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OPPD
Omaha Public Power District

OPPD BOARD OF DIRECTORS

BOARD MEETING MINUTES

April 18, 2024

The regular meeting of the Board of Directors of the Omaha Public Power District ("OPPD" or "District") was held on Thursday, April 18 at 5:00 p.m. at the Omaha Douglas Civic Center, 1819 Farnam Street, 2nd Floor Legislative Chamber, Omaha, Nebraska and via WebEx audio and video conference.

Present in person at the Civic Center were Directors A. E. Bogner, M. J. Cavanaugh, M. R. Core, S. E. Howard, J. M. Mollhoff, C. C. Moody, M. G. Spurgeon and E. H. Williams. Also present in person were L. J. Fernandez, President and Chief Executive Officer, Messrs. S. M. Bruckner and T. F Meyerson of the Fraser Stryker law firm, General Counsel for the District, E. H. Lane, Sr. Board Operations Specialist, and other members of the OPPD Board meeting logistics support staff. Chair E. H. Williams presided and E. H. Lane recorded the minutes. Members of the executive leadership team present in person included J. M. Bishop, K. W. Brown, C. V. Fleener, S. M. Focht, G. M. Langel, T. D. McAreavey, L. A. Olson, M. V. Purnell, B. R. Underwood, and T. R. Via.

Board Agenda Item 1: Chair Opening Statement

Chair Williams gave a brief opening statement, including reminders for using the WebEx audio and video conferencing platform.

Board Agenda Item 2: Safety Briefing

Josh Clark, Manager, Protective Services, provided physical safety reminders . L. J. Fernandez, President and CEO, provided psychological safety reminders, including current safety focus reminders about: (i) Speak up for safety; (ii) Working from heights; and (iii) Distracted driving awareness month.

Board Agenda Item 3: Guidelines for Participation

Chair Williams then presented the guidelines for the conduct of the meeting and instructions on the public comment process in the room and using WebEx audio and video conferencing features.

Board Agenda Item 4: Roll Call

Ms. Lane took roll call of the Board. All members were present in person.

Board Agenda Item 5: Announcement regarding public notice of meeting

Ms. Lane read the following:

> *"Notice of the time and place of this meeting was publicized by notifying the area news media; by publicizing same in the Omaha World Herald, OPPD Outlets newsletter, oppd.com and social media; by displaying such notice on the Arcade Level of Energy Plaza; and by e-mailing such notice to each of the District's Directors on April 12, 2024.*
>
> *A copy of the proposed agenda for this meeting has been maintained, on a current basis, and is readily available for public inspection in the office of the District's Corporate Secretary.*
>
> *Additionally, a copy of the Open Meetings Act is available for inspection on oppd.com and in this meeting room."*

Board Consent Action Items:

6. Approval of the December 2023, January 2024, and February 2024 Financial Reports, March 2024 Meeting Minutes and the April 18, 2024, Agenda
7. Board Policy Revisions: BL-1: Board-President and Chief Executive Officer Relationship, BL-7: Delegation to the President and Chief Executive Officer, GP-3: Board Job Description – Resolution No. 6639
8. SD-14: Retirement Plan Funding Monitoring Report – Resolution No. 6640
9. SD-5: Customer Satisfaction Monitoring Report – Resolution No. 6641
10. SD-4: Reliability Monitoring Report – Resolution No. 6642
11. NC2 Economizer Ash Segregation -- Labor Contract Award – Resolution No. 6643
12. Award RFP 6134 - Bennington Expansion Transmission Construction – Resolution No. 6644
13. North Omaha Station Unit 5 (NO5) Replacement LP Turbine Blades - Engineer's Certification – Resolution No. 6645

It was moved and seconded that the Board approve the consent action items.

Chair Williams noted the Board discussed the action items during the All Committees meeting held on Tuesday, April 16, 2024.

Chair Williams then asked for public comment. There was one comment from the public in attendance at the meeting.

David Begley, 4611 S. 96th Street, Omaha, provided comments on board policies and SD-5, and presented materials to the board which are attached to these minutes.

Chair Williams then asked for public comment on WebEx. There was one comment.

David Corbin, 1002 N. 49th St, representing the Nebraska Sierra Club, provided comments on the consent agenda items.

Thereafter, the vote was recorded as follows: Bogner – Yes; Cavanaugh – Yes; Core – Yes; Howard – Yes; Mollhoff – Yes; Moody – Yes; Spurgeon – Yes; Williams – Yes. The motion carried (8-0).

<u>**Board Discussion Action Item**</u>

14. Determination as to matter of state law under Southwest Power Pool Tariff – Resolution No. 6646

Director Bogner moved to approve the discussion action item and it was seconded by Director Mollhoff.

Chair Williams invited S. M. Bruckner to provide comments on the discussion action item.

Chair Williams then asked for public comment. There were no comments from the public in attendance at the meeting.

Chair Williams asked for comments from members of the public on WebEx. There was one comment.

David Corbin, 1002 N. 49th St, representing the Nebraska Sierra Club, provided comments on state law.

Chair Williams asked for comments from the board.

Thereafter, the vote was recorded as follows: Bogner – Yes; Cavanaugh – Yes; Core – Yes; Howard – Yes; Mollhoff – Yes; Moody – Yes; Spurgeon – Yes; Williams – Yes. The motion carried (8-0).

Board Agenda Item 13: President's Report

President Fernandez next presented the following information:

- March 2024 Baseload Generation
- March 2024 Balancing Generation
- March 2024 Renewables
- Renewable Energy Credits
- Chartwell Award
- In Memoriam – Michael W. Johnson

Board Agenda Item 14: Opportunity for comment on other items of District Business

Chair Williams asked for comments from the public in the room on other items of District business. There were two comments.

David Begley, 4611 S. 96th Street, Omaha, provided comments on global warming, and presented materials to the board which are attached to these minutes.

Susie Papadopoulos, Creighton University student, provided comments on climate change and interim metrics for board policy SD-7.

Kate Williams, Ben Blicken, and Caroline Brandeberry, Creighton University students, provided comments on carbon emission reductions and board policy SD-7.

Ryan Wishart, Professor, Creighton University, provided comments on climate change and net zero goals.

Mr. Laverne Treahn, Omaha, NE, provided comments on advanced conductor technology, and presented materials to the board which are attached to these minutes.

Chair Williams asked for comments from members of the public on WebEx. There was one comment.

David Corbin, 1002 N. 49th St, representing the Nebraska Sierra Club, provided comments on the climate action plan in Nebraska.

Mr. John Pollack, 1412 N. 35th Street, Omaha, provided comments on climate change and SD-7 and provided a weather update.

There were no additional comments from the public in attendance at the meeting or via WebEx.

There being no further business, the meeting adjourned at 6:00 p.m.

DocuSigned by:
S.M. Focht
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S. M. Focht
Vice President – Corporate Strategy and Governance and Assistant Secretary

DocuSigned by:
Erin Lane
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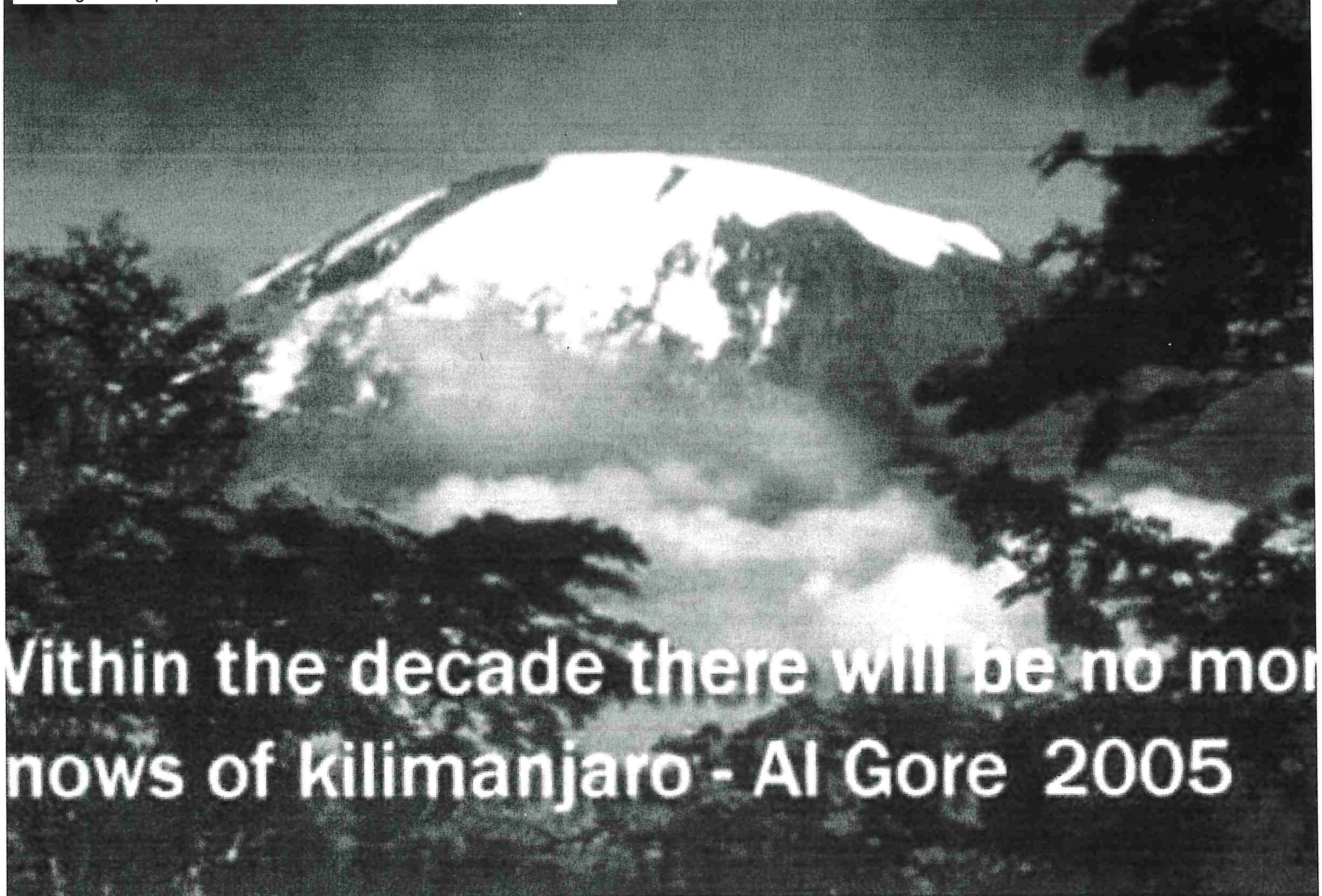
E. H. Lane
Sr. Board Operations Specialist

"The party told you to reject the evidence of your eyes and ears. It was their final, most essential command."

1984 by George Orwell, read by David D. Begley at Creighton Prep in 1971.

