CORROSION CONTROL FOR EXISTING ELECTRIC TRANSMISSION (ET) STEEL LATTICE TOWERS

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Electric Transmission (ET) Tower Corrosion Control Programs

- Tower Coatings Program
  - Lead based coatings encapsulation was the first initiative
  - Followed by coating of towers based on corrosion condition to extend tower life expectancy and reduce replacement/maintenance costs
- Tower Cathodic Protection (CP) Program
  - Direct Buried Tubular Steel Piles
  - Lattice Steel Structures
    - Directly buried in soil
    - Water-based Towers encased in concrete

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What Causes Corrosion?

Different environmental conditions contribute to the rate of corrosion, even on different areas of the same equipment. Factors that contribute to corrosion include:

Moisture and salt
These can get trapped around and inside joints and foundations and can cause corrosion.

Weather
Moist Atmospheres that frequently contact exposed parts of a tower can cause corrosion.

Soil and concrete
When in direct contact with equipment, these provide an electrolytic path that can cause corrosion.

Age
Corrosion is a time dependent process, therefore the older the structure is (the longer the time), the more corrosion may have occurred. Steel corrodes at about 18 lbs/amp-yr.

Infrequent Maintenance
Structures that do not receive regular maintenance are more likely to have some corrosion.

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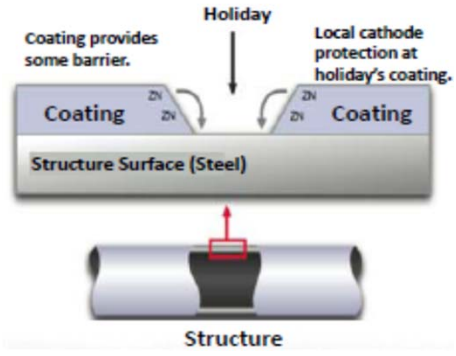
Typical Initial Corrosion Protection for Steel Towers

Sacrificial Coating

Galvanizing



All towers are typically installed with a galvanizing zinc coating as a corrosion protection barrier for above grade and below grade steel protection. This provides corrosion protection for the Tower for many years (up to 100 years or more) dependent on the corrosiveness of the environment the Tower is in and the original thickness of zinc in the galvanizing coating

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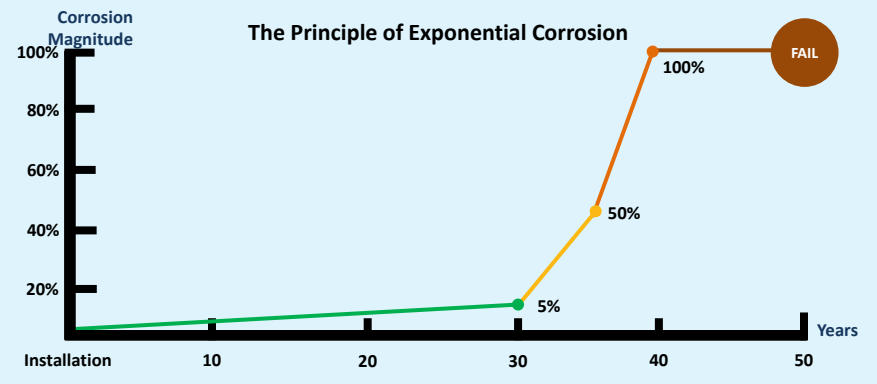
Why Corrosion on Towers is a Concern

- Once the galvanizing zinc corrosion protection layer on a tower is depleted, corrosion on the remaining steel lattice **advances rapidly**.
- An example is shown in chart below. This indicates, a tower with **less than five percent rust at age 30** can oxidize to the point of failure **within 10 years**.
- In addition, as the corrosion of the tower accelerates, so do the costs required to repair it.
- The majority of North American Transmission were built and put in-service between 1950 and 1990 (AMPP MP Sept 2022)



Note: This graph is also consistent with an exponential increase in corrosion at ages 30-70+ years

