Offshore Wind & Transmission Infrastructure in NW CA

Webinar presented by:

Arne Jacobson and Jim Zoellick
Schatz Energy Research Center
Cal Poly Humboldt

Sponsored by Redwood Region CORE Hub

March 25, 2024

Schatz Center Offshore Wind and Transmission Research

Primary Funders of Studies Related to Offshore Wind and Transmission

Partners for OSW and Transmission Studies

Publications:
schatzcenter.org/publications

Key points: offshore wind and transmission in NW CA

- The winds offshore from NW California are consistently strong, and wind farms in the region could contribute substantially to state and local climate and clean energy goals.

Image source: Wikipedia Commons (https://upload.wikimedia.org/wikipedia/commons/7/76/Agucadoura_WindFloat_Prototype.jpg)

Key points: offshore wind and transmission in NW CA

Schatz Energy Research Center

- The winds offshore from NW California are consistently strong, and wind farms in the region could contribute substantially to state and local climate and clean energy goals.
- Significant investments in electric transmission infrastructure are a pre-requisite for development of offshore wind (OSW) at scale in NW California.
- Transmission upgrades can enable regional benefits, including better electricity reliability, but some communities would not benefit without deliberate steps to ensure inclusive outcomes.
- Humboldt County's existing electrical system was established in the post-WWII period, and its geographic extent and capacity have not changed substantially since the mid 1960s.
- Offshore wind provides a generational opportunity for new infrastructure investment.

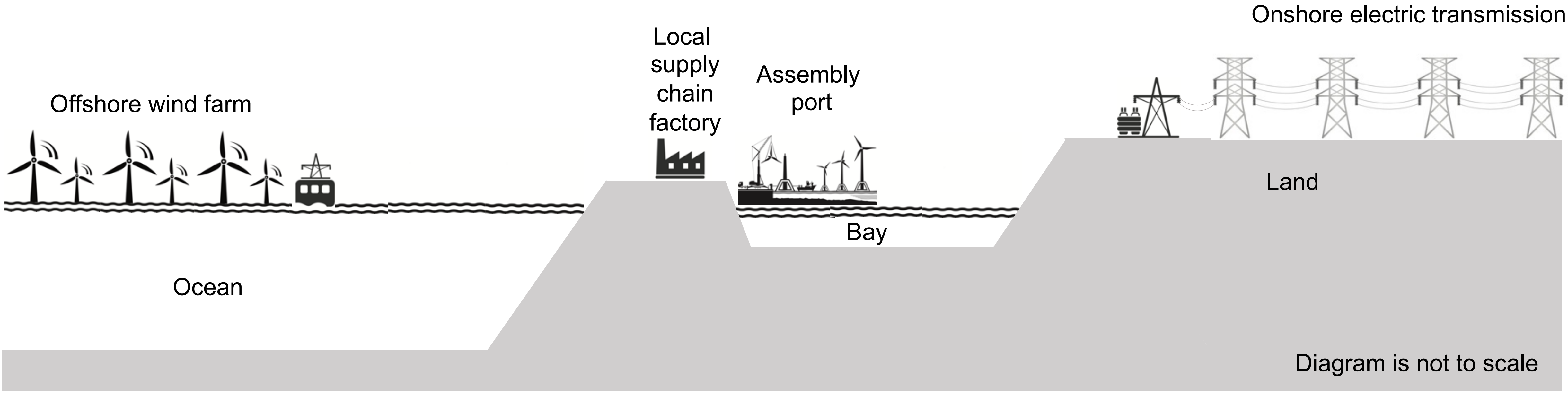
Offshore Wind Development is Complex and Multifaceted

- Offshore wind development requires multiple types of new infrastructure.
- Transmission is one of four major types of infrastructure that must be developed.

Infrastructure and Offshore Wind Development

Offshore wind development involves four main types of infrastructure:
(1) offshore wind farms, (2) ports (import/export, assembly, O&M),
(3) electric transmission (and conversion), (4) component supply chains.

Each of these four types of infrastructure involves its own set of developers and its own regulatory/permitting processes.

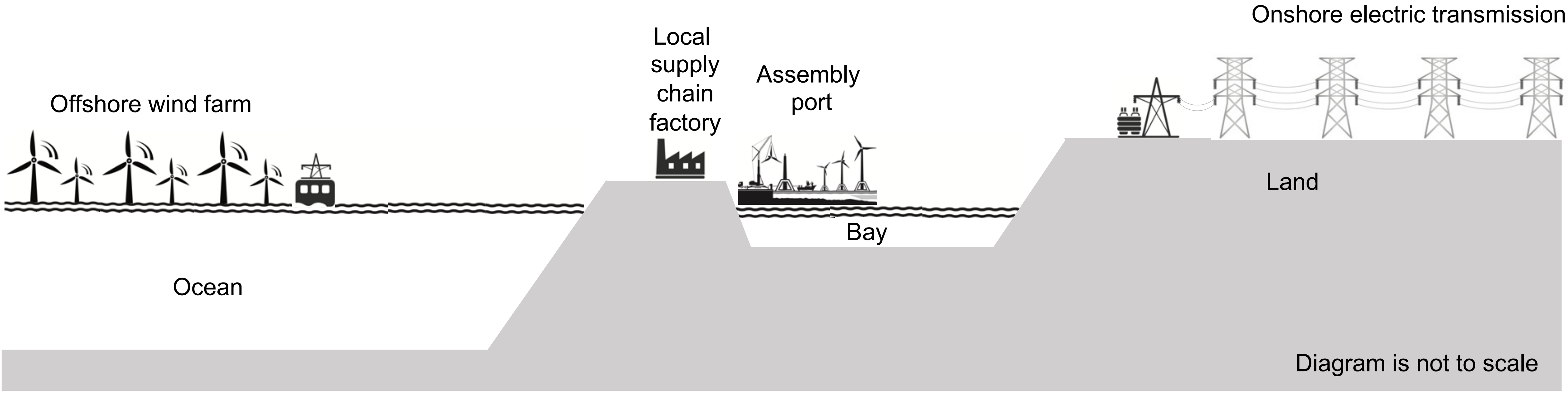


Infrastructure and Offshore Wind Development

Schatz Energy Research Center

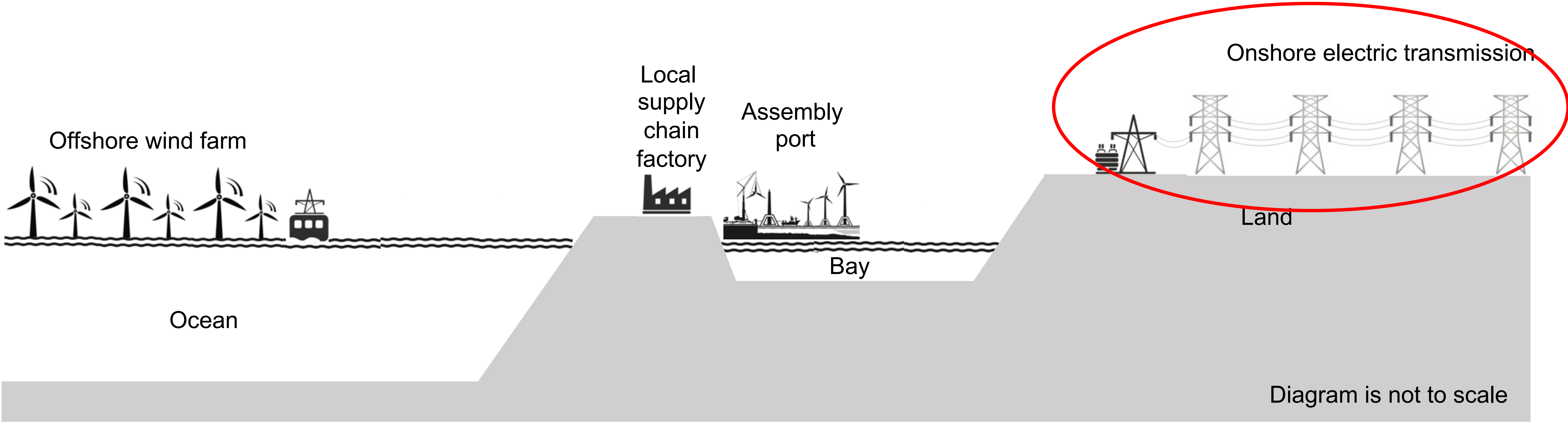
Offshore wind development involves four main types of infrastructure:
(1) offshore wind farms, (2) ports (import/export, assembly, O&M),
(3) electric transmission (and conversion), (4) component supply chains.

Each infrastructure type requires study to understand issues related to environmental, socio-economic, and cultural resource effects.

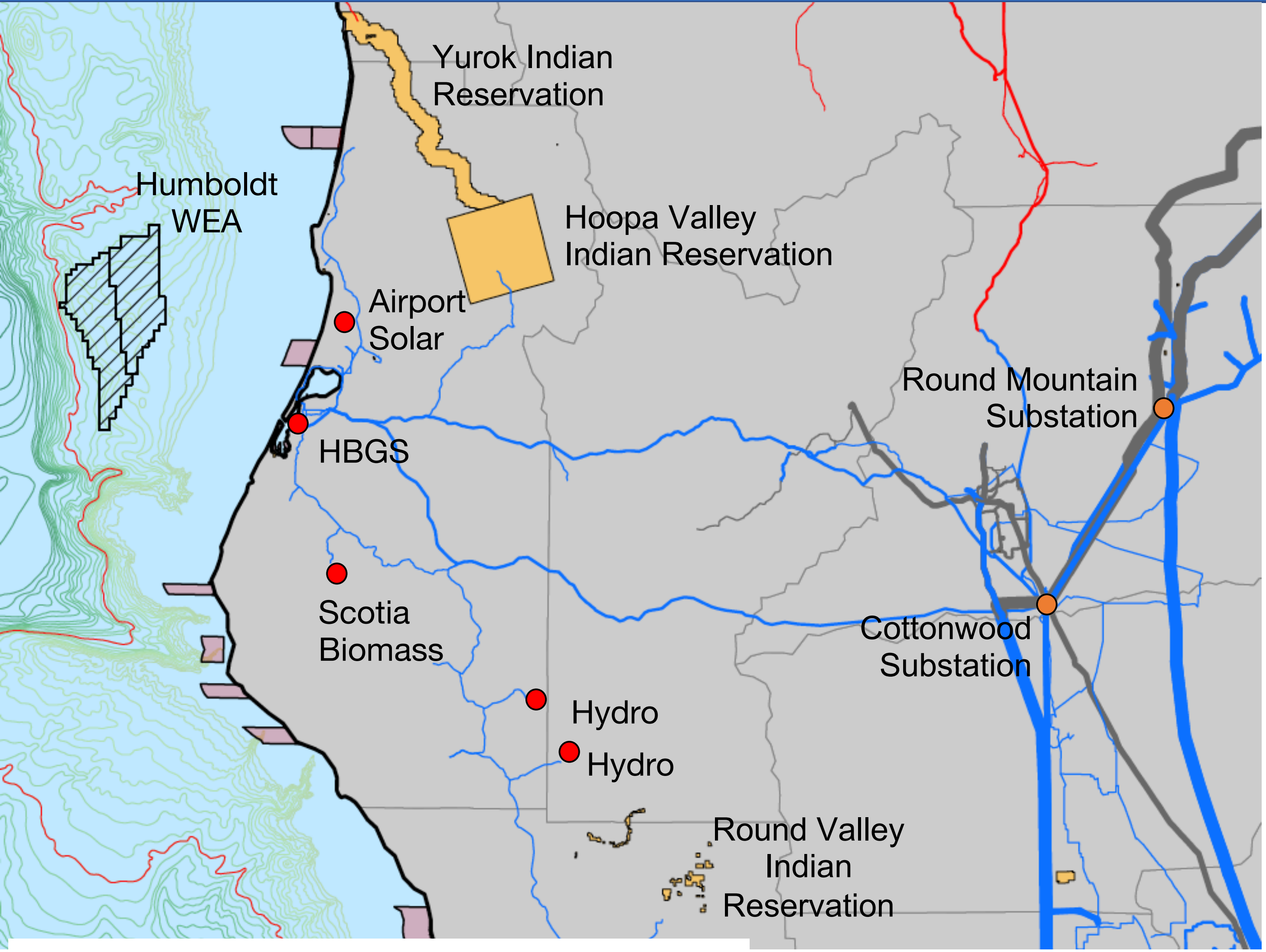


Infrastructure and Offshore Wind Development

Offshore wind development involves four main types of infrastructure:
(1) offshore wind farms, (2) ports (import/export, assembly, O&M),
(3) electric transmission (and conversion), (4) component supply chains.



Humboldt County Electricity System (Circa 2024)



HBGS = Humboldt Bay Generation Station

- Humboldt County's electrical system is relatively isolated from the main CA grid.
- Regional electricity use is concentrated in the Humboldt Bay area (avg use is ~90 MW).
- Local generation is needed to power the region. The 163-MW natural gas fired Humboldt Bay Generating Station plays this role.
- Major transmission corridors in CA run along the I-5 corridor, linking large generators and load centers.

Basic Elements of a Conventional Electrical Grid System

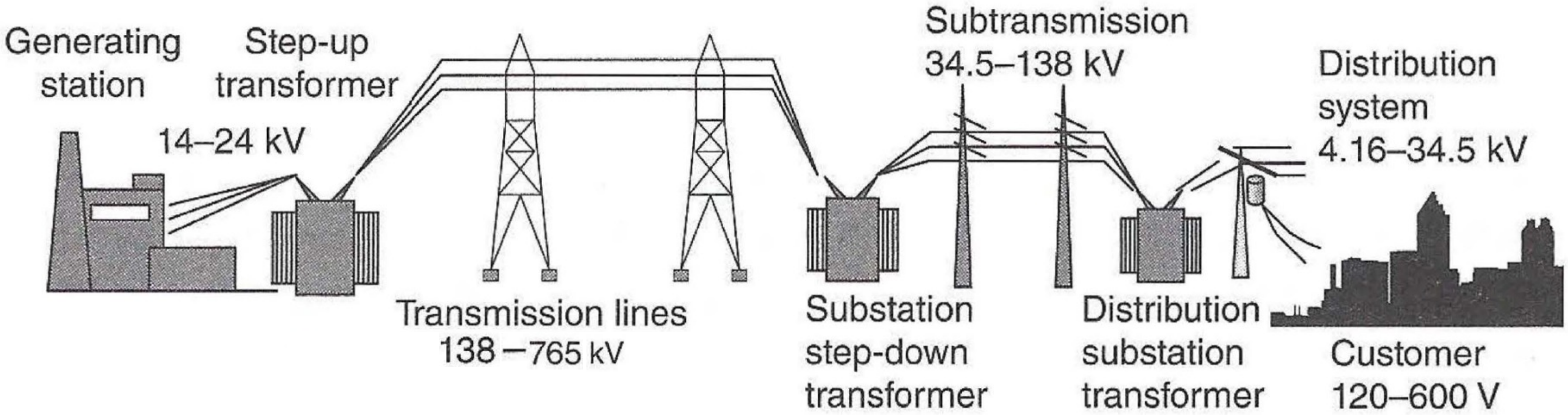


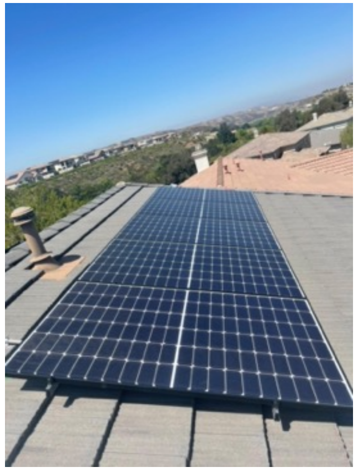
Image Source: Masters, 2013 (modified by A. Jacobson)

- Generation stations (power plants) produce power.
- Transformers are used to convert between lower voltage and higher voltage power.
- Power lines are used to move power between points of generation and use.
- The voltage is stepped up to deliver large amounts of power over long distances while minimizing losses.
- The voltage is stepped down for safety reasons as it gets closer to end users.

