BOLD®

Efficiency never looked so good®

BOLD®

BOLD®
(Breakthrough Overhead Line Design®)

The BOLD Challenge:

- Achieve greater capacity and efficiency at native voltages
  - Avoid series compensation and specialized equipment
  - Increase utilization of existing and future ROW's
- Reduce environmental and visual impacts
- Deliver technology that consumers and regulators desire
- Achieve the above – AND be cost competitive

If we could start from a blank page, what would transmission look like?

BOLD®

BOLD Delivers

- **Higher Capacity & Efficiency**
  - Significantly <u>increases capacity </u>(up to 60%)
  - Avoids complexity and cost of compensation
  - Avoids SSR issues with rotating generation
  - <u>Reduces Line Losses </u>(up to 33%)

- **Environmentally Friendly**
  - <u>Mitigates electromagnetic field effects </u>(up to 50%)
  - <u>Reduces structure heights </u>(as much as 30%)
  - Provides <u>simple</u>, <u>elegant</u>, low-profile design
  - Built-in <u>avian protection</u> features

- **Regulatory Answers**
  - Addresses need for <u>Advanced Transmission Technology</u>
  - More <u>rapidly brings </u>new and replacement <u>circuits into service</u>
  - <u>Maximizes right-of-way </u>utilization

- **BOLD is Cost Competitive**
  - BOLD <u>competes on a first-cost basis</u>
 - BOLD <u>excels on a $/MW basis</u>

BOLD Survey Summary

Public concerns regarding transmission include property value, health impacts, visual impacts

- **79%** value advanced technology

- **75%** would pay more for advanced technology

- **70%** preferred **BOLD** structures versus traditional double-circuit design

Acceptable monthly premium for advanced technology:

12% — $0.10
32% — $1
24% — $5
7% — $10
25% — $0
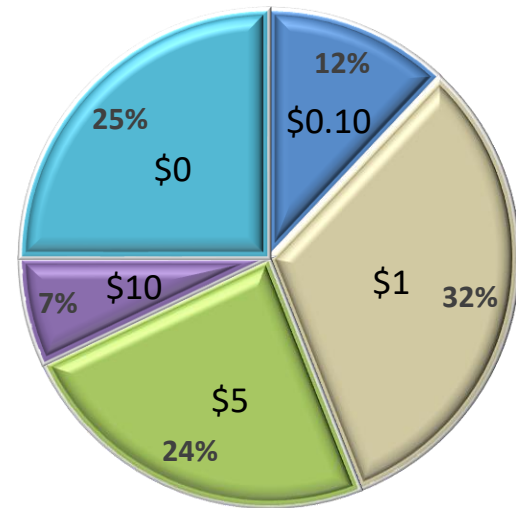
Survey conducted with 1,000 U.S. customers and 500 European customers.

BOLD®

BOLD Award-winning Technology

- 2017 Recipient of <u>Edison Electric Institute's</u>

  EDISON AWARD

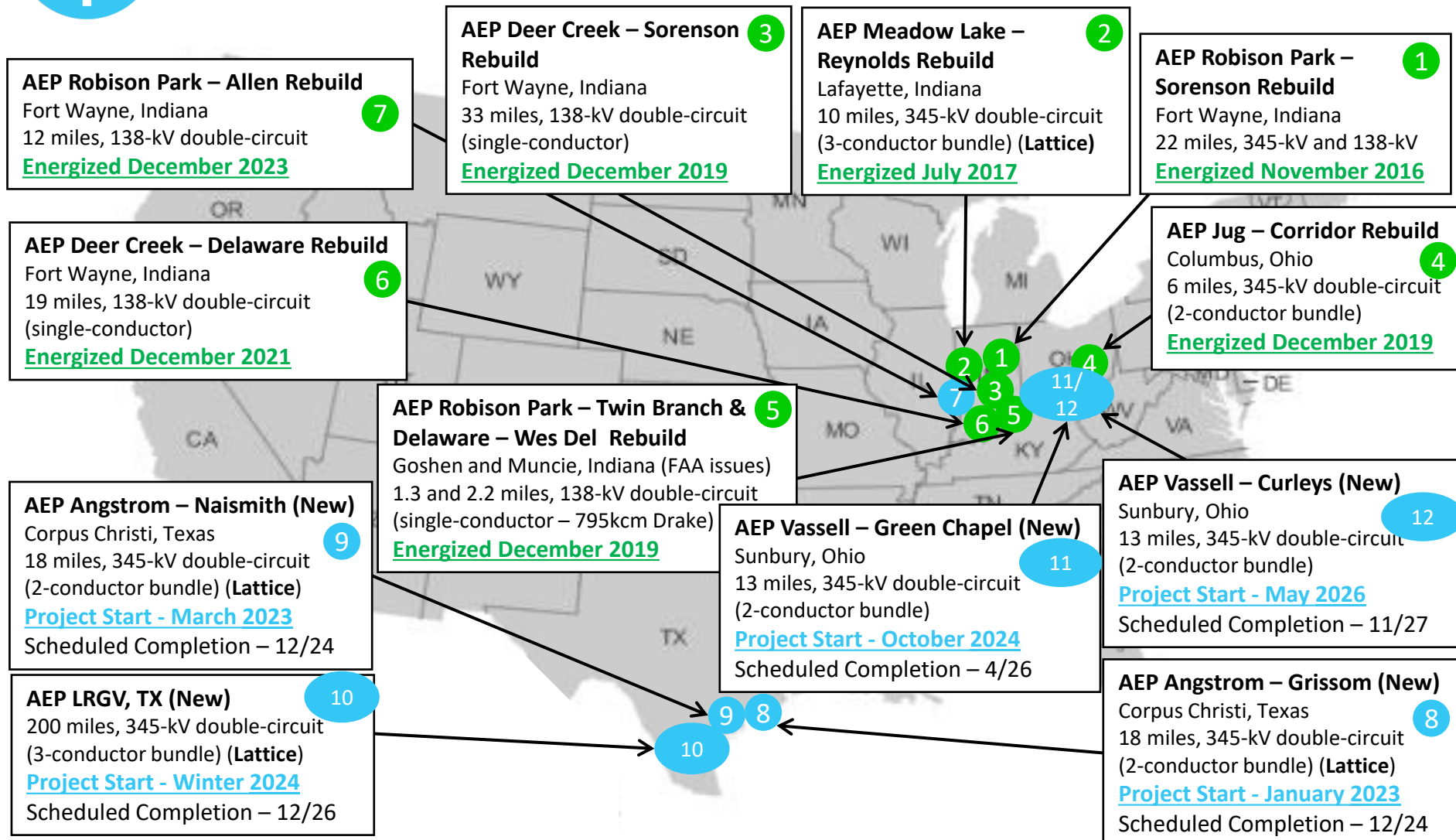- 2017 Recipient of <u>NARUC's</u>

  INNOVATION IN ELECTRICITY AWARD

- 2017 Grand Prize Recipient of <u>CIGRE/KEPCO's</u>

  INTERNATIONAL TOWER DESIGN AWARD

BOLD Project Deployment

as of Aug. 2024

AEP Deer Creek – Sorenson Rebuild 3
Fort Wayne, Indiana
33 miles, 138-kV double-circuit (single-conductor)
Energized December 2019

AEP Meadow Lake – Reynolds Rebuild 2
Lafayette, Indiana
10 miles, 345-kV double-circuit (3-conductor bundle) (**Lattice**)
Energized July 2017

AEP Robison Park – Sorenson Rebuild 1
Fort Wayne, Indiana
22 miles, 345-kV and 138-kV
Energized November 2016

AEP Robison Park – Allen Rebuild 7
Fort Wayne, Indiana
12 miles, 138-kV double-circuit
Energized December 2023

AEP Jug – Corridor Rebuild 4
Columbus, Ohio
6 miles, 345-kV double-circuit (2-conductor bundle)
Energized December 2019

AEP Deer Creek – Delaware Rebuild 6
Fort Wayne, Indiana
19 miles, 138-kV double-circuit (single-conductor)
Energized December 2021

AEP Robison Park – Twin Branch & Delaware – Wes Del Rebuild 5
Goshen and Muncie, Indiana (FAA issues)
1.3 and 2.2 miles, 138-kV double-circuit (single-conductor – 795kcm Drake)
Energized December 2019

