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Our Transportation and Energy Future – Industries Collide

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SUMMARY

The future of transportation will largely be defined by electric, connected, and autonomous vehicles. It will also be defined, and possibly delayed, by the infrastructure it takes to support these vehicles. To fully support these vehicles, our existing transportation infrastructure will need to evolve to incorporate the electric infrastructure to power these vehicles and the communications infrastructure to support their connected and autonomous functionality. In short, our existing infrastructure will need to become integrated. Frameworks for integrated infrastructure and policy to suport integrated infrastructure are just starting to emerge. In April 2021, the White House announced a coordinated set of actions by the US Department of Energy and the US Department of Transportation that would encourage the development of Clean Energy and Connectivity projects along the United States highway system.

Considering the broader needs of our existing energy and communications infrastructure, it is clear that interregional transmission presents an early opportunity for the development of integrated infrastructure. Interregional transmission is critical to the rapid and economic decarbonization of the existing electric system. Problematically, interregional transmission is notoriously hard to develop. Interregional transmission projects often face significant public opposition (because of their tall towers and lack of local benefits) and lengthy permitting times (due to the large number of government agencies and public interest groups involved). The combination of new transmission technology – buried HVDC transmission cables – and the existing highway right-of-way has the potential to directly reduce both public opposition and the lengthy permitting timeline.

However, before buried HVDC transmission and the existing highway right-of-way can be utilized to construct interregional transmission, there are safety and operational concerns that have to be addressed. Departments of transportation need to ensure that integrated infrastructure won't affect either the safety of the highway system or the flow of traffic on it. Common questions from departments of transportation include: what (if any) infrastructure will be above ground? how frequently will it require maintenance? Conveniently, the buried nature of HVDC transmission in a protected right-of-way mitigates many of these concerns.

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Utilities also have concerns with regards to buried HVDC transmission, with cost being the primary concern. Though the cost of buried HVDC transmission is 2-4 times more expensive than overhead HVDC transmission, it also has a number of benefits that work to offset its higher cost. The primary benefit is a clear path to the development of interregional transmission (as has been seen in Europe) and its associated system cost reductions – reductions that can offset the transmission cost increase. Additional benefits include protection against severe weather events and the option to harden against geo-magnetic and electro-magnetic disturbances.

The paper concludes by presenting an illustration of a reimagined highway cooridor that considers the economic development and resilience opportunities afforded through the development of integrated infrastructure.

KEYWORDS

Interregional Transmission; HVDC Transmission; Transportation Electrification

The Need for Integrated Infrastructure

Hundreds of billions of dollars are now being invested in electric, connected, and autonomous vehicles.[1] The successful operation of these vehicles will be entirely dependent upon a grid that can power them and communications infrastructure that enables operation in all weather conditions.

To enable the future of transportation, countries will have to undertake a massive infrastructure buildout that better integrates their existing transportation, electric, and communications networks.

This integrated and intelligent infrastructure will be key to countries achieving rapid decarbonization, a modern transportation system, and improved broadband access for all citizens. Integrated and intelligent infrastructure has the potential to create a plug-and-play platform that delivers timely interconnection for generators and loads with a significant reduction of site-specific engineering study and design work and of communications systems integration work.

Efforts are already underway in China and the United States to develop integrated infrastructure. China's Global Energy Infrastructure Development and Cooperation Organization (GEIDCO) is working to advance its Energy-Transportation-Information framework. In the United States, the author and partners have launched the NextGen Highways initiative. The initiative proposes to:

1. Uses a portion of the interstate highway system right-of-way to construct electric transmission facilities, including a national underground HVDC transmission grid
2. Strengthens the electric grid in key transportation corridors, thereby increasing the grid's capacity to support zero-emission medium and heavy-duty vehicles
3. Deploys broadband and 5G communications infrastructure in parallel with the above grid investments to reduce the digital divide and to prepare for connected and autonomous vehicles.

Notably, the NextGen Highways initiative builds upon recent federal policy changes in the US. On April 27th, 2021, the White House outlined a coordinated set of actions by the US DOT and the US DOE that enables integrated infrastructure.[2] Specifically, the US DOT established a vision for 'Clean Energy and Connectivity' projects and the US DOE provided $5 billion of funding for innovative transmission projects, including HVDC projects and projects that would utilize transportation right of way.

