Facilitate transmission line upgrade planning with new REFA tool

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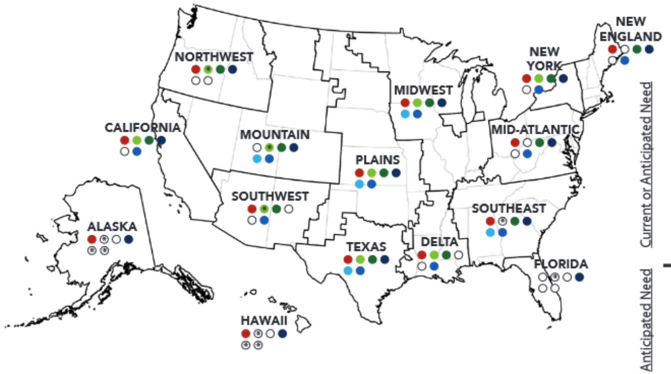
NASEO
National Association of State Energy Officials

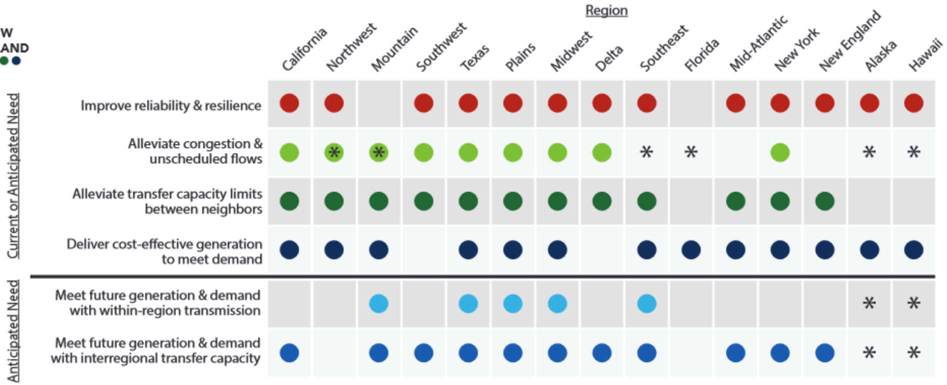
Outline

1. Background and Motivation
2. Proposed Value
3. Methodology of Reconductoring Economic and Financial Analysis (REFA) Tool
4. Example Case Study
5. Conclusions and Next Steps

Background

- Need to increase transmission capacity in the US to enhance bulk power system reliability, serve new loads, and improve interconnection capabilities.





* Department of Energy, "2023 National Transmission Needs Study", 2023

- At the planning level, infrastructure capacity upgrades can be achieved by new (or re-built) lines, voltage upgrades, or reconductoring projects.

Motivation

Transmission planning happens at different stages

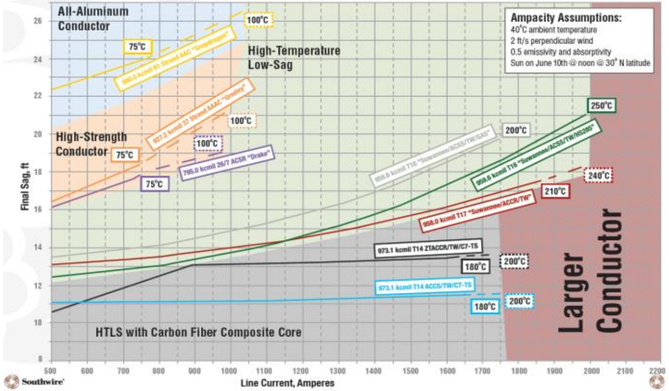
1. Transmission capacity expansion (system-wide) where a line capacity upgrade is identified

2. Capacity upgrade selection (reconductoring, rebuild, voltage upgrade)
   - Preliminary conductor selection

3. Detailed line design (e.g. PLS-CADD)

4. Project engineering and construction

- Decisions around transmission line capacity upgrade depend on conductor selection.
- The large offering of commercially-available advanced conductors reduces the ability to standardize designs.