Electricity comes from multiple generation sources

Generation sources can include power plants based on fossil fuels, hydropower, nuclear energy, wind, solar photovoltaics, and others.

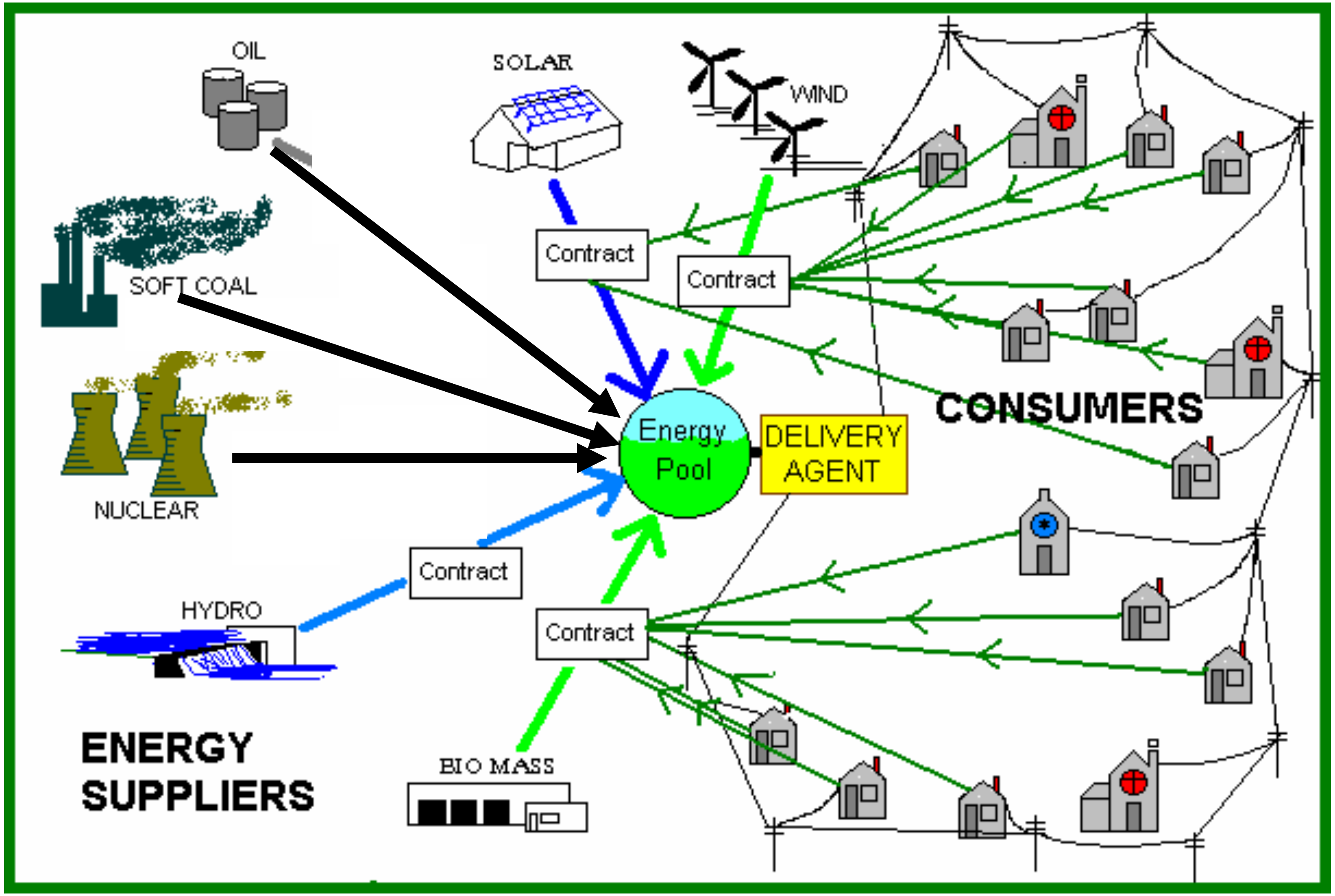
The portfolio of generation sources affects the environmental implications of the electric system.



Sources: Photos by A. Jacobson except the natural gas power plant (https://californialocal.com/localnews/statewide/ca/article/show/52650-southern-california-natural-gas-open-2026/) and rooftop solar (https://www.energysage.com/supplier/23561/elevation/gallery/).

Electricity comes from multiple generation sources

In practice, the system involves a complex network connecting generation sources to end use sites through the transmission and distribution grid.



Source: http://www.mainegreenpower.org/generic/basics.shtml

Ownership and Regulation of the Electrical System is Segmented

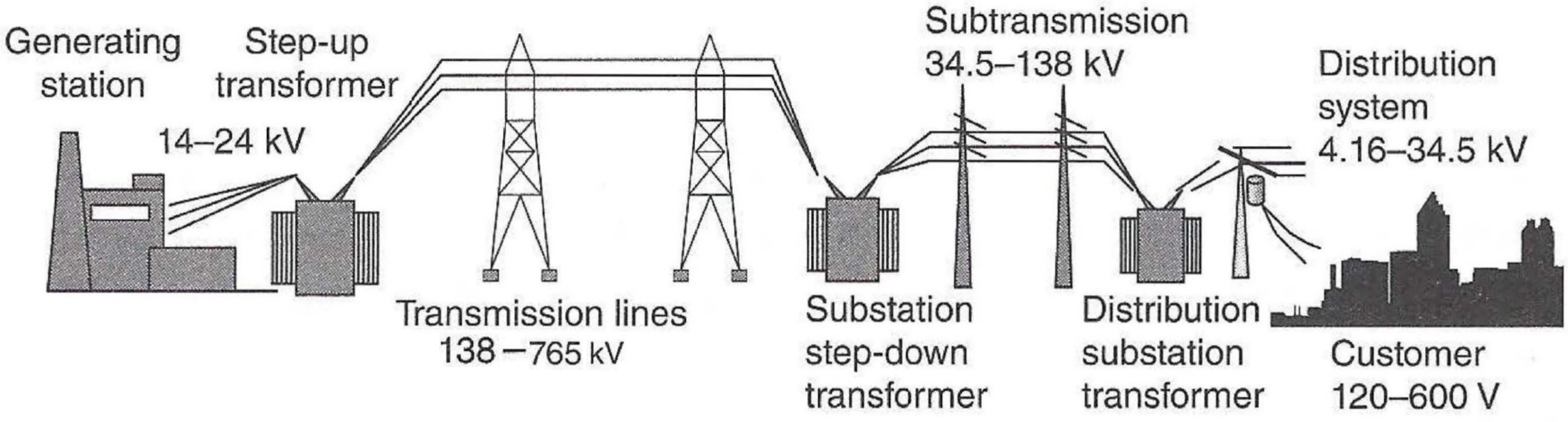


Image Source: Masters, 2013 (modified by A. Jacobson)

Owners: Independent power producers (IPPs) and utilities

Regulators: CEC (siting), CPUC (operation/safety), CAISO (market)

California agencies involved in electric sector regulation

- California Energy Commission (CEC)
- California Public Utilities Commission (CPUC)
- California Independent System Operator (CAISO)

Note: list of owners and regulators is not comprehensive

Ownership and Regulation of the Electrical System is Segmented

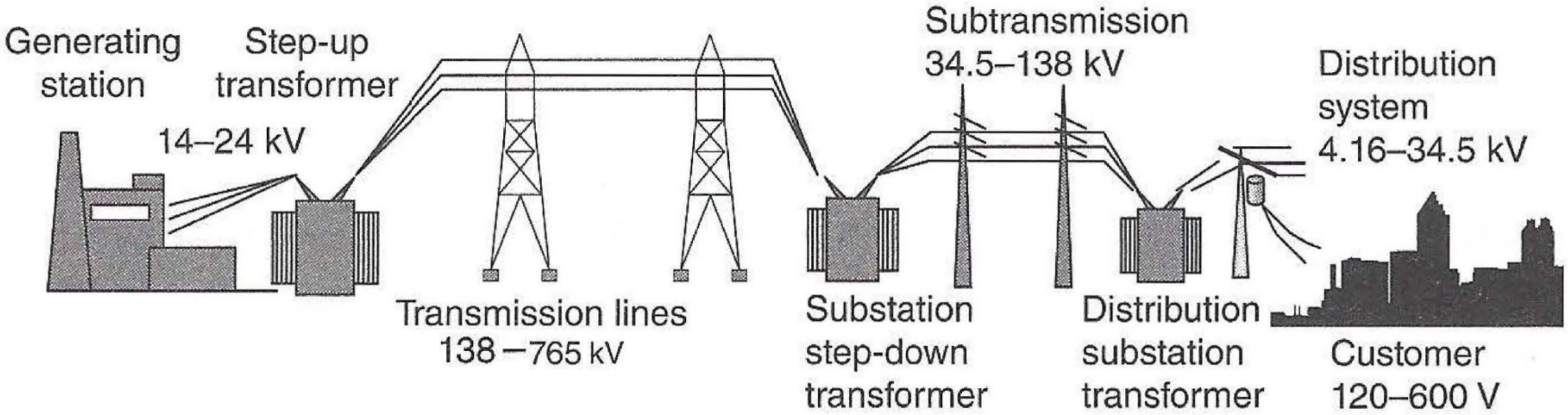


Image Source: Masters, 2013 (modified by A. Jacobson)

Owners: Independent power producers (IPPs) and utilities
Regulators: CEC (siting), CPUC (operation/safety), CAISO (market)

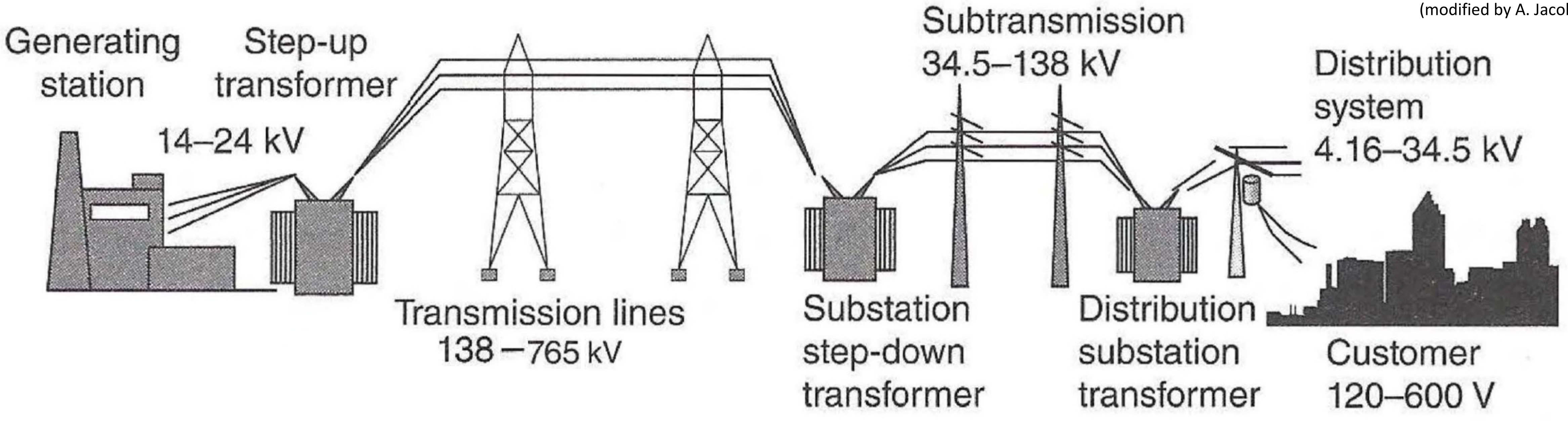
Owners: Utilities, government agencies, and merchant transmission companies
Regulators: CAISO (planning), CPUC (operation/safety)

Owners: Utilities (IOUs, munis, coops, Tribal utilities)
Regulators: CPUC (planning, operation/safety)

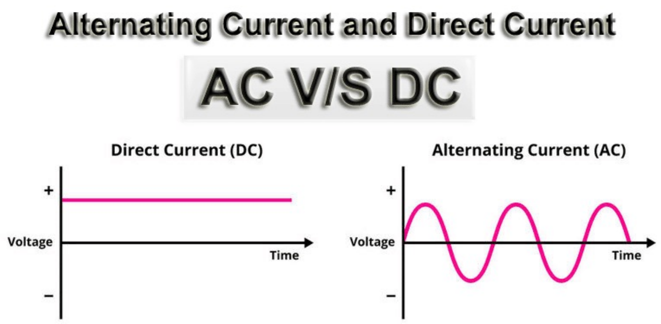
Note: list of owners and regulators is not comprehensive

Alternating Current vs. Direct Current

Image Source: Masters, 2013 (modified by A. Jacobson)



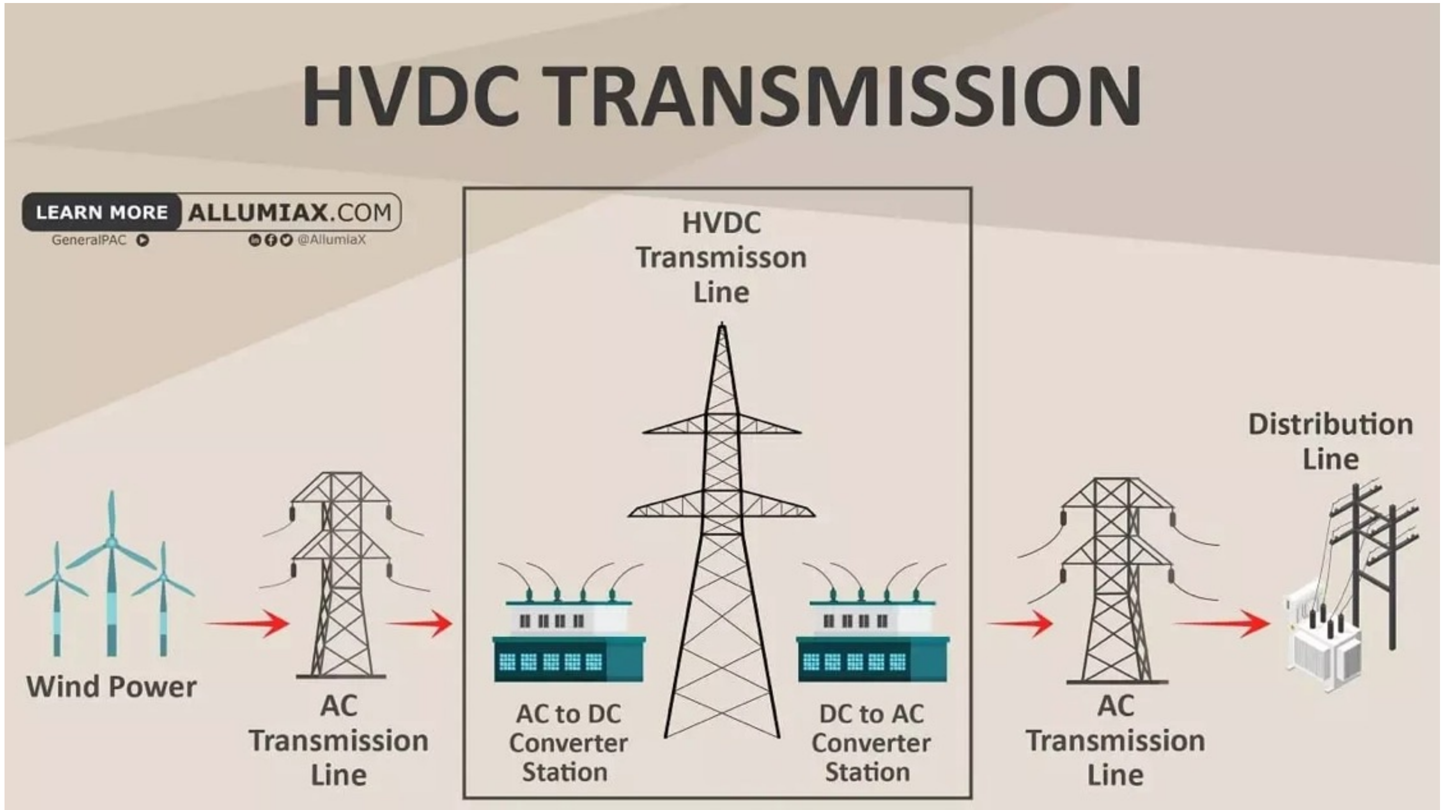
- The electrical grid is based primarily on alternating current (AC) power.
- In an alternating current system, the direction and magnitude of the voltage and current change back and forth many times per second.
- In a direct current (DC) system, the direction of the voltage does not change.
- Transformers only work with AC electricity.
- However, new(ish) technology allows DC voltage to be used in transmission systems.



