California North Coast Offshore Wind Studies

Interconnection Constraints and Pathways

This report was prepared by Mark Severy, Tanya Garcia, Zachary Alva, and Arne Jacobson of the Schatz Energy Research Center. It is part of the *California North Coast Offshore Wind Studies* collection, edited by Mark Severy, Zachary Alva, Gregory Chapman, Maia Cheli, Tanya Garcia, Christina Ortega, Nicole Salas, Amin Younes, James Zoellick, & Arne Jacobson, and published by the Schatz Energy Research Center in September 2020.

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The Schatz Energy Research Center at Humboldt State University advances clean and renewable energy. Our projects aim to reduce climate change and pollution while increasing energy access and resilience.

Our work is collaborative and multidisciplinary, and we are grateful to the many partners who together make our efforts possible.

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1. INTRODUCTION

The northern California coast has access to an enormous offshore wind resource that could be used for renewable energy production, but there is limited regional load and transmission capacity to either use this electricity locally or transfer it to other load centers in the state. The Bureau of Ocean Energy Management (BOEM) has identified an area of the coast of Humboldt Bay that is being considered for a competitive lease auction to offshore wind developers (BOEM, 2018a). The Humboldt Call Area, located west of Humboldt Bay (BOEM, 2018b), is large enough to accommodate an estimated 1.8 gigawatts (1.8×10^9 watts) of installed offshore wind capacity that could interconnect to the electrical grid in Humboldt County. While the offshore wind speed profile is well suited to energy generation, there are several challenges associated with development including the construction of new transmission infrastructure.

The electric transmission system in the Humboldt Planning Area is connected to California's bulk transmission system through four circuits at 60 kV and 115 kV (Figure 1). Electric load in the region is met through four local generators and electricity imported on the transmission network. The transmission is built to serve local load and not designed to be a large exporter of electricity. Interconnecting an offshore wind farm within the Humboldt Planning Area will require upgrades to the transmission system.

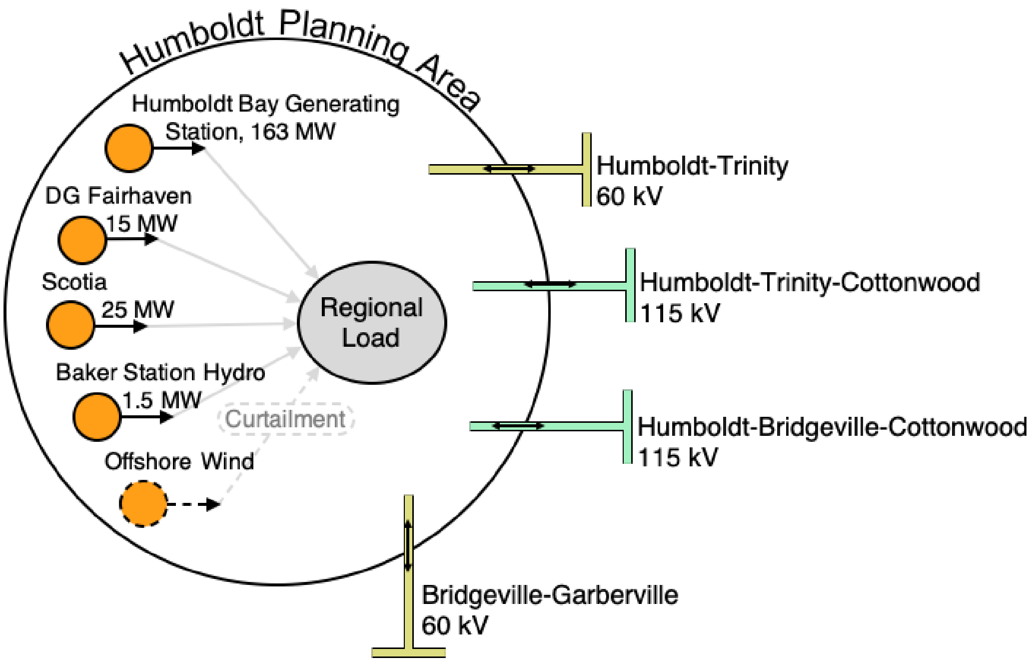


Figure 1. Humboldt County electrical system and model inputs and outputs.

This report describes the required transmission upgrades for interconnecting offshore wind on the north coast and the different pathways to develop the transmission infrastructure. The report presents:

- Permitting pathways for developing new transmission infrastructure in California (Section 2),
- Technical requirements for interconnection of offshore wind generation from the Humboldt Call Area (Section 3),
- Estimated costs of the transmission upgrades (Section 4)

2. PATHWAYS FOR TRANSMISSION DEVELOPMENT

The electric transmission system provides a link between different generation facilities and distribution networks to move energy from the generation source to the end use. The transmission system is designed to meet the capacity requirements of regional electricity load and electricity generating facilities. Transmission lines are built and expanded to ensure reliable and safe transfer of power. When new generation sources are proposed, such as offshore wind in the north coast, the existing transmission network must be evaluated to determine if the new generation source will exceed the capacity constraints of the system. Transmission improvements are then proposed as needed to allow safe and reliable interconnection of a new generation source. Transmission improvements can include upgrades or new construction of transmission cables or the substations that serve as connection points along the transmission path.

There are two pathways to build transmission in California to support new generation. One pathway is for the interconnection customer to propose a new generation facility then work with the regional transmission owner and the independent system operator to build transmission upgrades to accommodate the new generation source. In this approach, the cost of the upgrades is carried by the interconnection customer. Another pathway is for State policy to drive the support of new transmission to meet mandates for reliability, renewable generation, or safety. Under this state-led approach, the cost of the upgrades is ultimately carried by ratepayers, although some investments must be made by the interconnection customer. Both pathways are described in the subsections below.

2.1 Interconnection Customer

When a new generator proposes interconnection to the independent systems operator (ISO) controlled transmission system, the ISO must analyze the ability of the existing transmission infrastructure to absorb the proposed electricity generation without creating reliability or safety impacts to the grid. If the existing infrastructure cannot accommodate the proposed capacity, the ISO will require improvements to address the capacity constraints.