Prepared and submitted by customer-owner David D. Begley, 4611 South 96th Street, Omaha, NE 68127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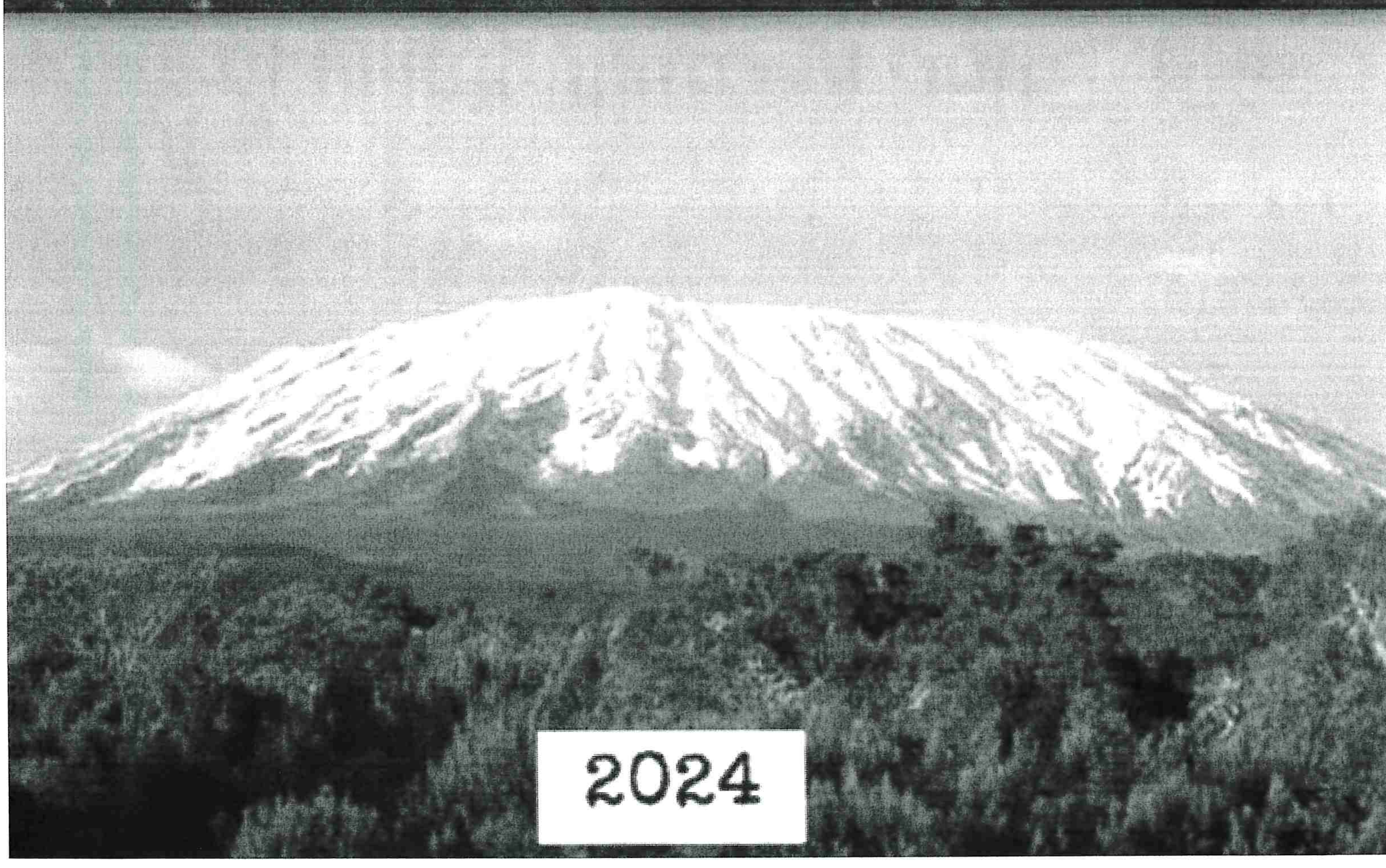
nows of kilimanjaro - Al Gore 2005


2024

Tony Heller
@TonyClimate

Arctic sea ice extent is about the same as 1996. #ClimateScam

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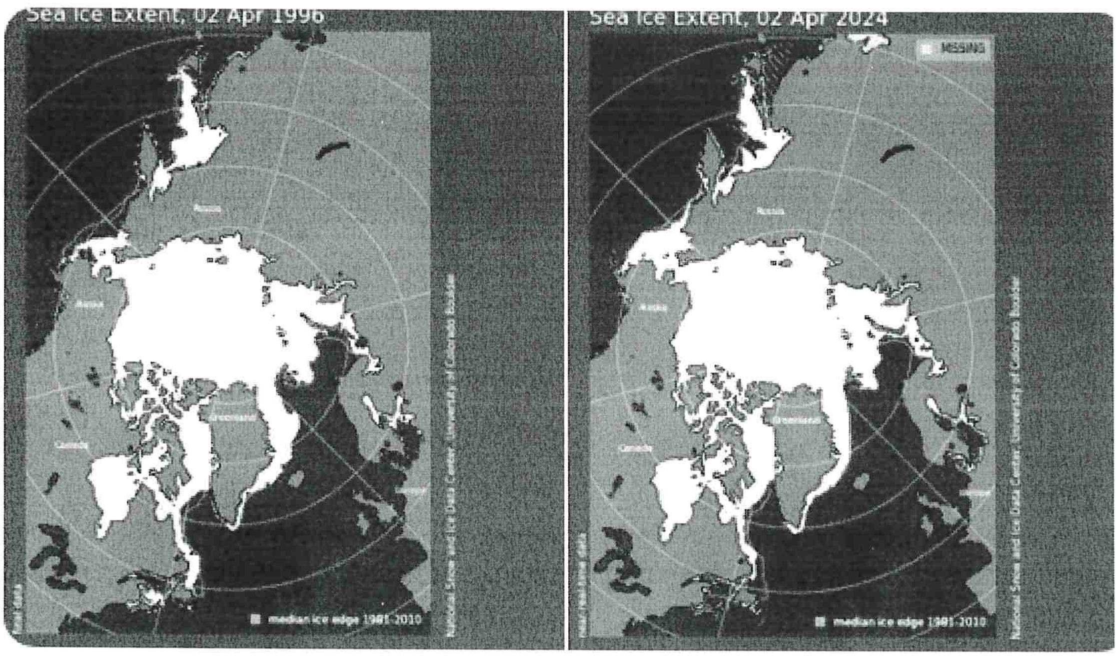

7:37 AM · Apr 3, 2024 · **2,323** Views

Tony Heller
@TonyClimate

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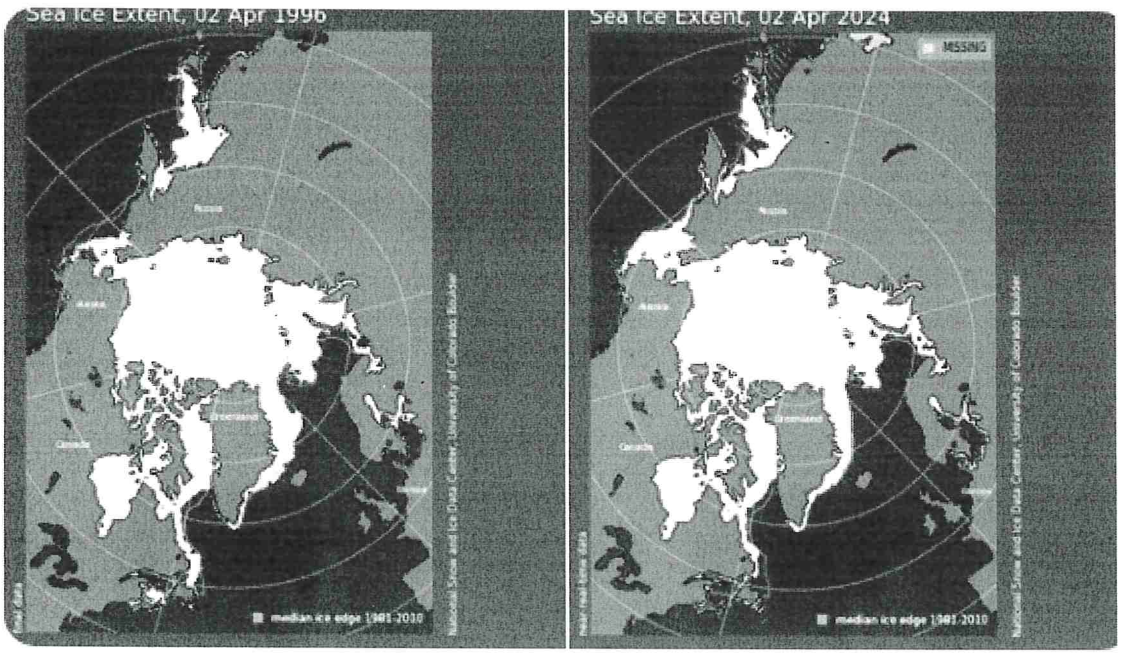

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GP – 3 Board Job Description

What's missing?

The Board shall perform its statutory duty of providing customer-owners with low cost and reliable electricity.

"Weigh matters carefully, and think hardest about those that matter most." B. Gracian, S.J.

The OPPD Board is ignoring what matters most.

SD – 5 Customer Satisfaction monitoring

"[E]valuate and prioritize its strategic plans, investments and operational activities…."

"We are going to make our customer-owners wait years longer, and that's just not acceptable to me." L. Javier Fernandez, *Omaha World-Herald*, April 14, 2024.

OPPD customer-owners have NOT been surveyed, in a comprehensible and neutral manner, on the following topics.

- Net Zero Carbon policy
- The true cost of Net Zero Carbon
- The fact that Net Zero Carbon will, more likely than not, triple rates
- The fact that if OPPD achieves Net Zero Carbon in 2050 it will not save the planet from burning up in 2100
- The fact that OPPD's own consultant wrote that Net Zero Carbon will cost at least $28 billion in 2020 dollars.
- The fact that Net Zero Carbon, more likely than not, will cause forced blackouts in January.

David D. Begley analysis of April 14, 2024, *Omaha World-Herald* story

1. The intermittent production of the nameplate value of 310 MW on 2,800 acres of prime farmland is highly inefficient.

2. **The OPPD Board is committed to Net Zero Carbon, but OPPD's customer-owners certainly aren't. I'd say 95% of OPPD's customers have no idea about this OPPD policy. Moreover, when they find out it will triple rates and cause blackouts in January, they will be opposed**. I've repeatedly told the OPPD Board this and have cited them to studies by the Center for the American Experiment (CAE).

3. Solar is all about the federal income-tax credits. That's it. Nothing about the saving the planet from burning up in 2100.

4. OPPD is keen on the K-Junction project because it has a favorable place in the SPP line to hook up to the grid. So what?

5. York County is near a large-capacity power line and an NPPD substation. That's another prime reason why OPPD wants this project built.

6. What?! Not even 24 farmers are in line to receive 3x to 5x the market rate for their land? And they claim they signed lease options, "For the kids." Give me a break!

7. The OPPD CEO says that his "customer-owners [will] wait years longer, and that's just not acceptable to me." Mr. Fernandez meant to say that a longer wait is not acceptable to his Board. OPPD customers have no knowledge about this.

8. Other than the OWH writer, who says that York County's proposed solar regs are "stricter-than-typical?" Maybe the other regulations are lax.

9. Yes, OPPD is facing increased demand for electricity. I told the Board last month that they need to build a 3,000 MW natgas baseload plant in Washington or Burt Counties. There are two natgas pipelines in those counties. Natgas is cheap and reliable. Solar is unreliable and expensive.

10. A UN climate report? Please!

11. CAE has a new report out about LCOE. Solar is the most expensive energy. The Center for Rural Affairs is a leftwing organization that has no expertise in calculating LCOE.

12. I agree with chairman Obermier. The Board needs to protect York County and this project is bad for York County.

13. CEO claims he is working "on behalf of the people of Nebraska." Nebraska is the Cornhusker State; not the Chinese solar panel state. Solar energy is inefficient, unreliable and expensive. It is bad for Nebraska.

14. Worth noting is that K-Junction represents 10% of the OPPD Board's solar goal. If K-Junction is approved, York County will become OPPD's solar dumping ground.

California's Electricity Disaster In Seven Charts

Residential electricity prices jumped nearly 12% in 2023 and they are going higher. But the carbon intensity of power generation isn't falling and low-income ratepayers are subsidizing the rich.