Integrating our Infrastructure

In many areas, our infrastructure is already integrated. The lack of space in dense urban cores forces all infrastructure (transmission, distribution, fiber, water, gas, and sewer) to be buried beneath the roads. In urban areas, distribution infrastructure is located along roads, while water, sewer, and gas lie beneath the roads. And in rural areas, transmission and distribution lines often run directly along local highways and county roads. These lines may also carry fiber to provide broadband for local residents.

However, in a key area for the future of transportation - interstate corridors - our infrastructure is largely not integrated. To integrate power and communications infrastructure in our interstate corridors there are a few barriers that need to be overcome.

The first major barrier to the integration of the interstate right-of-way (ROW) is institutional. Both state departments of transportation (DOTs) and utilities have legitimate concerns that need to be addressed to enable integrated infrastructure in interstate corridors.

The overarching concern for both DOTs and utilities is safety. Interstate-corridors and high-voltage power equipment are each dangerous in their own right. The high vehicle speeds on interstates mean that any fixed object adjacent to the highway ROW represents a significant risk to any vehicles (and their passengers) that depart the travel lanes. The high vehicle speeds also pose a significant risk to any individuals working on infrastructure within the highway ROW (whether that is the road-surface or other co-located infrastructure). It is for this reason that state DOTs tightly control access to the highway ROW. Similarly, electric utilities carefully safeguard their ROW for high-voltage transmission lines.

A few of the questions that will need to be answered to address safety, financial, and process concerns from DOTs and utilities include:

- What (if any) above ground infrastructure will exist?
- How much space will the power and communications infrastructure require?
- How long will it take to install the power and communications infrastructure?
- How often will the power and communications infrastructure require maintenance?
- How can maintenance of the power and communications infrastructure be done safely and without impacting traffic flow?
- How can lines be sited to minimize impacts in the event of highway expansion?

A second critical barrier to integrated infrastructure that some state DOTs will need to address is the prohibition of longitudinal siting of transmission along interstate ROW. Many states (either in their regulations or their DOT's utility accommodation manual) prohibit the siting of transmission along the interstate ROW. This prohibition was good policy when the interstate was first built (60 years ago), but will need to be updated in the light of our future transportation needs.

Once these and other barriers have been addressed, the interstate ROW will yield sizable opportunities for the deployment of integrated infrastructure. There are over 40,000 miles of interstate ROW in the US. All of this ROW has already been disturbed and undergone various studies. As a result, the required permitting (NEPA and 106) will be significantly easier than they would be for new ROW. In the context of interregional transmission, utilization of the highway ROW will avoid lengthy and contentious fights over eminent domain, not-in-my-backyard objections, and avian impacts.