There are three processing tracks for interconnection customers wishing to interconnect to the ISO controlled transmission system; the cluster study process, the independent study process, and the fast track process. The default process for ISO interconnection requests is the cluster study process, and the independent study process is applicable only in special circumstances. The fast track process is only available to projects no larger than 5 MW and will therefore not relevant to offshore wind.

The independent study process can happen at any time of the year, but must demonstrate that the cluster study process will not accommodate the desired commercial operation date of the project, and must pass a flow impact test or short circuit duty test to show that it is electrically independent of projects in the cluster queue. The independent study process only takes approximately 240 calendar days if applying for energy only status, but will require additional work for full capacity. Additionally, if a project is requesting resource adequacy deliverability, they will have to join the cluster study process in the next available window.

For the cluster study process, the interconnection request window is open once per year from April 1st-April 30th. A cluster study considers interconnection requests from a group of interconnection customers at once in order to understand the overall impact on the grid. Within the cluster study, both group studies which look at all projects, and individual studies may be performed for each project at the discretion of the ISO. The interconnection studies begin in late July and take approximately two years to complete.

Interconnection studies in a cluster track are completed in two phases. The first phase is preliminary and includes all projects in the cluster study to identify the needed upgrades to existing infrastructure. Phase one consists of a short circuit analysis, a stability analysis, a power flow analysis, and deliverability assessments. At this stage every project is given a maximum cost responsibility for transmission system upgrades. The second phase is an update to account for changes in interconnection requests such as withdrawn applications. At this stage the final upgrades are determined and the ISO will assign financial responsibility to the various interconnection customers.

The cost responsibility for transmission upgrades will fall on the interconnection customer - or wind farm developer - through this pathway.

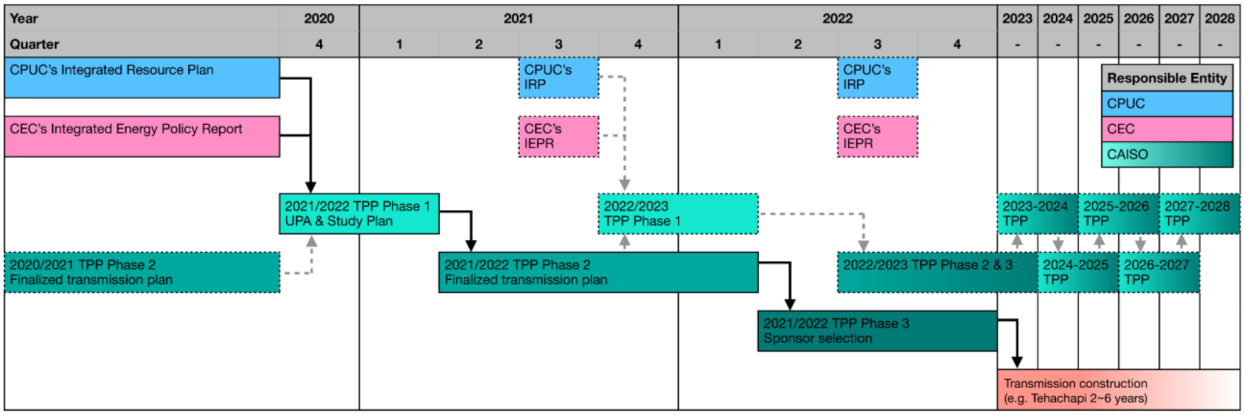
2.2 Public Policy Pathway

State policy guides the development of large-scale transmission in the state as needed in order to connect generation resources to electricity loads. As California policy has set a goal to achieve 100% clean energy by 2045 through Senate Bill (SB) 100, state agencies including the California Energy Commission (CEC) and California Public Utilities Commission (CPUC) will help create practical pathways to meet these targets. These state planning processes can help garner public policy support for offshore wind development if they determine that offshore wind can help meet the overall mandates set by the State. The California Independent System Operator (CAISO)'s transmission planning process (TPP) evaluates the need for new transmission lines to maintain reliability while meeting the projected future load and new generation sources. The TPP draws from the outcomes from the CEC and CPUC planning documents, described below.

Through the Integrated Energy Policy Report (IEPR), the CEC evaluates California's progress towards meeting the state's policy and renewable energy goals. The IEPR provides a forecast of future energy demand in California and is a cornerstone of infrastructure planning to support future demand.

The CPUC's Integrated Resource Plan is developed to ensure that California has a safe, reliable, and economic electricity supply that is consistent with environmental priorities and goals. Their analysis evaluates the need to new generation sources. Offshore wind was included as a candidate resource for the first time in the 2019-2020 IRP planning cycle Proposed Reference System Plan. However, offshore wind is only included in one sensitivity scenario, and is not considered an available resource until 2030. Sensitivity scenarios are used by CAISO to ensure energy projects are feasible from a transmission standpoint without prematurely indicating that a project is imminent (D. Hou, personal communication, April 21, 2020).

Projects that are included in the IEPR or IRP, are then incorporated into the following year's TPP (see Figure 2). CAISO's TPP is intended to serve as a unified transmission infrastructure plan for the entire CAISO balancing area (Billington, 2019, P.13). The TPP is the keystone of transmission planning and precursor to construction of any *ratepayer-funded* transmission infrastructure (since FERC's approval of the Generator Interconnection and Deliverability Allocation Procedures (GIDAP) in 2012). This funding is provided through transmission access charges to reach a rate of return approved by the Federal Energy Regulatory Commission. Charges are bundled together and paid for by utility and distribution companies, and ultimately charged to ratepayers (CAISO, 2017, P.4-5). Generators may still procure transmission outside of the TPP process, but without reimbursement from ratepayers (CAISO, 2019, P.45-46). According to D. Hou of CAISO, however, the upgrades *could* be refunded after completion (D. Hou, personal communication, April 21, 2020). The three-phase TPP begins every year but takes two years to complete.



Notes:
* High Level Needs (HLN) / Long Term Procurement Process (LTPP) only occurs for planning cycles beginning in odd years.
** UPA = Unified Planning Assumptions.