MAR 22, 2024

Why are these people smiling?

California's energy woes are getting worse. According to the latest numbers from the Energy Information Administration, the state's residential electricity prices, already among the highest in America, jumped by 3 cents per kilowatt-hour last year, an increase of 11.9%. The average California homeowner now pays 28.9 cents per kilowatt-hour for electricity, which is the third-highest price in the U.S., behind only Connecticut and Hawaii.

Unfortunately, the 2023 price increases are only a hors d'oeuvre. California's electric rates are headed for the exosphere. As I explained last March in "California Screamin," in 2022:

> The California Public Utilities Commission unanimously approved a scheme that aims to add more than 25 gigawatts of renewables and 15 gigawatts of batteries to the state's electric grid by 2032 at an estimated cost of $49.3 billion. In addition, the California Independent System Operator released a draft plan to upgrade the state's transmission grid at a cost of some $30.5 billion. The combined cost of those two schemes is about $80 billion.

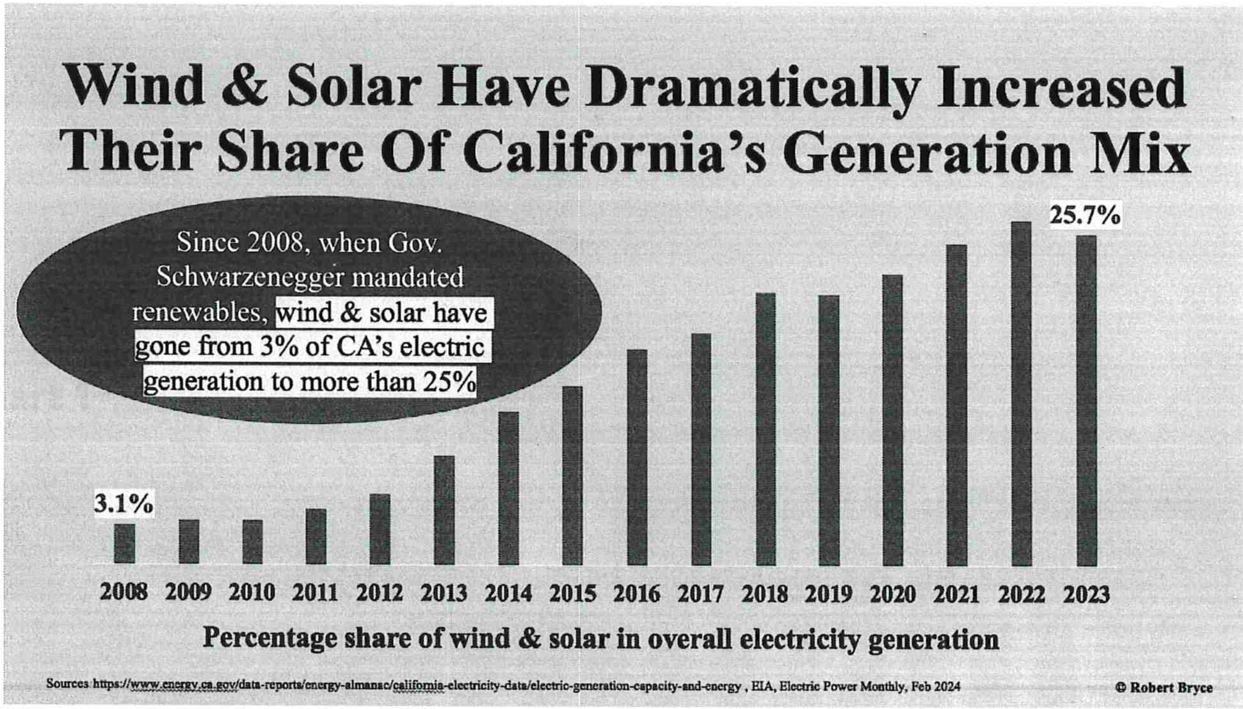
Given the raging inflation in utility products, that $80 billion estimate is undoubtedly too low. Whatever the ultimate price tag, the state's aggressive alt-energy plans will inflict more economic pain on the low-income residents of a state with the dubious distinction of having the highest poverty rate in the United States.

From natural gas bans to aggressive alt-energy mandates and bans on vehicles with internal combustion engines, the Golden State provides a clear example of what not to do. While California's lunatic energy policy decisions go back decades, the most relevant regulations began in 2008. That's when, as McClatchy newspapers explained:

> Governor Arnold Schwarzenegger signed an executive order calling on utilities to provide one-third of their power from renewable resources by 2020. "This will be the most aggressive target in the nation," he said. **Increased reliance on renewable energy conceivably could hike future rates, however, because of higher production costs and the need to upgrade transmission facilities.** Schwarzenegger's order came on the eve of today's international summit on global climate change in Los Angeles. (**Emphasis added.**)

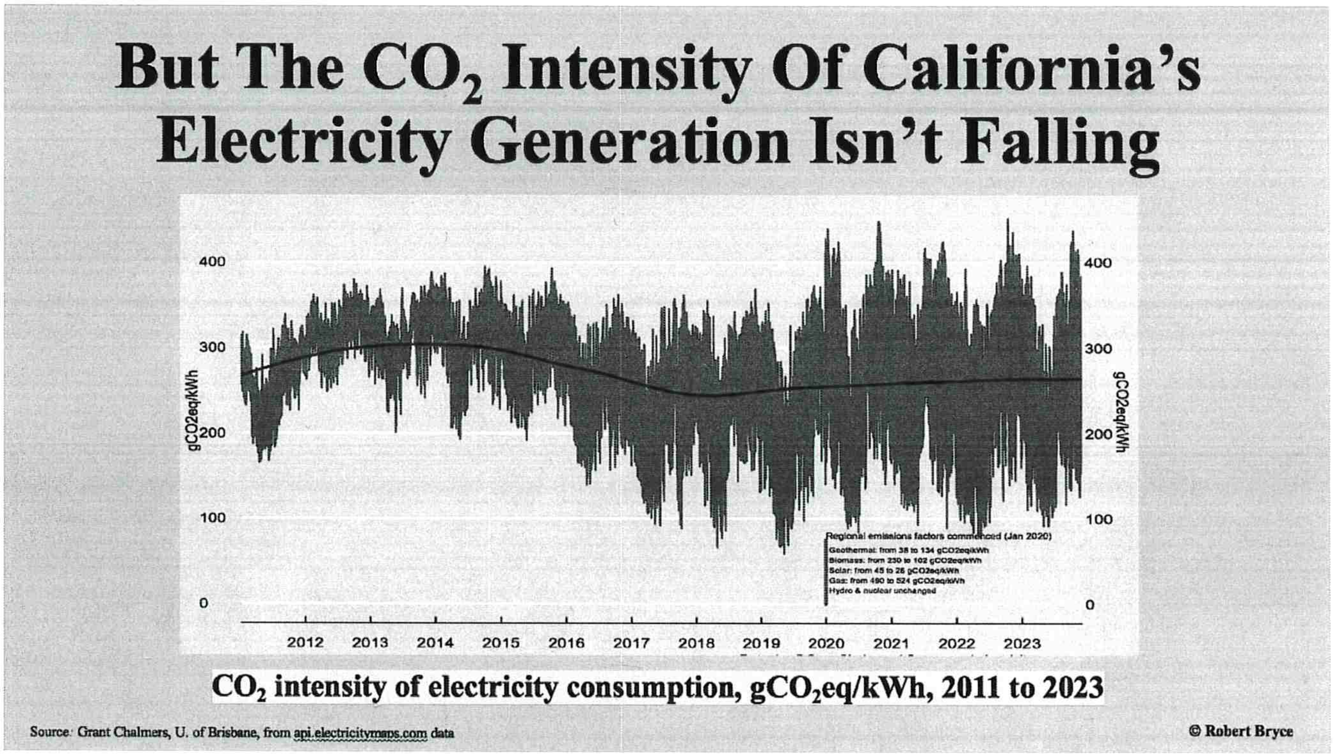
These seven charts show how California's electricity policies have unfolded since 2008.

Chart 1



The following chart uses a graphic created by Grant Chalmers, who works in information technology at the University of Brisbane. It shows that despite the massive increases in wind and solar production, the carbon intensity of California's electric generation isn't falling. To be clear, *total electricity use* in California *is* falling. All-sector electricity use in the state fell 11.2% between 2008 and 2023. (Hat tip to Joe Toomey.) That reduction in power use has likely helped reduce the state's overall CO2 emissions, which, as seen in this December 14, 2023, California Air Resources Board report, have declined since 2008. But California is nowhere near net zero, and the carbon intensity of electricity production hasn't budged in more than a decade.

Chart 2



Type your email... Subscribe

Meanwhile, the state's electricity prices are exploding.