Source: https://www.electronicsforu.com/tag/dc-current

High Voltage Direct Current (HVDC) Transmission Systems

- HVDC systems involve AC:DC and DC:AC conversion stations and transmission lines.
- They are used to transmit large amounts of power over long distances.
- The transmission lines and towers are less expensive than those for similarly sized AC transmission lines, but the converter stations are more expensive than conventional AC substations.
- HVDC transmission can be cost effective compared to AC transmission if the distance is long enough so that the savings from the lower cost transmission lines overcomes the high cost of the converter stations.



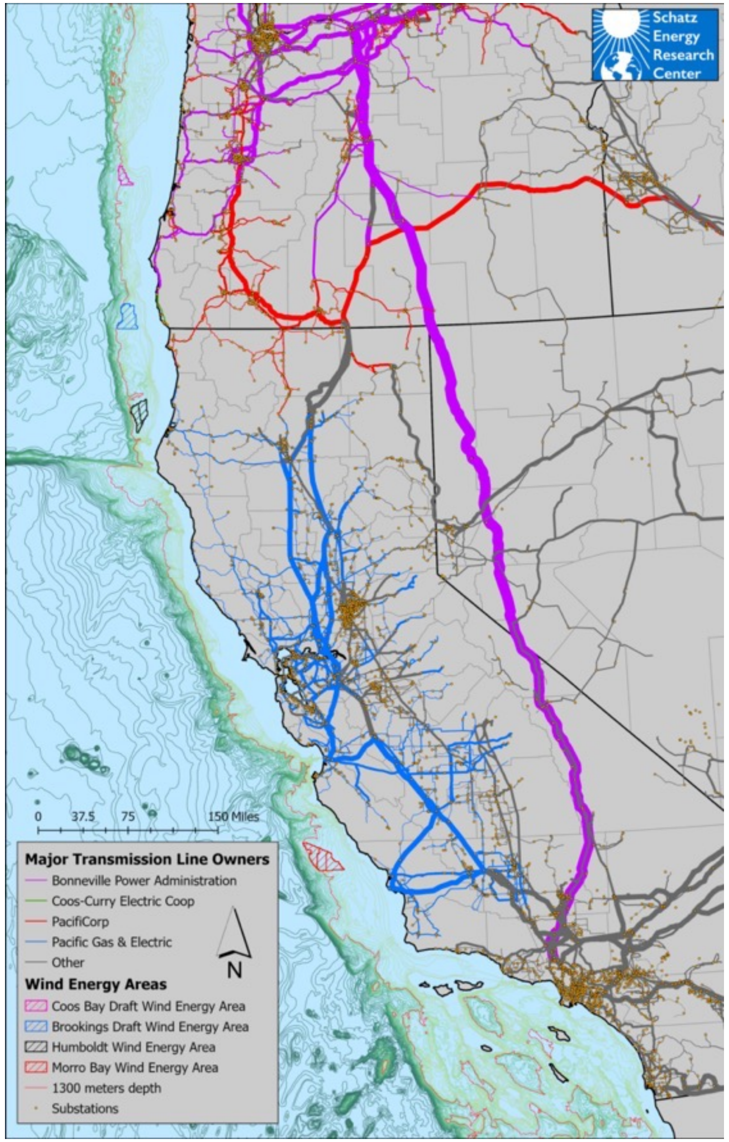
HVDC diagram image source: https://www.allumiax.com/blog/high-voltage-direct-current-hvdc-transmission
Photos by A. Jacobson

High Voltage Direct Current (HVDC) Transmission Systems

- An HVDC transmission line delivers Columbia River hydropower to the LA area.

Sylmar converter station (LA area)

Celilo to Sylmar HVDC transmission line near Greenville, CA. The line to the left is a conventional 230 kV AC transmission line



High Voltage Direct Current (HVDC) Transmission Systems

Schatz Energy Research Center

Image source: Randy Van Bibber Terra (2024)

- High voltage DC (HVDC) lines can carry a large amount of power over a long distance in a relatively narrow right of way.
- HVDC lines generally do not have many connection points, so communities along routes typically are not served (but those near the conversion stations can be).
- Long distance underground and undersea HVDC lines are possible.

HVDC cable for underground transmission.

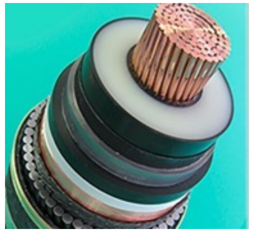
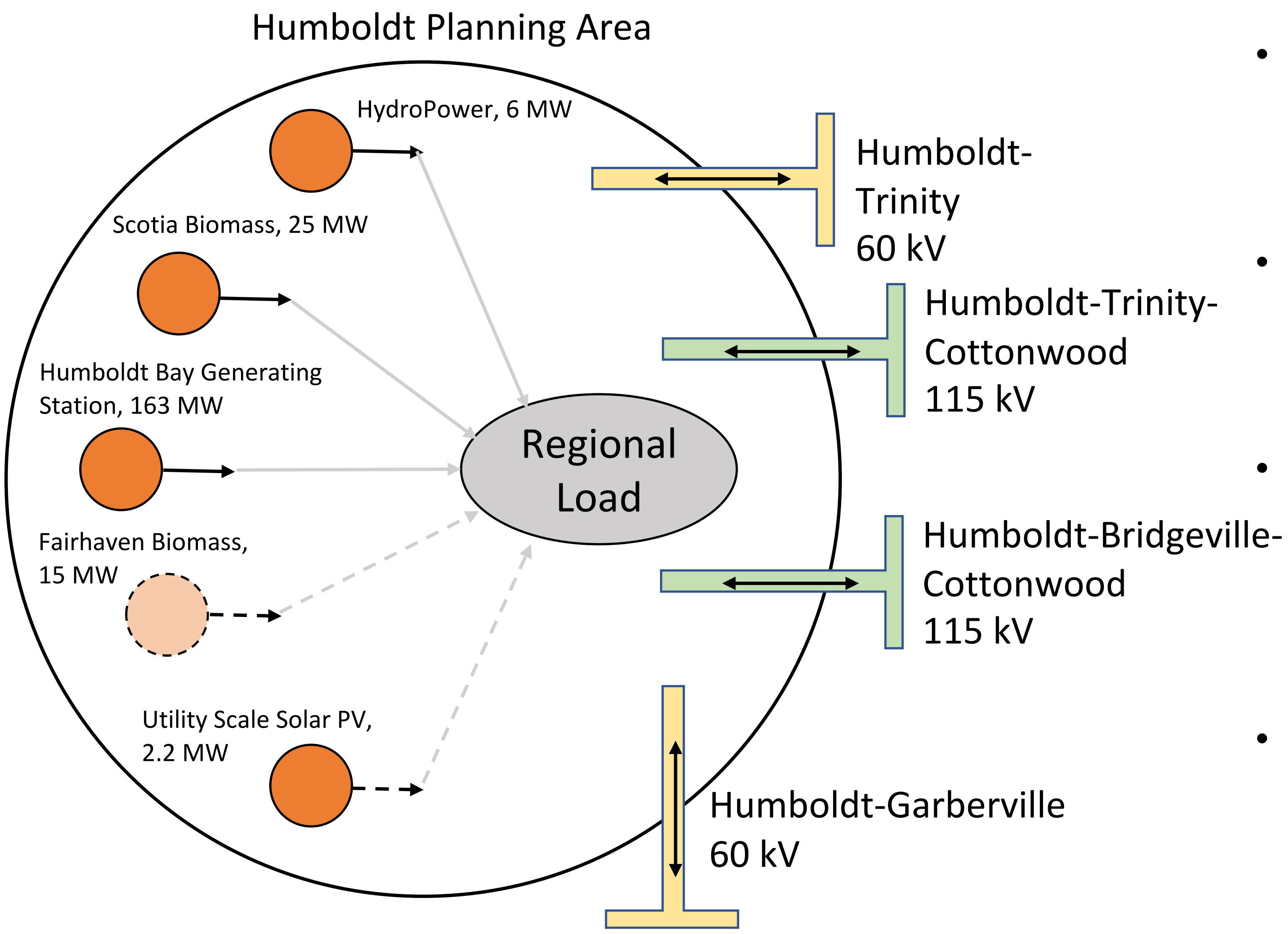


Image source: https://global-sei.com/power-cable-business/products/hvdc/

Celilo to Sylmar HVDC transmission line in the Owens Valley, CA.

Humboldt County Electricity System (Circa 2023)

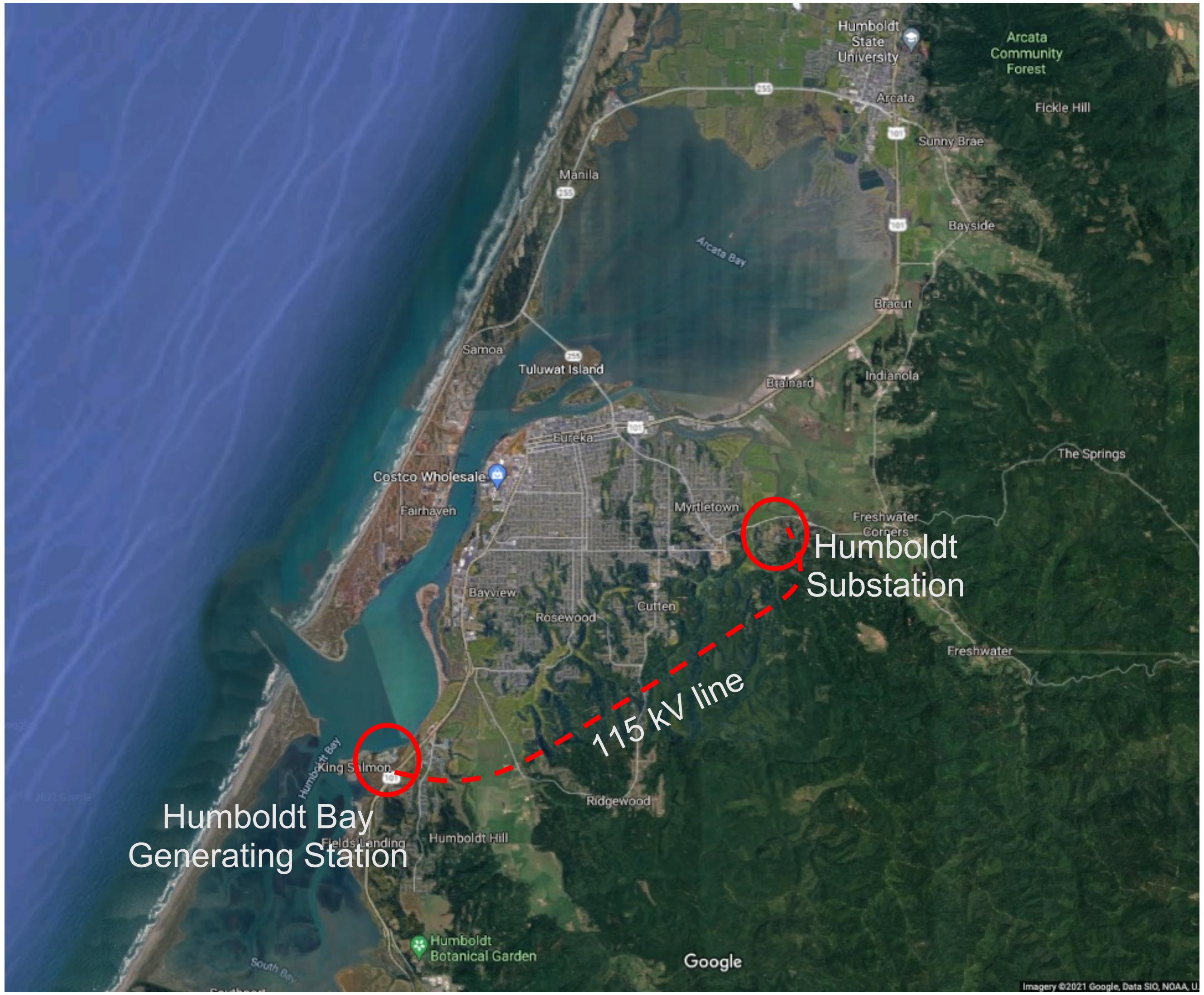


- Humboldt County's electrical system is relatively isolated from the main CA grid.
- Regional electricity use is concentrated in the Humboldt Bay area (avg use is ~90 MW).
- Local generation is needed to power the region. The 163-MW natural gas fired Humboldt Bay Generating Station plays this role.
- Major transmission corridors in CA run along the I-5 corridor, linking large generators and load centers.

Humboldt Bay Generating Station

- The 163 MW natural gas fueled Humboldt Bay Generating Station (HBGS) is the anchor power plant for the region.
- It depends on gas delivered via a single 12” pipeline that runs from Red Bluff to Eureka.
- In the event of a gas outage, the power plant can run on diesel fuel, and onsite storage tanks hold fuel for about 3 days of operation at full power.

Schatz Energy Research Center



There are two 115 kV substations in the region:

- Humboldt Substation (Mitchell Heights)
- Humboldt Bay Substation (HBGS site).

Images from Google Earth

Expansion of Energy Infrastructure After WWII

- PG&E made major investments to expand the electrical and gas infrastructure in the region during the post-WWII period.
- The installed electricity generation capacity serving the region expanded dramatically in the two decades following WWII. As of 2024, the regional installed generation capacity was only moderately higher than in 1965.
- The geographic extent and capacity of transmission lines and substations expanded significantly between 1946 and 1965, and it has not changed substantially since then (though there have been some upgrades and replacements).

Maple Creek Substation (2022)

Expansion of Energy Infrastructure After WWII

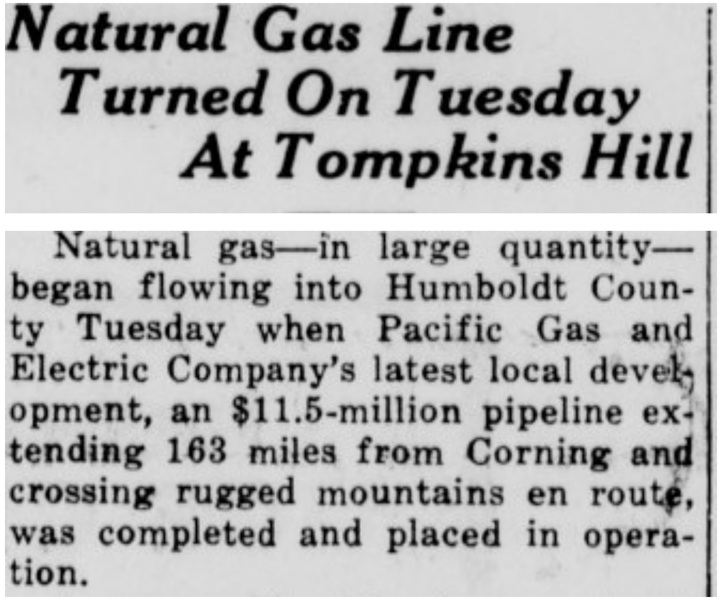
Schatz Energy Research Center

- PG&E made major investments to expand the electrical and gas infrastructure in the region during the post-WWII period.
- The installed electricity generation capacity serving the region expanded dramatically in the two decades following WWII. As of 2024, the regional installed generation capacity was only moderately higher than in 1965.
- The geographic extent and capacity of transmission lines and substations expanded significantly between 1946 and 1965, and it has not changed substantially since then (though there have been some upgrades and replacements).