Figure 2. Graphical timeline of Transmission Planning Process (TPP).

<u>Phase One</u>

Phase one begins in December of the prior year, and runs through the end of the first quarter of the first year.

> The objective of this process is to establish the goals of the current year TPP, agree on data assumptions and inputs for the creation of base cases…and allow transmission planning participants to review and comment on the scope of the upcoming technical studies. The intended outcome of this effort is to aggregate and incorporate into the study plan, as appropriate, all relevant information and data necessary for the CAISO to develop and finalize the unified planning assumptions and study plan prior to the commencement of the technical assessments performed during phase 2.
>
> Following the draft study plan publication, the CAISO will open a comment window to receive stakeholder comments regarding the study plan and for interested parties to submit economic planning study requests. After the comment window is closed, the CAISO will review stakeholder comments, evaluate economic planning study requests, select the high priority studies and publish the final study plan. (Billington, 2019, P.22)

This phase draws information primarily from three sources: the CEC's IEPR, CPUC's IRP, and the previous TPP (CAISO, 2019, P.12; Hou, 2017). The IEPR is a long-term forecast of energy demand, while the IRP is an energy efficiency, demand response, and generation resource procurement plan which "ensure[s] California has a safe, reliable, and cost-effective electricity supply" compliant with California's RPS (CPUC, 2020). The IRP has replaced the LTPP in this process (CAISO, 2019, P.12).

CAISO would only initiate transmission upgrades to address reliability issues. Said another way, in order to be included in this phase, offshore wind would have to be included in the policy-driven plans (e.g. the IRP or IEPR), of a state-level entity (e.g. CPUC or CEC) (D. Hou, personal communication, April 21, 2020). Preliminary feasibility studies of offshore wind could provide the confidence to CPUC to include offshore wind in the IRP, paving the way for inclusion in CAISO's TPP.

<u>Phase Two</u>

Once the UPA and study plan have been finalized, phase two of the process begins. Phase two runs from the second quarter of the first year through the first quarter of the second year. During phase two, the phase one study plan is executed and a finalized transmission plan is created. This phase also includes several opportunities for stakeholders to provide input before culminating in approval of the transmission plan by the CAISO Board of Governors (Billinton, 2019, P.23,32).

<u>Phase Three</u>

Phase three of the TPP starts in the second quarter of the second year, and runs through the end of the year. (Billinton, 2019, P.62) During this phase, project sponsors bid on transmission projects that were identified in Phase 2 for "[p]roposals to finance, construct, own, operate and maintain regional transmission facilities "(Billinton, 2019, P.63). At the end of Phase 3, approved project sponsors are reported.

Permitting and Construction

Once included in a board approved TPP, projects return to the CPUC and other agencies for the siting and permitting process (D. Hou, personal communication, April 21, 2020). Based on the timeline of the Tehachapi Renewable Transmission Project, the construction process can be completed in as little as two years, or as many as six years (SCE, 2019). It is worth noting that this projection is based on only two data points within a single project, and actual completion times could vary more significantly. For more information on CAISO's TPP, see Appendix A.

In order to understand the potential costs of the transmission upgrades needed to utilize offshore wind energy, studies were performed across the three scales of offshore wind development. For the pilot and small commercial scale, only a single option was evaluated, while in the large commercial case four possible transmission pathways were evaluated.

3. TRANSMISSION UPGRADE ALTERNATIVES

PG&E conducted an informational interconnection study for offshore wind in order to estimate the transmission upgrades required for offshore wind. The transmission study identified system impacts caused solely from the addition of an offshore wind farm then added system components to mitigate any thermal or voltage violations. The assumptions built into the study are:

- Evaluate three different scale wind farms independently, 48 MW, 144 MW, and 1,836 MW, all using 12 MW wind turbines (Severy et al., 2020)
- Power output for different wind farms modeled for Humboldt Call Area (Severy et al., 2020)
- Provide full deliverability of offshore wind power and other existing generation sources (i.e. no curtailment)
- Use load forecast for year 2029
- One-in-five year adverse weather conditions based on ambient temperature
- Model system under summer peak and spring off-peak scenarios
- Include all existing generators in the region but not new generators from the CAISO queue
- Mitigate overload under normal conditions (N-0 conditions, no contingency) and single contingencies (N-1 conditions, loss of one system element)
- Evaluate results against NERC TPL-001-4 standard to determine if the transmission system is acceptable based on Category P0, P1, P6, and P7 standards.

The assumptions, methods, and results from the informational interconnection study are described completely in Pacific Gas and Electric Company (2020). Transmission upgrades identified in this study are summarized in the subsections below for each scale wind farm.

3.1 Pilot Scale (48 MW)

At the smallest scale of offshore wind development considered in this study, 48 MW, PG&E recommends upgrades to the transmission system to mitigate thermal overload and avoid blackouts caused by failure of one system component (i.e. N-1 contingencies). After interconnecting a 48 MW offshore wind generator at the Humboldt Bay Substation, two sections of transmission line exceeded their thermal loading capacity during summer peak conditions (Pacific Gas and Electric Company, 2020 pg. 20). Furthermore, the addition of a 48 MW offshore wind generator would make the Humboldt transmission region susceptible to blackouts caused by failure of either 115-kV transmission line or the 115/60-kV transformer at the Bridgeville Substation (Pacific Gas and Electric Company, 2020 pg. 21). To mitigate these issues, PG&E recommends construction of a parallel 115-kV transmission line connecting the Humboldt Bay, Humboldt, Trinity, and Cottonwood Substations, plus construction of a 115- kV transmission line connecting the Bridgeville and Garberville Substations (Figure 3).

