay would best be implemented and operated through a regional body such as an RTO or ISO. While these bodies exist and currently serve regional markets in a beneficial way, we advocate for a nationwide and independent RTO/ISO structure to be the primary regulatory authority governing interstate transmission lines. This strikes a balance between local concerns and centralized federal authority. Such a regulatory shift would require Congressional action.

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5 Areas of further study

Building upon the research described in this publication, our team has identified several additional tasks that will further refine each area of research included in this document as we continue to study the challenges and benefits of the NAS:

1. Additional technical feasibility studies encompassing more varied geographical regions will be conducted, supplementing the two completed case studies that analyze grid configurations in the Western US and off the Atlantic Coast.

2. Determinations of the new system's consumer price allocation structure must be made. Preliminarily, we have identified lucrative locations for possible initial line siting. To date, little definitive research has been done examining the issue of rate allocation in a single national market once initial lines are built, and the network is expanded. Similarly, we will examine which of these lucrative regions in the NAS system are most essential to national security.

3. The potential for black starting (after an EMP or GMD event) to be more reliable or occur more rapidly with a EMP-GMD-cyber protected overlay system working in conjunction with a more outdated, non-EMP protected system. We will examine whether estimates of remaining critical infrastructure be made in current conditions so authorities can conduct precautionary planning.

4. Load balancing in national centralized systems can impact electricity prices. Modelling of transmission load balancing utilizing the North American Supergrid as a theoretical test case would allow for quantitative determination of price changes with an integrated, renewables-based system.

5. EMP threats are an imminent concern. While shielded HVDC cables afford some protection, it remains unclear if the transposition of DC lines (in both above and below ground configurations) would further cancel excess current in the event of an EMP or GMD event.

6. Outreach to key players in relevant aspects of this initiative (manufacturers of major components, construction companies, regional governing bodies) must be strengthened to promote the eventual construction of a pilot project (originating from one of our case studies).

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