AEP Vassell – Curleys (New) 12
Sunbury, Ohio
13 miles, 345-kV double-circuit (2-conductor bundle)
Project Start - May 2026
Scheduled Completion – 11/27

AEP Angstrom – Naismith (New) 9
Corpus Christi, Texas
18 miles, 345-kV double-circuit (2-conductor bundle) (**Lattice**)
Project Start - March 2023
Scheduled Completion – 12/24

AEP Vassell – Green Chapel (New) 11
Sunbury, Ohio
13 miles, 345-kV double-circuit (2-conductor bundle)
Project Start - October 2024
Scheduled Completion – 4/26

AEP LRGV, TX (New) 10
200 miles, 345-kV double-circuit (3-conductor bundle) (**Lattice**)
Project Start - Winter 2024
Scheduled Completion – 12/26

AEP Angstrom – Grissom (New) 8
Corpus Christi, Texas
18 miles, 345-kV double-circuit (2-conductor bundle) (**Lattice**)
Project Start - January 2023
Scheduled Completion – 12/24

Over 100 miles installed (In Indiana and Ohio), meeting or exceeding design criteria. An additional 250+ miles in construction or design.

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HOW IT WORKS

BOLD®

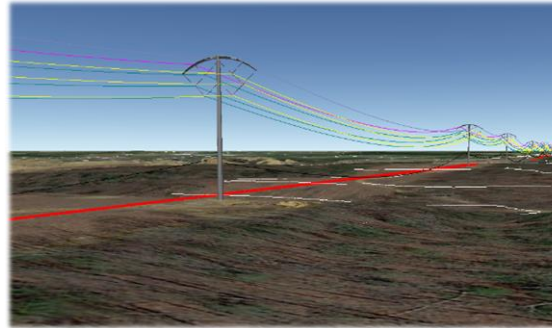# **BOLD** Development

Surge Impedance changes with $\sqrt{L^+/C^+}$ (ohm)

- $L^+ \approx \frac{\mu_o}{2\pi} ln\left(\frac{d_{eq}}{R_{eq}}\right) = 0.3219 \, ln\left(\frac{d_{eq}}{R_{eq}}\right) mH/mi$

- $C^+ \approx \frac{2\pi\epsilon_o}{ln(\frac{d_{eq}}{R_{eq}})} = \frac{89.41}{ln\left(\frac{d_{eq}}{R_{eq}}\right)} nF/mi$

- $Z^+ \approx 60 \, ln\left(\frac{d_{eq}}{R_{eq}}\right) \Omega$

- Where:
  - $d_{eq} = \sqrt[3]{d_{ab}d_{bc}d_{ca}}$ **Eq. Phase Spacing (ft)**
  - $R_{eq} = \sqrt[N]{NrR^{N-1}}$ **Eq. Bundle Radius (ft)**
  - $d_{ab}, d_{bc}, d_{ca} = Phase\ spacings\ (ft)$
  - $N = Number\ of\ subconductors\ per\ phase$
  - $r = Subconductor\ radius\ (ft)$
  - $R = Subconductor\ bundle\ radius\ (ft)$

Structural

Electrical

Theory → **Modeling** → **Testing** → **Field Validation**

How **BOLD** Works

- **Leverage physics to maximize electrical performance:**

  (1) Reduce phase separation into a "delta" configuration
  (2) Optimize conductor size and bundle diameter

- **Reduces inductance (L) and impedance (Z) and increases capacitance (C)**

- **Higher degree of intrinsic "self-compensation"**

- **Arched cross arm and inter-phase insulators**

Single arched crossarm to hold both circuits

Unique inter-phase insulator assembly

(1) Compaction of entire three-phase circuit arrangement into a delta

(2) Optimization of individual conductors in a 2, 3, 4 conductor bundle
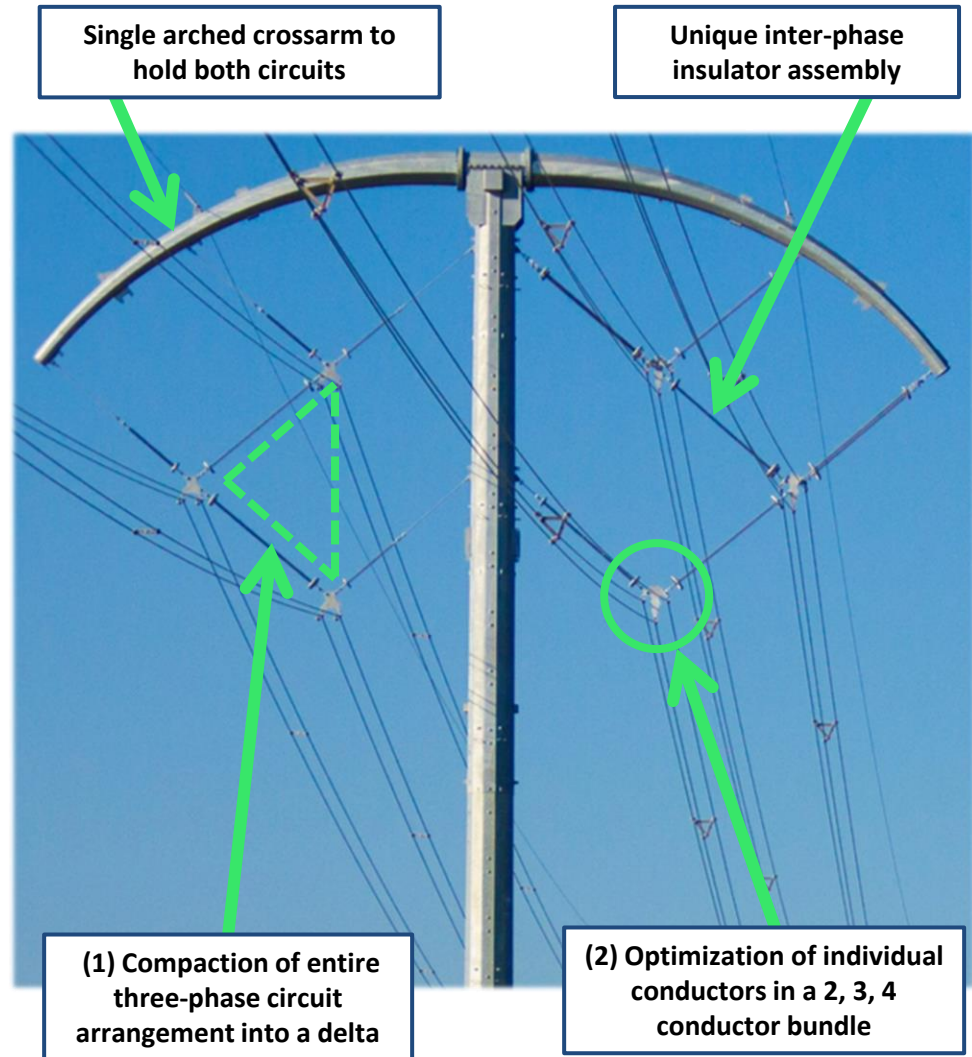
BOLD ADVANTAGE – THE MATH

- Surge Impedance changes with $\sqrt{L^+/C^+}$ (ohm)

  - $L^+ \approx \frac{\mu_o}{2\pi} ln\left(\frac{d_{eq}}{R_{eq}}\right) = 0.3219\ ln(\frac{d_{eq}}{R_{eq}})\ mH/mi$

  - $C^+ \approx \left.{2\pi\epsilon_o}\middle/{ln(\frac{d_{eq}}{R_{eq}})}\right. = \left.{89.41}\middle/{ln(\frac{d_{eq}}{R_{eq}})}\right.\ nF/mi$