Chart 3

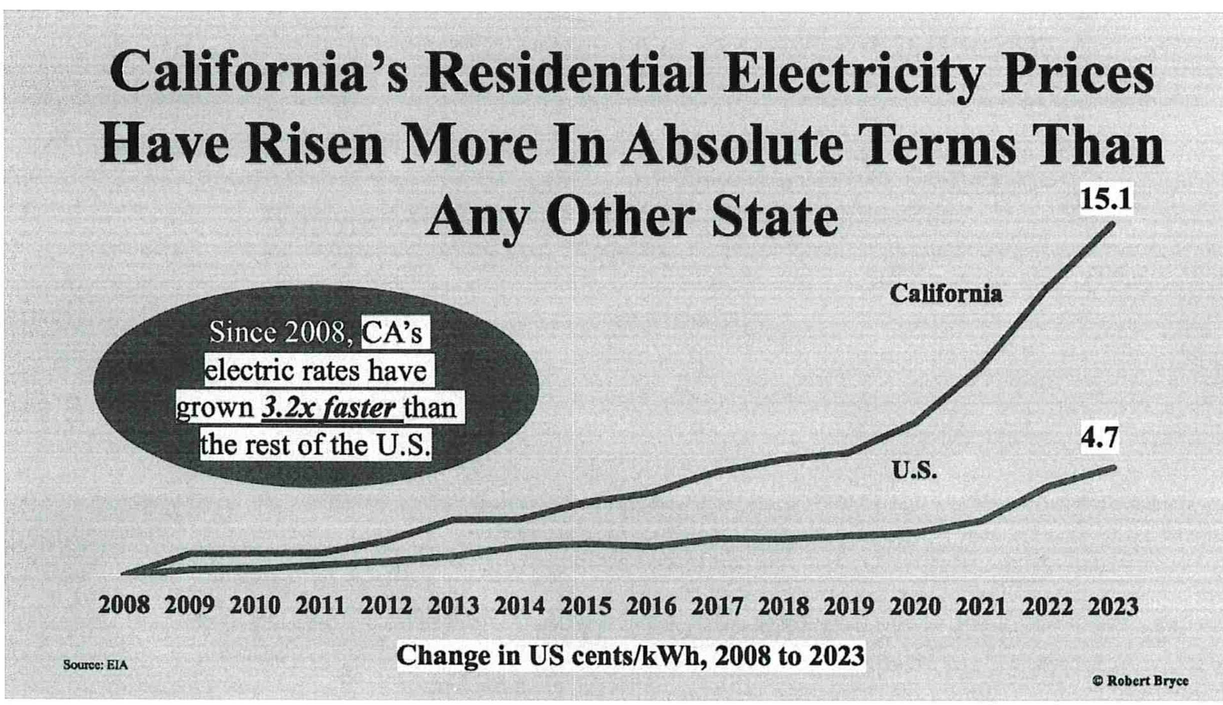
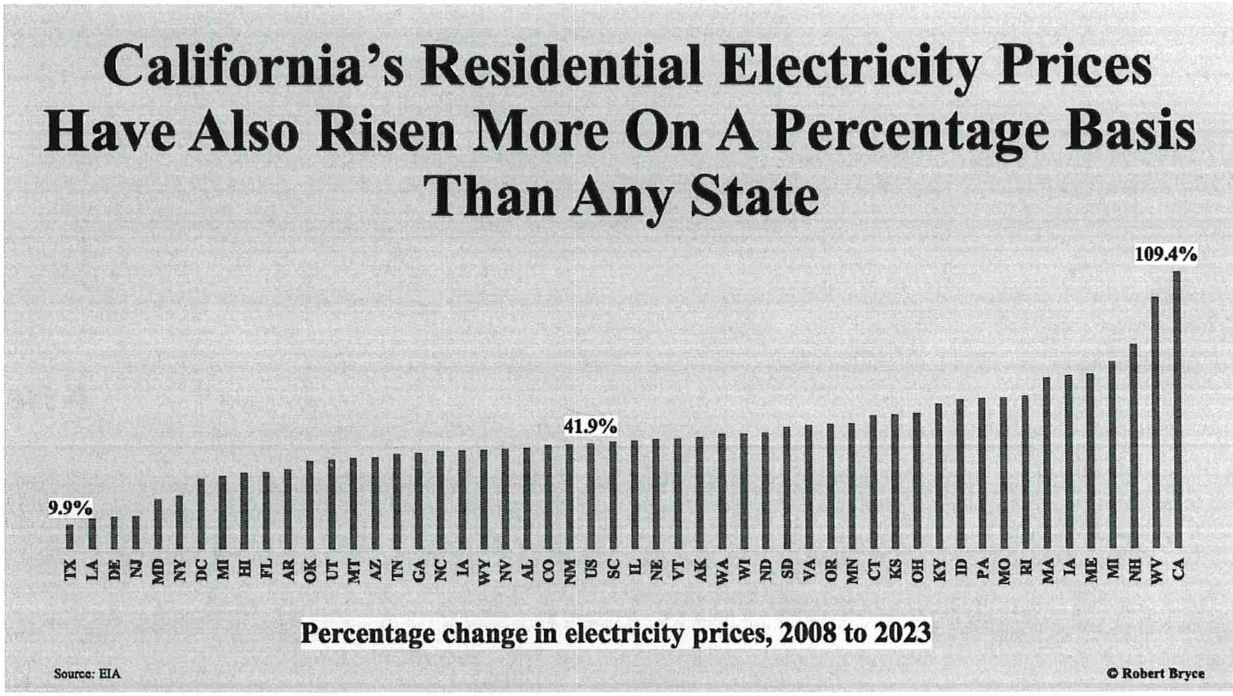
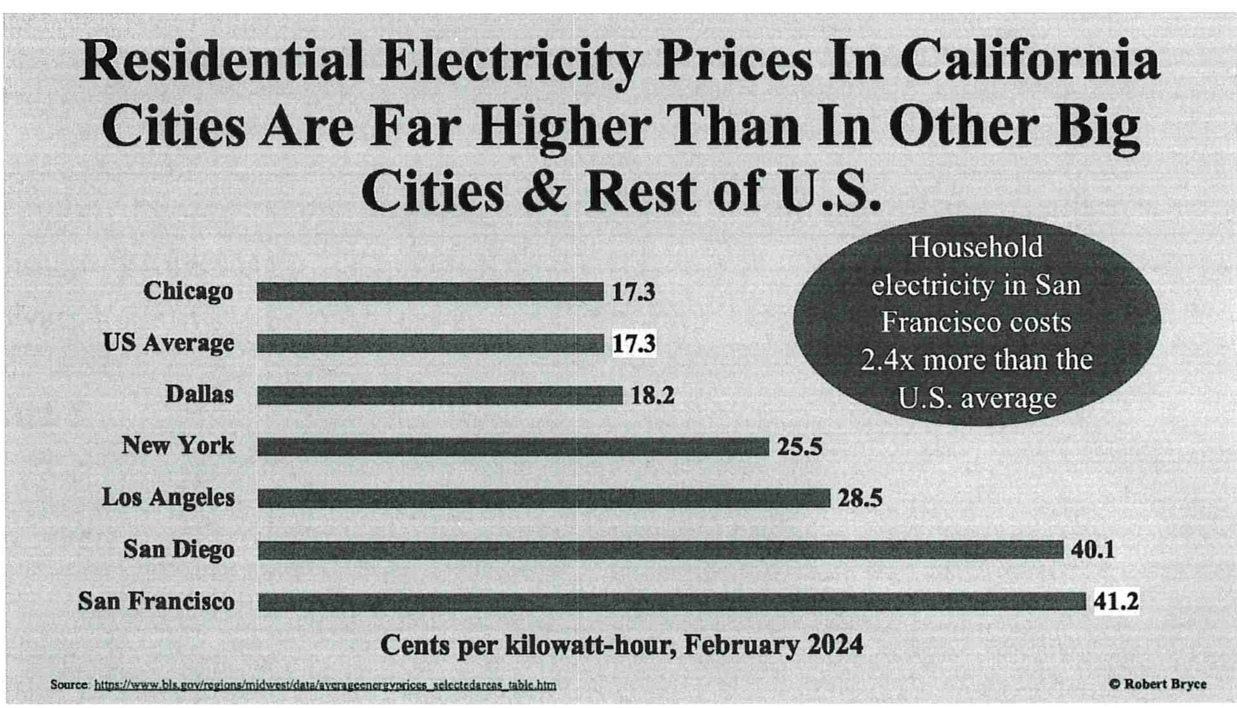


Chart 4



The following chart shows the latest figures from the Bureau of Labor Statistics. Although the average price of residential electricity in California is 28.9 cents per kilowatt-hour, it's even more expensive in the state's biggest cities.

Chart 5



A devastating February 8 report from The Public Advocates Office, estimated that rooftop solar incentives in California will cost "customers without solar an estimated $6.5 billion in 2024." The report is astonishing for its brevity and its findings. The office, which is part of the California Public Utility Commission, concluded that the cost of solar subsidies for ratepayers who don't have solar has nearly doubled since 2021. It explains: "The recent cost increases are driven by two main factors: (1) a surge in customers installing solar prior to the phase out of unsustainably lucrative program compensation terms, and (2) higher compensation to customers with rooftop solar for the excess energy their systems generate." The report goes on, saying the main incentive for homeowners to install rooftop solar is a program called net energy metering which compensates those homeowners for "the electricity they generate by *more than seven times its relative value to the grid*." (Emphasis added.) It continues:

> The Public Advocates Office estimates Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric customers without solar will pay an additional $6.5 billion in 2024 to support the program. In 2021, the cost was approximately $3.4 billion. Our analysis estimates that in 2024, more than 15% of the average household's electricity bill will go to subsidizing the program across all utilities if they do not have solar. The amount has trended upward in recent years: the program made up 8 to 17% of the average customer's bill in 2022, according to a prior CPUC estimate.

On January 10, less than a month before the Public Advocates Office published its report on rooftop solar, the Legislative Analyst's Office sent a 16-page letter to Senator Maria Elena Durazo, a Democrat from central Los Angeles, that detailed the myriad ways in which California's climate policies — in the words of The Two Hundred for Homeownership, a non-profit group that advocates for low- and moderate-income communities — "disproportionately burden lower-income people." The letter found that the state's net metering policies for rooftop solar:

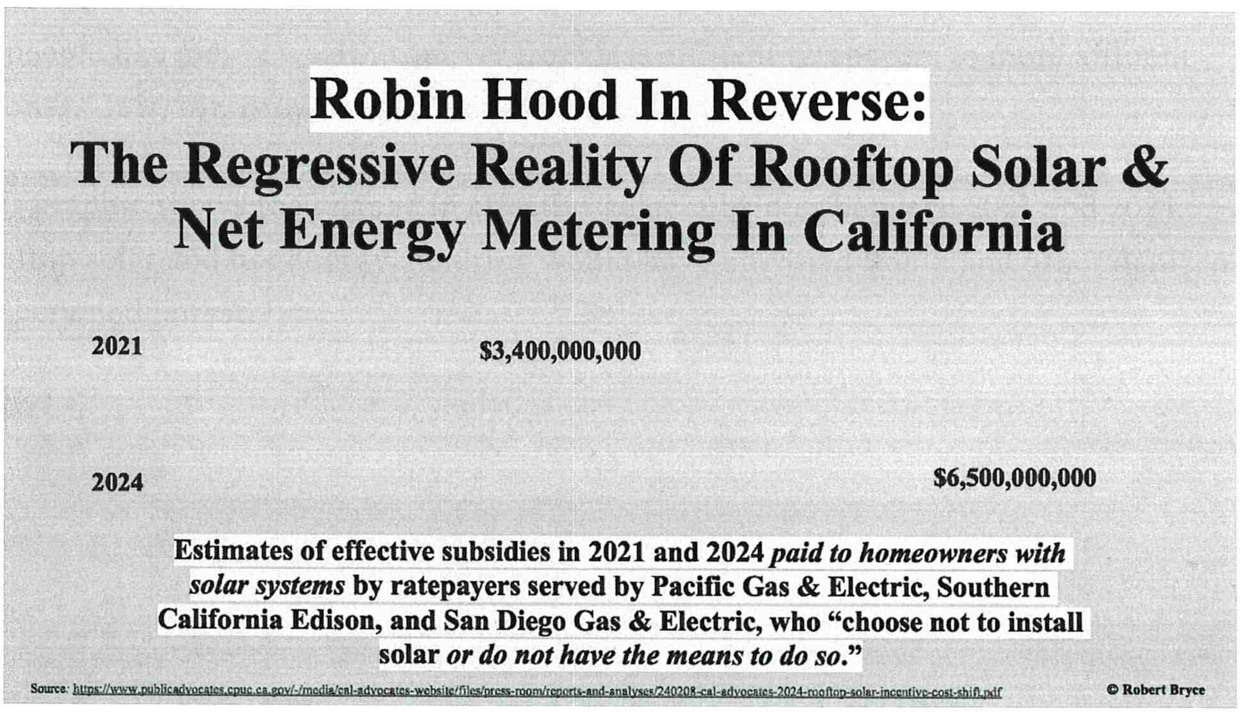
> Have historically subsidized electricity costs for households with rooftop solar while raising them for everyone else and researchers note that NEM is one driver of high increases in residential electricity prices. **The average customer without rooftop solar pays 10 percent to 20 percent on their electricity bills to subsidize rooftop solar on the homes of others. (Emphasis added.)**

None of this should be surprising. I spotlighted the class divide over solar energy and the transfer of wealth from poor to rich in 2017 in the *Wall Street Journal*. I wrote:

> According to a study done for the California Public Utility Commission, residents who have installed solar systems have household incomes 68% higher than the state average. Ashley Brown, executive director of the Harvard Electricity Policy Group, calls the proliferation of rooftop solar systems and the returns they provide to lucky people like me, "a wealth transfer from less affluent ratepayers to more affluent ones." It is, Mr. Brown says, "Robin Hood in reverse."

This graphic shows the change in effective solar subsidies between 2021 and 2024. Rooftop solar and net energy metering would have horrified Robin and other denizens of Sherwood Forest.

Chart 6



There's plenty of evidence the state's energy mandates are punishing low-income Californians. On March 10, Rob Nikolewski, a sharp-eyed reporter at the *San Diego Union-Tribune*, published an article that began, "Roughly one-quarter of San Diego Gas & Electric customers are still behind on their monthly bills." He continued, saying that about 3.48 million California ratepayers had "fallen behind on their monthly payments, as of January." He then quoted Mark Wolfe, the executive director at the National Energy Assistance Directors Association, who said the numbers in California are "alarming." Wolfe added: "The underlying problem is energy is very expensive in California and it's not surprising to see people owing as much as they do."