Steel transmission poles on the 60 kV line that runs from Maple Creek to Willow Creek and the Hoopa Valley (2022)

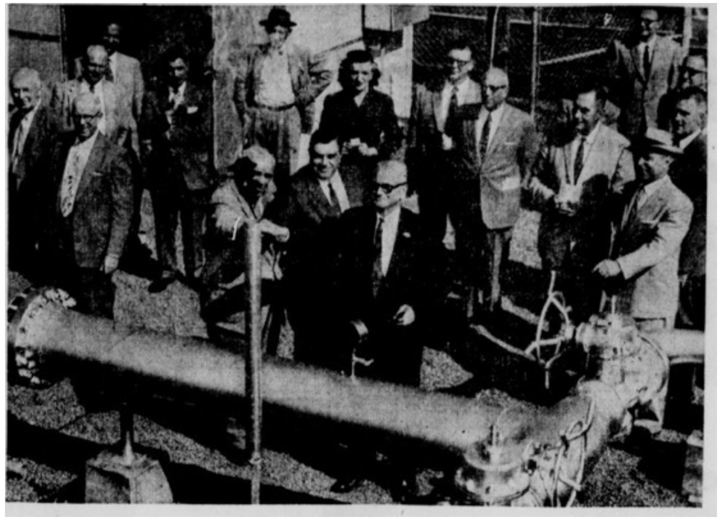
Expansion of Energy Infrastructure After WWII

- PG&E made major investments to expand the electrical and gas infrastructure in the region during the post-WWII period.
- The installed electricity generation capacity serving the region expanded dramatically in the two decades following WWII. As of 2024, the regional installed generation capacity was only moderately higher than in 1965.
- The geographic extent and capacity of transmission lines and substations expanded significantly between 1946 and 1965, and it has not changed substantially since then (though there have been some upgrades and replacements).
- Natural gas infrastructure also expanded in the 1950s and 60s, with the fossil-fuel based power plant and timber mills being a major consumers of gas.



Natural Gas Line Turned On Tuesday At Tompkins Hill

Natural gas—in large quantity—began flowing into Humboldt County Tuesday when Pacific Gas and Electric Company's latest local development, an $11.5-million pipeline extending 163 miles from Corning and crossing rugged mountains en route, was completed and placed in operation.



Images from Blue Lake Advocate (newspaper), August 21, 1958

Substation Name	Year Est.
Arcata	1946
Big Lagoon	1954
Blue Lake	1949
Bridgeville	1954
Carlotta	1952
Eel River	1956
Eureka A	1959
Eureka E	1953
Fairhaven	1965
Fort Seward	1948
Fruitland	1952
Garberville	1947
Harris (Eureka)	1960

Substation Name	Year Est.
Hoopa	1958
Humboldt (Eureka)	1950
Humboldt Bay	1956
Janes Creek	1957
Maple Creek	c1948
Newburg (Fortuna)	1955
Orick	1952
Rio Dell	1952
Rio Dell Tap	1952
Russ Ranch (Redwood Creek)	1952
Trinidad	Before 1954
Ultra Power (Blue Lake)	1985
Willow Creek	1949

Est. btw 1945 and 1959

Est. in 1960s

Est. in 1980s

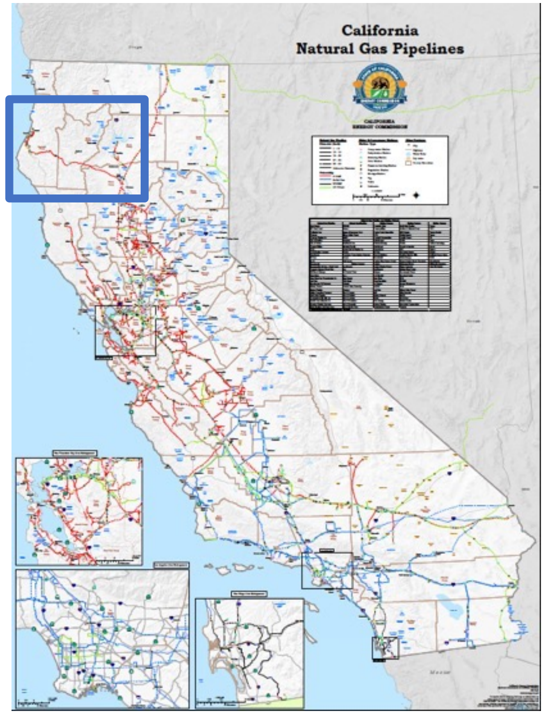
All substations in the table had 60 kV or 110 kV ratings as of the listed dates

Image source: California Energy Commission

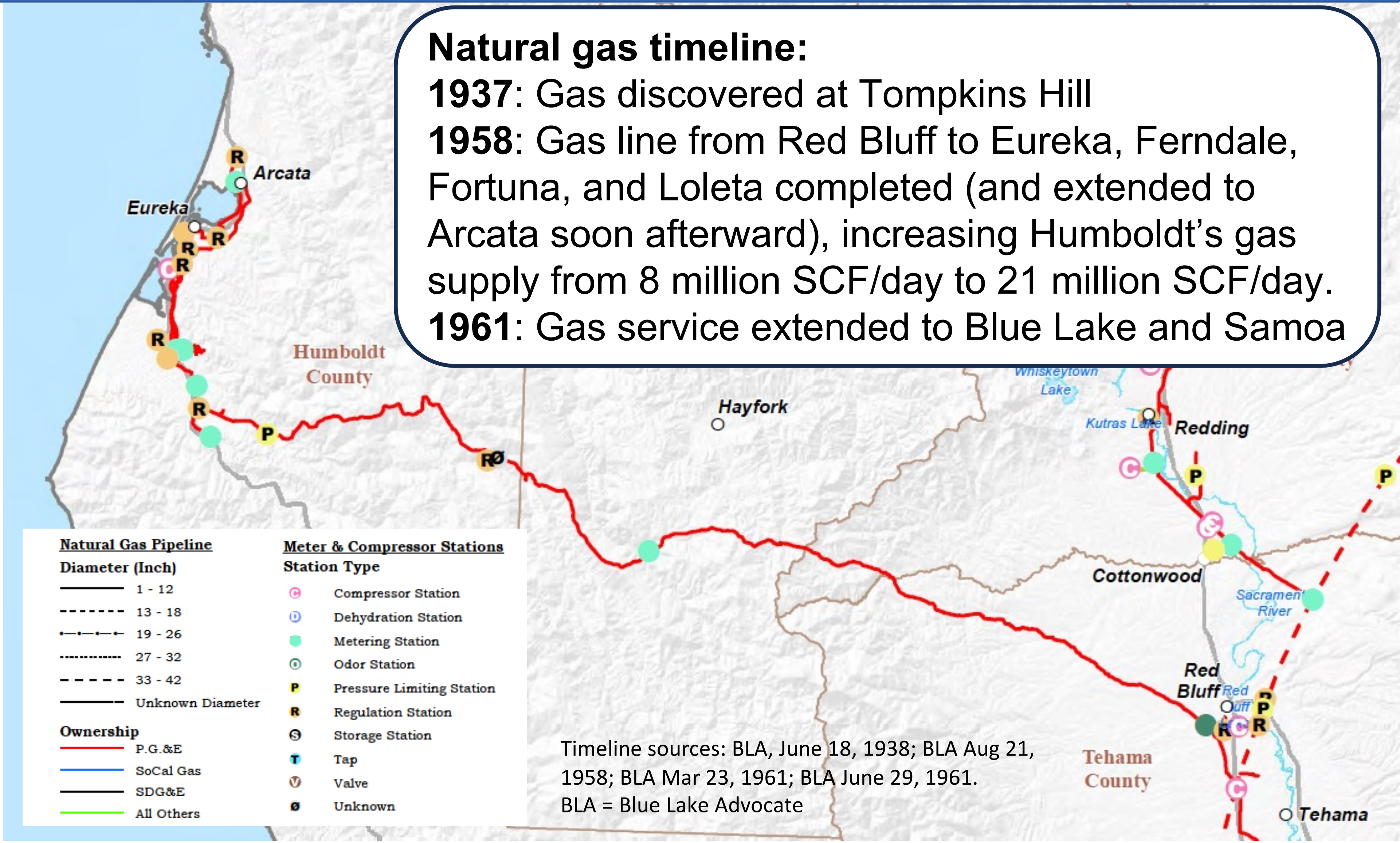
Sources included at end

Humboldt County Natural Gas Infrastructure

- Natural gas pipeline infrastructure serving Humboldt County



Source: California Energy Commission (2023)

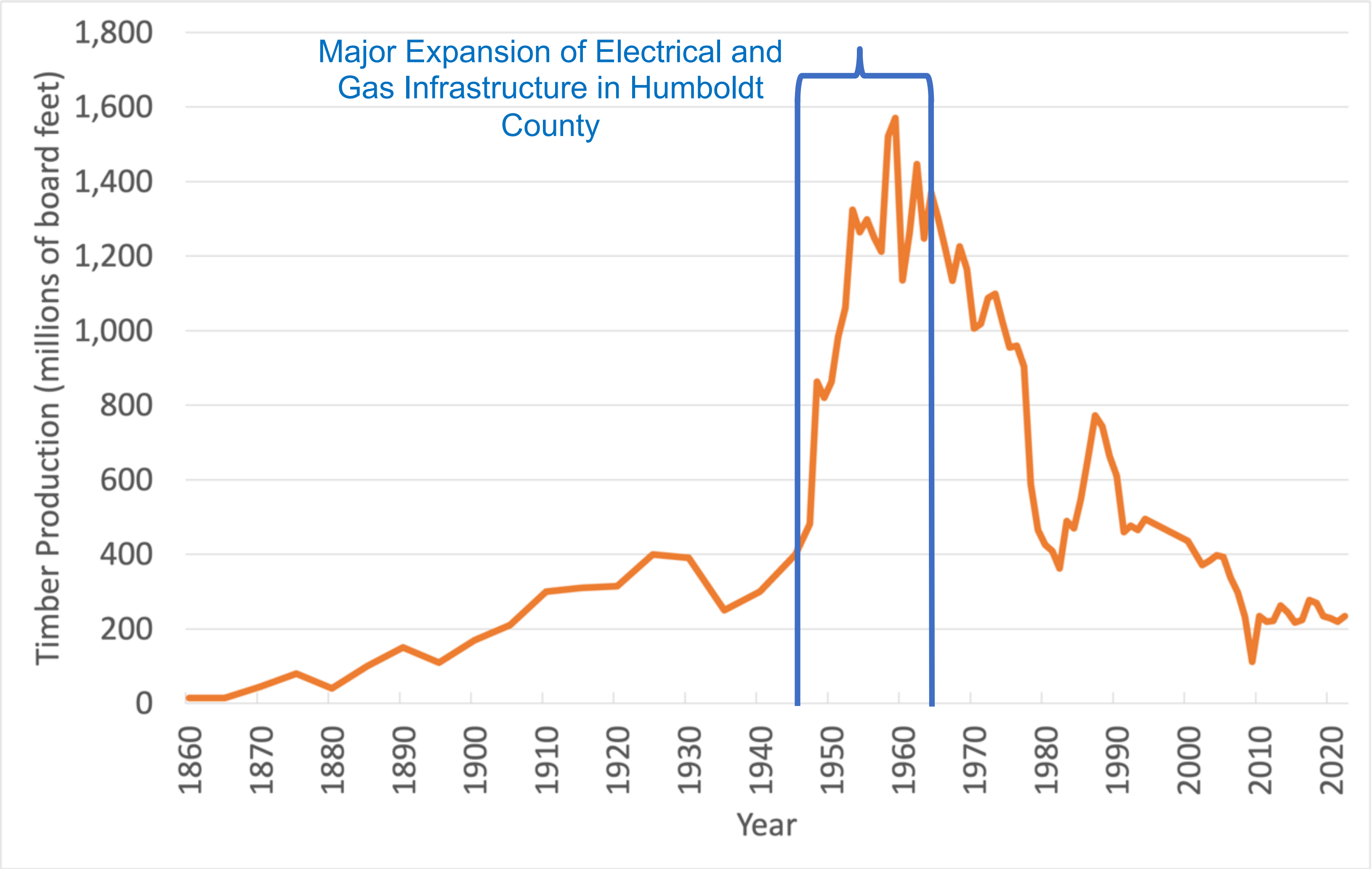


Natural gas timeline:
1937: Gas discovered at Tompkins Hill
1958: Gas line from Red Bluff to Eureka, Ferndale, Fortuna, and Loleta completed (and extended to Arcata soon afterward), increasing Humboldt's gas supply from 8 million SCF/day to 21 million SCF/day.
1961: Gas service extended to Blue Lake and Samoa

Timeline sources: BLA, June 18, 1938; BLA Aug 21, 1958; BLA Mar 23, 1961; BLA June 29, 1961.
BLA = Blue Lake Advocate

Humboldt County Timber Production, 1860-2022

(millions of board feet per year)



Data sources: Vaux, 1955; Waddell and Bassett, 1996; Morgan, et al., 2004; BBER, 2023 (data from 1860 to 1945 are estimated from a graph in Vaux, 1955).