  - $Z^+ \approx 60\ ln\left(\frac{d_{eq}}{R_{eq}}\right)\ \Omega$

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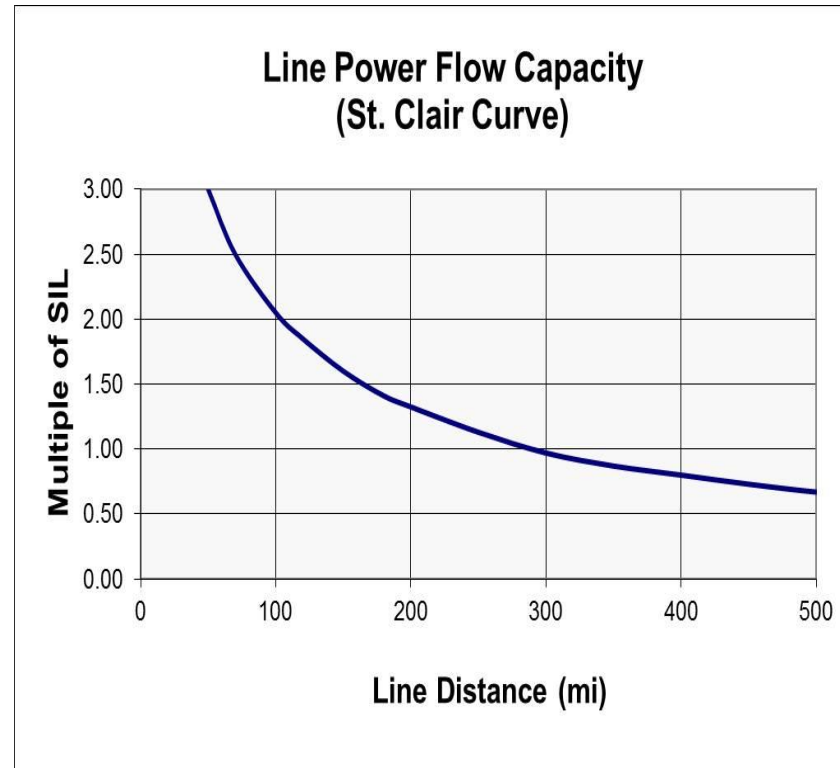   - $R = Subconductor\ bundle\ radius\ (ft)$

L, Z decrease; C increases with:

- Closer phase spacing

- More sub-conductors

- Larger bundle diameter

- Larger conductor diameter

  BOLD leverages these principles

LINE LOADABILITY BASED ON:
SURGE IMPEDANCE LOADING (SIL)

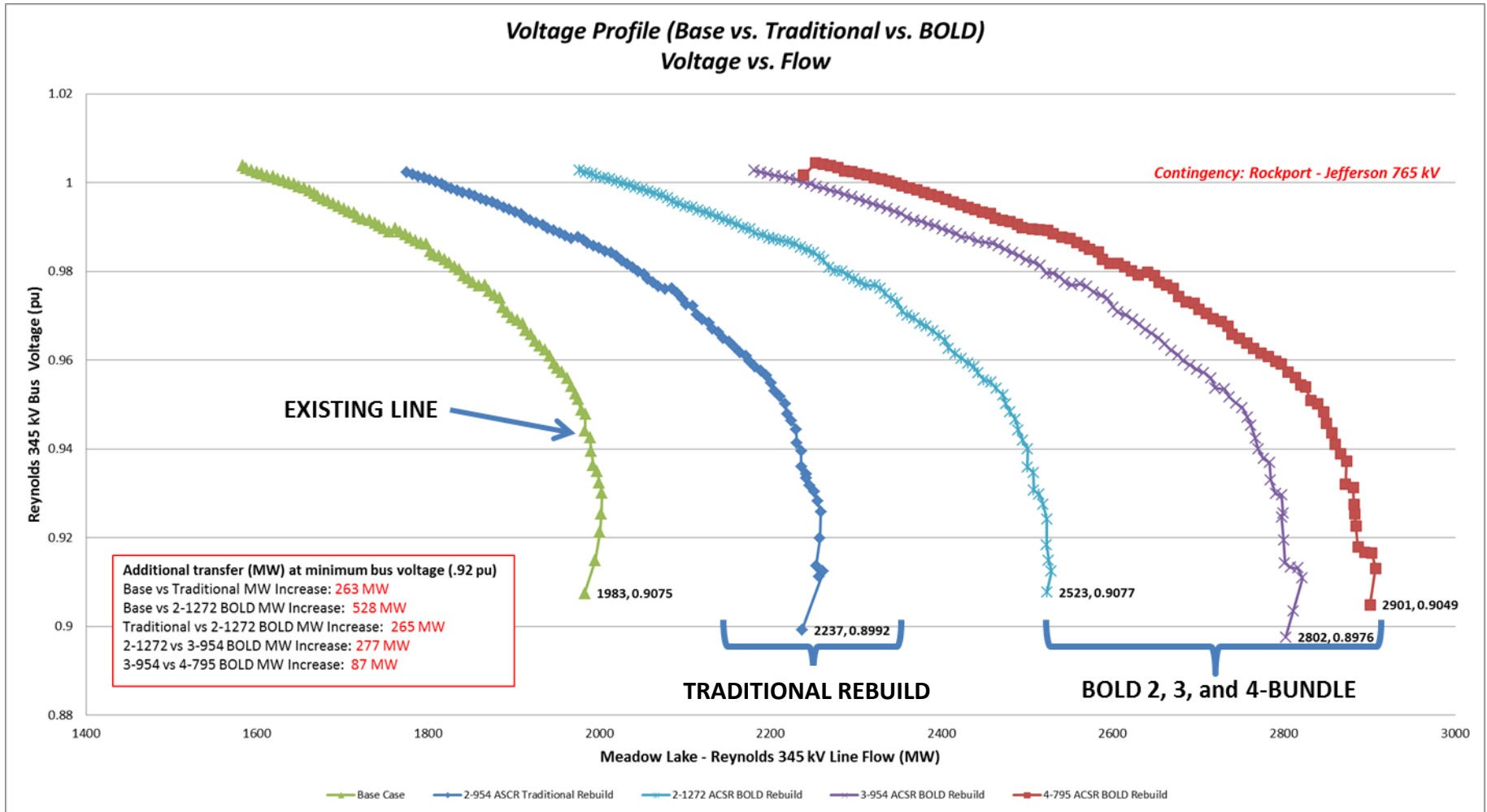**Line Power Flow Capacity
(St. Clair Curve)**

The St. Clair Curve represents a transmission line's power delivery capability over distance without reactive compensation.