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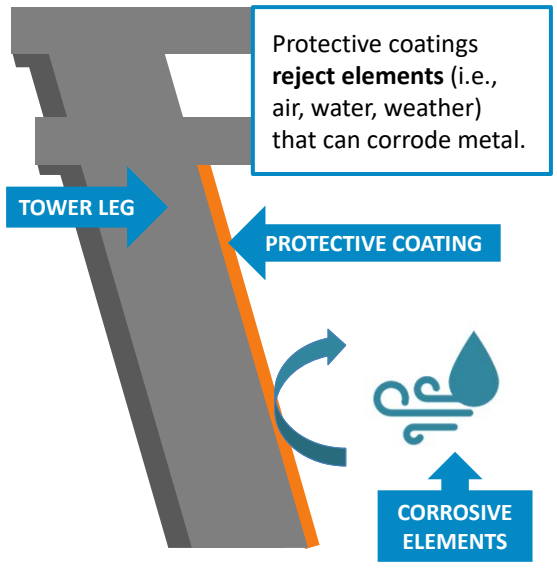
Mitigating Corrosion Through Protective Coating

Protective Coating

- Though corrosion control on electric transmission towers is **not required** by federal law, **structural weakness caused by metal loss** from corrosion is a significant safety concern.
- For this reason, PG&E **voluntarily** and **proactively** conducts corrosion protection on its transmission towers.
- We do this by applying a protective coating (paint) that slows down the process of corrosion, which **maintains the integrity** and **extends the life** of our transmission towers for ~60 + years.



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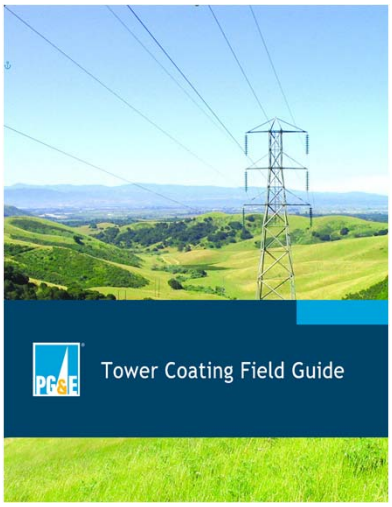
Tower Coating Program Overview



- Electric Transmission Steel Lattice Towers are continuously exposed to a wide range of environmental threats which may affect overall integrity. One of the primary environmental threats influencing steel structure integrity is corrosion.
- In 2020, PG&E initiated a Tower Coating Program which applies a comprehensive coating system that provides a cost-effective atmospheric corrosion protection barrier to the steel components in transmission towers.
- PG&E conducted a review of industry standards, best practices, corrosion control materials, our own testing and third-party laboratory testing. These factors resulted in new Tower Coating standards and procedures to the program as well as a Tower Coatings Field Guide.
- PG&E believes that the Tower Coating Program can extend the original estimated useful life of its transmission towers by 20 - 25 years or more by utilizing coating systems specific to the corrosion factors towers are experiencing.

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Coatings Engineering Initiatives

The Coatings Engineering team is **continuously looking to improve our processes and understanding of corrosion protection best practices**. Some of the things we're working on include:

	Drafting the **standards and procedures** for tower coating
	Staying up-to-date on **new and existing best practices** for coating application
	Continuing to evaluate our methods and materials
	Creating **coating applicator training** profiles
	Establishing **new quality controls** for tower coating materials

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Corrosion Control Standards and Procedures Flowchart

External Corrosion Control for Electric Transmission Towers
TD-ABCD-S
Overarching guidance for corrosion control
Including Atmospheric Corrosion Control, Underground / electrolyte corrosion control, and internal corrosion control*
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*Later

Field-Applied Coatings for Atmospheric Corrosion Control on Electric Transmission Steel Structures
TD-1019S
This utility standard provides specifications and requirements for the application and quality control of field-applied coatings on electric transmission steel structures. (TD-1019P-01 through TD-1019P-08).