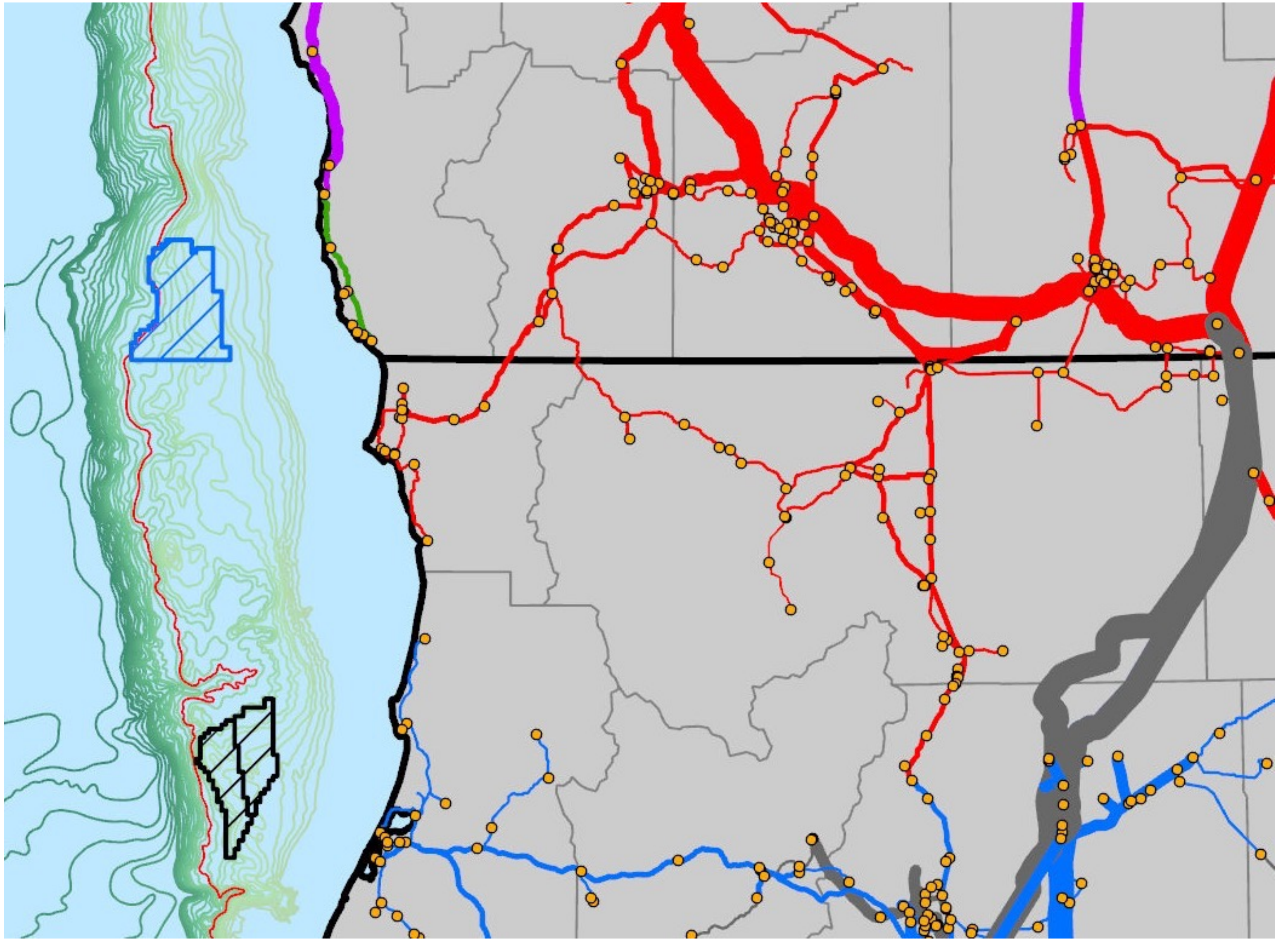
Implications of Humboldt County’s Energy Infrastructure History

Schatz Energy Research Center

- Significant investments in electrical and natural gas infrastructure in Humboldt County occurred during the post-WWII economic boom, a time when the region’s timber resources were in high demand to support economic development across California and beyond.
- Investments in new infrastructure since then have been comparatively modest.
- Offshore wind represents a potential opportunity for investment in new infrastructure, including investments that can bring benefits (reliability, capacity, jobs) to the region.

Del Norte County Transmission System (brief overview)

- Like Humboldt’s, the electrical system serving Del Norte County is isolated.
- The grid operator in the region is Pacific Power (red lines).
- The region is supplied by two 115 kV transmission lines.
- The average regional load is about 25 MW.
- There is no local generation source that can carry the local load, so the system is vulnerable to transmission line outages.



Del Norte County Transmission System (brief overview)

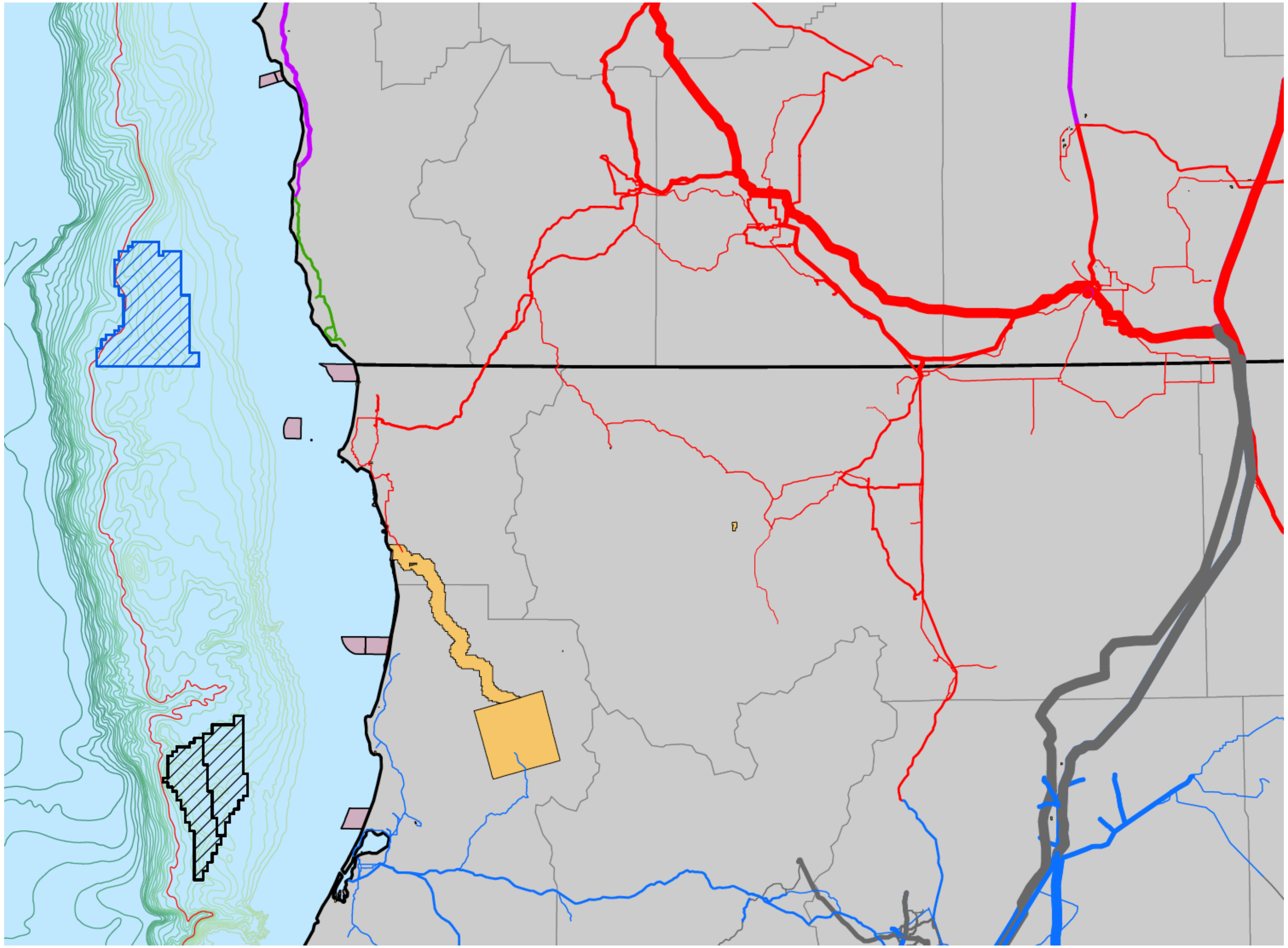
- Like Humboldt’s, the electrical system serving Del Norte County is isolated.
- The grid operator in the region is Pacific Power (red lines).
- The region is supplied by two 115 kV transmission lines.
- The average regional load is about 25 MW.
- There is no local generation source that can carry the local load, so the system is vulnerable to transmission line outages.

Diesel generators powering a section of Crescent City during a regional power outage in Sept. 2023 caused by wildfire near transmission lines that supply the area.

Del Norte County Transmission System (brief overview)

Schatz Energy Research Center

- While BOEM has not yet defined a wind energy area along the Del Norte County coast, this may happen in the future.
- If a wind energy area is defined, significant transmission upgrades would be needed to enable offshore wind development in the region.
- A local connection to new transmission could provide reliability and capacity benefits to the region.



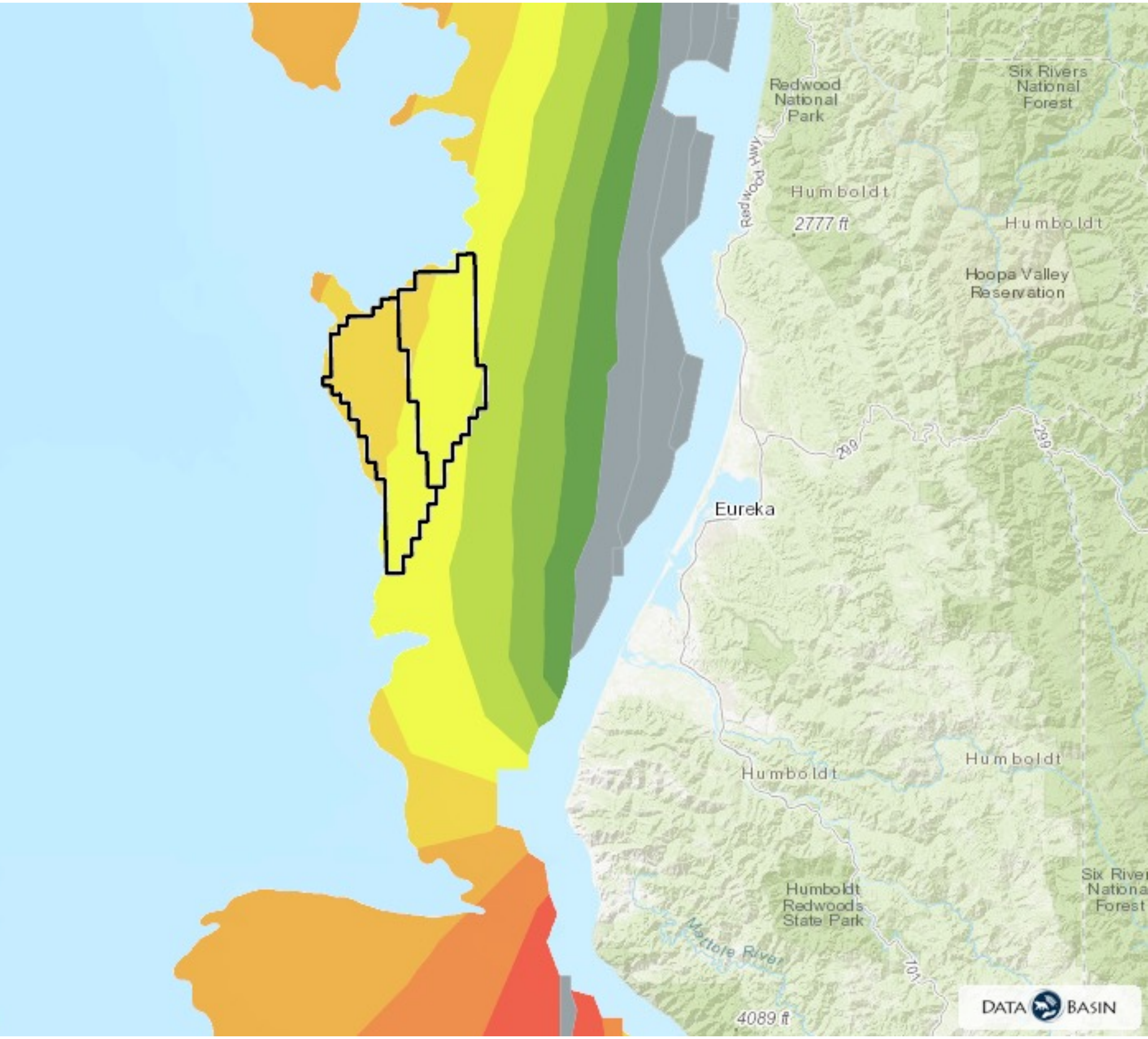
Schatz Center Analysis of Transmission for OSW

Over the past five years, the Schatz Center and partners have engaged in three major studies focused on understanding the transmission infrastructure needs of offshore wind.

Analysis has covered multiple scenarios:

- Large-scale wind farm in Humboldt Wind Energy Area (WEA): 1,836 MW
- Small-scale wind farm in Humboldt WEA: e.g., less than 200 MW
- Large-scale wind farms at multiple sites in NW California and SW Oregon: 7,200 to 25,800 MW

schatzcenter.org/wind
schatzcenter.org/publications



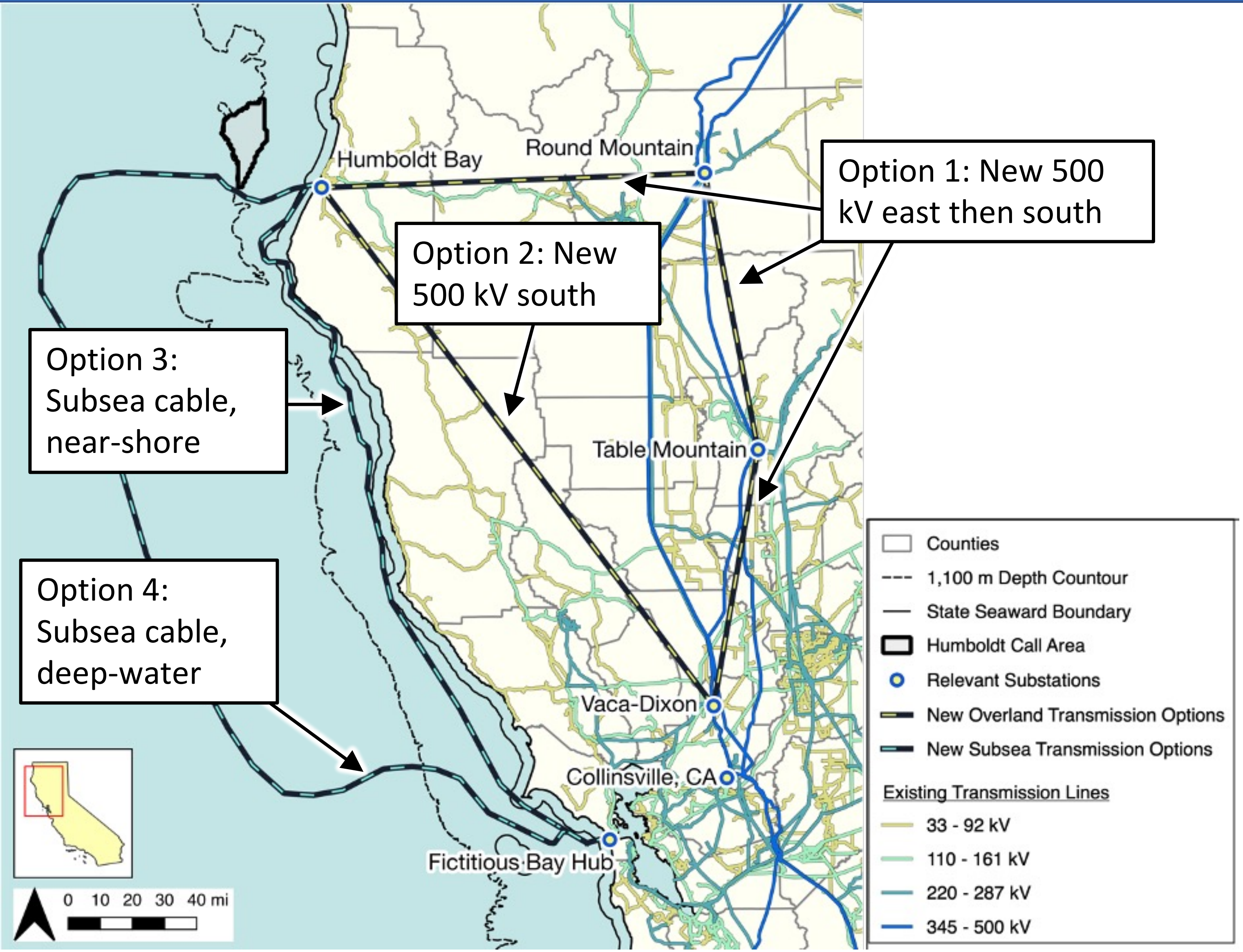
OSW at scale in the Humboldt WEA will require transmission expansion

- The output of an 1,800 MW wind farm is over 20 times the export capacity of existing lines serving Humboldt County.
- A large-scale expansion of transmission capacity would be needed to deliver OSW to major load centers (estimated cost: $2 to $5 billion, depending on specifics)

[Note also that offshore wind developers indicate that even more wind capacity could be installed in the Humboldt WEA, perhaps up to 3,000 to 4,000 MW.]