Chart 7

3.4 Million California Ratepayers Are Behind On Their Utility Bills With Total Outstanding Balances Of $2.2 Billion

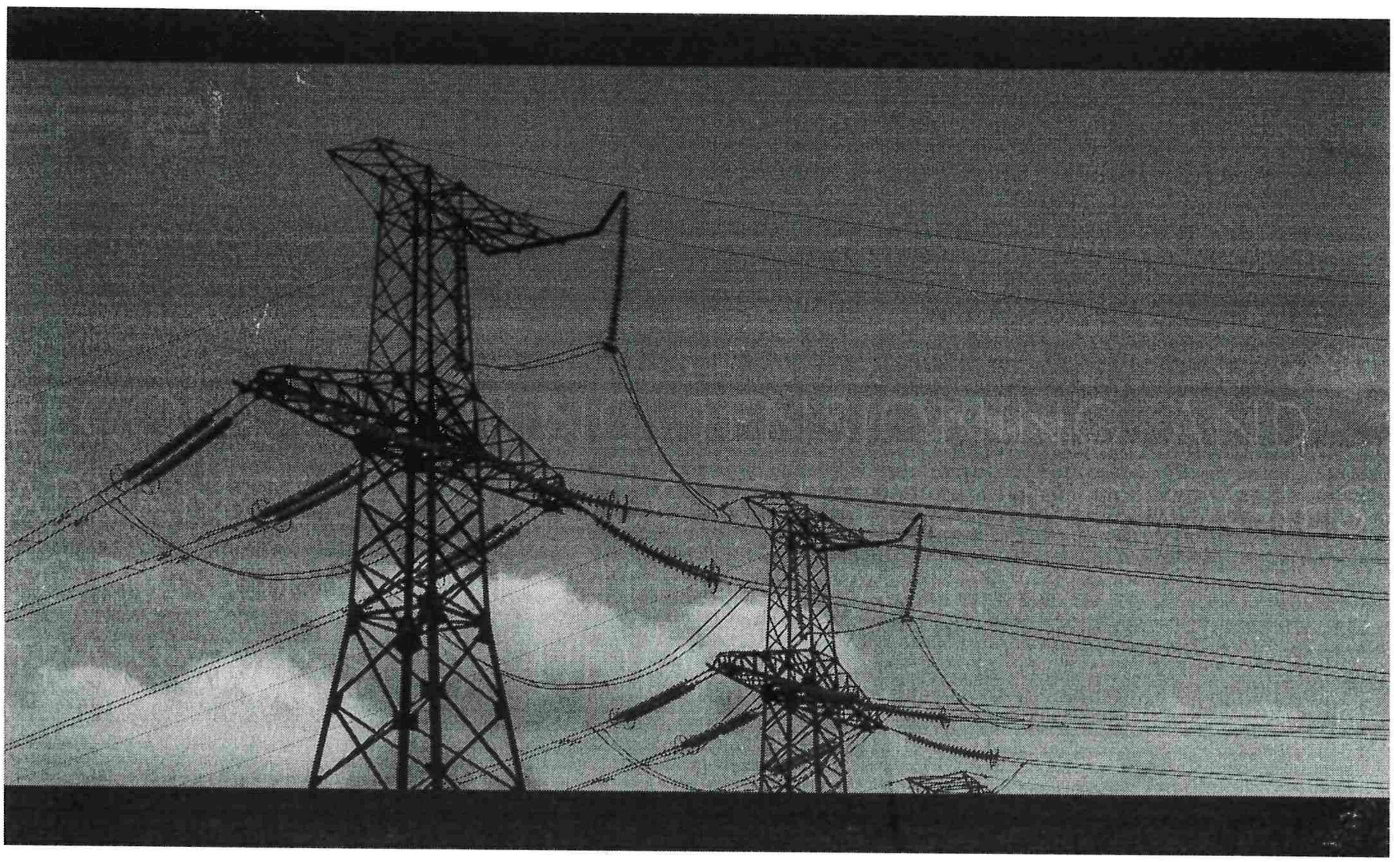
Utility	Customers behind on bills	Percentage of customers past due	Total amount of late payments	Average owed per customer
SDG&E	361,162	26.7%	$255.8M	$708
PG&E	1,018,270	18.5%	$648.73M	$637
SCE	869,646	16.4%	$922.27M	$1,061
SoCalGas	1,234,084	20.0%	$348.06M	$282

Source: Rob Nikolewski, *San Diego Union-Tribune* from CPUC data. https://archive.ph/wDyyZ#selection-1547.0-1547.99

© Robert Bryce

Given California's soaring energy costs and exorbitant cost of living, it's unsurprising that people are leaving for less-expensive pastures. In December, the Census Bureau reported that California lost some 75,000 residents in 2023, an exodus surpassed only by New York, which lost about 102,000 people. In January, Fox News reported, "For the fourth year in a row, liberal California topped U-Haul's Growth Index list for having the largest net outbound movers in 2023."

RECONDUCTORING, TENSIONING, AND ADVANCED CONDUCTOR TECHNOLOGIES FOR INCREASING THE CAPACITY OF TRANSMISSION LINES



April 2022

Introduction

The need and range of options for upgrading the capacity of existing overhead transmission lines or building new high-capacity lines is reviewed in The Electric Power Research Institute's (EPRI's) White Paper: Increasing Transmission Capacity on Transmission Lines and Rights-of-Way [1]. The upgrade options discussed in the paper included re-rating, dynamic and ambient adjusted ratings [2], voltage upgrades [3] and AC to DC conversion [4]. This White Paper provides a more in-depth discussion on conductor technologies and techniques for both increasing the capacity of existing lines or building new high-capacity new lines.

Capacity increases from conductors may be achieved through the following (in order of increasing cost):

- Re-tensioning
- Span-specific clearance enhancement
- Applying high emissivity coatings
- Reconductoring with either standard or non-proprietary high temperature low sag (HTLS) conductorsReconductoring with proprietary HTLS conductors

Each option is discussed in this paper.

Conductor Types

For many transmission lines (that are not thermally limited), conventional conductors (Figure 1) such as ACSR (Aluminum Conductor Steel Reinforced), AAAC (All Aluminum Alloy Conductor), and ACAR (Aluminum Conductor Alloy Reinforced) provide adequate performance. Continuous operating temperatures range from 90-95°C for ACSR and 80-100°C (for AAAC and ACAR). [5]

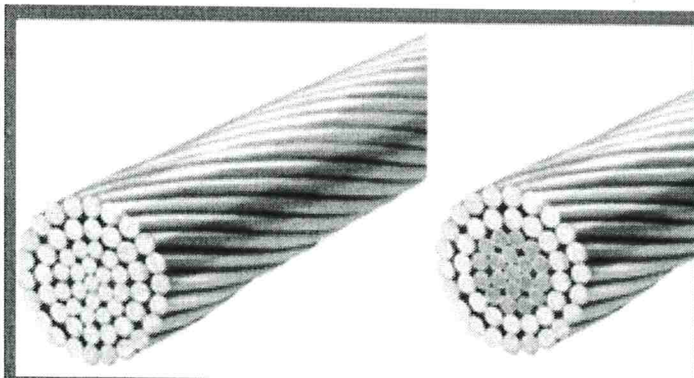


Figure 1. Conventional AAAC, ACAR and ACSR Conductors

High Temperature, Low Sag (HTLS) conductors are designed for applications where continuous operation is above 100°C.

HTLS conductors may include both Non-Propriety Conductors, on which patents have expired making them often more cost-effective alternatives, as well as Propriety Conductors (Advanced Conductors), which generally have a cost premium.

Non-Propriety Conductors are typically standard conductors with the addition of different alloys enabling higher temperature operation, e.g., Zirconium may be added to an aluminum (Al) alloy to provide resistance against annealing, at the expense of conductivity. An example is Gap-type GZTASCR conductor (Figure 2) that uses a Zirconium aluminum alloy decoupled from the steel conductor core, which is coated in high temperature grease.

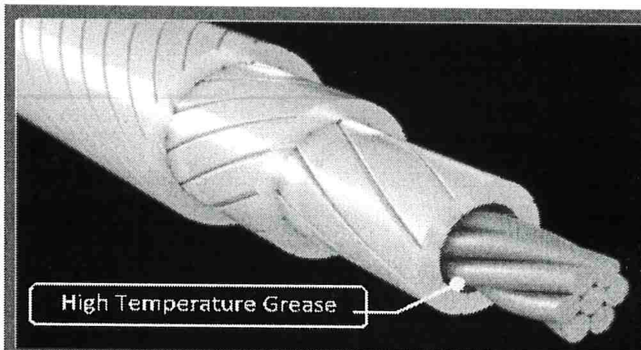


Figure 2. Gap-Type Conductor [Courtesy of Lamifil]

Table of Contents

ACSS (Aluminum Conductor Steel Supported) is a Non-Propriety Conductor that uses fully annealed Al strands. Construction includes round or compact trapezoidal Al strands that are fully supported by a variety of high strength steel cores (Figure 3).

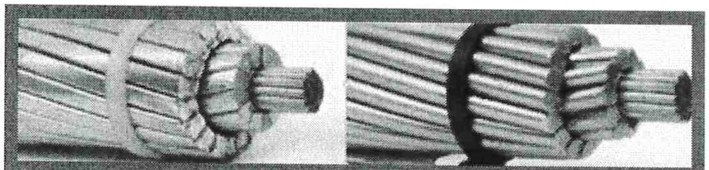


Figure 3. Trapezoidal vs. Conventional Stranded ACSS Conductor

The maximum allowable conductor temperature (MACT) of ACSS is constrained to the degradation limits for the steel core, ranging from 200°C for galvanized strands to 250°C for mischmetal alloy coated strands. Fully annealed, or zero temper Al strands are used in Proprietary HTLS options using solid composite cores such as ACCC (Aluminum Conductor Carbon Core) and ACPR (Aluminum Conductor Polymer Reinforced), as well as stranded composite cores like ACFR (Aluminum Conductor Fiber Reinforced) and C7® (Figure 4). In these variants, the MACT is typically governed by thermal limits of the core material, typically 200°C.

Before discussing uprating options, it is useful to understand fundamental thermo-electrical and thermo-mechanical aspects affecting conductor performance.

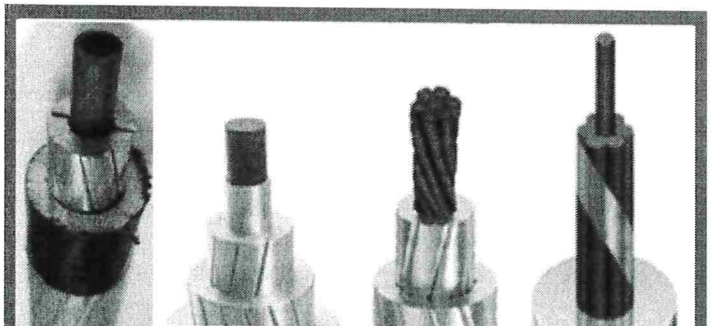


Figure 4. Proprietary HTLS conductors utilizing carbon cores (ACCC, ACPR, ACFR, C7 ®)

Thermo-Electrical Response of Conductor

The basis of all conductor uprating initiatives is the heat balance equation (Figure 5), which equates input energy (current and solar radiation) with dissipated energy (convective and radiative cooling).