EXAMPLE
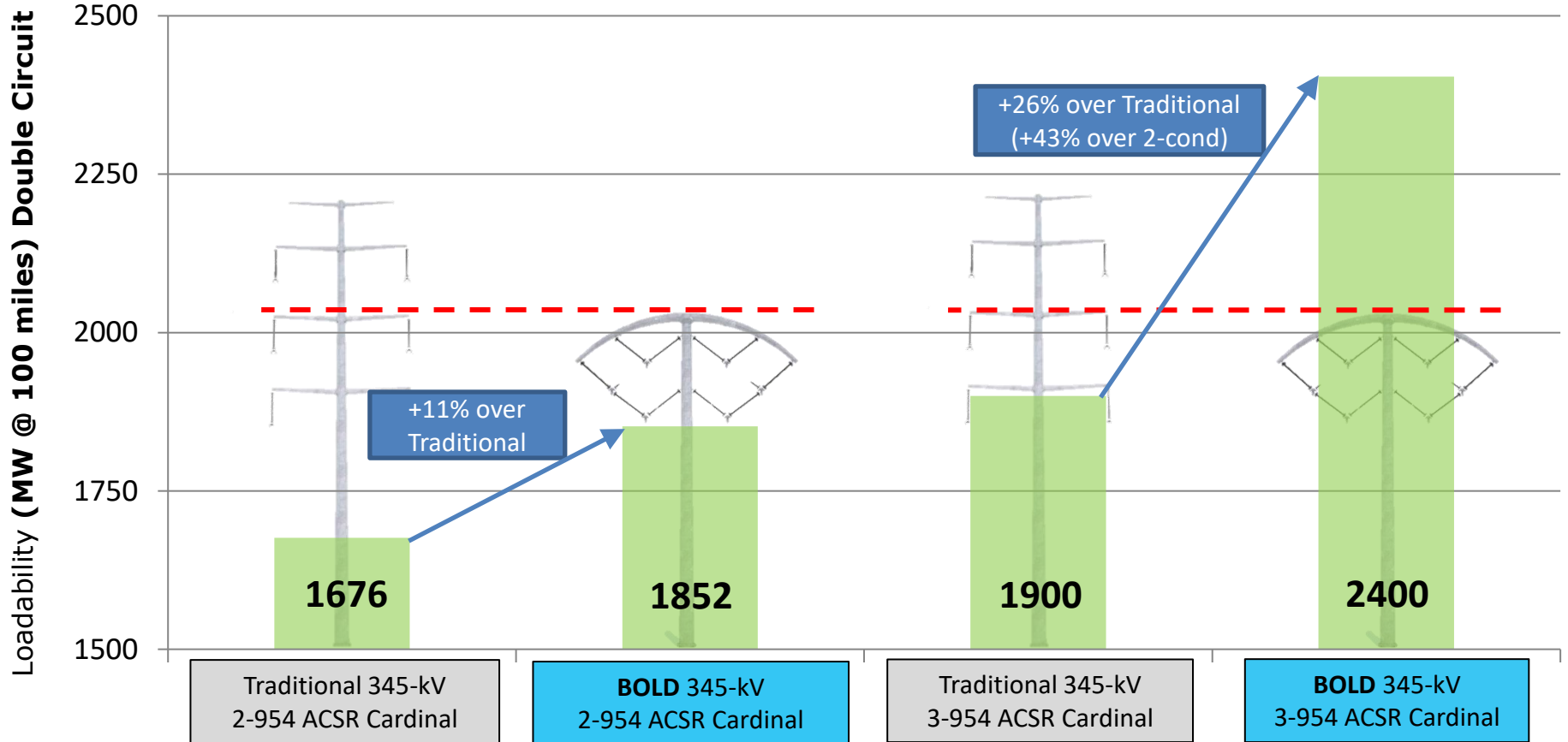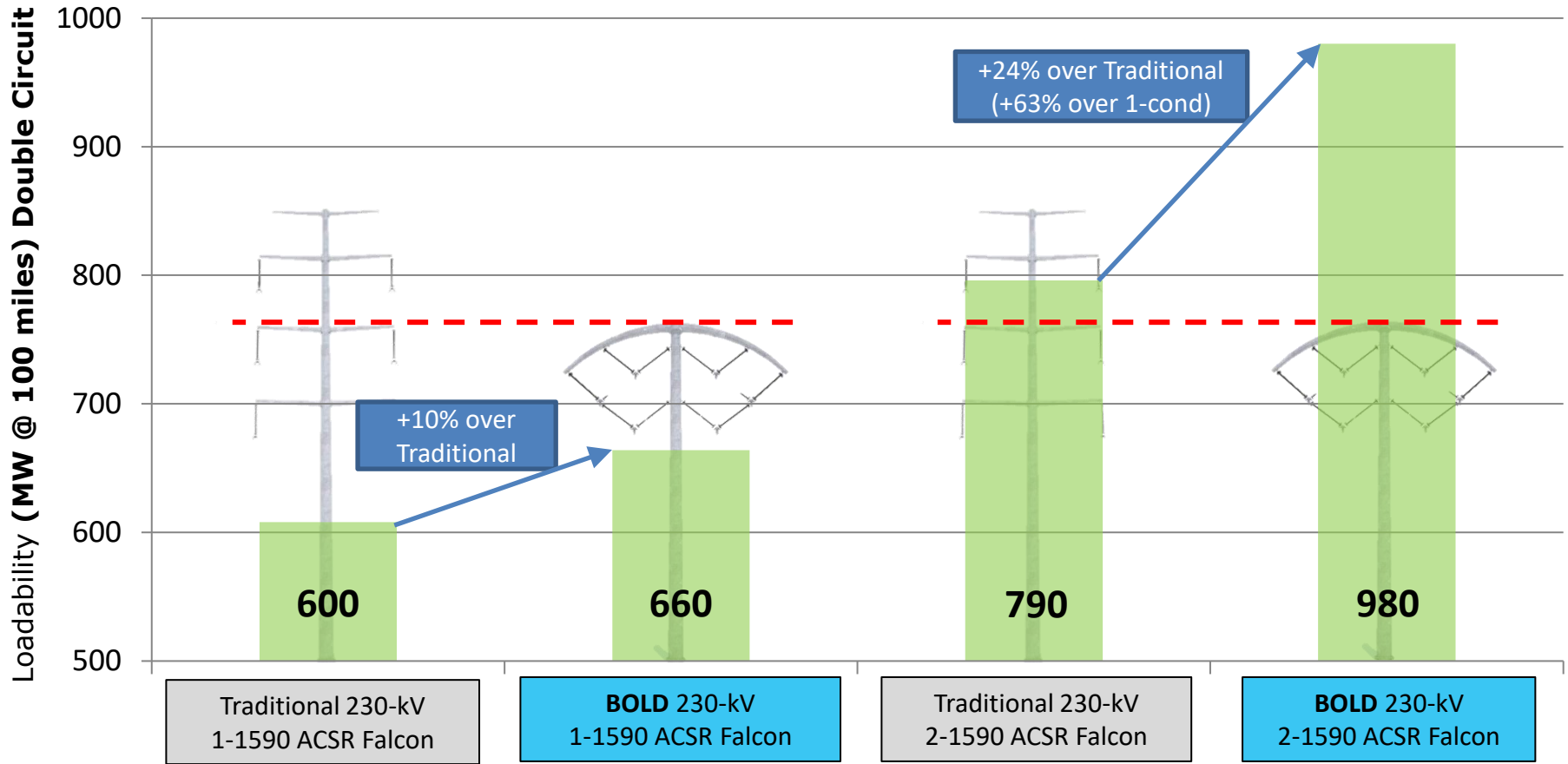## Meadow Lake – Reynolds 345-kV

Voltage Profile (Base vs. Traditional vs. BOLD)
Voltage vs. Flow

Contingency: Rockport - Jefferson 765 kV

EXISTING LINE

Additional transfer (MW) at minimum bus voltage (.92 pu)
Base vs Traditional MW Increase: 263 MW
Base vs 2-1272 BOLD MW Increase: 528 MW
Traditional vs 2-1272 BOLD MW Increase: 265 MW
2-1272 vs 3-954 BOLD MW Increase: 277 MW
3-954 vs 4-795 BOLD MW Increase: 87 MW

1983, 0.9075
2237, 0.8992
2523, 0.9077
2802, 0.8976
2901, 0.9049

TRADITIONAL REBUILD

BOLD 2, 3, and 4-BUNDLE

Reynolds 345 kV Bus Voltage (pu)

Meadow Lake - Reynolds 345 kV Line Flow (MW)

Base Case — 2-954 ASCR Traditional Rebuild — 2-1272 ACSR BOLD Rebuild — 3-954 ACSR BOLD Rebuild — 4-795 ACSR BOLD Rebuild

Higher Capacity – 345 kV

(Values are approximate)

Higher Capacity – 230 kV

Bar chart — Loadability (MW @ 100 miles) Double Circuit

Y-axis: Loadability (MW @ 100 miles) Double Circuit, scale 500 to 1000

- Traditional 230-kV 1-1590 ACSR Falcon: 600
- **BOLD** 230-kV 1-1590 ACSR Falcon: 660 — +10% over Traditional
- Traditional 230-kV 2-1590 ACSR Falcon: 790
- **BOLD** 230-kV 2-1590 ACSR Falcon: 980 — +24% over Traditional (+63% over 1-cond)

(Values are approximate)

15

SIL Comparisons

765kV Single-circuit
(6-conductor)

~2,400 MW

200' ROW

345kV **BOLD** Double-circuit
(3-conductor)

~1,200 MW

150' ROW

345kV Traditional Double-circuit
(3-conductor)

~950 MW

345kV Traditional Double-circuit
(2-conductor)

~850 MW

150' ROW

500kV Single-circuit
(3-conductor)

~950 MW

175' ROW

BOLD is a relevant option for long-haul power Transmission

BOLD®

Better Use of RoW

BOLD allows you to deliver **more** power in a given right-of-way when compared to traditional transmission line designs. That means less land is needed to fulfill capacity needs.