115 kV line serving Humboldt County passes under 500 kV lines near Cottonwood, CA

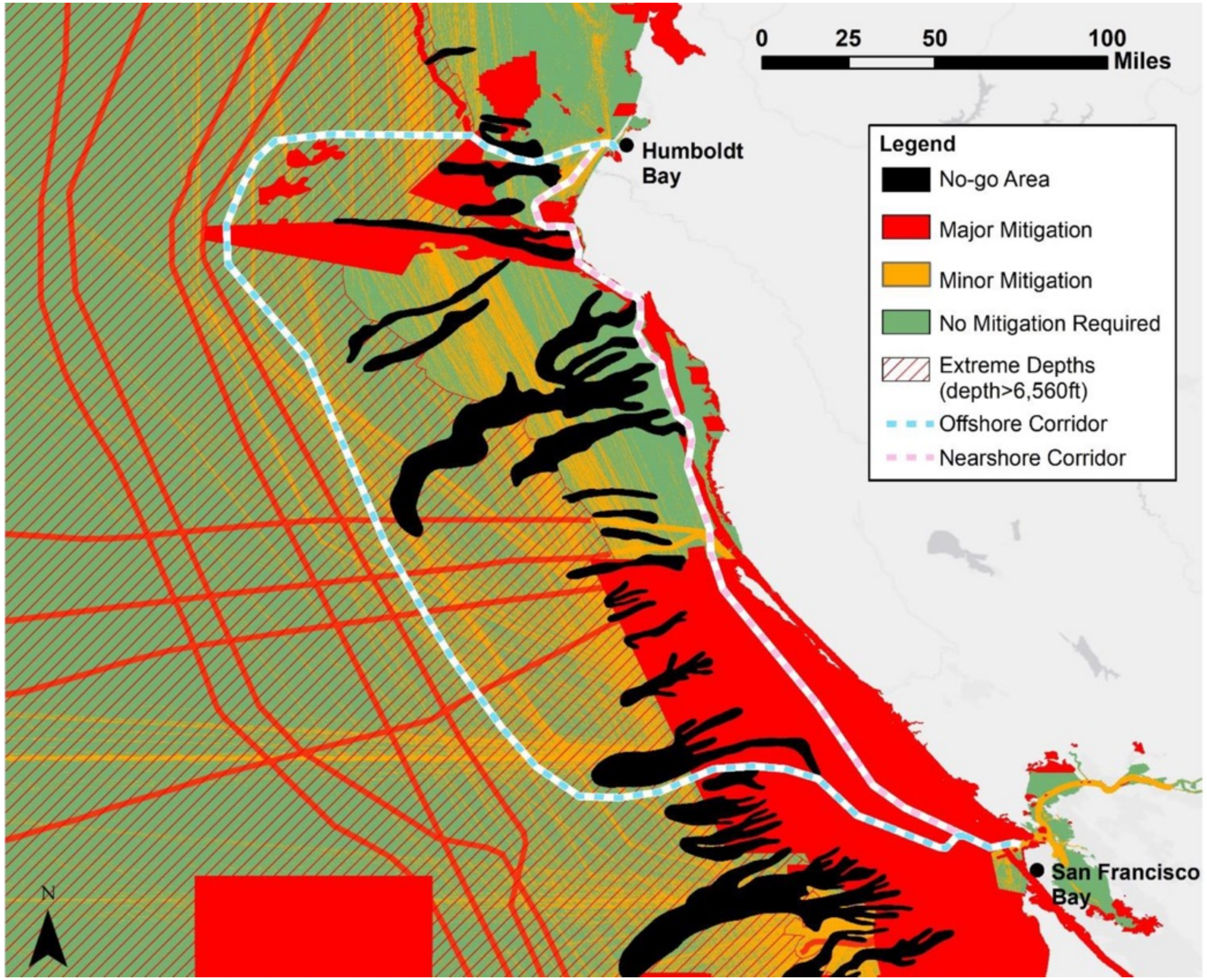
PG&E / Schatz Center Analysis of Transmission Alternatives (1.8 GW)



- Transmission lines to support OSW in the Humboldt WEA could follow overland and/or undersea routes.
- Two lines are generally needed to meet redundancy requirements.

Source: Severy, et al., 2021: schatzcenter.org/pubs/2020-OSW-R12.pdf

Undersea Cable Corridor Alternatives
(developed by Mott MacDonald)

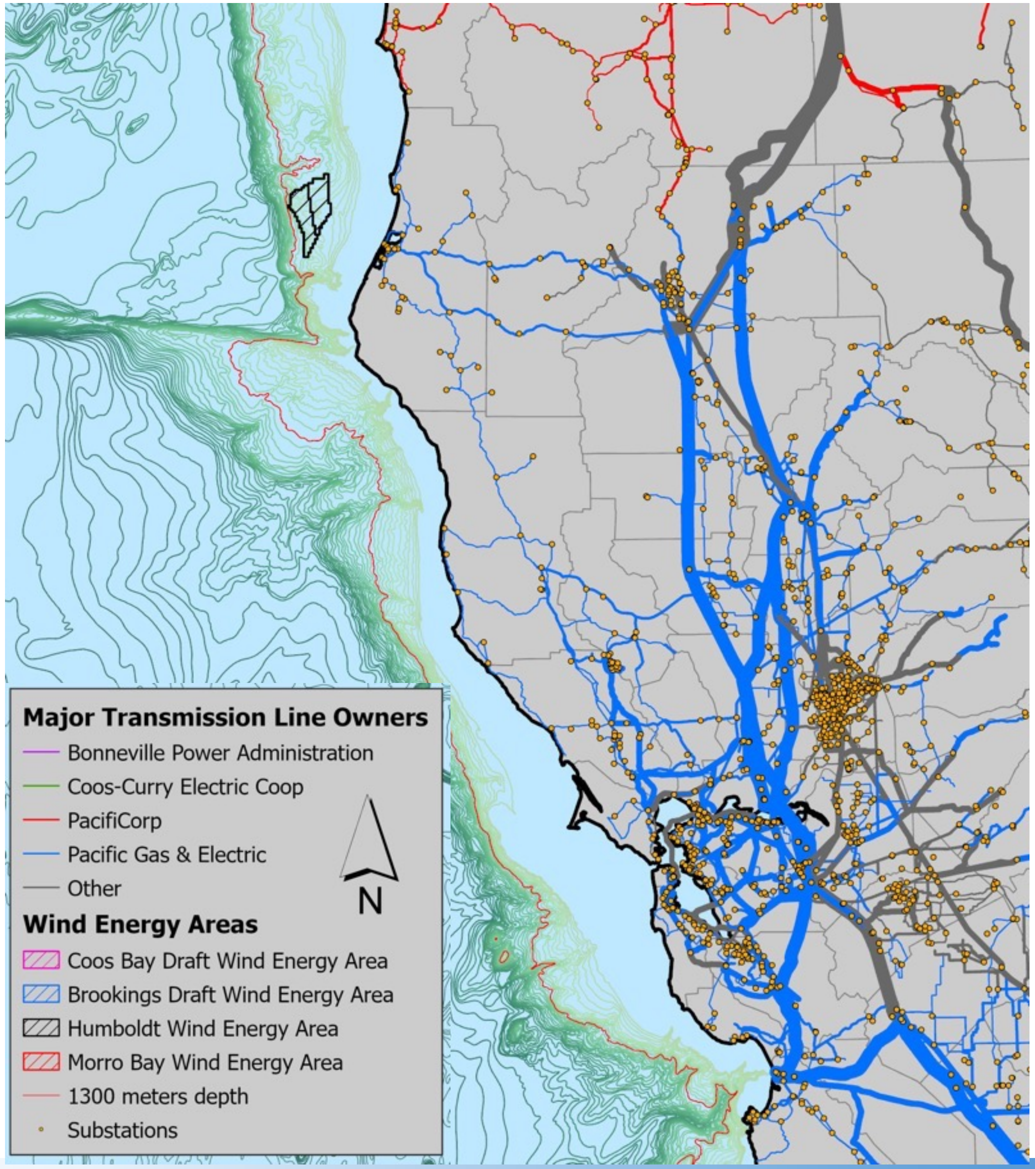


- Undersea transmission routes from Humboldt to the Bay Area may be more challenging due to deep waters, undersea canyons, ecological considerations, and marine protected areas.

See http://schatzcenter.org/pubs/2020-OSW-R5.pdf

Overland Transmission Route Options

- Specific routes for overland transmission lines have not yet been identified.
- The most likely possibility may be to follow existing transmission line rights-of-way (but these rights-of-way would likely need to be widened).
- Environmental permitting, land ownership, cultural resources, wildfire risk, military-mission compatibility, and cost play key roles in determining eventual routes.
- Large scale transmission projects often take a decade or more, mainly due to route and permitting challenges.

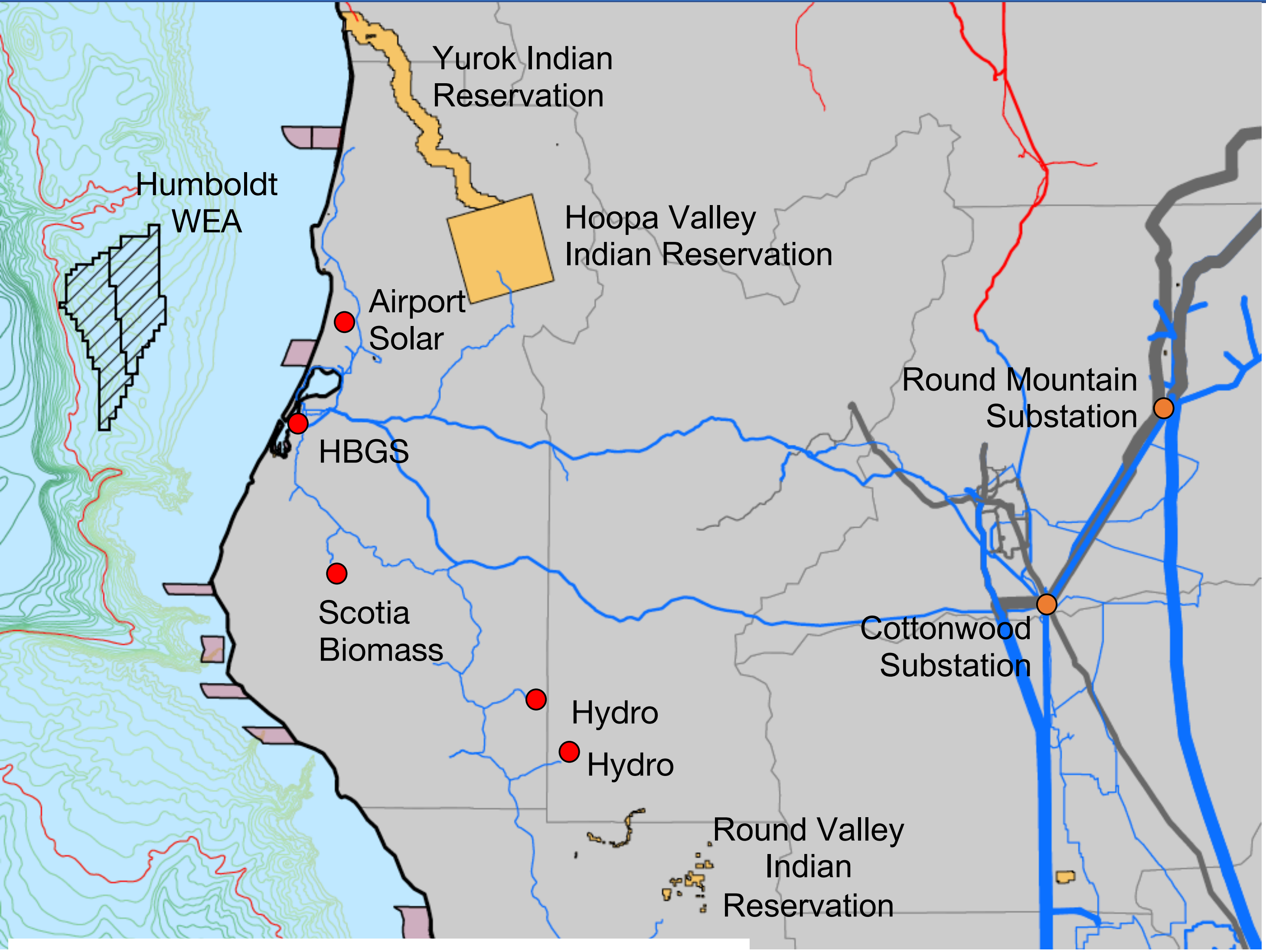


Potential local benefits from transmission to support OSW

- Access to clean energy from offshore wind farms.
- Increased access to transmission capacity, which could allow for regional load growth.
- Improved electricity reliability due to increased transmission capacity and associated redundancy.
- Reduced local air and water pollution from retirement of combustion-based power plants.
- Regional jobs and economic activity (mostly construction phase).


Credit: Senu Sirnivas/NREL

Transmission to Support Offshore Wind and Regional Benefits



HBGS = Humboldt Bay Generation Station

- Large-scale transmission lines to Humboldt Bay can increase capacity and improve reliability in that area, assuming a local grid connection (cost to do this is low).
- Large-scale transmission could also enable eventual phase out of the Humboldt Bay Generation Station.
- However, communities on radial lines that extend from Humboldt Bay would still be limited by the capacity and reliability of those lines and the associated local distribution system.

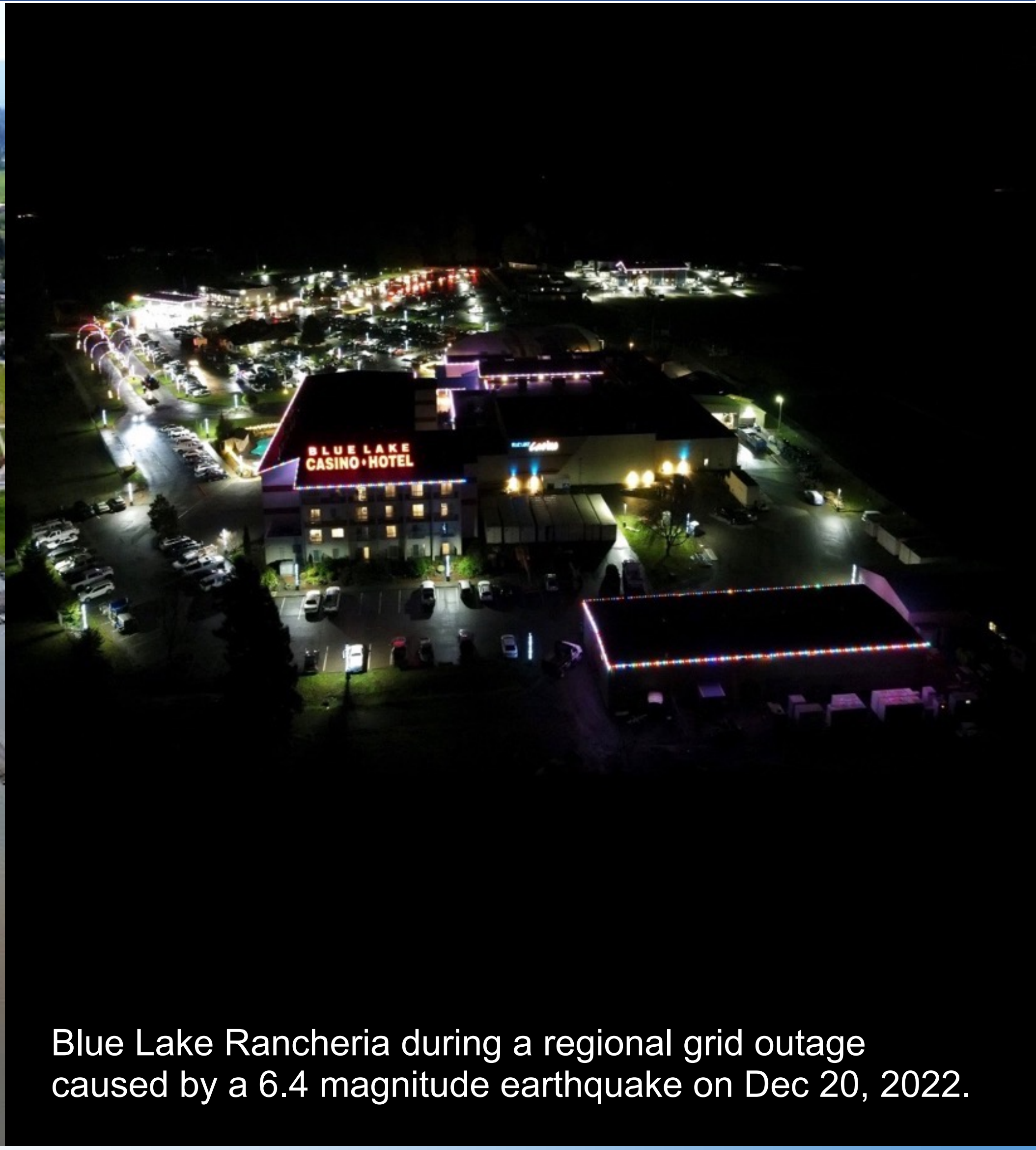
Renewable Energy Microgrids for Regional Resilience

Schatz Energy Research Center

Transmission upgrades cannot address all issues. Reliability challenges are often caused by issues on distribution circuits.