While traditional thermal rating methods require the assumption of conservative values for solar radiation, convective and radiative cooling, re-rating initiatives seek to maximize current by providing greater certainty on these variables. [2]

Since the main source of thermal input energy is proportional to the square of current flowing in the conductor, large increases in the conductor operating temperature are needed for useful increases in rated ampacity (Figure 6).

Such large temperature elevations potentially impact the strength of the Al stands in ACSR conductors, typically limiting their continuous operating temperatures to 90-95°C (while short duration-MACT values of up to 140°C have been permitted).

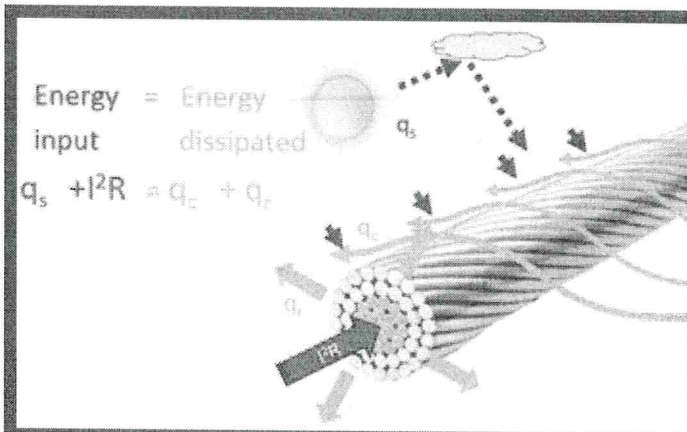


Figure 5. Heat Balance on a Conductor

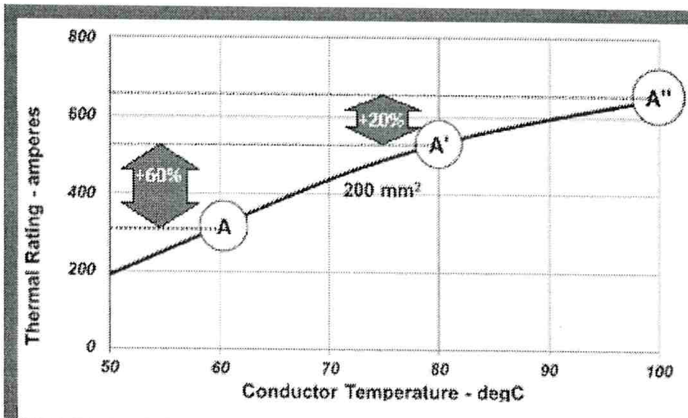


Figure 6. Ampacity vs. Conductor Temperature

Thermo-Mechanical Response of Conductor

Most conductor uprating initiatives are not constrained by the thermal limits of the material, but by the available clearance to ground. Simply put, higher currents result in higher conductor temperatures and expansion. This expansion increases conductor sag resulting in smaller conductor to ground clearances. Consequently, two important components are creep, and the effective thermal expansion coefficient.

ACSR conductors rely on the supporting strength of both Al strands and steel core, and consequently the medium- and long-term sag is characterized by non-recoverable Aluminum plastic deformation (creep). Although prestressing has been used to eliminate creep, time and safety implications during construction typically preclude this option.

Since the thermal expansion coefficient of Al is twice that of steel, the rate of expansion can be significantly reduced by using the steel core to carry the entire mechanical load. In Gap-type conductor or GZTACSR (Figure 2), this is achieved by a greased, de-coupled steel core. In non-decoupled constructions, such as ACSS, improved sag performance is achieved solely via a reduction in creep.

The lowest amount of MACT sag is achieved in carbon core variants (Figure 4), which are typically the only HTLS variants capable of leveraging the full thermal capacity limits of the conductor, since additional sag at MACT is often low enough to prevent clearance violations.

Conductor Options to Increase Capacity
Re-Tensioning of Conductors

Establishment of the precise conductor position, calibrated with respect to the concurrent conductor temperature, is the essential starting point for all capacity increase studies. This is often achieved through field or LiDAR surveys.

Re-tensioning of conductors involves removing the slack in spans that accompanies permanent stretch (creep) induced by years of service under thermal and mechanical load events.

Removing excess slack in conductors may be achieved by placing suspension points in travelers (Figure 7), pulling up the conductors to the appropriate level and taking up the slack at tension insulator assemblies. This procedure requires minimal new material and has a relatively low cost of implementation.

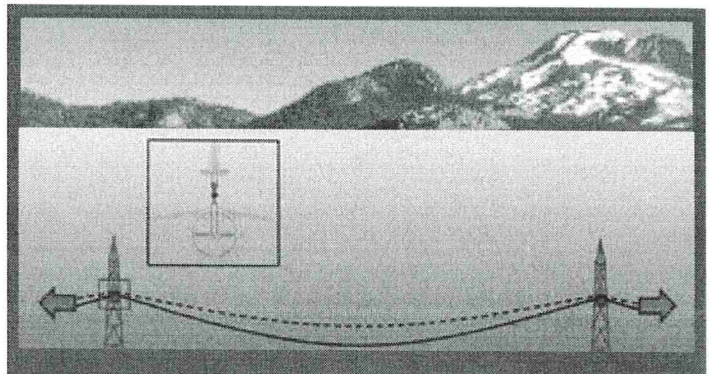


Figure 7. Re-tensioning of conductors

Re-tensioning may provide a moderate increase in capacity but is sometimes also required for safety code compliance and is also an appropriate technique when used in conjunction with voltage upgrading [3].

In some studies, especially those where lines are old and have a high probability of having experienced extreme climatic events, the allowable increase in transfer capacity following an uprating study may be negative (necessitating de-rating) if conductor creep has stretched conductor beyond limits assumed during design. Since re-tensioning operations have a minimal capital cost in comparison to other options, it may be an option where smaller increases in capacity are required. Re-tensioning is more likely to be used to complement other techniques such as re-rating studies and voltage upgrades.

Span-Specific Clearance Enhancement

The capacities of some transmission lines are limited by the clearance on only a few spans. These spans can sometimes be addressed by adopting HTLS conductors on that span, more compacted insulator assemblies, or obstacle removal. Significant advancements have been made to facilitate raising of structures under live conditions (Figure 8), which may be a cost-effective option where sufficient structural capacity is present in existing supports and foundations.

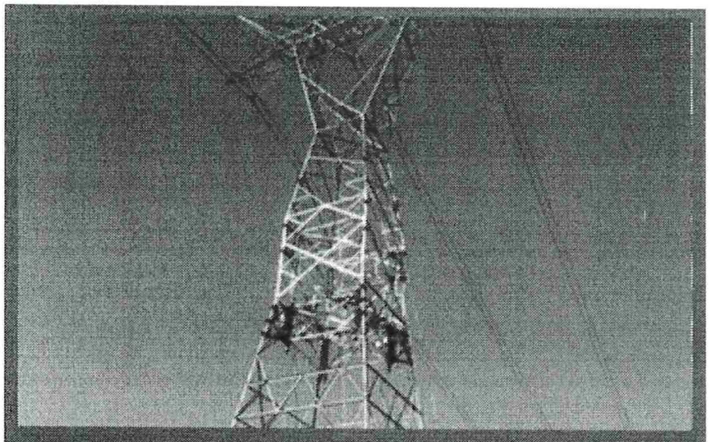


Figure 8. Raising of lattice tower for clearance enhancement [Courtesy of Ampjack]

Coated Conductors

Coatings on conductors have been developed to reduce absorptivity, and increase the emissivity of conductors, allowing greater heat dissipation, and theoretical increases of 10-20% in current for the same conductor temperature. The durability of such coatings is not proven and a subject of current EPRI research and future investigation. [2]

Reconductoring – Conventional Conductors

It may be possible to re-conductor overhead lines using larger traditional ACSR and AAAC conductor options where additional structural capacity is available. The original design parameters together with a condition assessment is required to establish structure limits to accommodate additional loads from larger conductors.

Transverse wind loads may potentially be reduced by using trapezoidal stranding (Figure 3) which enables approximately 20% of additional aluminum cross sectional area for an equivalent diameter.

More difficult to control, however, is the reduction of conductor weight, which translates into higher longitudinal loads, affecting both strain structures at angles and broken conductor loads.

Reconductoring – Non-Proprietary HTLS

Gap-type ACSR (GZTACSR) and ACSS conductors may offer efficient capacity increases in conditions where sufficient ground clearance exists. Gap-type conductor offers a lower expansion coefficient (1/2 that of Aluminum conductors), while ACSS expands at the same rate as ACSR, but with significant reductions in creep. Where clearance is not a constraint, increases of up to 100% are achievable.

Reconductoring – Proprietary HTLS

Proprietary HTLS conductors incorporate several aspects that enable increased power flow:

- The ability of conductor materials to accommodate temperature increases
- Reduced thermal expansion characteristics
- Reduced conductor weight and installed tension (in carbon core and ceramic composite core conductors)

While these conductors have been on the market for several years, there are still knowledge gaps regarding the installation, long-term performance and inspection methods for these conductors and their associated hardware. Many of these HTLS conductors have different installation requirements when compared to the traditional steel core conductors. Most failures of HTLS conductors experienced to date have been attributed to improper installation.

Despite being significantly more expensive (typically between 2.5 to 5 times the cost of equivalent ACSR), the majority of proprietary HTLS options offer capacity increases which would otherwise not be achievable with conventional or non-propriety conductors.

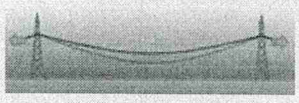
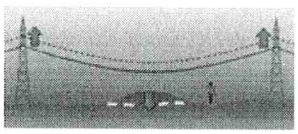
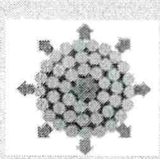
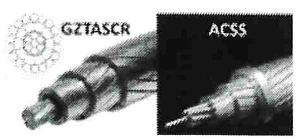
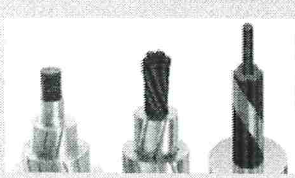
Where a carbon core is used, the expansion coefficient becomes negligible, allowing maximum operating temperatures of 180-200°C.

Reconductoring an existing line with new HTLS (High temperature Low Sag) conductor has mostly been adopted when rebuilding the line is prohibitive from a network constraint perspective. In some cases, the cost of proprietary HTLS options may be comparable with the cost of building a new line.

In addition, experience has shown that additional care needs to be exercised when installing composite core conductors, which are more readily damaged than conventional steel core options.

For this reason, older generation, non-proprietary HLTS options, may also be a cost-effective option, and should be considered along with proprietary conductors.

Table 1. Conductor specific uprating options for increasing power flow

Option	Relative Cost	Typical Increase in Transfer Capacity*	Key Considerations
Re-tensioning 	Low	Low - Moderate 5-20%	Useful for compliance to statutory clearance following extreme events causing excessive creep, or in conjunction with re-rating or voltage upgrades.
Span-specific clearance enhancement 	Low-Moderate	Low Variable (<10%)	Obstacle removal not practical for entire line. Useful at specific clearance compromised critical spans. Structure raising may be possible on longer sections.
Coated conductors 	Moderate 1.2-1.5 x ACSR Cost	Moderate 10-20%	Durability of coatings unknown. Benefits reduced at night. Requires reconductoring, not readily applied to in-service conductors.
Reconductoring – non-proprietary HTLS 	Moderate 1.15-1.65 x ACSR Cost	Moderate - High 20-100%	May be the most efficient solution ($/MVA added) Often constrained by clearance considerations
Reconductoring – proprietary HTLS 	High 2.5-5 x ACSR Cost	High 50-110%	Carbon core variants not constrained by ground clearance during MACT Excessive sag during in icing events on carbon core variants. Limited long-term experience Care to prevent damage during installation is critical. End of life Inspection technologies unavailable.