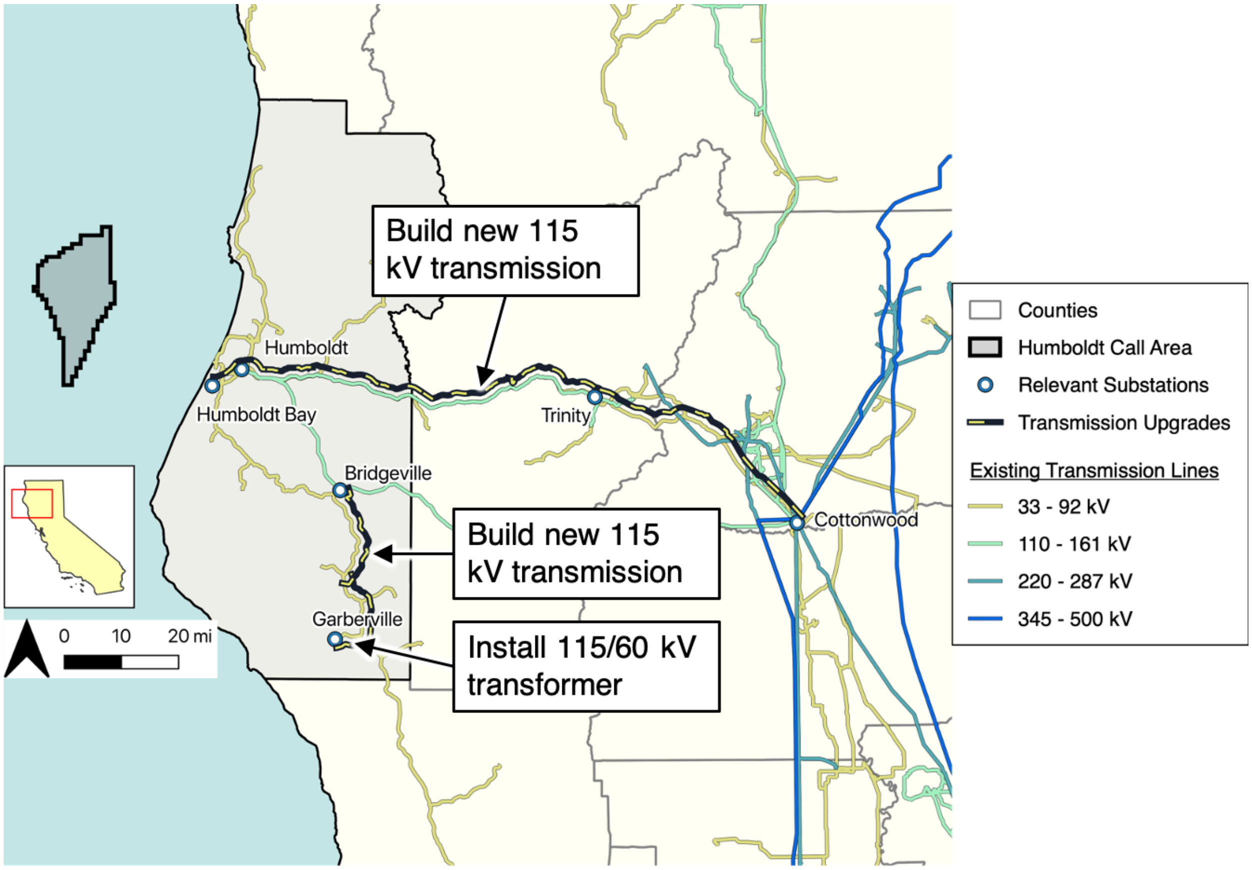


Figure 3. Transmission improvements for 48 MW wind farm scenario.

3.2 Small Commercial Scale (144 MW)

Interconnecting a 144 MW offshore wind generator creates the same overload issues identified in the 48 MW interconnection but to a greater extent (Pacific Gas and Electric Company, 2020 pg. 31). To mitigate these issues and provide reliable service without voltage or thermal overload, PG&E recommends the same new transmission lines identified for the 48 MW scenario plus additional reconductoring of the existing 115-V transmission line going east to the Trinity Substation and reconductoring the existing 115-kV and 60-kV transmission lines going south to the Willits Substation (Figure 4).

The transmission upgrades described above for a 48 MW or 144 MW generator allow those wind farms to interconnect to the grid, but do not build a pathway for larger deployment of offshore wind in the region. Larger offshore wind farms will require higher voltage transmission and wider rights-of-way that connect with major load centers in the state. Transmission upgrades at these smaller scales do not contribute to the transmission needs of gigawatt-scale development. In other words, investments made for smaller, initial projects become sunk costs that do not contribute directly to the build out of larger, future wind farms.