Underground Corrosion Control Standard
TD-ABCD-S2
TBD

General Work Practices and Safety During Field Coating Application on Electric Transmission Steel Structures
TD-1019P-01

Field-Applied Coatings for Electric Transmission Steel Structures in Severe Corrosion Zones
TD-1019P-02

Field-Applied Coatings for Electric Transmission Steel Structures in Moderate/Low, Agricultural and Industrial Corrosion Zones
TD-1019P-03

Field-Applied Coatings for Electric Transmission Steel Structures and Concrete Foundations in the Air-to-Electrolyte Transition Interface
TD-1019P-05

Field-Applied Sealants for Crevices at Bolted or Riveted Connections on Electric Transmission Steel Structures
TD-1019P-06

Field-Applied Coatings for Electric Transmission Steel Structures: Rapid Cure Coting Systems
TD-1019P-08

Underground CP, TD-ABCD-P-2.1
CP for Direct Buried Metal, Grillage, Steel Pipe

Underground Coatings, TD-ABCD-P2.2 Coating Buried Metal and Concrete Foundations

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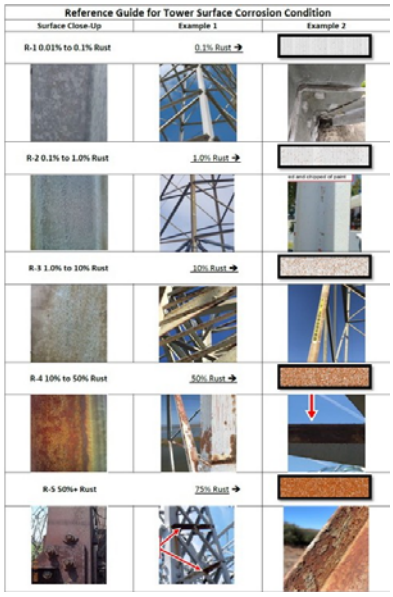
Tower Coatings Field Guide – Corrosion Ranking

- As part of this Tower Coatings Program, a transmission tower is evaluated, and the corrosion condition is ranked based on a joint NACE/IEEE standard (NACE SP0315-2015/IEEE Std 1835-2014) and a PG&E Utility Standard (TD-1001M-JA04, 2020). The tower's corrosion condition ranking is based on its environment and overall condition.
- The corrosion condition ranking, along with other factors, informs the program which coating system are approved for use and this ensures the coating systems selected are appropriate for the environmental threats and will achieve expected life of 20-25 years or more.
- The coating systems include state of the art epoxy and acrylic coatings, designed for the specific corrosive environments which enable long term corrosion protection of the steel, protection from UV exposure, and resistance to adverse environmental factors.



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Tower Coatings Program Coating Strategy

Non-Lead Steel Structures

Corrosion Zone	Number of Non-Lead Towers [ET-GIS]
Extreme	72
Very High	164
High	683
Medium	1,802
Low	41,173
Total Number of Non Lead Structures	43,894

Lead Steel Structures

Corrosion Zone	Number of Lead Towers [ET-GIS]
Extreme	94
Very High	60
High	108
Medium	469
Low	5,896
Total Number of Lead Structures	6,627

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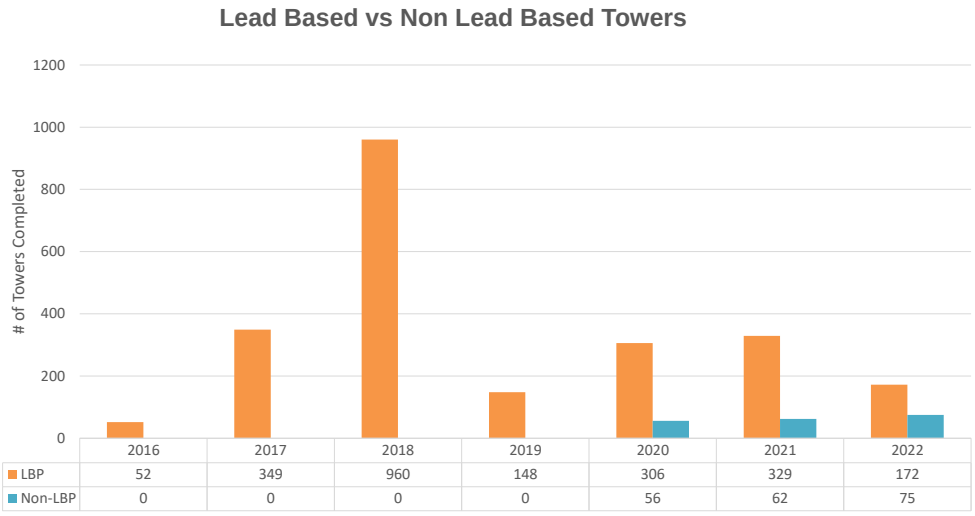
Tower Coatings Program – Historical Metrics