* SouthWire, “C7 Overhead Conductor”, 2019

Proposed Value for SEOs

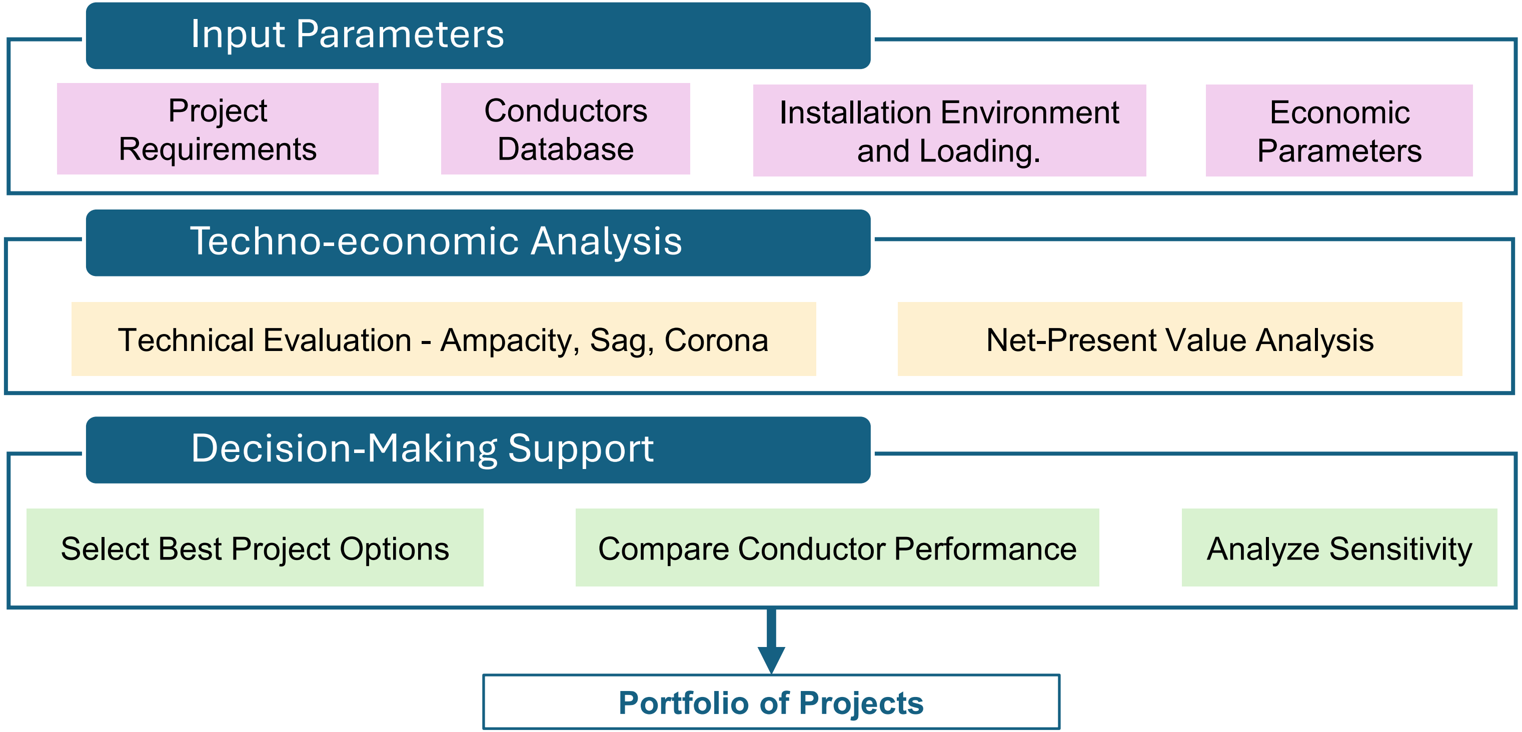
- A simple and intuitive tool, REFA, short for Reconductoring Economic and Financial Analysis tool
  - Compare different transmission capacity options.
  - Assess economic performance of different conductors.

- The tool is publicly available and technology-neutral.

- Helps state energy offices
  - Understand intricate relationships between techno-economic parameters and the cost of transmission upgrade projects.
    - Identify important parameters.
  - Communicate with utilities and regulators regarding the selection of transmission upgrade projects.
  - Better represent transmission upgrade costs to inform state-wide comprehensive energy plans.
  - Workforce training.

Reconductoring Economic and Financial Analysis (REFA) Tool

Access at: refa.lbl.gov



Technical Evaluation

- Ampacity calculations are based on the IEEE 738-2023 standard for calculating the current-temperature of bare overhead conductors
- Sag calculations follow the guidelines from CIGRE TB-324
- Corona inception voltage calculations use Peek's empirical formula

[1] Youba Nait Belaid, Miguel Heleno, Kristina LaCommare. **"Reconductoring Economic and Financial Analysis (REFA) Tool"**, Oct. 2025, LBNL, url: https://refa-app.lbl.gov/refa-documentation

Net-Present Cost Analysis

- The Net-Present Value of project costs (NPC) is evaluated for each conductor over a defined time horizon *Y*.

- The total cost includes structure, conductor, losses, and congestion costs.

$$NPC = \sum_{y=0}^{Y} NPC_y = \left(C_y^{st} + C_y^{cd} + C_y^{ls} + C_y^{cg}\right) * IF_y * \frac{1}{(1+W)^y}$$