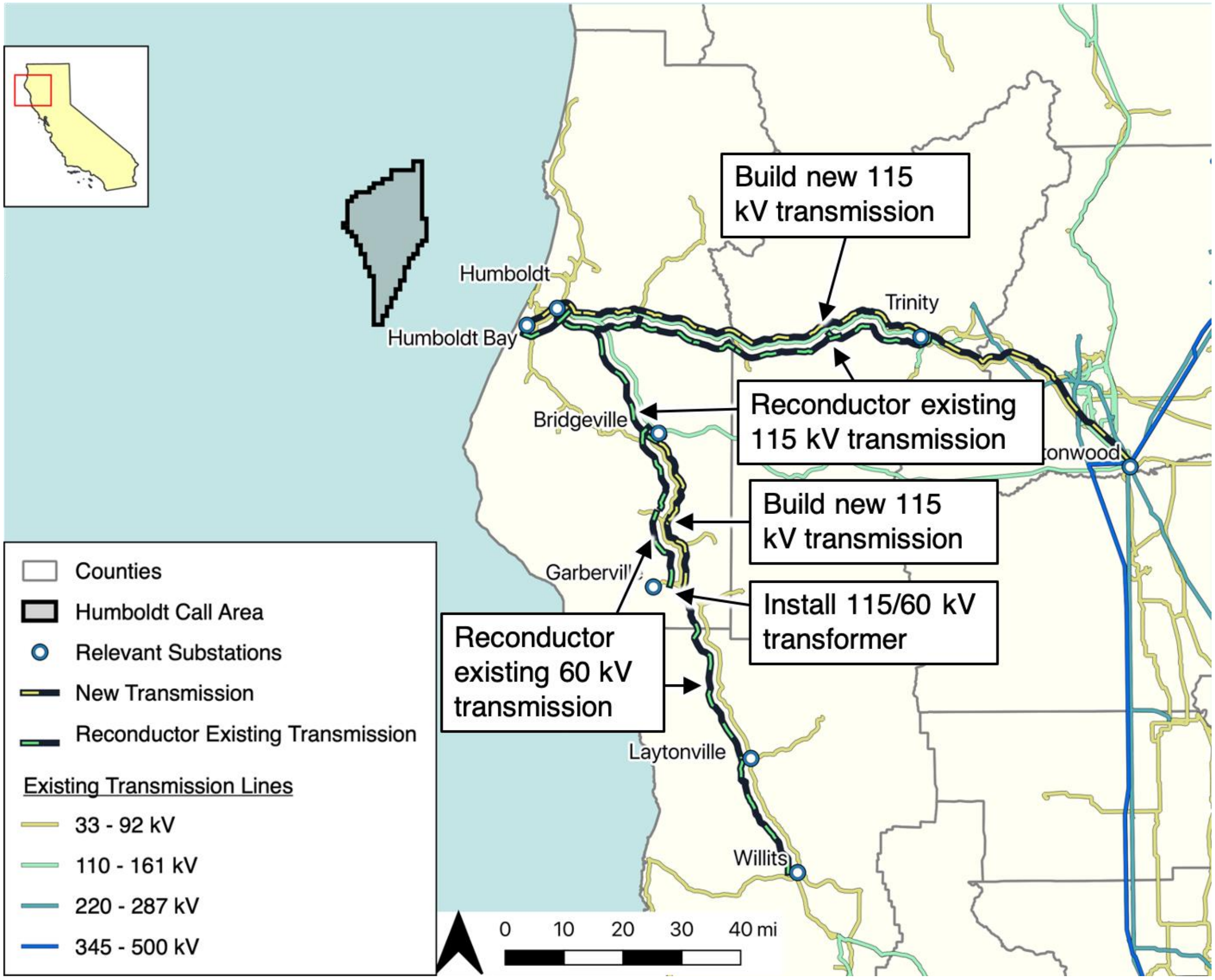


Figure 4. Transmission improvements for 144 MW wind farm scenario.

3.3 Large Commercial Scale (1,836 MW)

Interconnection of a larger offshore wind development on the order of 1,836 MW far exceeds the capacity of the Humboldt transmission system and regional electricity demand. For this large-scale scenario, transmission options were considered that connect the wind farm into major north-south transmission lines or larger load centers in the state. Three alternatives were identified by PG&E for the 1,836 MW scenario, including two over-land options and one subsea option (Figure 5). The subsea transmission alternative is separated into nearshore and far-from-shore cable corridors, both of which include the same onshore transmission infrastructure.

The alternatives presented below were developed as part of a conceptual planning study and would need much more evaluation to determine the feasibility. There would be challenges associated with developing any of the alternatives. Constructing new, long-distance overland transmission would face several barriers, including widening existing or acquiring new utility rights-of-way; environmental permitting across a diverse set of ecological conditions; engineering, access, and construction of transmission in mountainous, forested terrain with limited road access; social concerns from stakeholders or adjacent communities; and wildfire and safety concerns associated with substations and overhead transmission lines. A conceptual subsea cable was evaluated as a separate option for long-distance transmission to connect large-scale wind generators offshore from the northern California coast to major load centers in the state. A subsea power cable would face some of the same barriers and also several different challenges. The analysis presented below does not provide a comparison between the alternatives, but instead only identifies the conceptual alternatives based on a power flow analysis.