450 Foot RoW
345-kV Traditional
(3) Single Circuit Towers

300 Foot RoW
345-kV Traditional
(1) Single Circuit Tower
(1) Double Circuit Tower

150 Foot RoW
345-kV BOLD
(1) Double Circuit Tower

450'   **300'**   **150'**
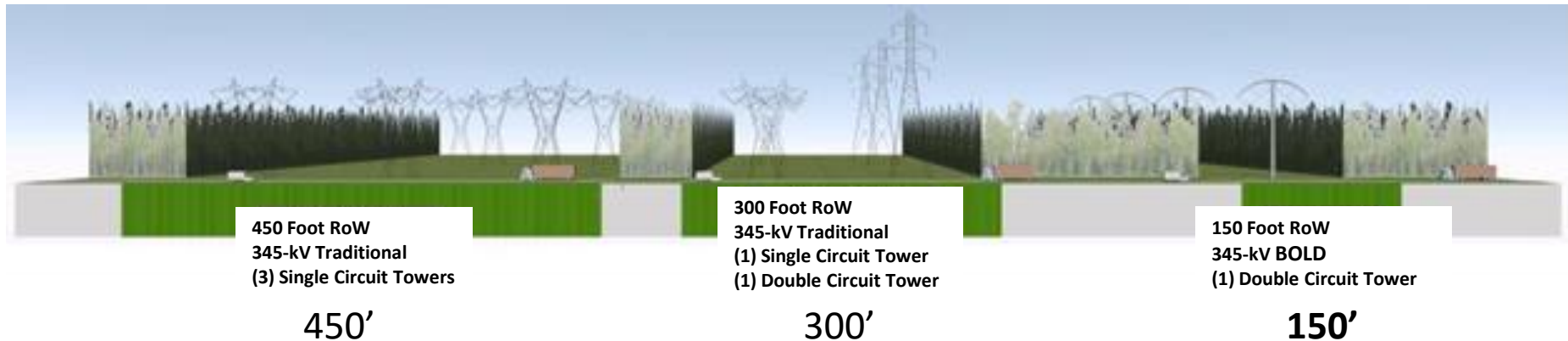
One **BOLD** 345-kV double-circuit line can deliver the same power carrying capacity as three traditional 345-kV single- circuit lines creating a smaller environmental footprint of roughly 1/3 by comparison

Magnetic Field Mitigation

Traditional 345-kV

Magnetic Field Profile @1000MVA Per Circuit
Traditional 345-kV 2-Falcon 25.5ft Phase Spacing 18" Bundle Diameter
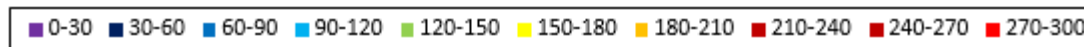**Super Bundle Arrangement (A-B-C / A-B-C)**
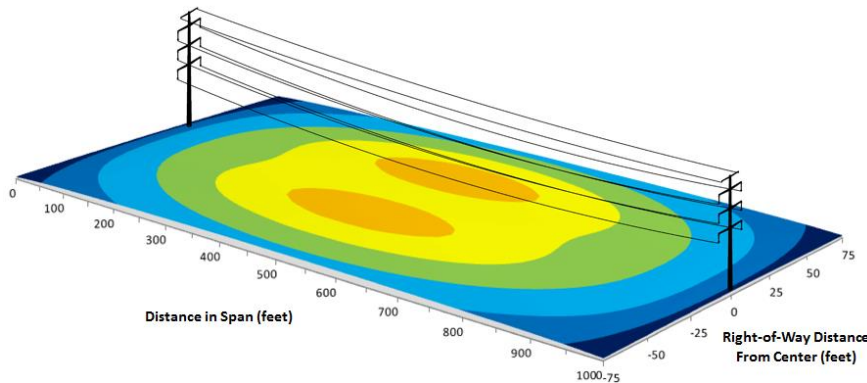
Min = 34.5 mG
Max = 193.4 mG

BOLD 345-kV

Magnetic Field Profile @1000MVA Per Circuit
BOLD 345-kV 3-Cardinal 15ft Phase Spacing 29" Bundle Diameter
Super Bundle Arrangement (A-B-C / A-B-C)
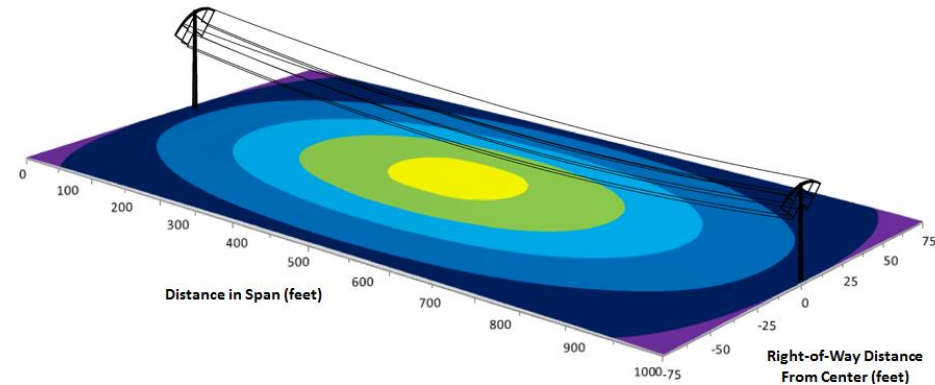
Min = 16.2 mG
Max = 157.6 mG

Magnetic Field Intensity (mG)

■ 0-30 ■ 30-60 ■ 60-90 ■ 90-120 ■ 120-150 ■ 150-180 ■ 180-210 ■ 210-240 ■ 240-270 ■ 270-300
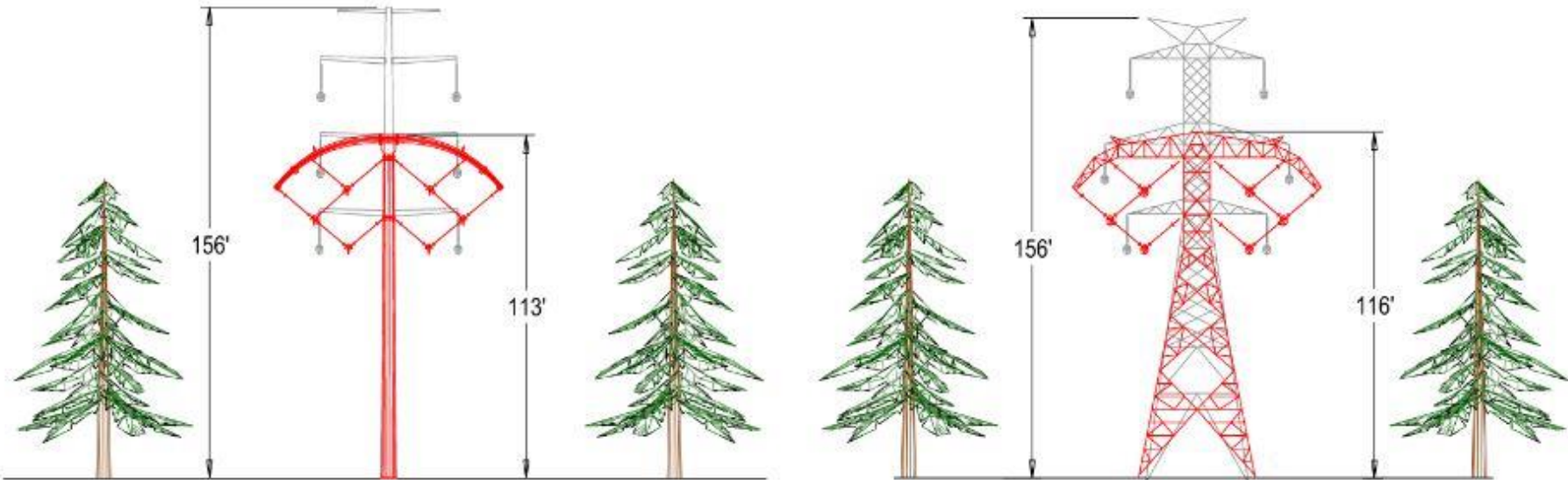
1000' Span Lengths