Discount Factor $\frac{1}{(1+W)^y}$

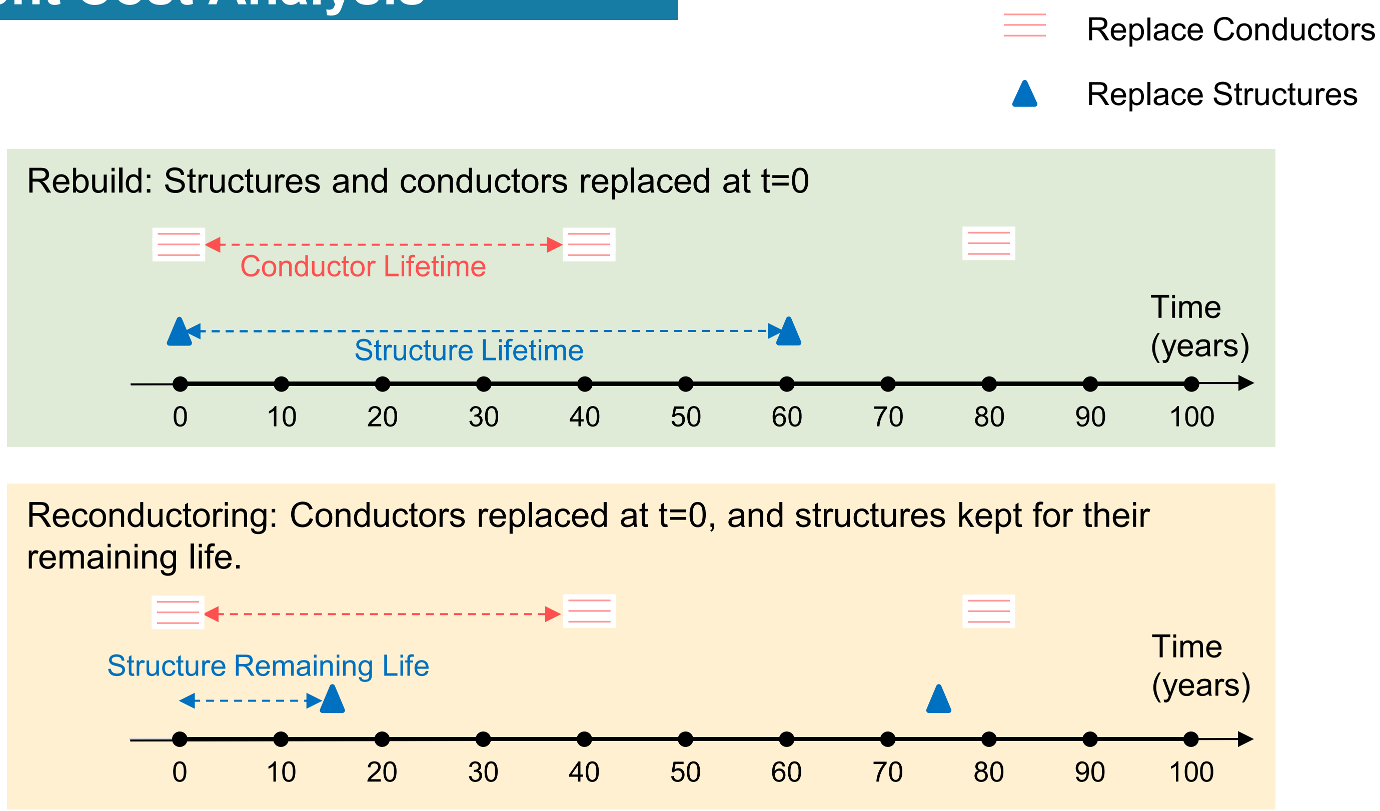
Inflation Factor

$$IF_y = (1+f) * IF_{y-1}$$

- Conductor cost: material cost, installation cost, accessories cost.

- Structure cost
  - By default, modeled as a generic per-unit cost.
  - Can be customized based on the structure type (tangent, angled, deadend, etc.).

Net-Present Cost Analysis



Cost of Line Losses

- REFA only considers losses due to the Joule heating effect.
- Two specific entries from the users are needed to calculate the cost of losses
  - Cost of energy $C^{dol,MW}$ (in $/MW)
  - Load Factor (average load / peak load)
- The calculation considers a typical approximation of the Loss of Load Factor (LLF) based on the Load Factor (LF).

$$C^{ls} = R * \left(I^{peak}\right)^2 * LLF * C^{dol,MW}$$

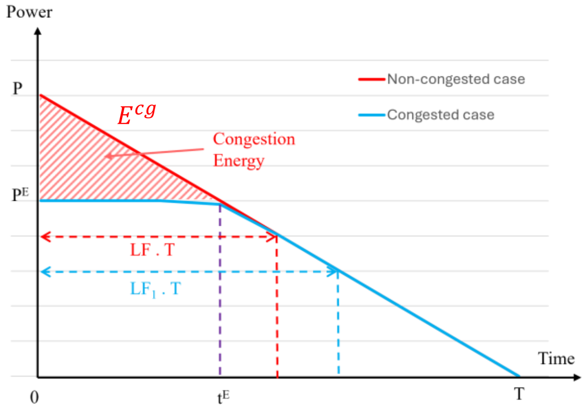
$$LLF = 0.3 * LF + 0.7 * LF^2$$

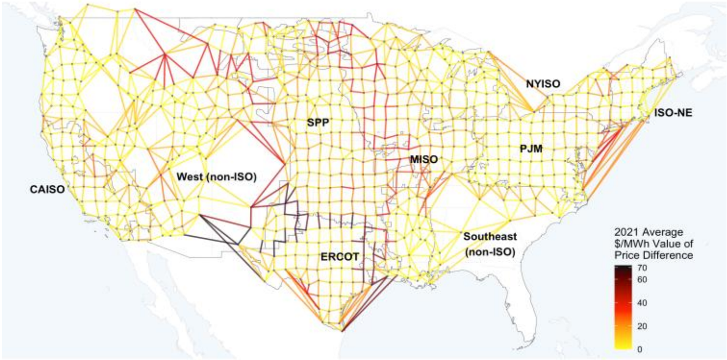
Cost of Congestion

- The cost of congestion is calculated by multiplying the marginal cost of congestion $C^{dol,MWh}$ (in $/MWh) by the energy that must be re-routed to other lines (at higher costs) due to congestion E^{cg}.

$$C^{cg} = E^{cg} * C^{dol,MWh}$$

- The marginal cost of congestion $C^{dol,MWh}$ is estimated using the difference in locational marginal prices (LMPs) in adjacent nodes of ISO/RTO regions.