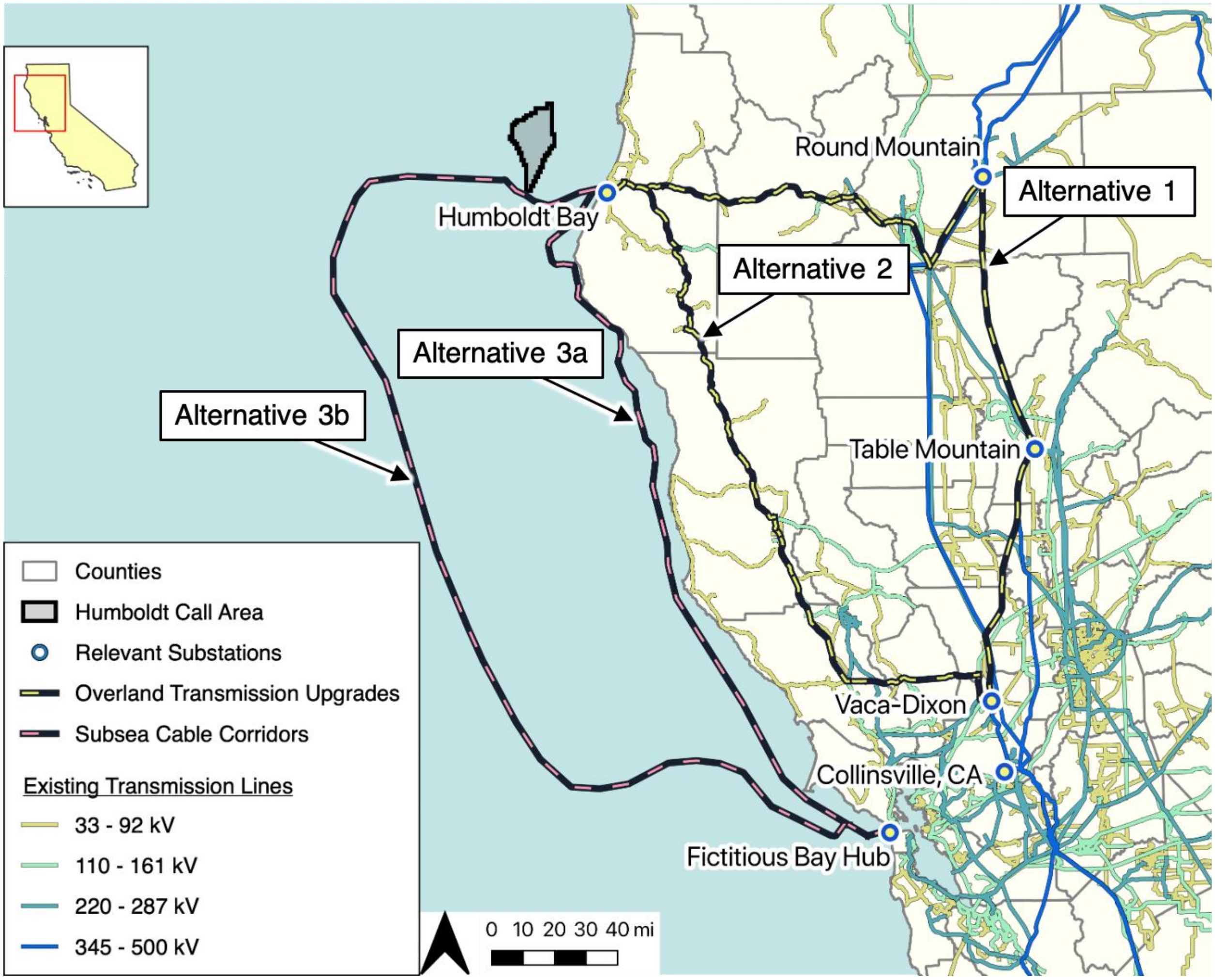


Figure 5. Transmission alternatives for 1,836 MW wind farm scenario.

3.3.1 Overland Transmission

Two overland transmission alternatives were investigated for interconnecting offshore wind. Both alternatives involve building new transmission to connect to the 500-kV transmission system running north-south in California's Central Valley.

The California-Oregon Intertie (COI) is a system of three parallel 500-kV transmission lines connecting southern Oregon (near Klamath Falls) to northern California (near Redding) with a capacity of 4,800 MW (north to south) (Pacific Gas and Electric Company, 2020, pg 43-44). Alternative 1 was developed in an attempt to connect offshore wind into COI at the Round Mountain Substation. During the analysis of this alternative, two key capacity challenges were identified: 1) interconnection at Round Mountain would cause thermal overload during summer peak conditions on the 500-kV transmission lines from Round Mountain to Table Mountain and Vaca-Dixon, and 2) there is not enough available capacity allocated on COI to sustain this connection due to existing contractual obligations and reserved capacity (Pacific Gas and Electric Company, 2020 pg 47). Therefore, new transmission capacity would need to be constructed beyond the connection to Round Mountain to accommodate 1,836 MW of offshore wind. In addition to building a 500-kV transmission line connecting Humboldt to Round Mountain, new 500-kV transmission would need to be constructed from the Round Mountain to the Table Mountain and then Vaca-Dixon Substations in parallel with existing lines.

Alternative 2 uses a different pathway to move energy directly to densely populated regions of the state with greater power demand. Instead of connecting through two other large substations in Round Mountain and Table Mountain, Alternative 2 creates a path directly to the Vaca-Dixon Substation. New transmission infrastructure is added between Vaca-Dixon and the East Bay Area to deliver power to the substations that serve larger loads, including the Pittsburg Power Plant and Tesla Substations and construction of a new 230/500 kV substation in Collinsville, CA (Pacific Gas and Electric Company, 2020 pg 61-63).

3.3.2 Subsea Cable

A conceptual high-voltage, direct-current (HVDC) subsea cable was evaluated as a separate option for long-distance transmission to connect large-scale wind generators offshore from the northern California coast to major load centers in the state. PG&E identified the Greater San Francisco Bay Area (SF Bay Area) to be the target location for interconnection because of the significant load, limited generation facilities, and potential reliability issues within different transmission planning divisions in the region. Two conceptual subsea cable corridors were identified that could connect the Humboldt Bay and SF Bay Areas: one near-shore corridor and one deep-water corridor located further from shore (Porter & Philips, 2020).[1] Either subsea cable corridor will require the same on-land infrastructure including HVDC converter stations at the northern and southern terminal.

A subsea transmission cable to the SF Bay Area would connect at a central location and distribute power to three separate transmission sub-regions because no single region in the SF Bay Area can absorb an additional 1,836 MW of capacity (Pacific Gas and Electric Company, 2020 pg. 71). From a generic central node (location not identified), power would spread to the SF Peninsula (Potrero Substation), the South Bay (Los Esteros Substation), and the East Bay (East Short Substation). Connecting the central node to three sub-regions would results in power flows that exceed the capacity of existing transmission lines if alternating current power is allowed to flow uncontrolled (Pacific Gas and Electric Company, 2020 pg 71). To control the power flow to each sub-region, PG&E recommends installing phase shifters or using DC-transmission lines between the central converter station to the sub-regional substations (Pacific Gas and Electric Company, 2020 pg 71).

4. TRANSMISSION COSTS

PG&E estimated the transmission upgrade costs for each alternative using the unit cost guide provided by CAISO (2020). The cost estimate included a 100% contingency factor to provide an upper bound that would account for difficult terrain, limited road access, and permitting challenges (see the range in Figure 6). Within the range, the Schatz Energy Research Center identified an adjusted cost estimate (black line in Figure 6) by adding specific cost multipliers for terrain and estimates land acquisition and excavation. The adjusted cost estimates were $540 million for the 48 MW scale, $970 million for the 144 MW scale, and between $1.7 and $3.0 billion for the 1,836 MW scale.

[1] Each subsea cable corridor would face a variety of design and permitting challenges. More information about the conceptual engineering design, technology, and corridors is provided in the report from Porter and Phillips (2020).