BOLD reduces Magnetic Field values by up to 50%!
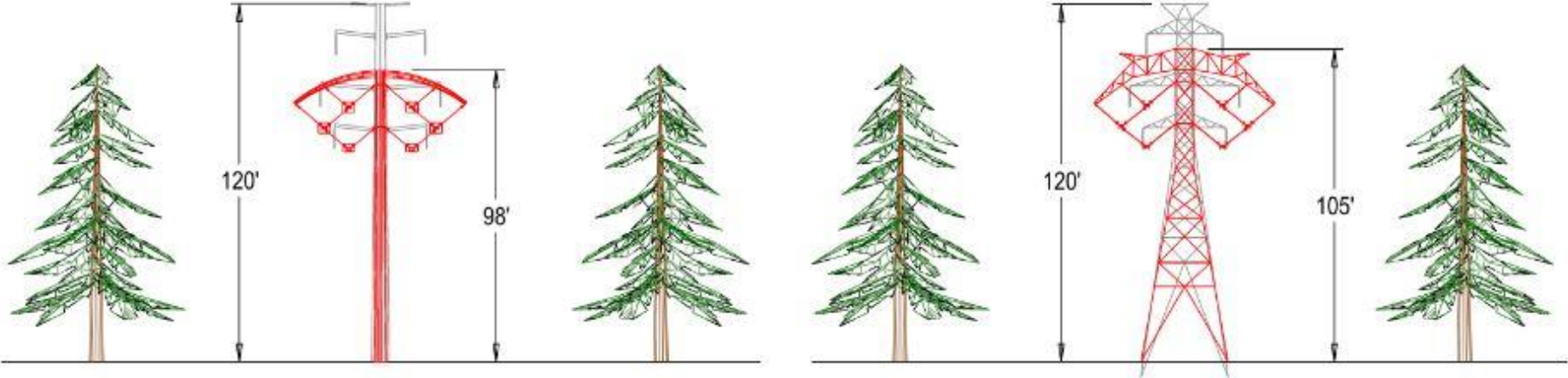
Structure Comparison – 345 kV

1000' Span Lengths

Structure Comparison – 230 kV

1000' Span Lengths

BOLD Reduces Avian Interaction*

- **Nesting**
  - **BOLD** <u>eliminates cavity nests</u> and should <u>minimize corvid and raptor stick nests</u> due to the unique arch-shaped cross member.

- **Collision**
  - **BOLD** has design elements to <u>reduce collision</u> risk

- **Feces**
  - **BOLD** <u>should reduce pollution outages</u> by limiting perching and creating a barrier; it may also reduce streamer outages.

- **Predation Management**
  - **BOLD** may <u>minimize avian predation on sensitive species</u> by reducing nesting on transmission structures.

- **Electrocution**
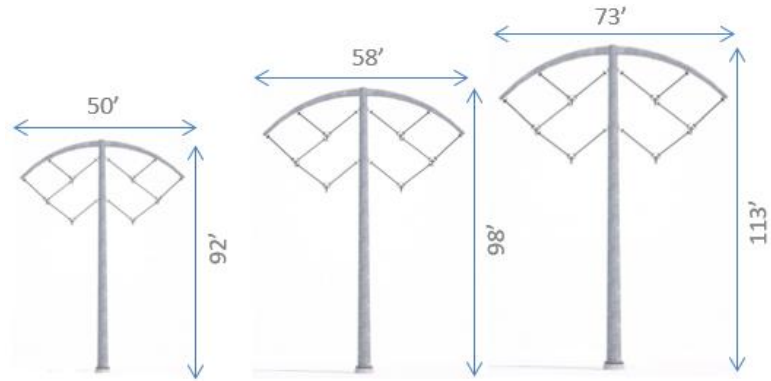 - **BOLD** can be implemented as <u>eagle friendly</u>

* Source: EDM International, Inc. study (2018)

BOLD STRUCTURE FAMILY
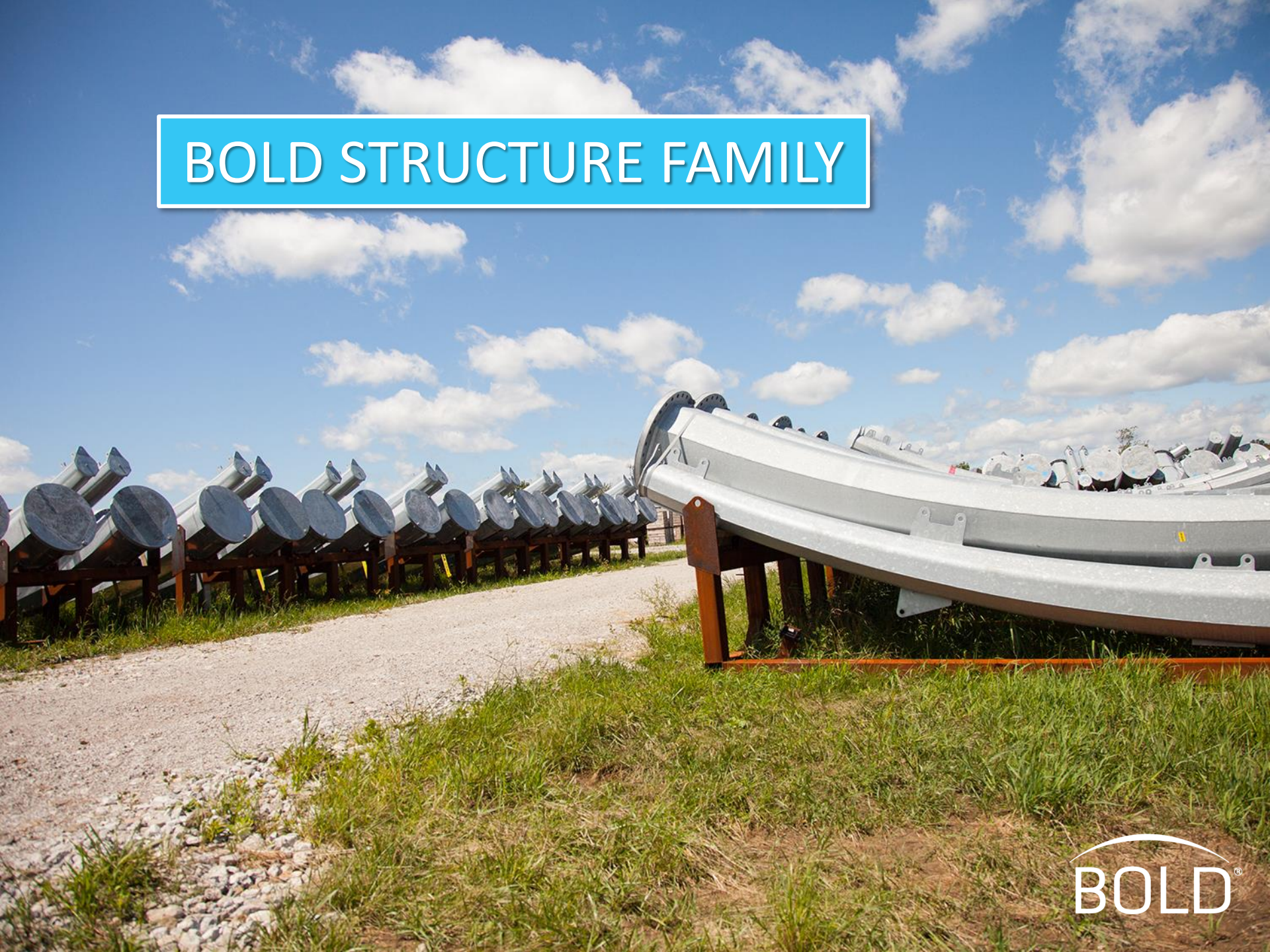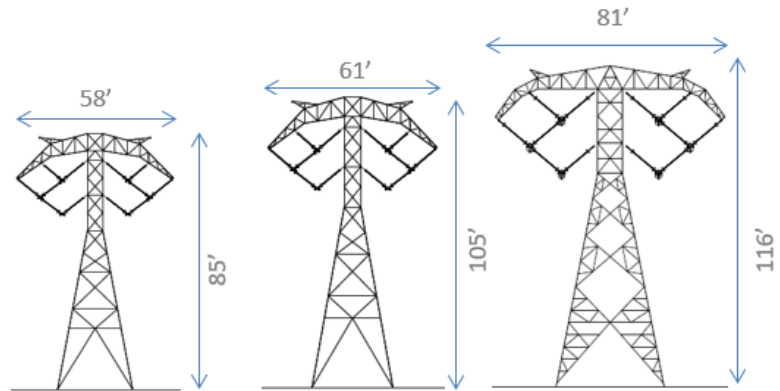
BOLD®