* Capacity increases based on ampacity increases from actual studies. Not including gains from re-rating.

Cost vs. Benefit

Table 1 highlights key aspects for these options. Low, or No-Cost options are potentially attractive where a moderate increase in capacity delays the need for more extensive upgrades.

Moderate cost options, which may utilize established, non-proprietary conductor technologies have been identified as preferred solutions in some studies as they can offer the highest capacity added per dollar spent.

High cost, high capacity re-conductoring options may be attractive as an alternative to underground cabling or other high-cost options, or where clearance constraints dominate.

Physical and Operational Implementation

Increasing power transfer using methods that concern work and upgrades solely on overhead conductor are attractive since they enable reduced outage duration compared to techniques that require more structure modification, such as voltage upgrades.

Reduced supply interruption impacts are also possible where live line construction methods are safely adopted especially on double circuit lines where the existing conductor can be used as the pilot wire for the new HTLS conductor, while the adjacent circuit remains energized.

In cases where live line work is not possible, the use of temporary supported insulated crane mounted lifts (Figure 9) may allow continued supply. In these cases, the management of induced currents and working grounds are important safety considerations.

Implementation Challenges and Maturity

Care needed during implementation is partially a function of product maturity, with the latest products carrying greater implementation risks.

Non-proprietary HTLS conductors are mature technologies with a relatively low installation risk, however there are currently no standards for HTLS conductors. Gap-type conductors do require an additional installation effort due to the need to de-couple the steel core from the outer conducting layers.

The low elastic modulus for carbon core conductors may lead to excessive sag during icing and extreme wind events. In some cases, this may be solved by selection of a larger carbon core.

Experience with installation of both composite ceramic and carbon core conductors has revealed that care to prevent damage during installation is critical, as damage to such conductors has been experienced where the bending radii limits have been exceeded. Recent iterations in some carbon core HTLS options have introduced multiple strand carbon cores (Table 1) to reduce the allowable bending radius, while other variants offer increased protection to the carbon core.

Knowledge Gaps

Notable knowledge gaps for HTLS conductor include:

- Improved installation procedures for newer generation conductors to prevent installation damage.
- Inspection and assessment of new HTLS conductors, including determination of carbon core integrity.
- Long-term durability of factory applied high emissivity coatings to conductors, some of which also purport ice-phobicity.
- Safe installation tensions for ACSS conductors, which have improved, and yet, unleveraged, self-damping characteristics.

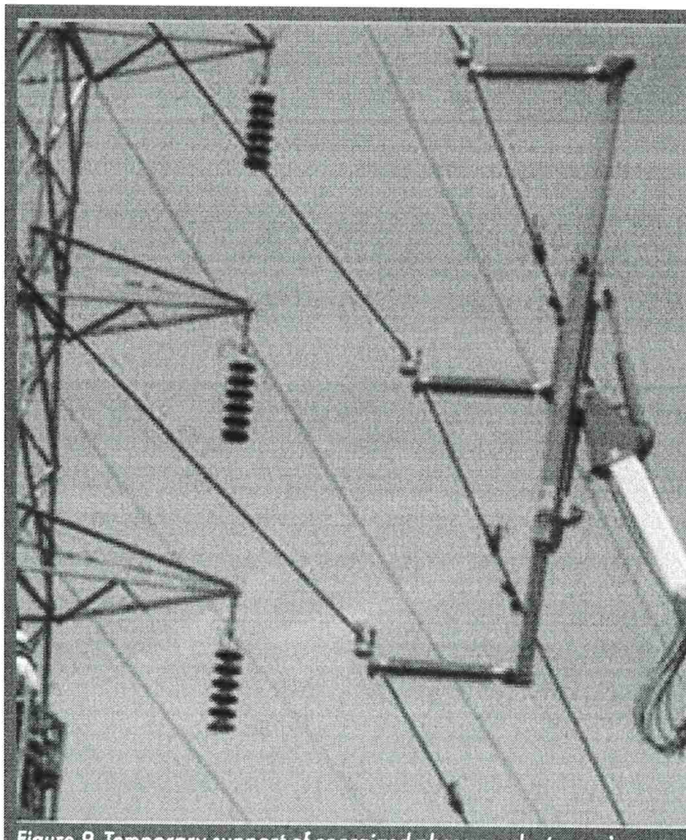


Figure 9. Temporary support of energized phase conductors using insulated crane mounted lift [6]

How Can EPRI Support?

Over the last several years, EPRI has performed a significant amount of work to determine the impact of high temperature operation of overhead transmission lines on the conductors and associated hardware components.

The EPRI Conductor Aging Test Frame (Figure 10) allows simultaneous application of installed tension and thermal cycling, simulating 40 years of operation.

Performance of different HTLS conductors and fittings (Figure 11) has been validated by resistance, infra-red, direct temperature measurements, and x-rays.

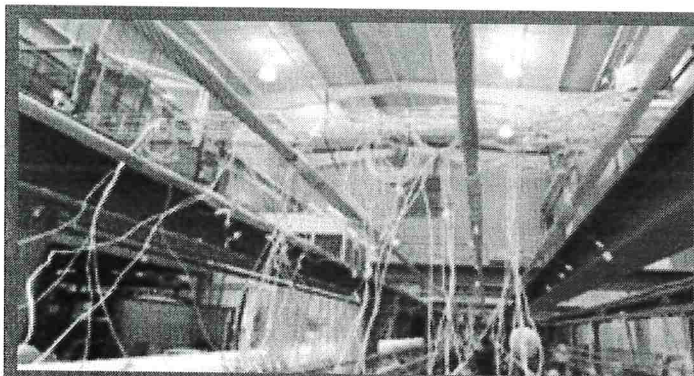


Figure 10. EPRI Conductor Aging Test Frame

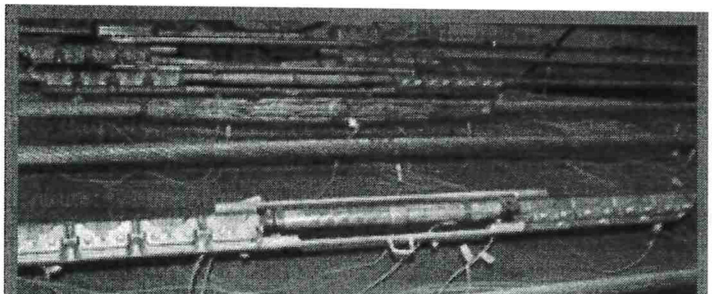


Figure 11. Shunt Device Testing

This work has revealed the vulnerability of compression connectors to high temperature excursions [7], failures of HTLS conductors, and has shaped industry standards, such as the IEEE 1283 Guide for High Temperature Operation.

HTLS specific software developed by EPRI includes the HTC Matrix (Figure 12), which highlights sensitive installation aspects, contains calculators to determine the effects of annealing and creep on conductors, AC and DC conductor resistance at elevated temperatures and conductor temperatures and time constants under different operating and weather conditions [8].

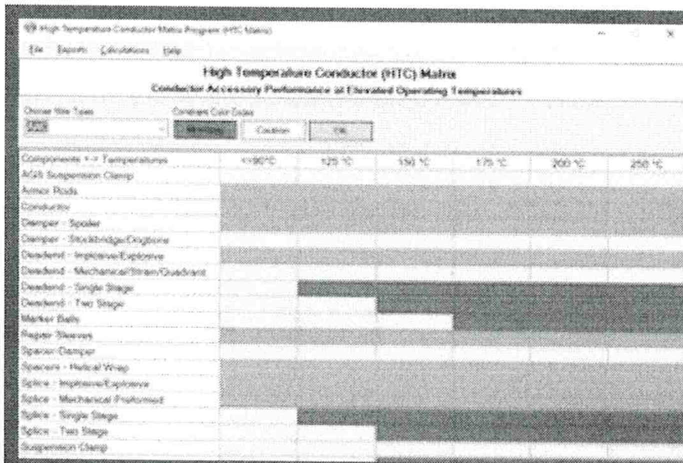


Figure 12. HTC Matrix Software [8]

EPRI has also developed a shorter-term qualification testing procedure for carbon fiber core conductors for utilities to include in their specifications. This test determines the thermal and mechanical performance of carbon core conductors and connectors in a relatively short period of time. Up to the end of 2020, only 40% of the conductors evaluated have passed the test, using specific criteria developed [9].

Other testing conducted has included determining the effects of rain on the performance of compression connectors, understanding the impact of improper connector installation, high temperature effects on marker balls and fired wedge connectors.

Two real-time monitored field trials of advanced conductors have been undertaken by EPRI. The first field trial evaluated 5 different conductors at 4 different utility locations [10].

Presently end of life inspection technologies for carbon/ceramic cored conductors are being investigated as well as guides for installation.

EPRI has developed a comprehensive guide [11] on the selection and application of HTLS conductors which is regularly updated with the latest information. This guide contains information on the different types of HTLS conductors currently available as well as several case studies of how utilities have applied these conductors in their transmission systems.

Conclusion

Reconductoring, re-tensioning, and advanced conductor technologies are one of the techniques to obtain a moderate increase in capacity. The approaches are well known and regularly used for small to moderate gains in capacity. When considering against other options a comprehensive evaluation which includes a) considers all practical options, and b) includes a life-cycle cost-based approach which quantifies the operational cost of running different solutions is required.

Significant advances have been made in the field of new HTLS conductors. HTLS conductors have the highest potential rating increases for existing lines, but also exhibit some sensitivity during installation and there is some unknown in terms of life expectancy and inspection techniques.

Improved care during installation is important to leverage the full capacity of these new generation HTLS options.

The large range of uprating options open to utility engineers lends itself to creative hybrid options where aspects of other increased transfer capacity solutions, such as combining uprating with forecast-based re-rating or real-time rating, may be combined to allow even greater increases.

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Glossary of Conductor Terms

- AAAC – All Aluminum Alloy Conductor
- ACAR – Aluminum Conductor Alloy Reinforced
- ACCC – Aluminum Conductor Composite Core HTLS conductor with fully annealed Al alloy
- ACSR – Aluminum Conductor Steel Reinforced conductor
- ACSS – Aluminum Conductor Steel Supported HTLS conductor with fully annealed Al alloy
- GZTACSR – Gap-type conductor utilizing ZTAl alloy
- HTLS - High Temperature, Low Sag (conductor)
- MACT - Maximum Allowable Conductor Temperature (often defined over a period, e.g., 1 hour)
- Continuous operating temperature: the temperature that a conductor can operate at continuously.

EPRI RESOURCES

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Program 35: Overhead Transmission

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

3002023335

April 2022

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Americans for a Clean Energy Grid

High temperature, low sag conductor

Growing U.S. electricity demand from 1990 through 2005 increased load on existing transmission lines, many of which were built far before such magnitudes of load were considered. Even after substantial recent additions to the transmission network, about 70% of transmission lines are at least 25 years old and are incapable of handling any further increases in load reliably [3]. Although national electricity demand has grown only marginally in recent years, there are some regions of stronger growth, and even where rates of growth are not high, load will continue to increase with population and as new sectors are electrified. Furthermore, transmission developers experience difficulties in obtaining rights of way required for new transmission lines. This combination of potential increases in load, old age of existing transmission lines, and lack of new transmission lines creates a risk of increased congestion, which can lead to grid failure.