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Three Types of Transmission Tower Corrosion

Transmission towers experience corrosion in three distinct ways:

Atmospheric
Corrosion through regular contact with weather, moisture and salt

Air-to-Electrolyte Transition
Corrosion through direct contact with concrete and/or a soil foundation

Buried
Corrosion through regular contact with soil and other materials underground

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Examples of Corrosion on Transmission Towers







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Transmission Towers in Coatings Program



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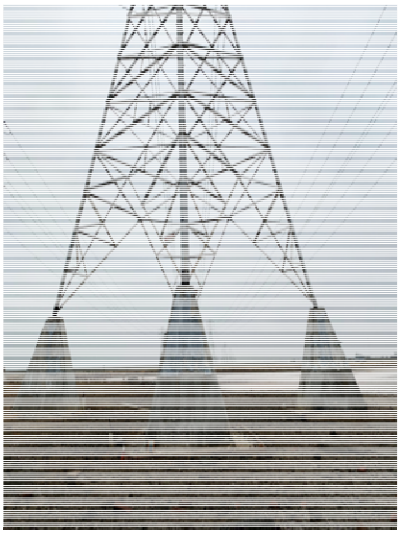
Transmission Towers in Coatings Program





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Transmission Towers in Coatings Program



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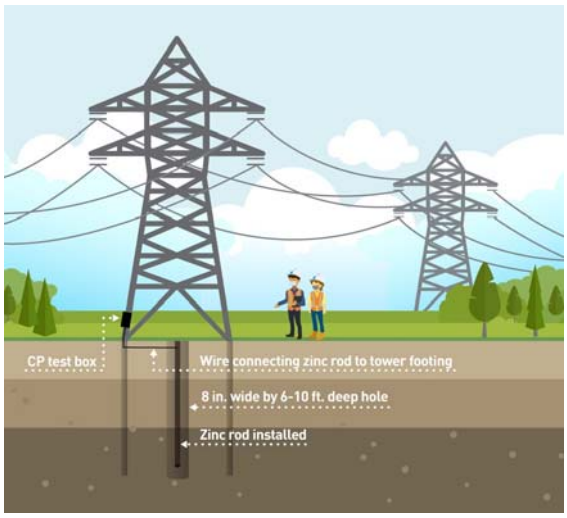
Mitigating Corrosion Through Cathodic Protection

Tower Cathodic Protection

- **Cathodic Protection** is another method of corrosion protection that involves digging minor holes and trenches under or near the base of the tower in order to install corrosion protection materials.
- **This can extend the tower's life by more than 30 years** and, in some cases, up to **60 or even 90 years**.
- **In 2021,** PG&E conducted a pilot program for this work that includes **approximately 350 towers** across **eight geographic regions.**



CP installation locations may be within the tower base or adjacent, depending on the location.