Renewable energy microgrids and other energy resilience strategies can be used to provide benefits for communities served by radial transmission lines.

Renewable energy microgrid at the Blue Lake Rancheria



Blue Lake Rancheria during a regional grid outage caused by a 6.4 magnitude earthquake on Dec 20, 2022.

Images courtesy of Blue Lake Rancheria

Renewable Energy Microgrids for Regional Resilience

Schatz Energy Research Center

Transmission upgrades cannot address all issues. Reliability challenges are often caused by issues on distribution circuits.

Renewable energy microgrids and other energy resilience strategies can be used to provide benefits for communities served by radial transmission lines.

Front of meter microgrid at the Arcata/Eureka Airport

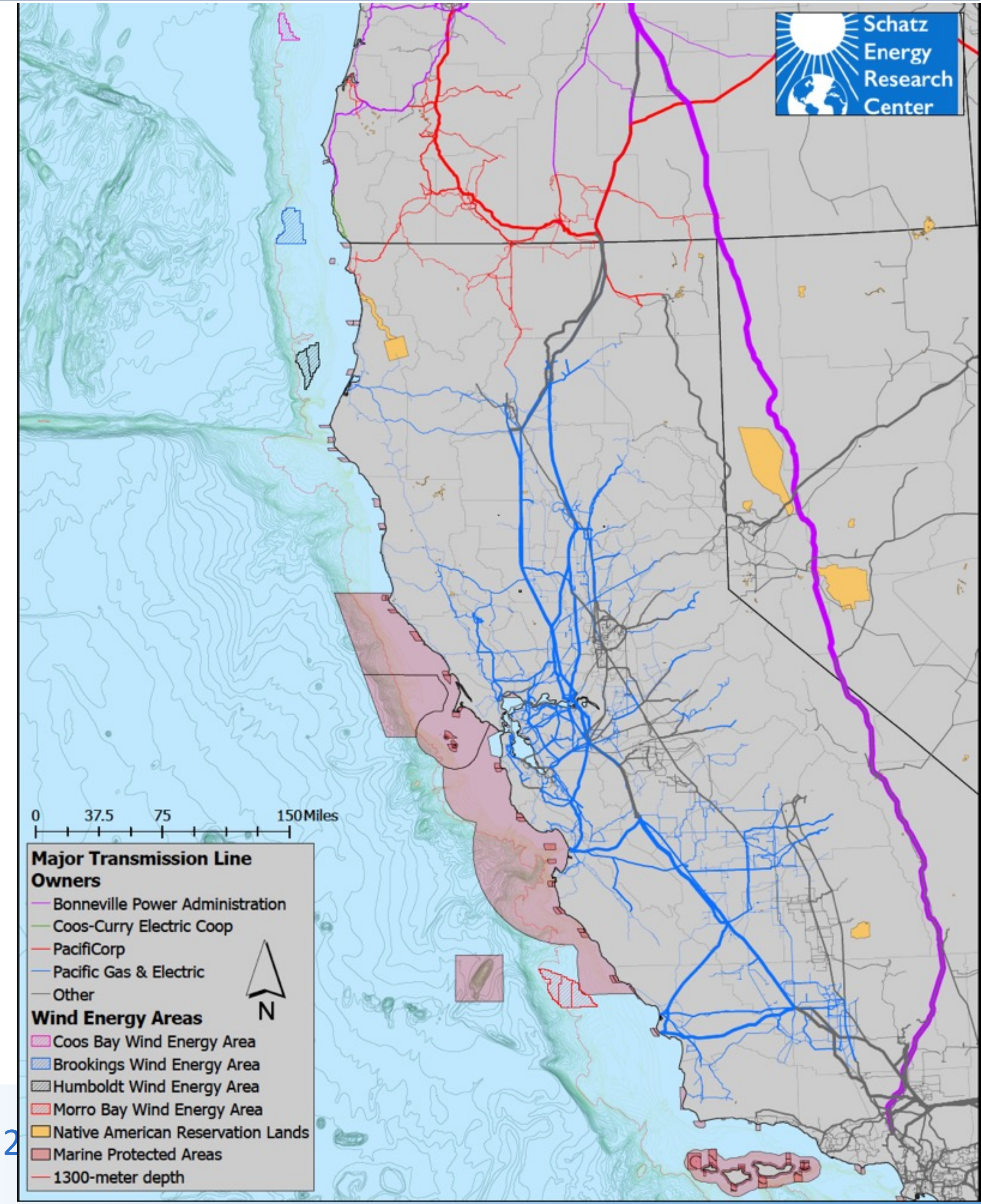
Offshore Wind and CA’s Transmission Planning Process

Transmission planning in California involves 3 entities:

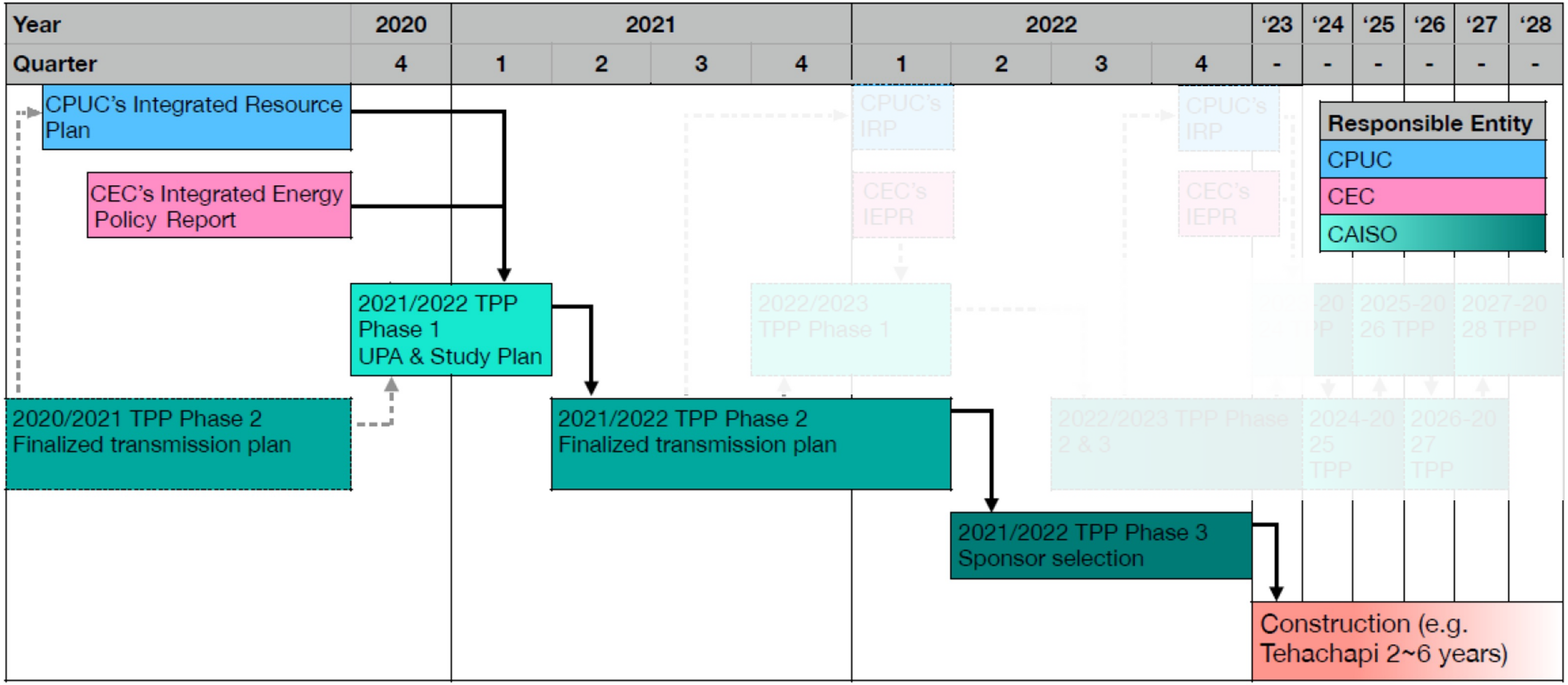
- California Energy Commission (CEC)
- California Public Utilities Commission (CPUC)
- California Independent System Operator (CAISO)

The Transmission Planning Process (TPP) occurs in 2-year cycles:

- CEC creates an electric load forecast.
- CPUC identifies the generation mix expected to meet the load.
- CAISO determines what transmission infrastructure upgrades are needed to deliver electricity from generation sources to meet the forecasted load.



CA Transmission Planning Process Cycle (2021-2022 example)



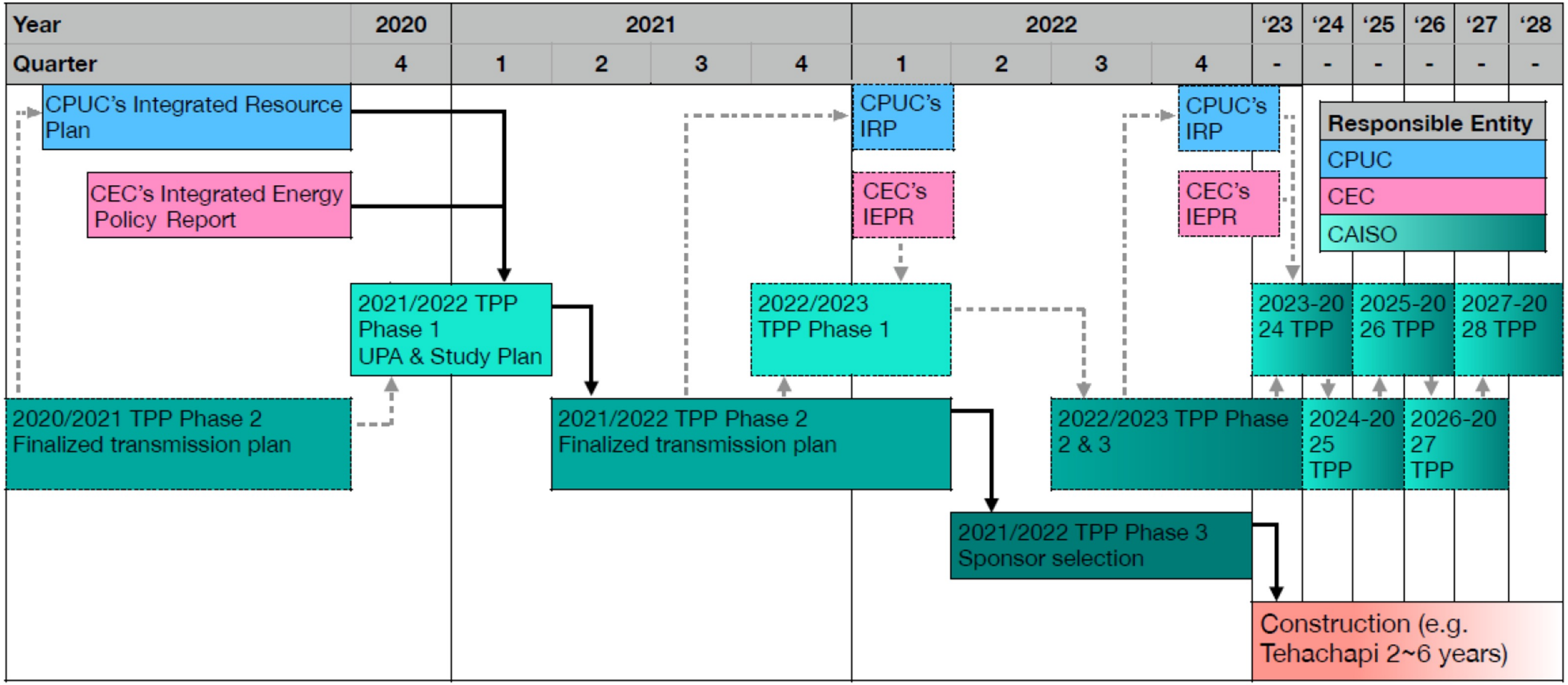
Notes:
* UPA = Unified Planning Assumptions.

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

Image source: CAISO, 2022

CA Transmission Planning Process Cycle (2021-2022 example)

Note: Annual cycles take place concurrently and overlap each other in a phased fashion as shown below.



Notes:
* UPA = Unified Planning Assumptions.

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

Image source: CAISO, 2022

Offshore Wind and CA's Transmission Planning Process

Schatz Energy Research Center

CAISO is currently assessing transmission needs across the state, including transmission to support development of offshore wind in the Humboldt Wind Energy Area.