* Millstein et al., "Empirical Estimates of Transmission Value using Locational Marginal Prices", 2022

Create and Manage Projects

1

REFA
Reconductoring Economic & Financial Analysis Tool
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REFA Tool

Accessing the REFA Application

Existing users may log in to the site to access the application. New users must first create an account.

New Users

First create an account on the **account creation page**. You will then receive an email with a one-time access link, which will allow you to log in and set your password.

Existing Users

If you have already created a user account on this site, you may access the tool after successfully **logging in** and clicking on the "REFA Tool" link in the site navigation.

2

REFA
Reconductoring Economic & Financial Analysis Tool
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Documentation Projects

Name	Updated		
Test2	11/09/2025	Share	Delete
Test1	10/27/2025	Share	Delete

Start new project

3

Project Name*

Test

System of Units

Imperial

Re-use conductor parameters

--use default conductor parameters--

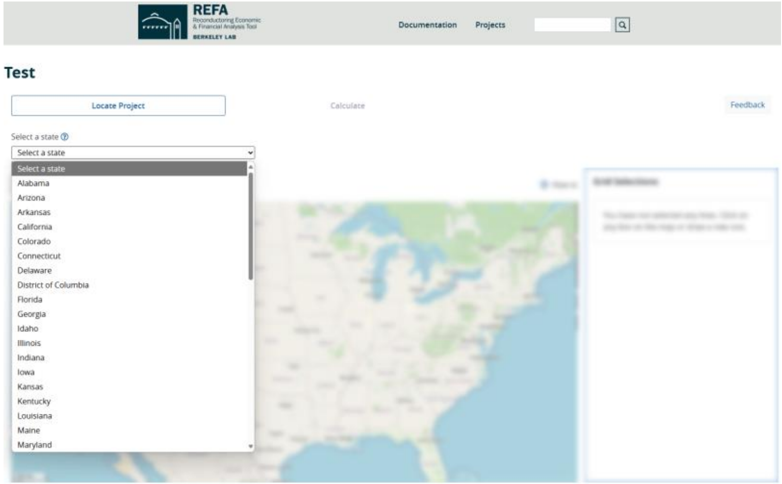
You can either start your project from the default conductors, or re-use the conductors from an existing project.

Begin project

Using the REFA Tool

Locate Projects

1



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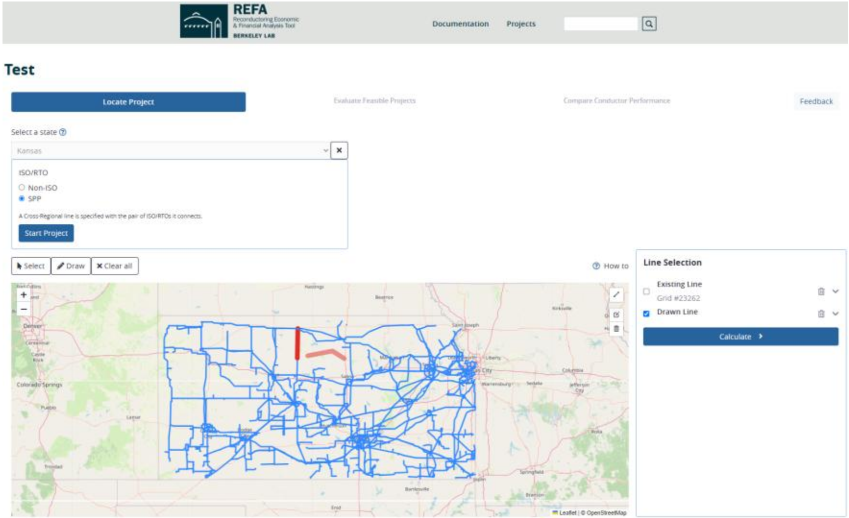
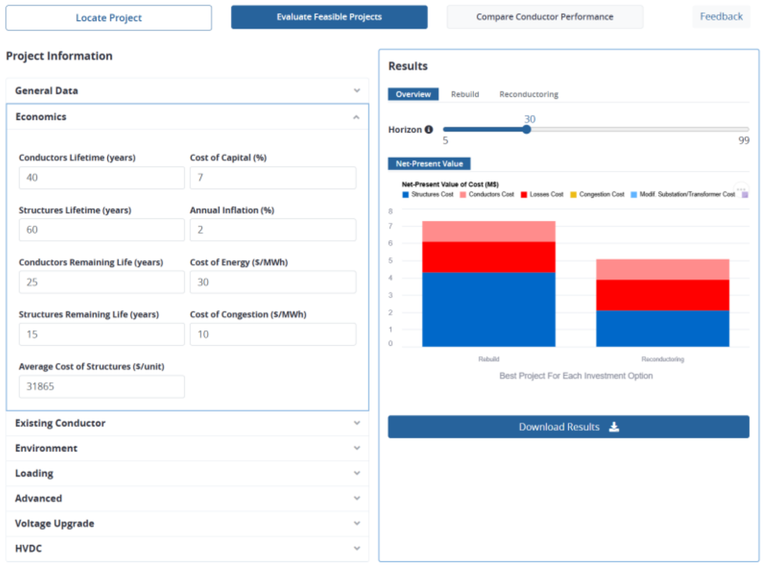