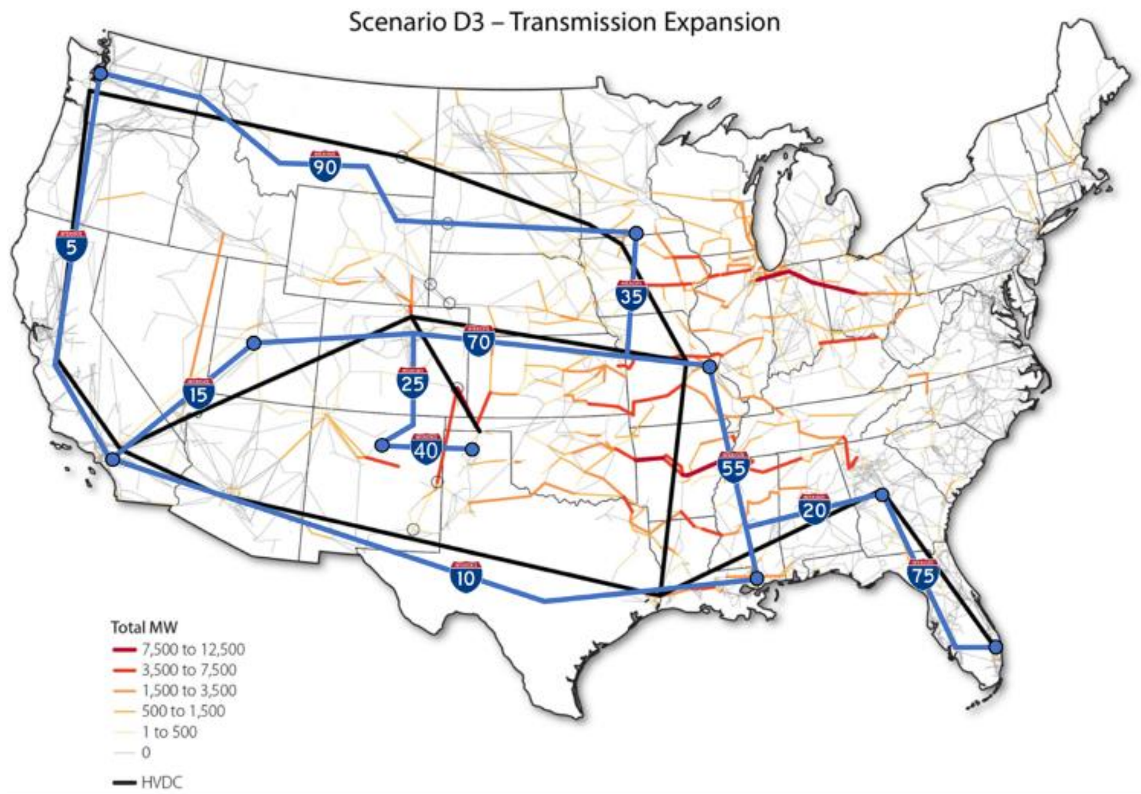
Interregional Transmission - a Starting Place for Integrated Infrastructure

The construction of interregional transmission across North America is a logical starting place for the development of integrated infrastructure. The benefits of interregional transmission have been widely documented. The challenges of interregional transmission have also been widely documented. Buried HVDC transmission in existing transportation ROW has the potential to overcome two of the larger barriers to interregional transmission - public opposition to overhead lines and lengthy permitting timelines.

Figure 1 illustrates how select parts of the existing federal highway system in the United States aligns well with the HVDC grid identified by the National Renewable Energy Lab's Interconnection Seam Study.[3] The black lines in the figure represent the hypothetical

HVDC grid that was modeled. The dark blue lines represent the parts of the existing US interstate system that could be used for the construction of a nearly equivalent HVDC grid. As can be seen, there is a strong overlap between the two.

Figure 1. Alignment of existing federal highway system with the national HVDC grid evaluated in NREL's Interconnection Seam Study. This figure is modified from Figure 5 of a paper describing NREL's Interconnection Seam Study.[4]



The Cost & Benefits of Interregional Transmission in the Highway ROW
Cost is in many ways a third critical barrier as it relates to transmission in the interstate ROW. Buried HVDC transmission - the type of transmission that state DOTs are willing to consider having in their ROW - is buried. And buried transmission has a reputation within the electrical utility industry for being costly.

When discussing the costs of buried HVDC transmission it is important to note that:

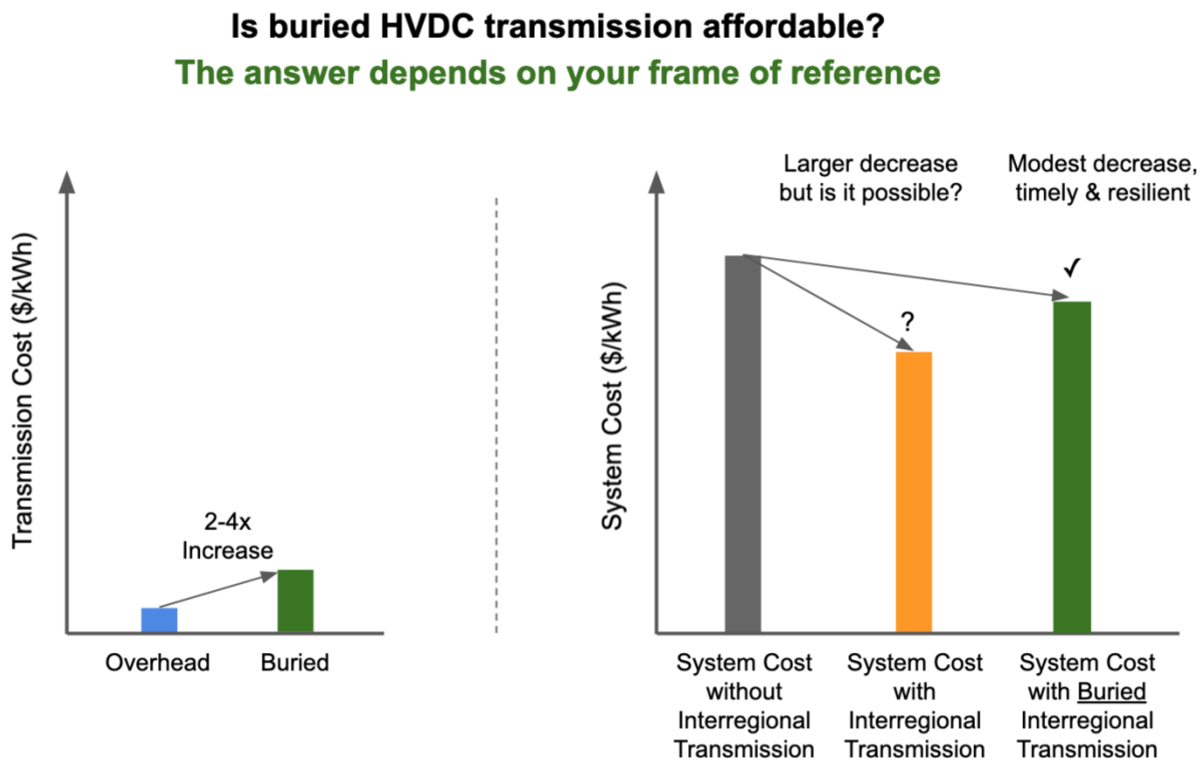
1. it is 2-4X the cost of overhead HVDC, which is relatively much lower than the 5-10X the cost increase for buried AC transmission[1]
2. it provides benefits that overhead transmission doesn't (e.g., greatly reduced public opposition and hardening against physical threats)

When evaluating the cost of buried HVDC transmission it is important to consider not just the transmission cost difference, but the total system cost difference. Figure 2 illustrates how the cost increase of buried HVDC transmission can appear unaffordable from a transmission cost perspective and nonetheless affordable from a system cost perspective. The transmission cost

[1]It is important to note this because buried HVDC transmission is often dismissed without due consideration because of an immediate association with buried AC transmission costs

perspective considers the project as a single financial asset absent the surrounding system. The system cost perspective considers the project as part of a larger system. A larger system where transmission costs are a small fraction of the total system cost. Critically, the system cost perspective takes into account that the project may deliver highly valuable interregional transmission capacity in a much more timely manner and with greater certainty than an overhead project.

Figure 2. Illustration of how the affordability of buried HVDC transmission depends on the frame of reference.