2023-2024 TPP Adopted Base and OSW Sensitivity Portfolios (2035)

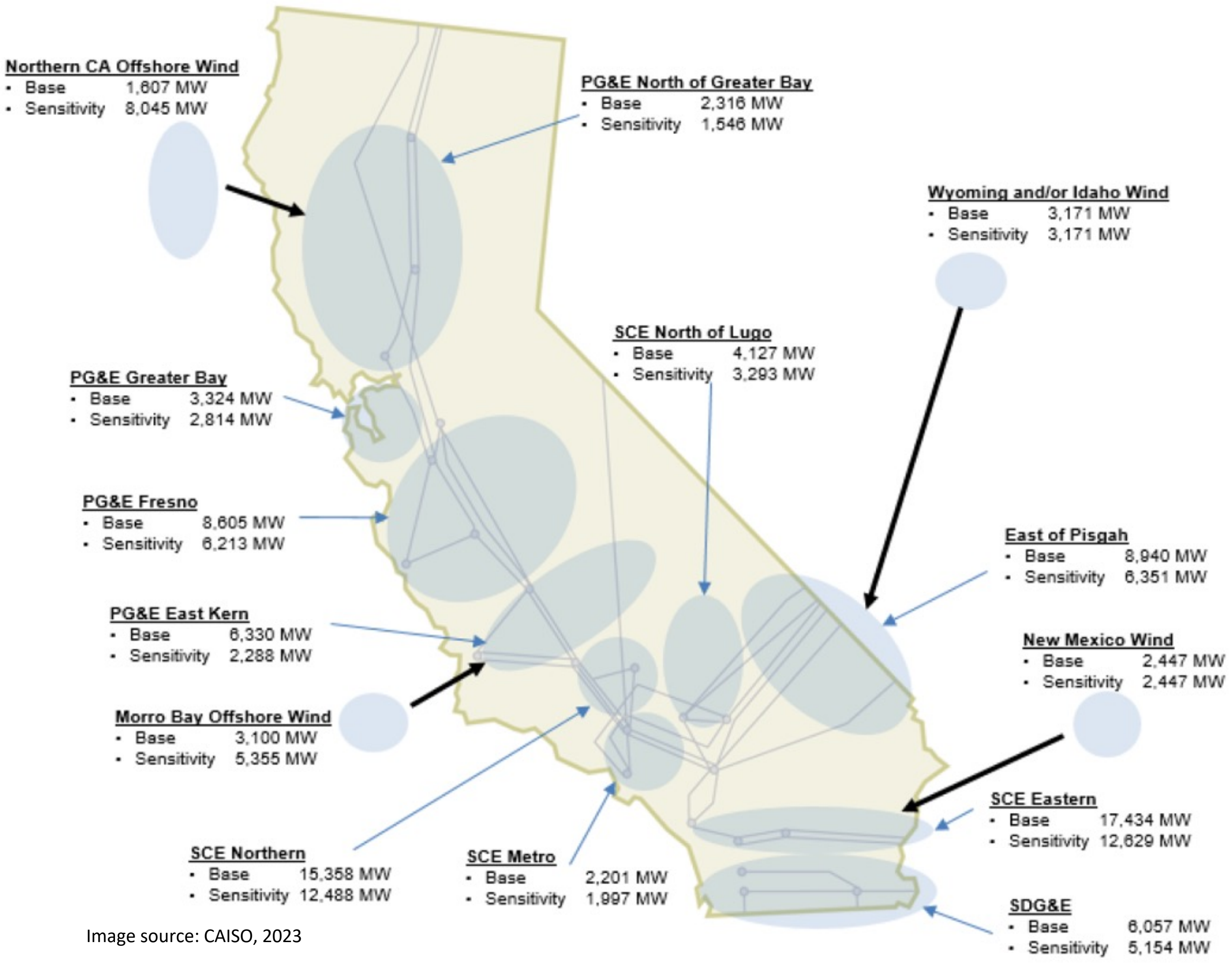


Image source: CAISO, 2023

Offshore Wind and CA's Transmission Planning Process

Schatz Energy Research Center

For the Humboldt Wind Energy Area, CAISO has been considering several potential transmission pathways, including:

- Onshore AC transmission from Humboldt to the planned Fern Road Substation (east of Redding)
- Onshore HVDC transmission from Humboldt to the planned Collinsville Substation (east of the Bay Area)
- Offshore HVDC transmission from Humboldt to the Bay Area or Moss Landing

All alternatives are likely to have a connection to the local system in the Humboldt Bay region

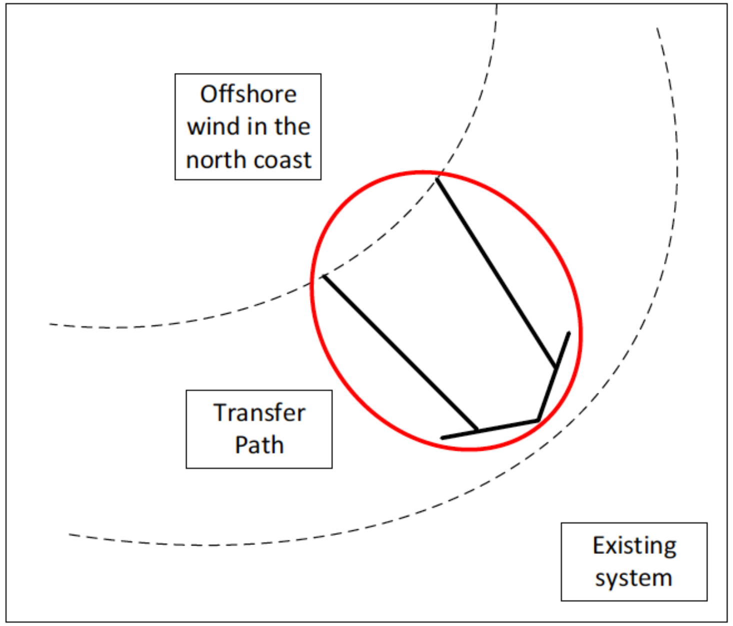
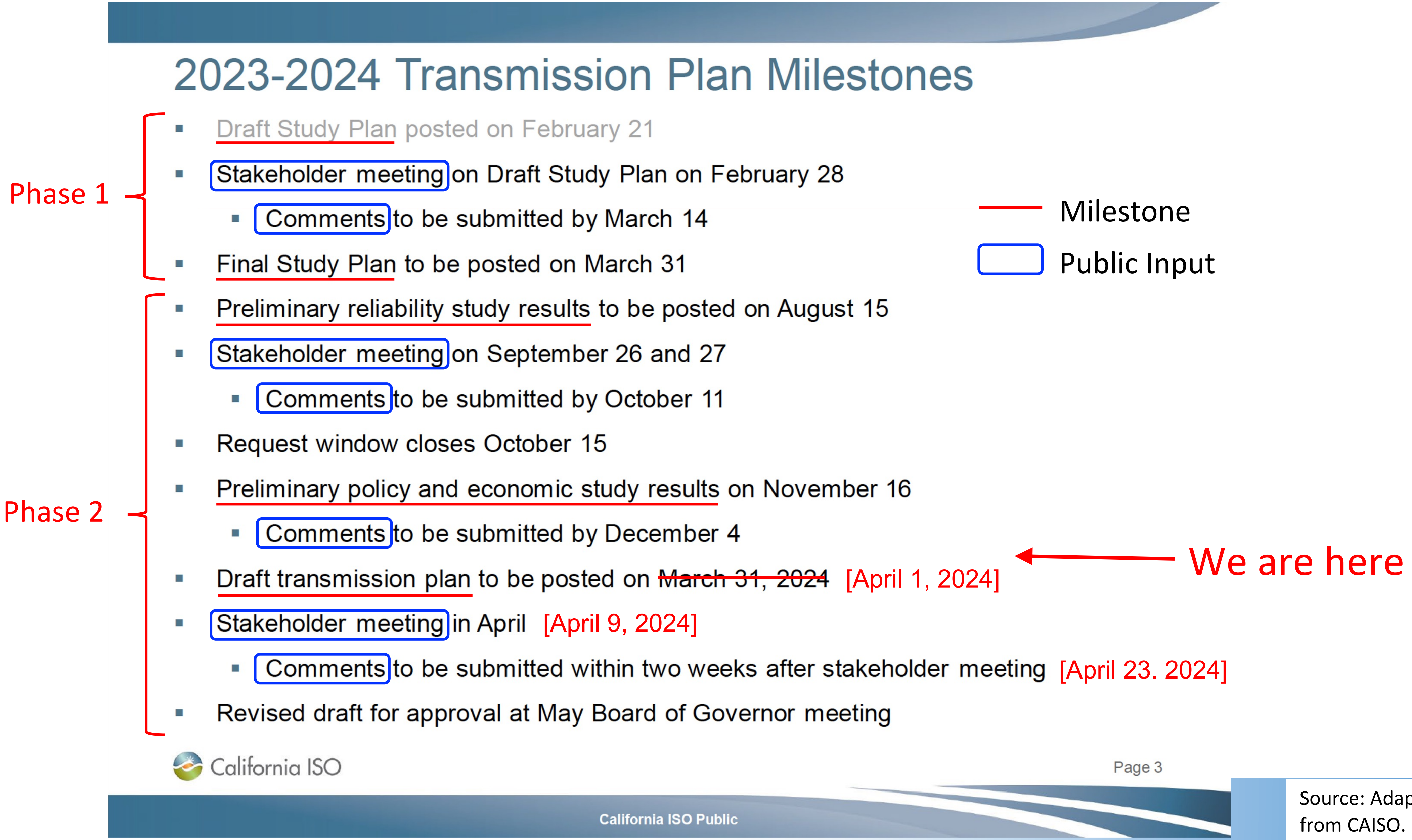


Image sources: CAISO, 2023

Technology	Normal Rating Assumptions (MVA)	Emergency Rating Assumptions (MVA)
500 kV AC line to Fern Road	3,500	4,500
Onshore overhead VSC-HVDC to Collinsville Substation	3,000	3,500
Offshore sea cable VSC-HVDC to a Substation in the Bay Area	2,000	2,500

CAISO 2023-24 Transmission Planning Milestones

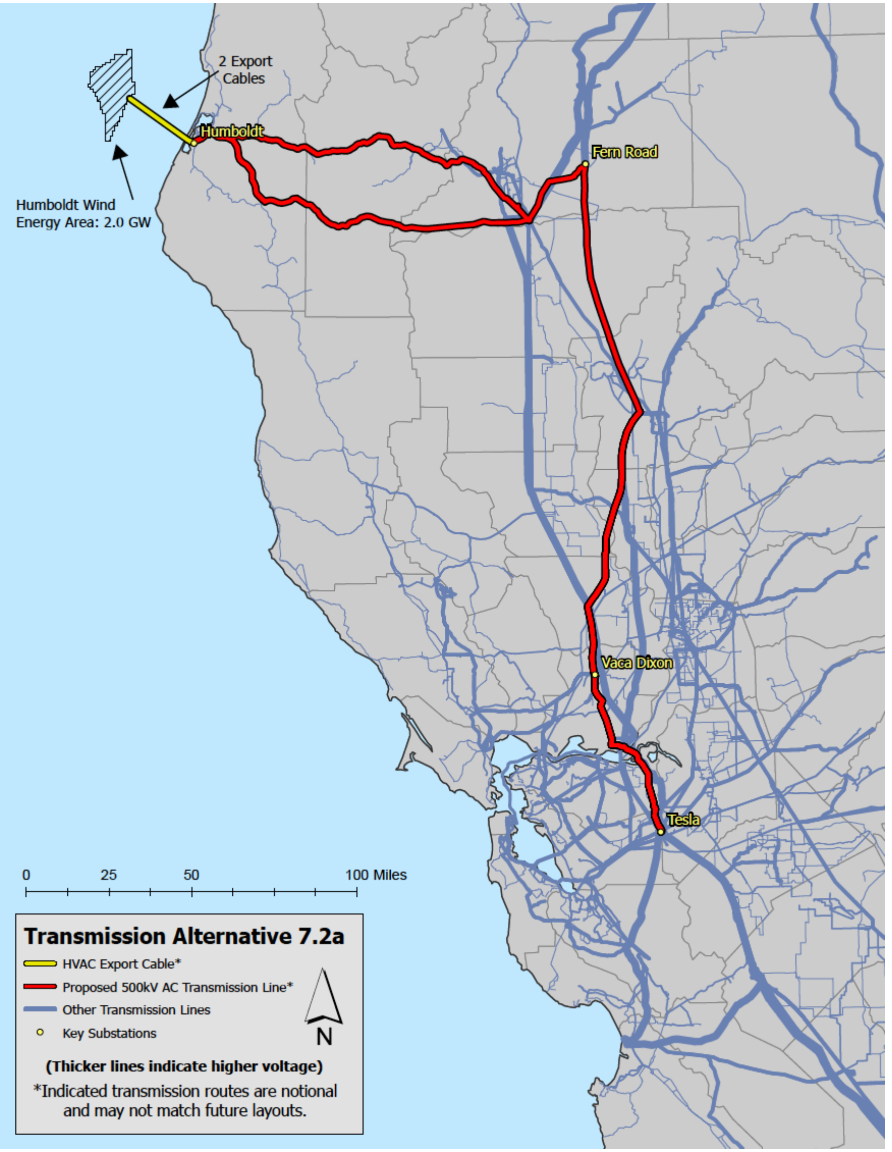
Schatz Energy Research Center



Source: Adapted from CAISO. 2023

Upcoming studies related to offshore wind & transmission

- Study of potential routes for transmission from the Humboldt Wind Energy Area



Potential routes for high voltage AC transmission to support offshore wind in the Humboldt Wind Energy Area (indicated routes are notional and may not match future layouts)

Next Steps for Analysis about Grid Integration of Offshore Wind

Upcoming studies related to offshore wind & transmission

- Study of potential routes for transmission from the Humboldt Wind Energy Area

Commercial scale battery energy storage

- Study assessing the role that energy storage (e.g. batteries) can play when combined with offshore wind and transmission

Utility scale battery energy storage facility at the Moss Landing power plant site

Key points: offshore wind and transmission in NW CA

- The winds offshore from NW California are consistently strong, and wind farms in the region could contribute substantially to state and local climate and clean energy goals.
- Significant investments in electric transmission infrastructure are a pre-requisite for development of offshore wind (OSW) at scale in NW California.
- Transmission upgrades can enable regional benefits, including better electricity reliability, but some communities would not benefit without deliberate steps to ensure inclusive outcomes.
- Humboldt County's existing electrical system was established in the post-WWII period, and its geographic extent and capacity have not changed substantially since the mid 1960s.
- Offshore wind provides a generational opportunity for new infrastructure investment.

Contact Information


Photo credit: Maia Cheli

Arne Jacobson, Ph.D.
Director, Schatz Energy Research Center
Cal Poly Humboldt
arne.jacobson@humboldt.edu

Jim Zoellick
Principal Engineer, Schatz Energy Research Center
Cal Poly Humboldt
james.zoellick@humboldt.edu

www.schatzcenter.org/wind

Substation timeline sources

Substation Name	Year Est.	Source
Arcata	1946	BLA, 7/27/1946
Big Lagoon	1954	BLA, 12/2/1954
Blue Lake	1949	BLA, 5/7/1949
Bridgeville	1954	BLA, 10/28/1954
Carlotta	1952	BLA, 12/31/1952
Eel River	1956	TS, 7/11/1956
Eureka A	1959	TS, 12/18/1959
Eureka E	1953	TS, 8/6/1953
Fairhaven	1965	BLA, 10/21/1965
Fort Seward*	1948	BLA, 7/31/1948
Fruitland	1952	BLA, 12/31/1952
Garberville	1947	ST, 12/19/47
Harris (Eureka)	1960	TS, 11/10/1960

Substation Name	Year Est.	Source
Hoopa	1958	BLA, 9/18/1958
Humboldt (Eureka)	1950	TS, 8/6/1953
Humboldt Bay	1956	BLA, 10/18/1956
Janes Creek	1957	BLA, 9/12/1957
Maple Creek	c1948	BLA, 7/31/1948
Newburg (Fortuna)	1955	TS, 8/18/1955
Orick	1952	BLA, 3/27/1952
Rio Dell	1952	BLA, 12/31/1952
Rio Dell Tap*	1952	BLA, 12/31/1952
Russ Ranch (Redwood Creek)	1952	BLA, 12/31/1952
Trinidad*	Before 1954	BLA, 12/2/1954
Ultra Power (Blue Lake)	1985	LCT, 1984 and Zoellick, 2005
Willow Creek	1949	BLA, 7/9/1949

BLA = Blue Lake Advocate; TS = Times Standard; HT = Humboldt Times; ST = Sebastopol Times; LCT = Lassen County Times

* Notes: Fort Seward received electricity in 1948, but the substation may have been installed at a later date. The Rio Dell Tap was not mentioned explicitly in the cited article; this listing assumes it was installed at the same time as the Rio Dell substation. The Trinidad substation was installed at some point before 12/2/1954. Based on its relationship to other regional electricity infrastructure, it is very likely that it was built in the late 1940s or early 1950s.