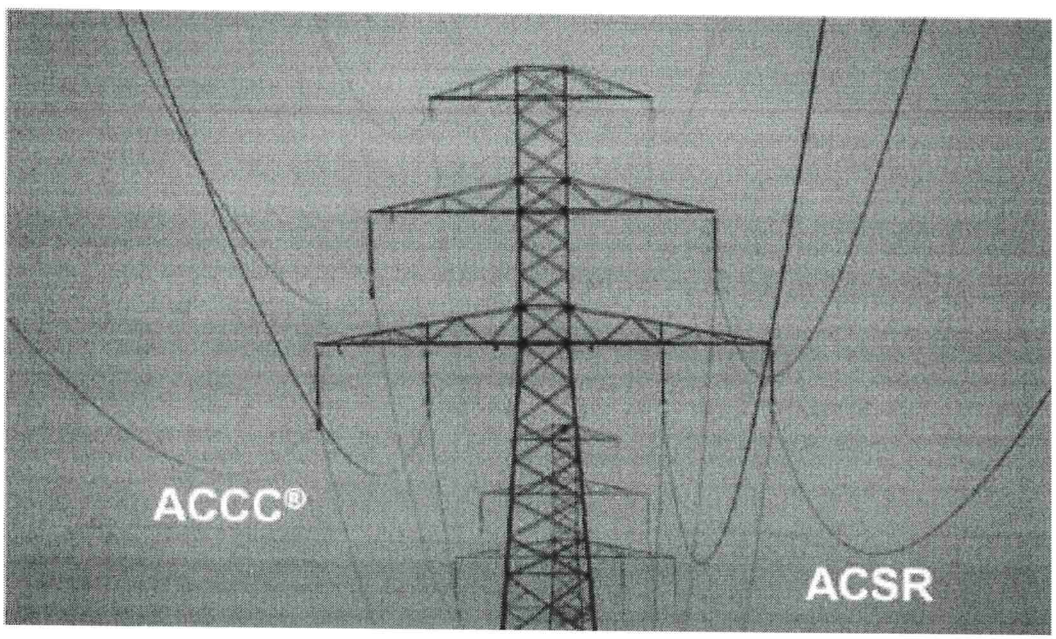
Traditionally, overhead high voltage transmission lines have used the "aluminum conductor steel reinforced" (ACSR) design. ACSR cables are characterized by strands of aluminum wrapped around steel cables. The outer aluminum strands conduct electricity, while the steel core provides tensile strength to the ACSR cable. Aluminum is ductile, meaning that it can deform under tensile stress. The steel core, in turn, prevents aluminum strands from stretching out extensively and sagging lower than the permissible levels.

Although ACSR transmission lines are relatively cheap and have been used over a hundred years for high voltage transmission, they are disadvantaged by their high coefficient of thermal expansion, which causes the cables to expand and sag and generate more resistance with increasing load, causing the lines to overheat [1]. Transmission lines cannot sag beyond a certain limit, after which they pose a threat to public safety. Additionally, greater resistance means greater transmission losses on ACSR lines as grid operators push more power across the system. Because the use of ACSR transmission lines is restricted by these technical inadequacies, they cannot reliably transmit power in excess of their line ratings (under assumed weather conditions) to meet increased demand.

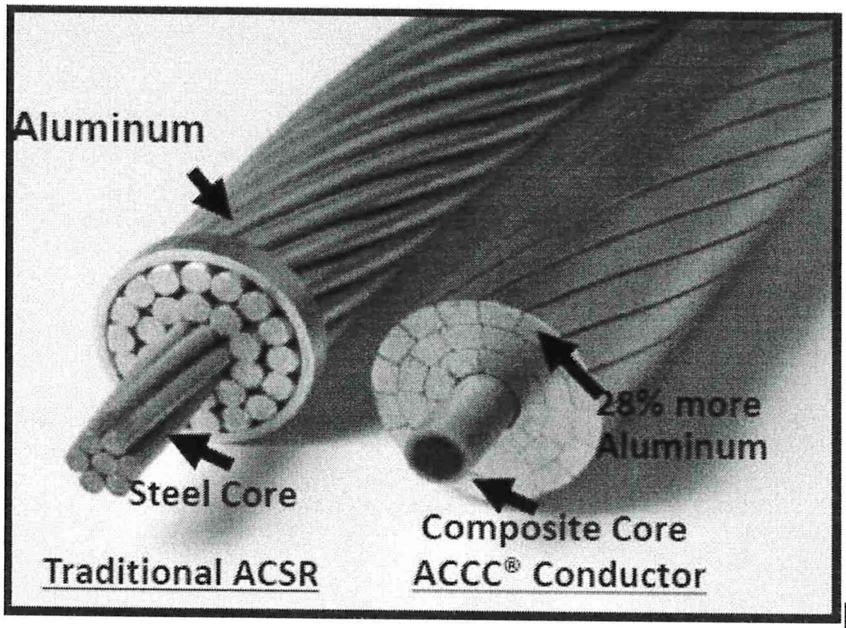
Line losses (the loss of power during transmission) can range from zero to more than 20% of the electricity being transmitted as a function of line and weather conditions [3]. The current national average is that roughly 8% of power generated at central stations is lost in transmission, which is converted into waste heat by the resistance of the transmission lines. This loss is greatest when power is most valuable and needed: under peak demand conditions, in hot and wind-free weather [3]. Technologies that can increase the capacity of the transmission network by making lines more capable of carrying higher volumes of power without overheating or sagging can significantly reduce this loss and increase the efficiency of the installed transmission infrastructure.

So how can the transmission capacity of the power grid network be increased without acquiring new rights of way? One option is to replace ACSR with "aluminum conductor composite core" (ACCC) transmission lines through "reconductoring," the process of exchanging new cables for original cables using the existing towers and rights of way. Reconductoring requires that the transmission line be taken out of service during the work, which imposes a burden on the rest of the grid and creates costs to transmission operators. The reconductoring process may be undertaken in several portions of the transmission line simultaneously to reduce down time, but the overall downtime depends on the length of the transmission line and the size of the crew working on the project. Reconductoring with ACCC cables can increase the transmission capacity of the power grid without having to acquire new rights of way. In ACCC lines, aluminum strands conduct electricity, while the carbon fiber composite core provides tensile strength to the cable. Carbon fiber composite core is up to 25% stronger than steel core, which significantly reduces the sag of ACCC transmission lines at high temperatures [1]. This means that ACCC cables can carry more current while sagging less than ACSR cables. Additionally, ACCC cables are up to 60% lighter than ACSR cables, which allows ACCC cables to have longer spans and require fewer and shorter supporting structures [1]. The smaller number of supporting structures required reduces the capital costs of transmission line installation projects. Because they sag less, electricity flowing through the conductor experiences less resistance, meaning that ACCC can also reduce transmission losses of power from 25% to 40% [1]. If transmission losses are reduced, less electricity generation is required to meet the same amount of load, and emissions of greenhouse gases from fossil fuel-based power plants decrease. Finally, ACCC cables resist degradation from vibrations, corrosion, ultraviolet radiation, corona, chemical and thermal oxidation, and cyclic load fatigue [1].

The picture below demonstrates the reduced sag of ACCC versus ACSR [2]:



CTC Global, for example, developed an ACCC cable that has 28% more aluminum compared to an ACSR cable of the same size, which allows the cable to carry more current while suffering lower power losses [4]. The image below shows a CTC ACCC cable compared to a traditional ACSR cable of same size.

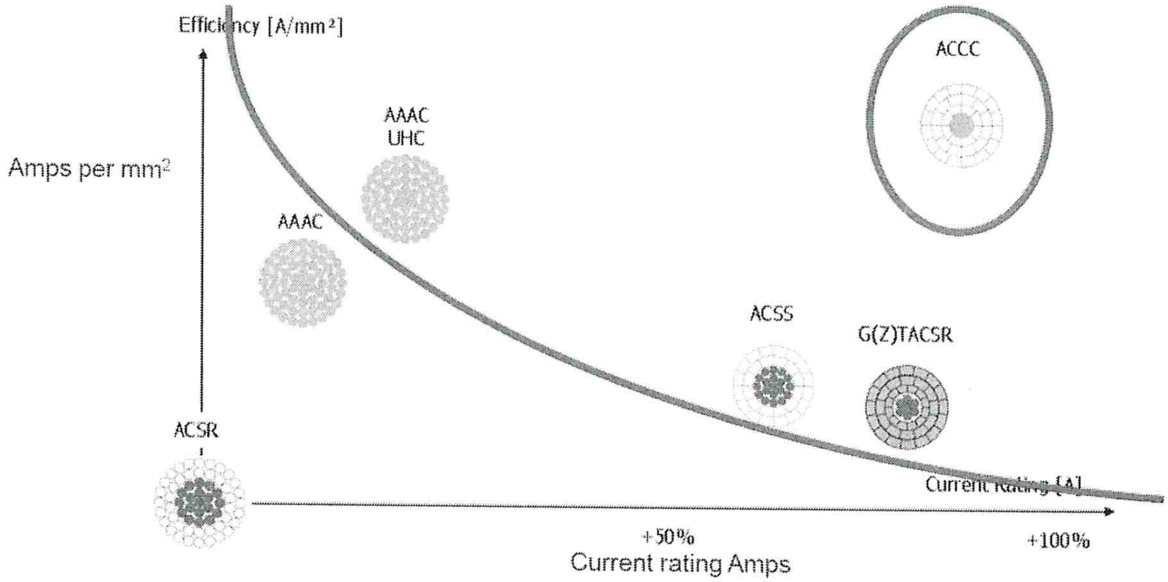


[1]

Because ACCC cables experience lower transmission power losses, they save money for utility companies. A study done by the CTC Cable Corporation highlights the economic benefits of reduced power losses for a 100-kilometer ACCC three-phase transmission line operating with a 53% load factor [1]:

	Peak Amps	**Temp. at Peak Amps (C)**	**MVA**	**Annual Line Losses (MWh)**	**Line Loss Reduction**	**Value of Reduction (at $50/MWh)**	**Value of Reduction per linear conductor (meter) (foot)**	
ACSR	1000	95	398	76,917	---	---	---	---
ACCC	1000	82	398	56,588	20,329	$1,016,450	$3.39	$1.03

The graph below shows how various cable designs line up in terms of efficiency and current carrying capacity [1]:



As can be seen, ACCC cables combine efficiency with increased power carrying capacity to create a clear financial advantage over other lines, and especially ACSR lines. Additionally, after a certain current threshold, ACCC cables are less expensive than the traditional ACSR cables. The table below provides the cost analysis of ACCC versus ACSR for various current requirements and conductor sizes (note, conductor sizes are represented by given names rather than precise measurements) [2]:

	ACCC		**ACSR**	
Current Requirement	**Conductor Size**	**Cost/Foot**	**Conductor Size**	**Cost/Foot**
1000	Linnet	$3.80	Gannet	$ 3.06
1260	Hawk	$3.36	Rail	$2.84
1400	Dove	$3.69	Bunting	$3.50
1520	Grosbeak	$4.01	Martin	$4.63
1760	Drake	$4.78	Lapwing	$4.90
1960	Cardinal	$5.17	2032	$7.20

In summary, ACCC cables offer the following benefits:

- Increased current carrying capacity and reduction in transmission congestion;
- Reduced power losses during transmission reduces the electricity generation needed;
    - Reduced levels of electricity generation reduce greenhouse gas emissions;
- Reconductoring of existing ACSR cables with ACCC cables can increase the capacity of the grid without having to acquire more rights of way;
- Fewer and shorter structures are required to support ACCC cables, and this can reduce the cost and environmental impact of transmission projects.

The lower cost and power losses of ACCC cables make them the preferred conductor for reconductoring and new installation projects. CTC alone has installed over 22,000 km of ACCC cable at various projects worldwide as of 2013 [1]. As the demand for power increases, more ACCC cables will likely be installed to increase the current carrying capacity of the grid without acquiring new rights of way.

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