Analyze Projects

1



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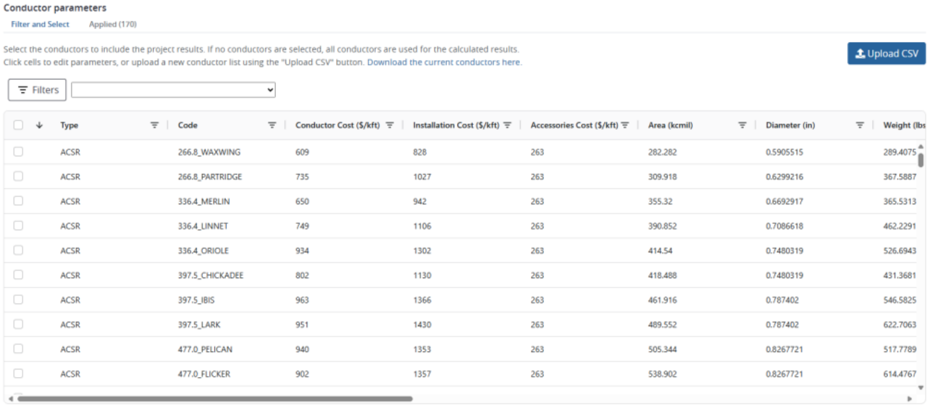


Type	Code	Conductor Cost ($/kft)	Installation Cost ($/kft)	Accessories Cost ($/kft)	Area (kcmil)	Diameter (in)	Weight (lbs
ACSR	266.8_WAXWING	609	828	263	282.282	0.5905515	289.4075
ACSR	266.8_PARTRIDGE	735	1027	263	309.918	0.6299216	367.5887
ACSR	336.4_MERLIN	650	942	263	355.32	0.6692917	365.5313
ACSR	336.4_LINNET	749	1106	263	390.852	0.7086618	462.2291
ACSR	336.4_ORIOLE	934	1302	263	414.54	0.7480319	526.6943
ACSR	397.5_CHICKADEE	802	1130	263	418.488	0.7480319	431.3681
ACSR	397.5_IBIS	963	1366	263	461.916	0.787402	546.5825
ACSR	397.5_LARK	951	1430	263	489.552	0.787402	622.7063
ACSR	477.0_PELICAN	940	1353	263	505.344	0.8267721	517.7789
ACSR	477.0_FLICKER	902	1357	263	538.902	0.8267721	614.4767

Case Study

- A real reconductoring project in Louisiana is selected from publicly available data.*

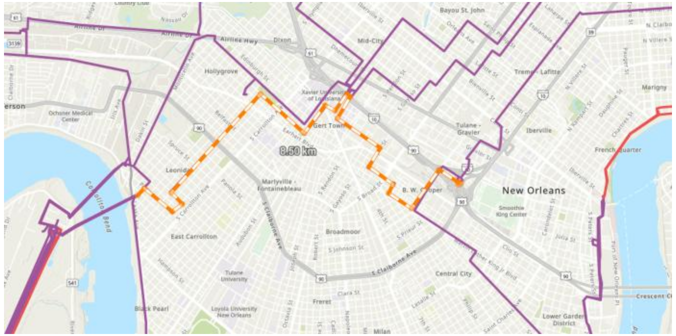


Fig. 1. Selected case study (cyan highlight)

Parameter	Value	Parameter	Value
Wind speed	0.61 (m/s)	**Azimuth**	90°
Wind direction	90°	**Ambient Temp.**	30°
Emissivity	0.5	**Day of year**	249th
Solar absorptivity	0.5	**Time**	15:00
Horizon	30 years	**Annual Inflation**	2 %
Conductor Lifetime	40 years	**Structure Lifetime**	60 years
Conductor Remaining Life	25 years	**Structure Remaining Life**	15 years
WACC	7 %	**Ruling Span**	90 m
Cost of Energy	30 $/MWh	**Max Span**	110 m