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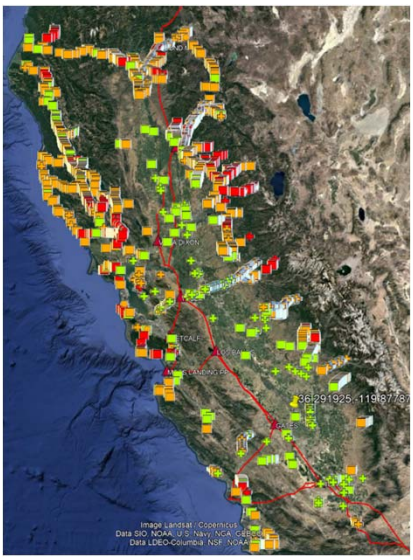
Proactive Leader on Corrosion Protection

PG&E is **voluntarily and proactively coating our towers and installing cathodic protection on tower footings** as part of our efforts to continuously improve the safety and reliability of our electric system.

- PG&E **is legally required to use a protective coating on 100% of its steel gas pipelines**.
- For any **buried pipelines**, PG&E is also **legally required to install cathodic protection systems**.
- PG&E is **not** required by law to **apply protective coating** on its steel towers or **install cathodic protection systems** for tower footings to protect them from corrosion.
- **We voluntarily conduct this proactive safety work** to further extend the lives of our electric infrastructure.
- This work ensures that our electric system can be **operated safely and reliably** for many years to come.

Cathodic Protection Scope Identification



- A diverse population of towers are prioritized based on varying soil characteristics, land usage, weather, etc. using PG&E's risk model with a focus on towers with ***direct buried foundations***
  - There are estimated to be over 5,000 existing towers with direct buried grillage within the PG&E transmission tower network.
- Based on field investigation and visual assessment of a specific structure, Engineering will assess field data to determine whether Cathodic Protection is necessary to prevent tower foundation corrosion failure using the following criteria:
  - Soil resistivity/corrosivity at the specific tower location
  - Direct assessment of the condition of the steel below grade and the amount of corrosion found

Primary Goals For CP Program

There are three primary goals of the Cathodic Protection (CP) Program:

1. Field Investigation/Visual Investigation (FI/VI) within 2 feet of the air-to-soil transition of tower legs
   - Assess fitness for service of the asset
2. Cathodic Protection applied to appropriate direct buried tower footings using industry standards to ensure CP effectiveness and protection
   - Extend life of the asset
3. Collect data to improve PG&E's risk model and drive risk-based decisions

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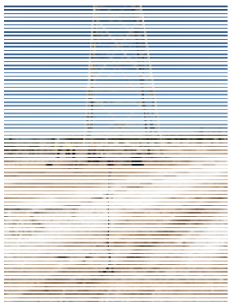
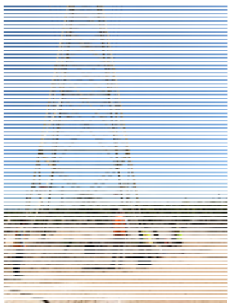
Tower Cathodic Protection – Field Testing And Design





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CP Design

Dwight's Eqn - Multiple Vertical Anodes Resistance to Earth

$$R_N = \frac{\rho}{2\pi NL}\left(\ln 8\frac{L}{d} - 1 + \frac{2L}{s}\ln 0.656N\right)$$

Input

N = number of anodes(wells) in parallel	1	User select the number of parallel wells
S = Anode (wells) spacing (ft)	15	User select distance between wells
Anode material (3-Zn, 2-Mg)	2	User select anode material
C = Configuration Option	A3	See Anode Options sheet
ρ = soil resistivity in ohm-cm	22448	Uses '0' Barnes layer Pulls Resistivity from Profile
W = Weight of a single wall (lbs)	60	Anode weight is the weight of all Anodes in the well
L = length of active anode well (ft)	6.83	
D = diameter of anode well (ft)	0.67	
Rw = Resistance-to-earth (ohms)	30.59	
Ireq = required current from design (mA)	17.0	Ireq comes from Current Rqmt sheet (to meet 100mV shift)
L = Life (years)	30	Uses Life from Current Rqmt sheet
Wt = Total weight of all anodes (lbs)	60	Total weight per well = The number of wells
Icalc = estimated current to -850mV (mA)	24.5	850 Not Required, use 100mV criterion
L = Life in Years (Polarized to -850mV)	45.9	850 Not Required, use 100mV criterion
L = Life in Years (@ Ireq)	66.2	Red when not meeting design