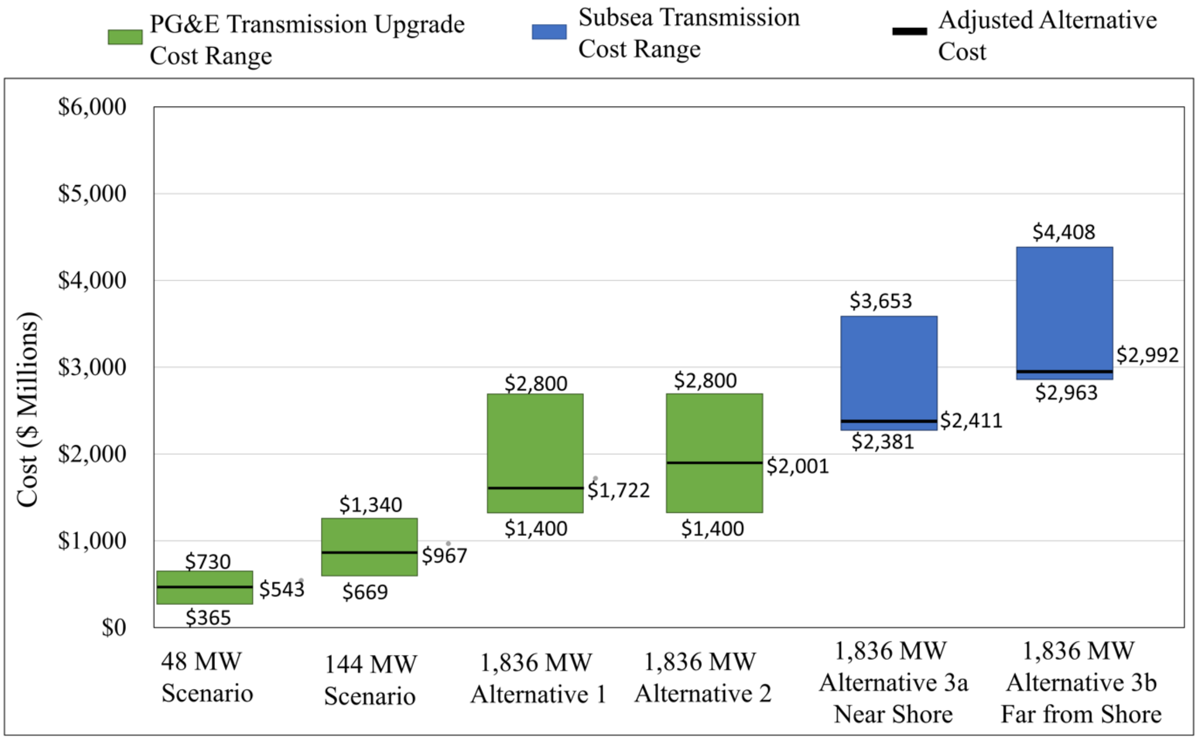


Figure 6. Transmission upgrade costs for different offshore wind scenarios showing the range of costs from PG&E study (colored bar), with adjusted value estimated (line).

As expected, the transmission upgrades are more expensive for larger capacity wind farms. But since the large-scale transmission costs are spread across more generation capacity, they have a lower cost per unit of installed wind farm capacity (Figure 7).

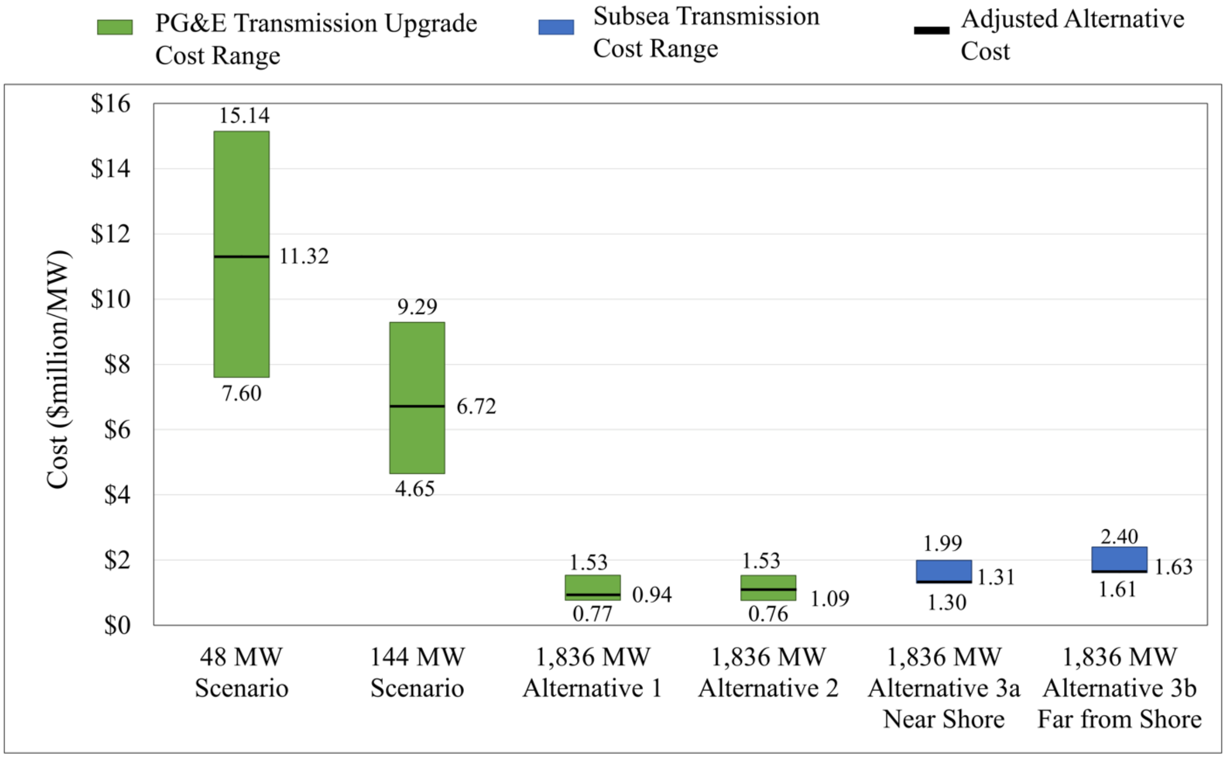


Figure 7. Transmission cost upgrades per unit of installed offshore wind capacity showing the range of costs from PG&E study (colored bar), with adjusted value estimated (line).