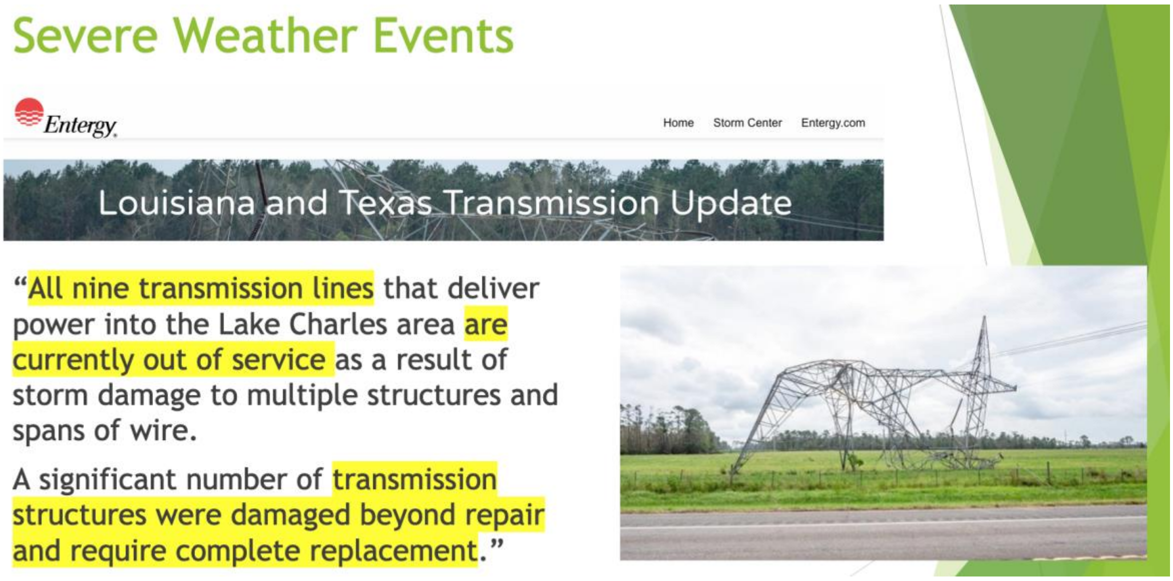


Buried HVDC transmission also provides a number of benefits that overhead HVDC transmission does not. These benefits include:

- significantly lower public opposition
- protection from severe weather events (e.g, hurricanes, ice storms, wildfires)
- optional protection from geomagnetic disturbances (e.g., solar flares or an EMP attack)
- significantly lower land use impacts (compared with new ROW)
- and the potential for greatly reduced permitting timelines

As one example of the potential value of buried HVDC transmission during a severe weather event, consider the effects of Hurricane Laura in 2020. Hurricane Laura knocked out all nine transmission lines delivering power into the Lake Charles area of Entergy's service territory.[5] And many of the transmission structures were damaged beyond repair, such as the tower shown in Figure 3. Hopefully it is clear that the ability to provide a basic amount of energy to critical infrastructure during an event like this would have tremendous value to the local residents and businesses and that an underground transmission line with an appropriately sited converter station could deliver exactly that.

Figure 3. Impact to Entergy's transmission system as a result of Hurricane Laura.[6]



The value of these benefits can be hard to quantify and even harder to pay for upfront, but that doesn't mean they aren't real. In a future where we electrify larger and larger portions of our economy and where we experience a greater frequency of severe weather events, the value of these benefits will only grow.

Last but not least it is worth touching upon the EV benefits that would be associated with the construction of buried HVDC transmission within the interstate ROW. The West Coast Clean Transit Corridor Initiative conservatively estimately almost $1 billion of grid upgrades that would be needed to support modest electrification of medium and heavy-duty vehicles.[6] It also found that nowhere along the west coast does sufficient grid capacity exist to support over-the-road charging of heavy-duty vehicles and that sufficient grid capacity for the charging of medium-duty vehicles only exists in urban areas.

Now consider interregional HVDC transmission lines buried within the interstate ROW and having converter stations situated every 100-150 miles. The main function of these converter stations would be to pick up solar and wind power from rural areas for delivery into major urban centers. But there is no reason that these converter stations and adjacent storage couldn't secondarily support over-the-road charging needs for medium and heavy-duty vehicles. In fact, doing so would make perfect sense and would likely reduce a majority of the $1 billion of grid upgrade costs identified by the West Coast Clean Transit Corridor Initiative.

What Would Integrated Infastructure Look Like?

Figure 4 provides an illustration of a re-imagined Interstate-35 corridor. In this reimagined interstate corridor integrated infrastructure would create an energy and communications backbone that drives economic development in both rural and urban areas.

Critically, this energy and communications backbone would be hardened against physical and cyber-attacks, allowing it to operate as a provider of last resort in the event of an attack on the existing electric grid and communications infrastructure.

In rural areas, economic development would be focused on data centers, energy resources (e.g., solar, wind, storage), and over the road charging of electric vehicles.

In urban areas, economic development would be focused on fleet electrification, re-development of retired generation assets (including their transmission infrastructure), data centers, and energy resources.

In between these rural and urban areas, integrated infrastructure would deliver wireless broadband services to communities adjacent to the highways and would support the operation of connected and autonomous vehicles.

Figure 4. Illustration of an Interstate Corridor with Integrated Infrastucture.

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