Mag for increased current

Changed to 0-5' layer for horizontal anode due to rock and lower soil res

Summary of Design

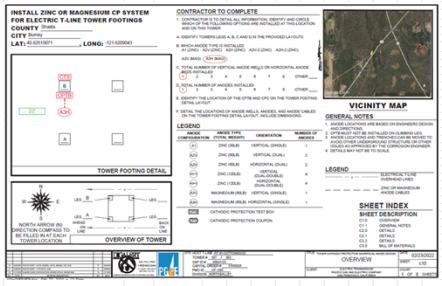
-Recommend to install One (1) A3H mag anode well between A-B

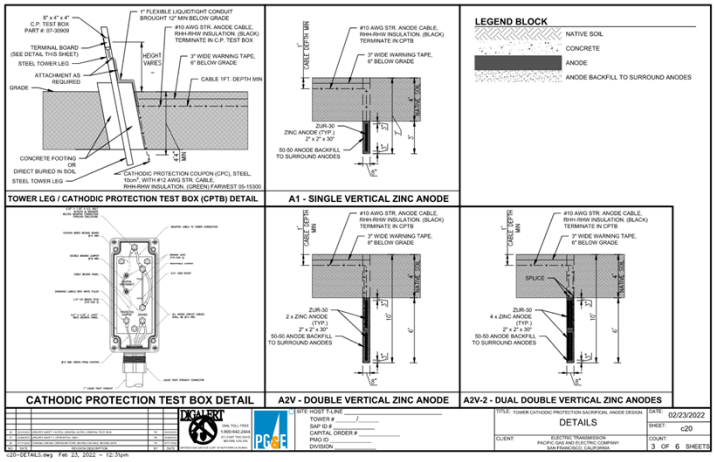
Total # of anodes wells	1
Design Reviewed By	B. Vidal
Land ID	BTeN
NACE CP4 Certification Number	#4204

USER NOTICE

For these equations to be valid the soil must be homogeneous and L >> d. With low resistance backfill, d and L are the diameter and total length of the packaged anode(s). Typical installation would have the top anode starting at 4' below the surface.

Tower CP Overview





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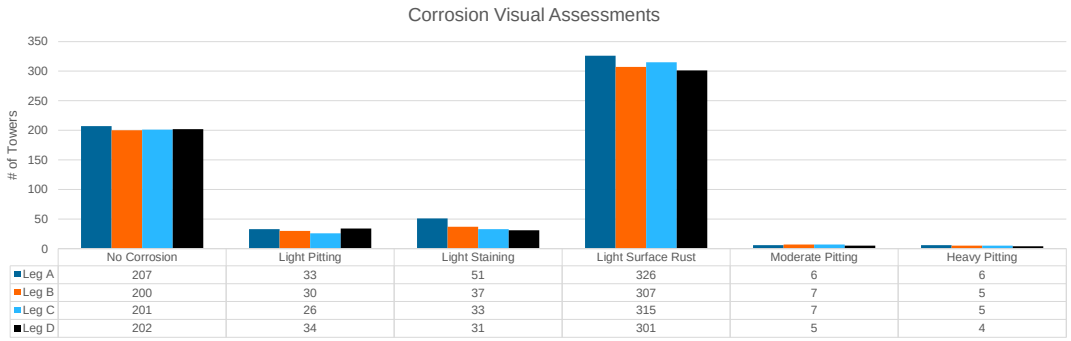
2021/2022 FIELD FINDINGS – VISUAL ASSESSMENTS



	No Corrosion	Light Pitting	Light Staining	Light Surface Rust	Moderate Pitting	Heavy Pitting
Leg A	207	33	51	326	6	6
Leg B	200	30	37	307	7	5
Leg C	201	26	33	315	7	5
Leg D	202	34	31	301	5	4

Light Staining | Light Surface Rust | Light Pitting | Moderate Pitting | Heavy Pitting

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Examples of Corrosion on Transmission Towers Grillage