BOLD Structure Families

OPTIONS	115/138-kV	230-kV	345-kV
Single Circuit	✓	✓	✓
Double Circuit	✓	✓	✓
Various Conductor Options	✓	✓	✓

1000' Span Lengths

BOLD Conductor Options

	3-954 BOLD Lattice	3-954 Traditional Lattice	2-1590 BOLD Lattice	2-1590 Traditional Lattice	2-954 BOLD Lattice	2-954 Traditional Lattice
Average Line Cost* ($/mile)	100%	105%	97%	102%	87%	92%
Tangent Structure Weight (lbs.)	100%	118%	95%	108%	85%	97%
Foundation (cu. yd)	100%	106%	97%	103%	91%	97%
Impedance (Ω)	100%	+127%	+122%	+136%	+130%	+145%

*Indicative cost comparison, using common assumptions and unit pricing.

Baseline

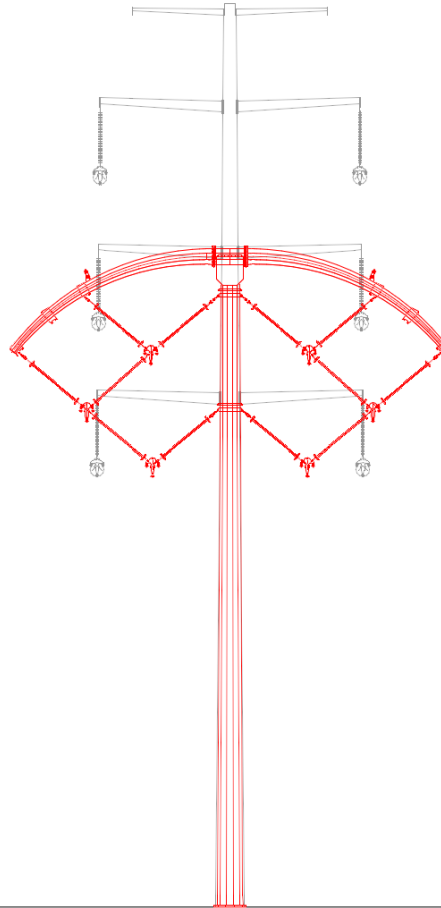**BOLD is the optimal design for cost and impedance.**

A Cost Competitive **BOLD** Solution

Traditional

Pole Weight	36,600 lbs
Arm Weight	10,378 lbs
GL Moment	6,000 ft-K
Foundation Size	6.5 ft x 25ft

Pole Cost	100%
Arm Cost	100%
Anchor B Cost	100%
Foundation Cost	100%
Total Cost	100%

BOLD

Pole Weight	33,098 lbs
Arm Weight	11,070 lbs
GL Moment	4,600 ft-K
Foundation Size	6 ft x 22 ft

Pole Cost	90%
Arm Cost	157%
Anchor B Cost	60%
Foundation Cost	75%
Total Cost	99%

Typical 345-kV Tangent Structure

2-1590 ACSR Falcon

A Cost Competitive **BOLD** Solution

Traditional

Pole Weight	42,100 lbs
Arm Weight	10,500 lbs
GL Moment	6,150 ft-K
Foundation Size	6.5 ft x 25ft
Pole Cost	100%
Arm Cost	100%
Anchor B Cost	100%
Foundation Cost	100%
Total Cost	100%
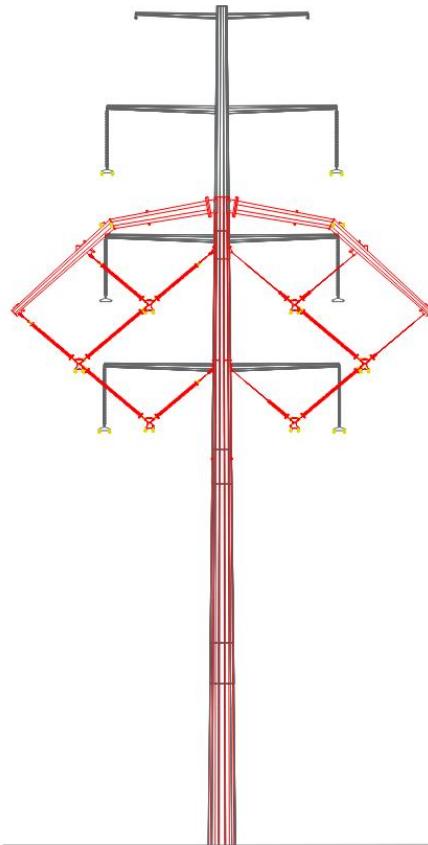
BOLD

Pole Weight	33,700 lbs
Arm Weight	11,100 lbs
GL Moment	4,650 ft-K
Foundation Size	6.0 ft x 22 ft
Pole Cost	82%
Arm Cost	132%
Anchor B Cost	82%
Foundation Cost	75%
Total Cost	93%

Typical 345-kV Tangent Structure

2-1590 ACSR Falcon

Span Length: 1100'

NESC Medium

A Cost Competitive **BOLD** Solution

Traditional

Tower Weight   31,000 lbs
Uplift force   114 kips
Foundation Size 4.0 ft x 13ft

Tower Cost   100%
Foundation Cost 100%
Total Cost   100%
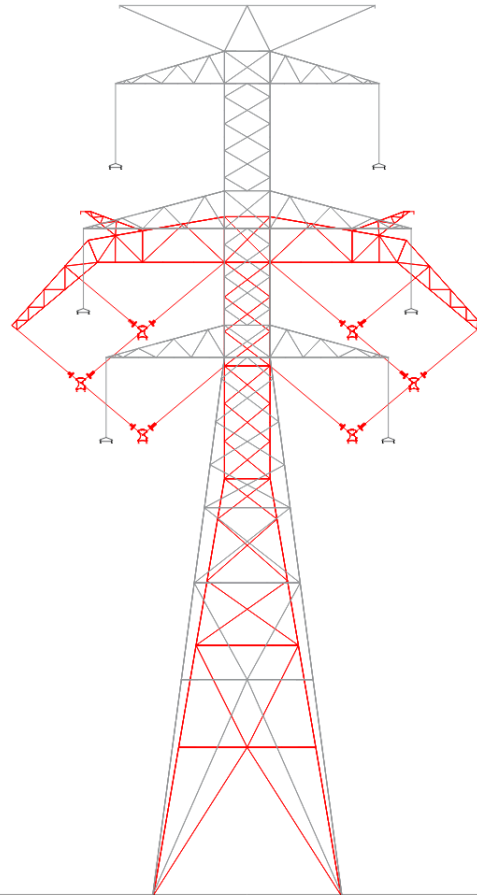
BOLD

Tower Weight   25,700 lbs
Uplift force   94 kips
Foundation Size 4.0 ft x 12ft

Tower Cost   82%
Foundation Cost 92%
Total Cost   86%

Typical 345-kV Tangent Structure

2-1590 ACSR Falcon

Span Length: 1200'

NESC Medium

BENEFITS

BOLD Benefits Summary

BOLD Benefits Summary

Higher Capacity

- Up to 60%
- Can avoid costly and complex compensation

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Increased Efficiency

- **Reduces Line Losses** (up to 33%)

BOLD Benefits Summary

Mitigates EMF Effects

- Up to 50%

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Reduces Avian Interaction

- Nesting
- Collision
- Contamination
- Electrocution

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33

BOLD Benefits Summary

Higher Capacity
- Up to 60%
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Mitigates EMF Effects
- Up to 50%

Reduces Structure Heights
- By nearly 30%

Increased Efficiency
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Maximizes Right-of-Way Utilization

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Aesthetically Pleasing for Customers
- 70% preferred