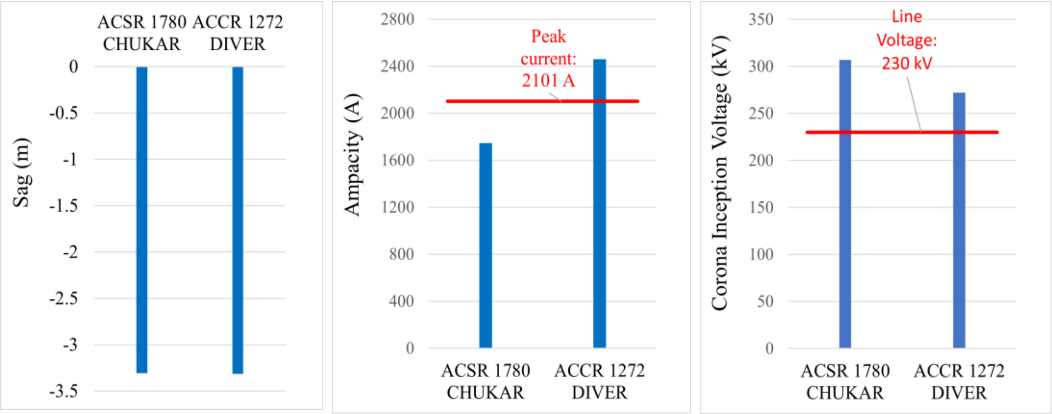
State	Louisiana	**Voltage**	230 kV	**Structure Unit Cost**	105,479.1 $
Length	8.5 km	**Loading**	NESC 250B Light	**Congestion Cost**	6.0 $/MWh
Initial Capacity	640 MW	**Required Capacity**	837 MW	**Candidate Conductors**	ACSR CHUKAR 1780 kcmil ACCR DIVER 1272 kcmil

More details:
https://escholarship.org/uc/item/58v3d3m5

* EPRI, “Advanced Conductor Experience”, 2024 https://msites.epri.com/rd/research/024056/advanced-conductor-experience

Comparison of Candidate Conductors

- Performance of conductors based on sag, ampacity, and corona inception voltage is evaluated for each conductor
- ACSR 1780 does not satisfy the current rating requirement
- Congestion costs make using ACSR 1780 more costly than the ACCR 1272.



(a) Sag (b) Ampacity (c) Corona Inception Voltage

Fig. 3: Technical performance of candidate conductors.

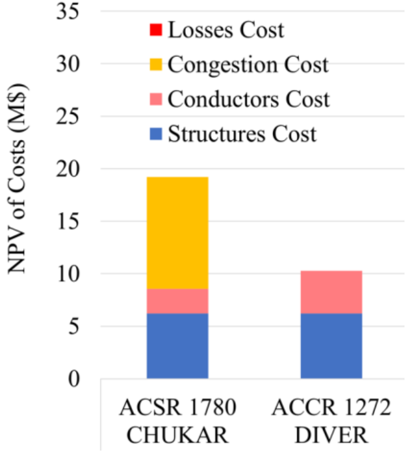
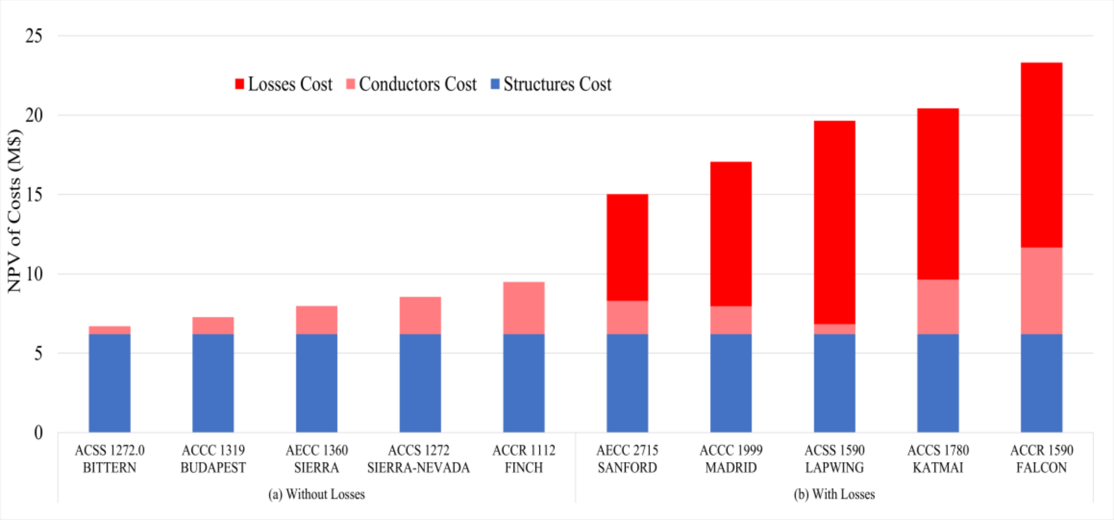


Fig. 4: Net-present cost of reconductoring using candidate conductors

Conductor Selection Using REFA

- Results from REFA using its conductor database show that other conductors can achieve a lower cost, while satisfying the project requirements

- The selection of least-cost conductors changes when losses are considered



Case With Losses
(Load Factor = 0.63,
Time Horizon = 30 years,
Cost of Energy = 30 $/MWh)

Fig. 5: Net-present cost of reconductoring using REFA conductor database

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Case Study

Selection of Project Options Using REFA

- Different project options (rebuild, reconductoring, voltage upgrade) can be evaluated and compared
- The tool shows the conductor achieving the least-cost for each project option