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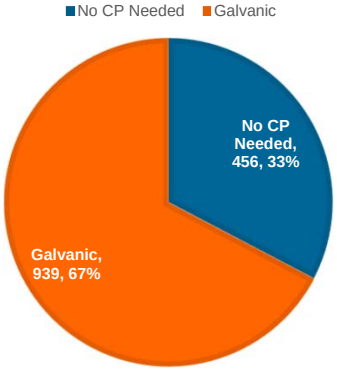
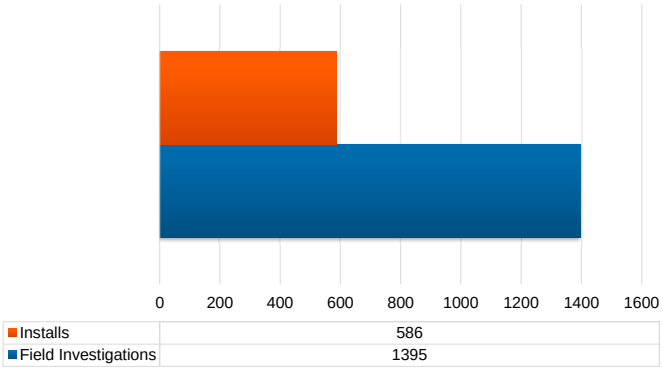
2021/2022 FIELD FINDINGS – METRICS

ENGINEERING REVIEWS



FIELD INVESTIGATIONS V. CP INSTALLS



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CP Construction



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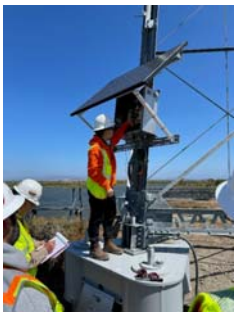
Impressed Current Systems



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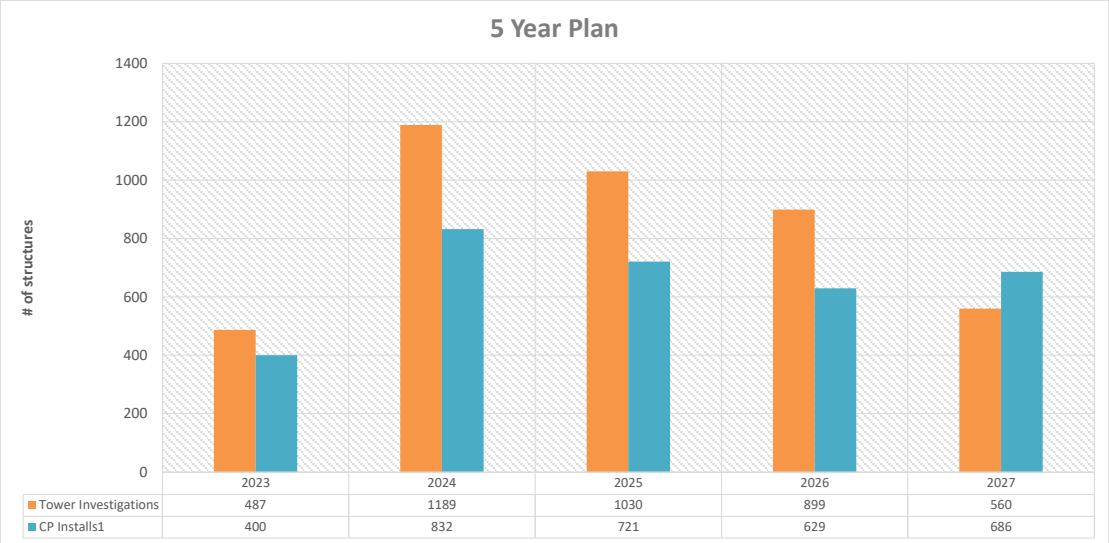
Cathodic Protection 5-Year Plan



	2023	2024	2025	2026	2027
Tower Investigations	487	1189	1030	899	560
CP Installs1	400	832	721	629	686

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Thank You

For more information, contact:

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