To compare against recent large-scale transmission development projects in California, the upgrade costs were normalized by the transmission line length (Figure 8). Recent costs for transmission developments over 2 GW capacity are roughly $10 million per mile. The cost estimates for the 1,836 MW wind farm transmission line alternatives fall within the expected range of costs. The smaller scale wind farm transmission costs fall outside the capacity range of previous case studies, as they have lower estimated costs per mile values. This may be due to their lower transmission line voltages.

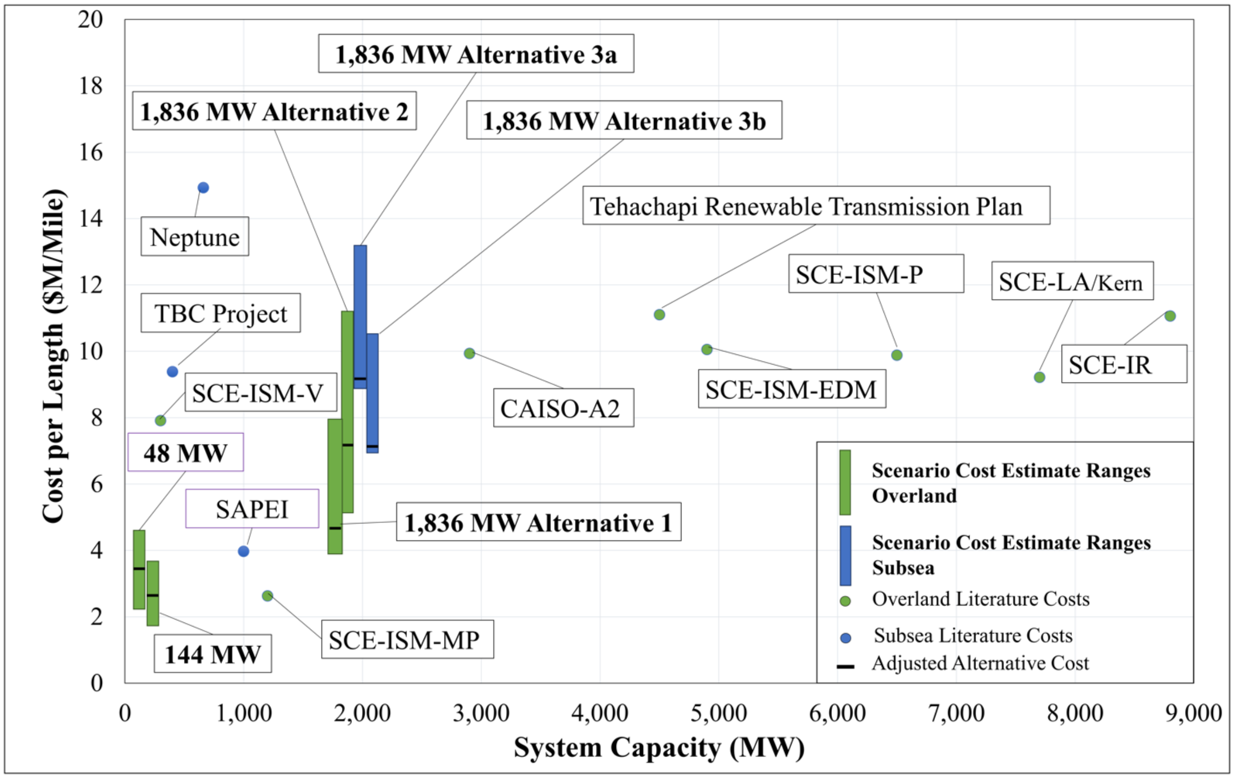


Figure 8. Cost per mile of the wind farm alternatives compared to recent project costs in California. Description and source for recent California transmission projects are provided in Appendix A.

5. ACRONYMS

Acronym	Name
CAISO	California Independent System Operator
CARB	California Air Resources Board
CEC	California Energy Commission
CPUC	California Public Utilities Commission
FERC	Federal Energy Regulatory Commission
GIDAP	Generator Interconnection and Deliverability Allocation Procedures
IEPR	Integrated Energy Policy Report
IRP	Integrated Resource Plan
LTPP	Long-term Procurement Process
RPS	Renewables Portfolio Standard
TPP	Transmission Planning Process

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APPENDIX A - TRANSMISSION UPGRADE CASE STUDIES

Transmission cost, capacity, and line distance data were collected from a Lawrence Berkeley National Laboratory report on transmission for wind energy (Mills et al., 2009) and online transmission reviews (Dombek, 2012; TransmissionHub, 2018). They are summarized in Table 1.

Table 1 Summary of cost and capacity of completed transmission projects in California.

Project Abbreviation	*Location*	*Project capacity (MW)*	*Cost (Millions $)*	*Source*
CAISO-A2	Mira Loma, CA	2,900	$1,500	(Mills et al., 2009)
SCE-LA/Kern	Los Angeles and Kern Counties	7,700	$2,610	
SCE-ISM-P	Inyo, San Bernardino, and Mono Counties, Pisgah	6,500	$1,550	
SCE-ISM-EDM	Inyo, San Bernardino, and Mono Counties, El Dorado/Mohave	4,900	$1,900	
SCE-ISM-MP	Inyo, San Bernardino, and Mono Counties, Mountain Pass	1,200	$110	
SCE-ISM-V	Inyo, San Bernardino, and Mono Counties, Victorville	300	$70	
SCE-IR	Imperial and Riverside Counties	8,800	$2,670	
Tehachapi Renewable Transmission Plan	Kern, Los Angeles, and San Bernardino Counties	4,500	$2,500	(TransmissionHub, 2018)
Trans Bay Cable Project	San Francisco Bay	400	$400	(CAISO, 2007)
Neptune	Lower Bay (New Jersey to Long Island)	660	$744	(Ardelean, M., Minnebo, Philip, 2015) (Hocker, C., Martin, L. 2020)
SAPEI	Tyrrhenian Sea (Italy to Sardinia)	1,000	$1,035	(Ardelean, M., Minnebo, Philip, 2015) (Dotti, 2017)