Maximizes Right-of-Way Utilization

BOLD Benefits Summary

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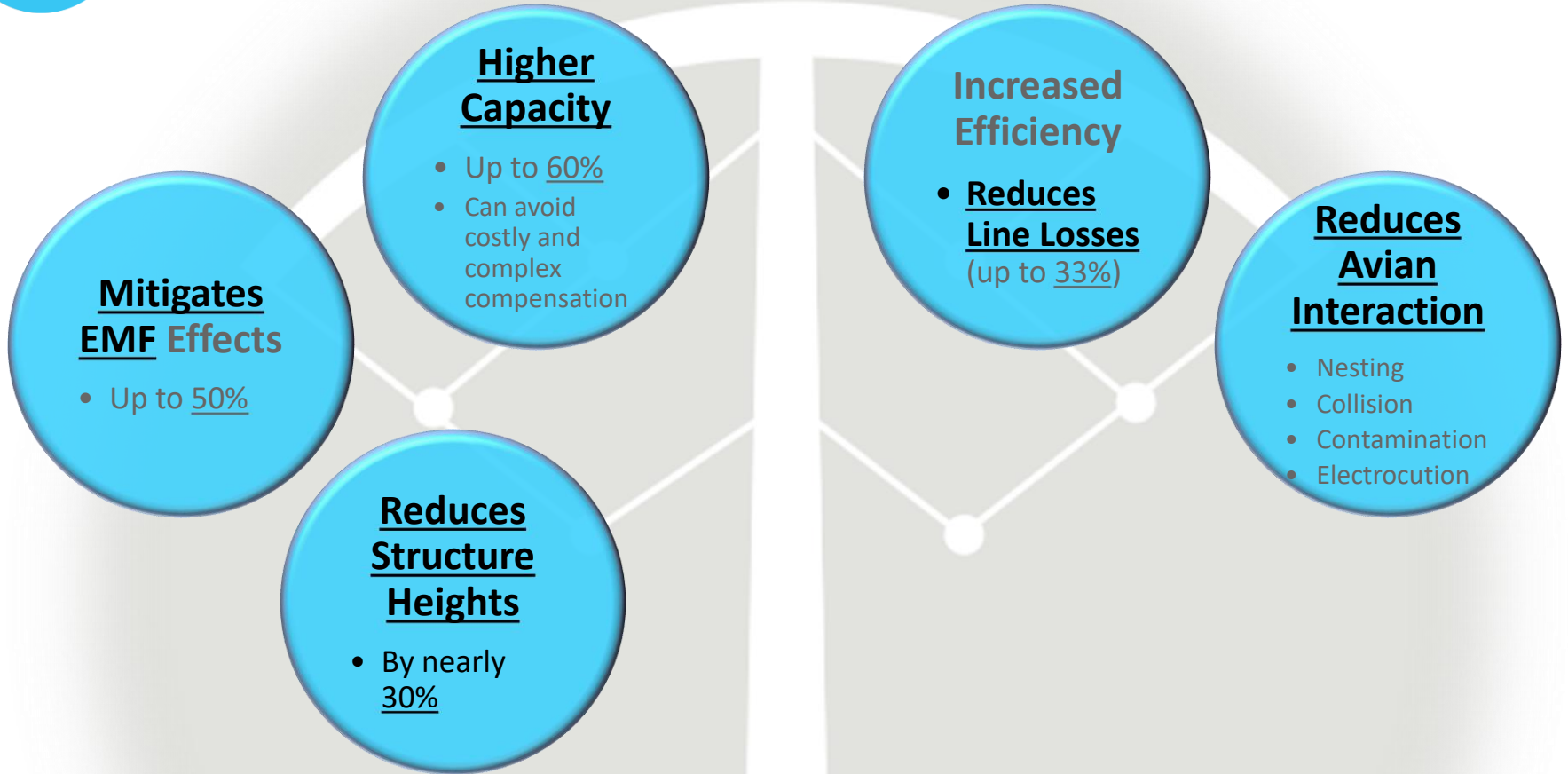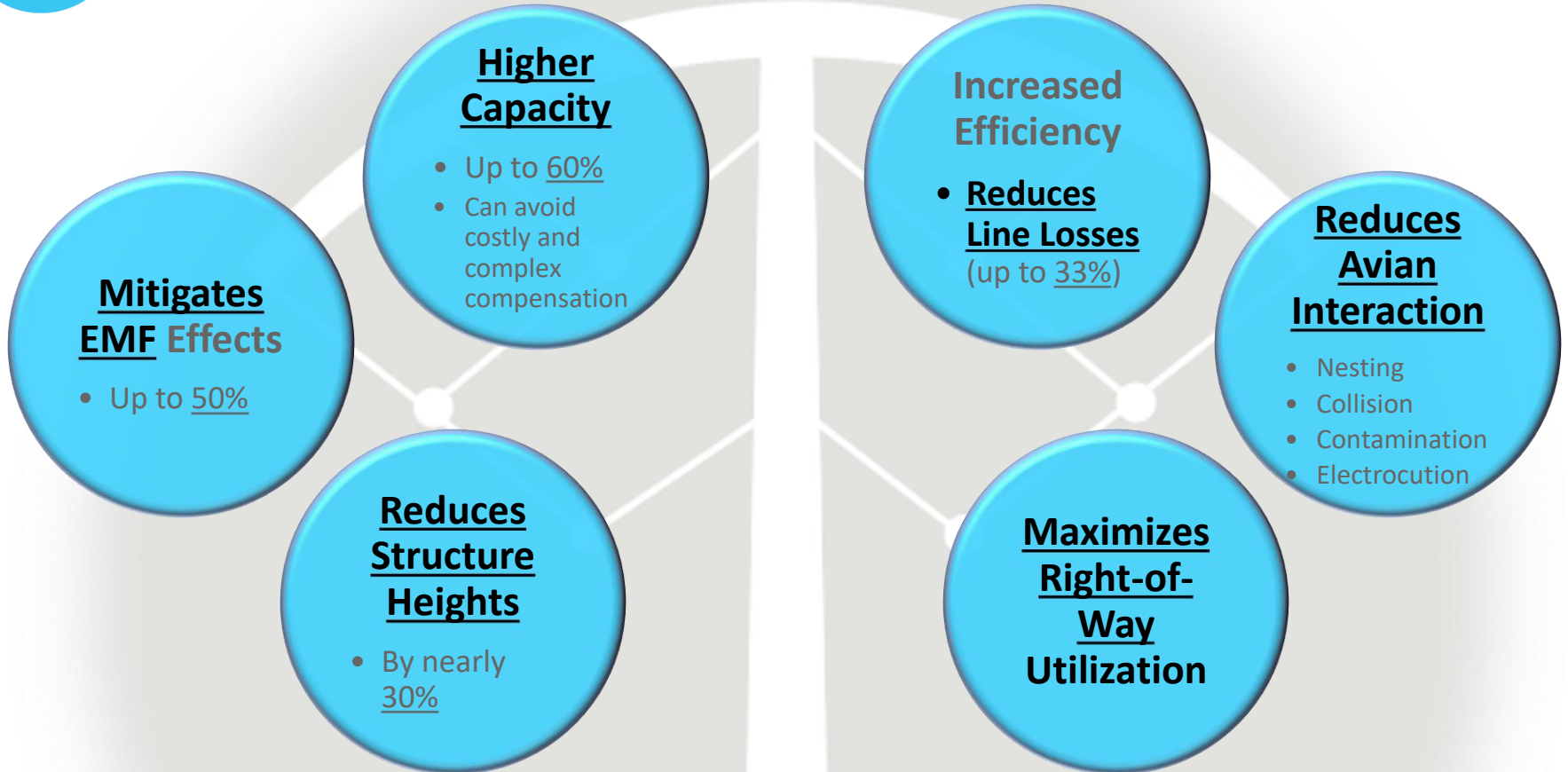**Mitigates EMF Effects**
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Maximizes Right-of-Way Utilization

Regulatory
- Addresses desire for Advanced Transmission Technology

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37

BOLD Benefits Summary

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Cost Competitive!

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Efficiency never looked so good.®

Presentation to PJM TEAC – Special Session, Order 1920
September 6, 2024

Thank You!

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