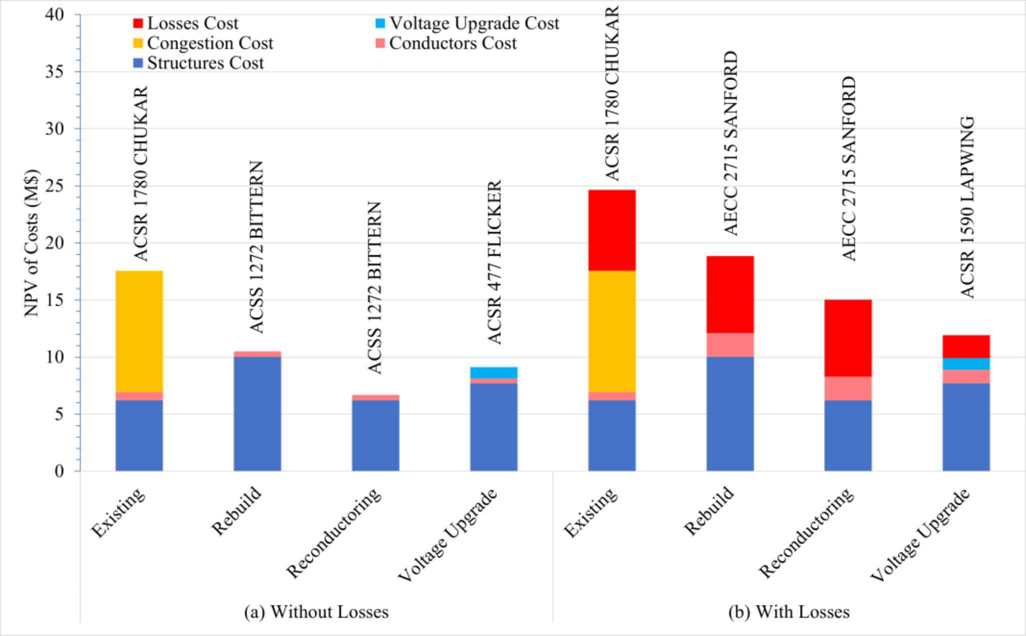

Fig. 6: Net-present cost of different investment options

Conclusions and Next Steps

- REFA fills a critical gap between transmission expansion and detailed line design
  - Provides a simple techno-economic comparison of different project options, including advanced conductors
  - Evaluates projects over a selected time horizon

- The tool can be used to communicate investment options to non-technical audiences
  - Simple and intuitive
  - Publicly available
  - Technology-neutral

- Continue calibrating the tool with real-world case studies and enhancing the tool based on user feedback. We welcome your thoughts and suggestions!

Contact

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Kristina LaCommare : kshamachi@lbl.gov

Access the REFA tool at:

refa.lbl.gov

Thank You!

Related References

[1] Youba Nait Belaid, Miguel Heleno, Kristina LaCommare. **“Reconductoring Economic and Financial Analysis (REFA) Tool”**, Oct. 2025, LBNL, url: https://refa-app.lbl.gov/refa-documentation

[2] Youba Nait Belaid and Miguel Heleno. **“A cost–benefit framework to evaluate capacity upgrade options in overhead line transmission planning”**. In: Electric Power Systems Research 251 (Feb. 2026),p. 112150. issn: 0378-7796. doi: 10.1016/j.epsr.2025.112150. url: https://www.sciencedirect.com/science/article/pii/S0378779625007382

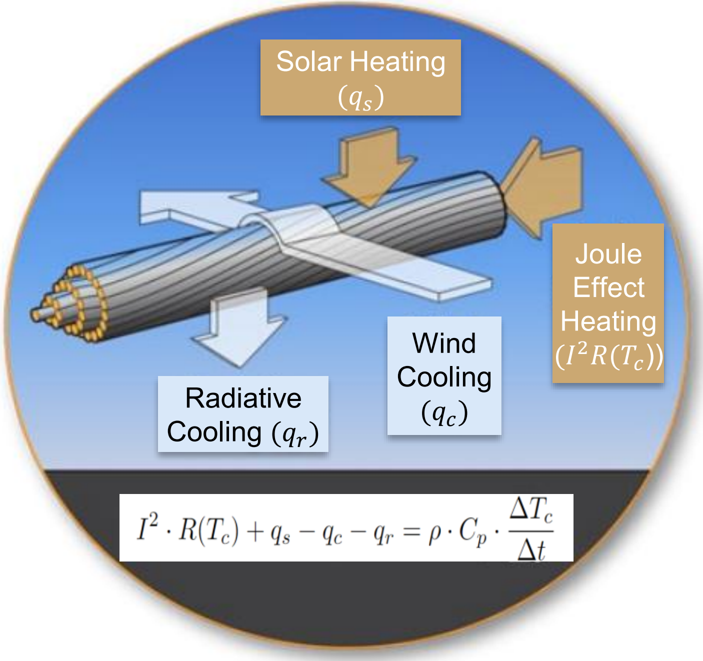
[3] Youba Nait Belaid and Miguel Heleno. **“Guidelines for Economic and Installation Environment-Based Selection of Overhead Transmission Conductors”**. In: 2025 IEEE Green Technologies Conference (Green-Tech). ISSN: 2166-5478. Mar. 2025, pp. 1–5. doi: 10.1109/GreenTech62170.2025.10977693. url:https://ieeexplore.ieee.org/document/10977693

[4] Youba Nait Belaid and Miguel Heleno, **“A Decision-Making Framework for Streamlined planning of Overhead Transmission Capacity Upgrades”**, CIGRE US Grid of the Future Symposium, Nov. 2025, LBNL, url: https://escholarship.org/uc/item/58v3d3m5

Appendix

Ampacity Calculations

- Ampacity calculations are based on the IEEE 738-2023 standard for calculating the current-temperature of bare overhead conductors
- The heat transfer model is implemented to calculate the conductor ampacity I_c at the maximum conductor temperature $T_c = T_{max}$
- The conductor temperature and resistance are calculated for the peak current
- The conductor ampacity varies due to changes in installation environment

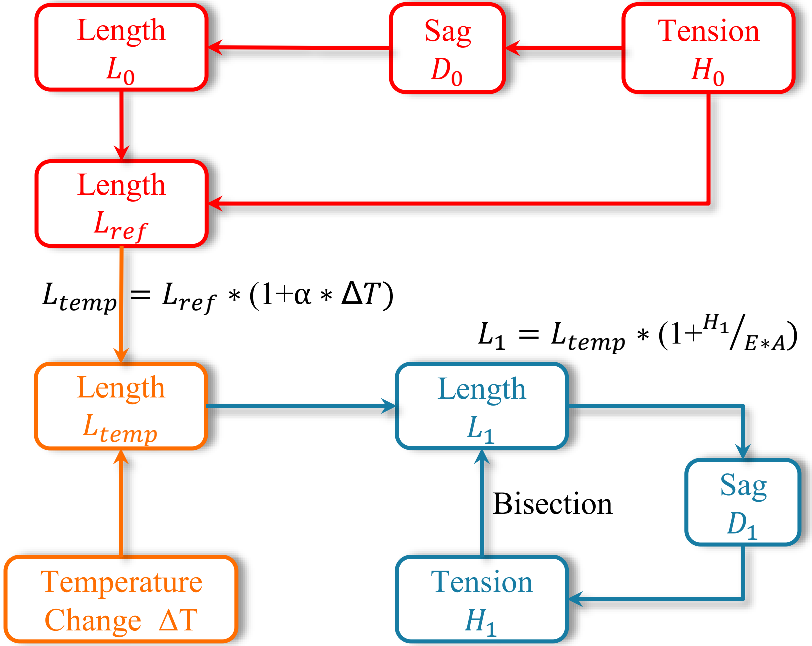


$$I^2 \cdot R(T_c) + q_s - q_c - q_r = \rho \cdot C_p \cdot \frac{\Delta T_c}{\Delta t}$$

* Adapted from: DoE report on Dynamic Line Rating, June 2019

Sag Calculations

- Sag calculations follow the guidelines from CIGRE TB-324
- Conductor length is assumed to evolve linearly with horizontal tension, *H,* and change in temperature, ΔT
- The methodology considers both thermal expansion of the conductor and strain from conductor weight, wind, and ice

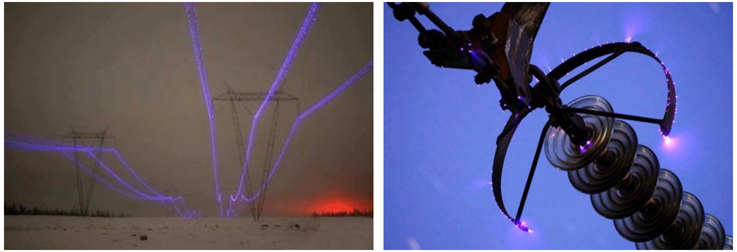


* CIGRE Technical Brochure 324,
* Alawar et al., "A hybrid numerical method to calculate the sag of composite conductors", 2006

Corona Effect Calculations

- Corona effect depends on the conductor geometry/material, phase bundling, voltage level, pollution, aging, and atmospheric/weather conditions

- The voltage at which the corona inception field produces a discharge, called the inception voltage, V^c, is calculated for each considered conductor*



Corona effect shown as a visible glow (Image credit: https://electronicslovers.com/2018/07/corona-effect-can-influence-the-overhead-transmission-lines.html)

$$V^c = \frac{29.8}{\sqrt{2}} \cdot m_c \cdot \delta \cdot m_t \cdot r \cdot N^{cd} \cdot \ln\left(\frac{GMD}{r}\right)$$

$$\delta = P \cdot \left(\frac{293}{273+T}\right) \cdot e^{-0.00012 \cdot h}$$

$\boldsymbol{V^c}$ is the inception voltage [kV].
$\boldsymbol{m_c}$ is the rugosity coefficient of the conductor (1 for polished conductors, 0.92-0.98 for dirty conductors, and 0.8-0.87 for stranded conductors).
$\boldsymbol{\delta}$ is the air correction factor (calculated using the atmospheric pressure *P* in atm, the temperature *T* in °C, the altitude *h* in meters).
$\boldsymbol{m_t}$ is the weather correction factor (considered as 0.8 for rainy conditions).
$\boldsymbol{r}$ is the conductor's radius.
$\boldsymbol{GMD}$ is the geometrical mean distance between phases.
$\boldsymbol{N^{cd}}$ is the number of conductors in the bundle.

* F. W. Peek. “The law of corona and the dielectric strength of air”. In: Proceedings of the American Institute of Electrical Engineers 30.7 (July 1911).