Efficiency never looked so good®

ABOUT 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 Delivers

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

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

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

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

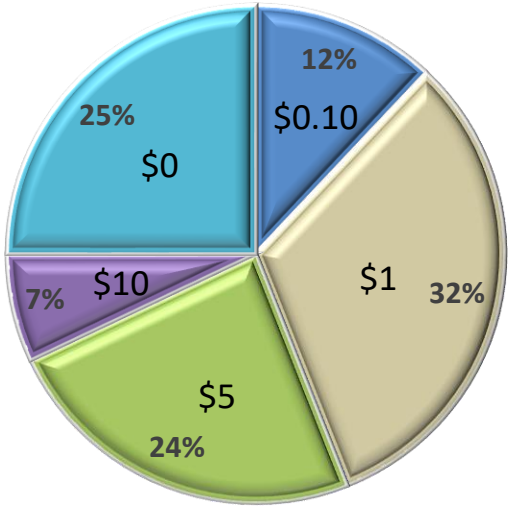
BOLD®

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:



Survey conducted with 1,000 U.S. customers and 500 European customers.

BOLD®

BOLD Award-winning Technology

- 2017 Recipient of Edison Electric Institute's

  EDISON AWARD

- 2017 Recipient of NARUC's

  INNOVATION IN ELECTRICITY AWARD

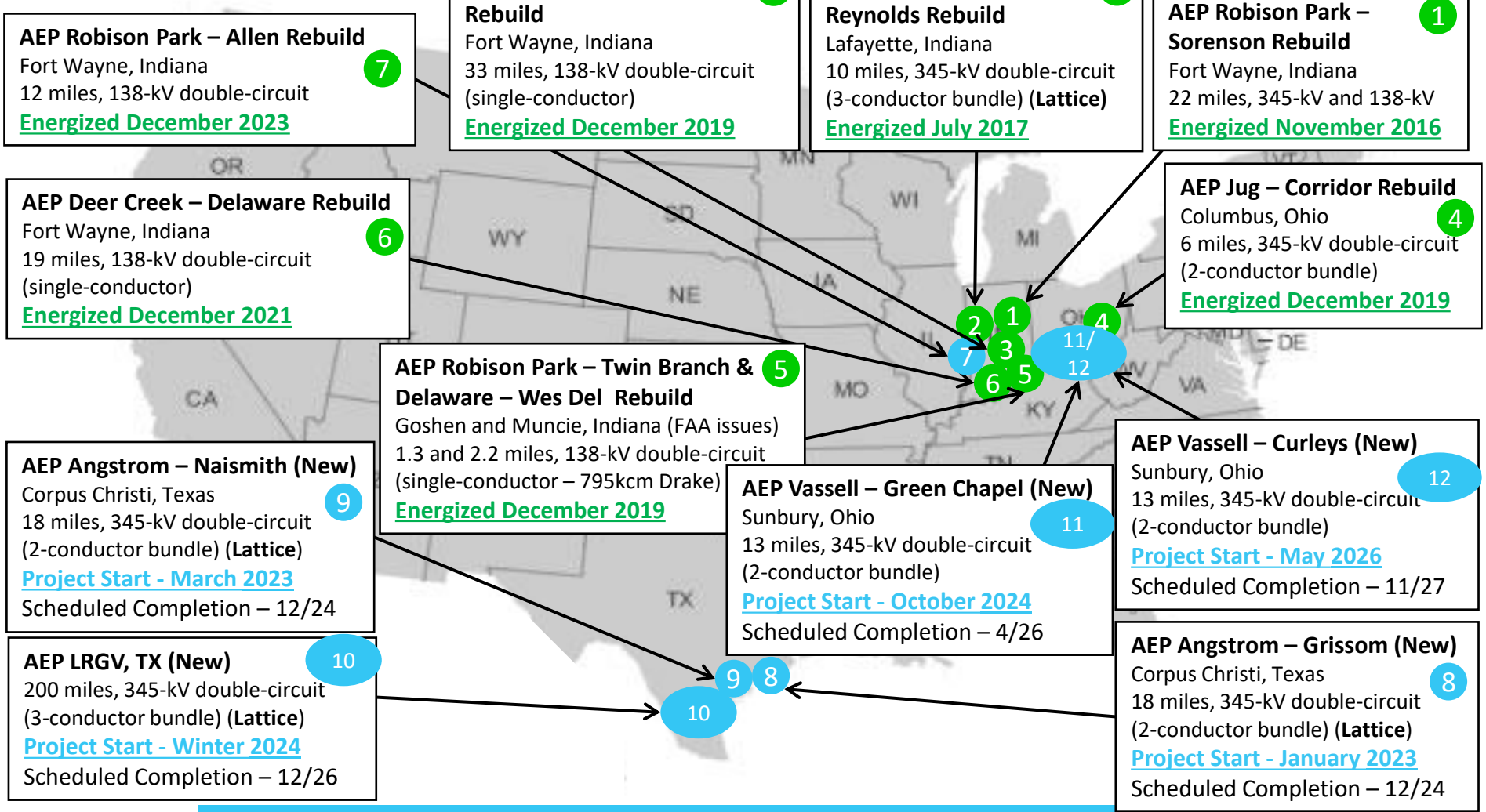
- 2017 Grand Prize Recipient of CIGRE/KEPCO's

  INTERNATIONAL TOWER DESIGN AWARD

BOLD®

BOLD Project Deployment

as of Aug. 2024



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

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

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

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

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

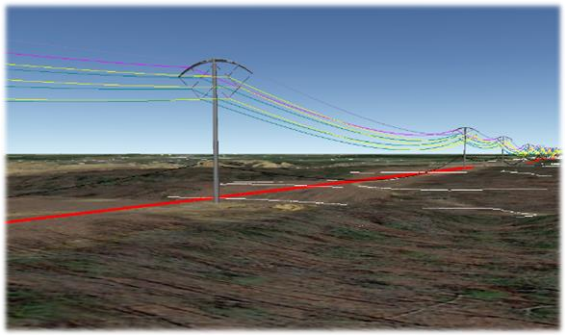
Over 100 miles installed (In Indiana and Ohio), meeting or exceeding design criteria. An additional 250+ miles in construction or design.


HOW IT WORKS
BOLD®

BOLD Development

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

- $L^+ \approx \frac{\mu_o}{2\pi} ln\left(\frac{d_{eq}}{R_{eq}}\right) = 0.3219\, ln\left(\frac{d_{eq}}{R_{eq}}\right) mH/mi$
- $C^+ \approx {}^{2\pi\epsilon_o}\Big/_{ln\left(\frac{d_{eq}}{R_{eq}}\right)} = {}^{89.41}\Big/_{ln\left(\frac{d_{eq}}{R_{eq}}\right)} nF/mi$
- $Z^+ \approx 60\, ln\left(\frac{d_{eq}}{R_{eq}}\right) \Omega$
- Where:
  - $d_{eq} = \sqrt[3]{d_{ab} d_{bc} d_{ca}}$ ***Eq. Phase Spacing (ft)***
  - $R_{eq} = \sqrt[N]{N r R^{N-1}}$ ***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

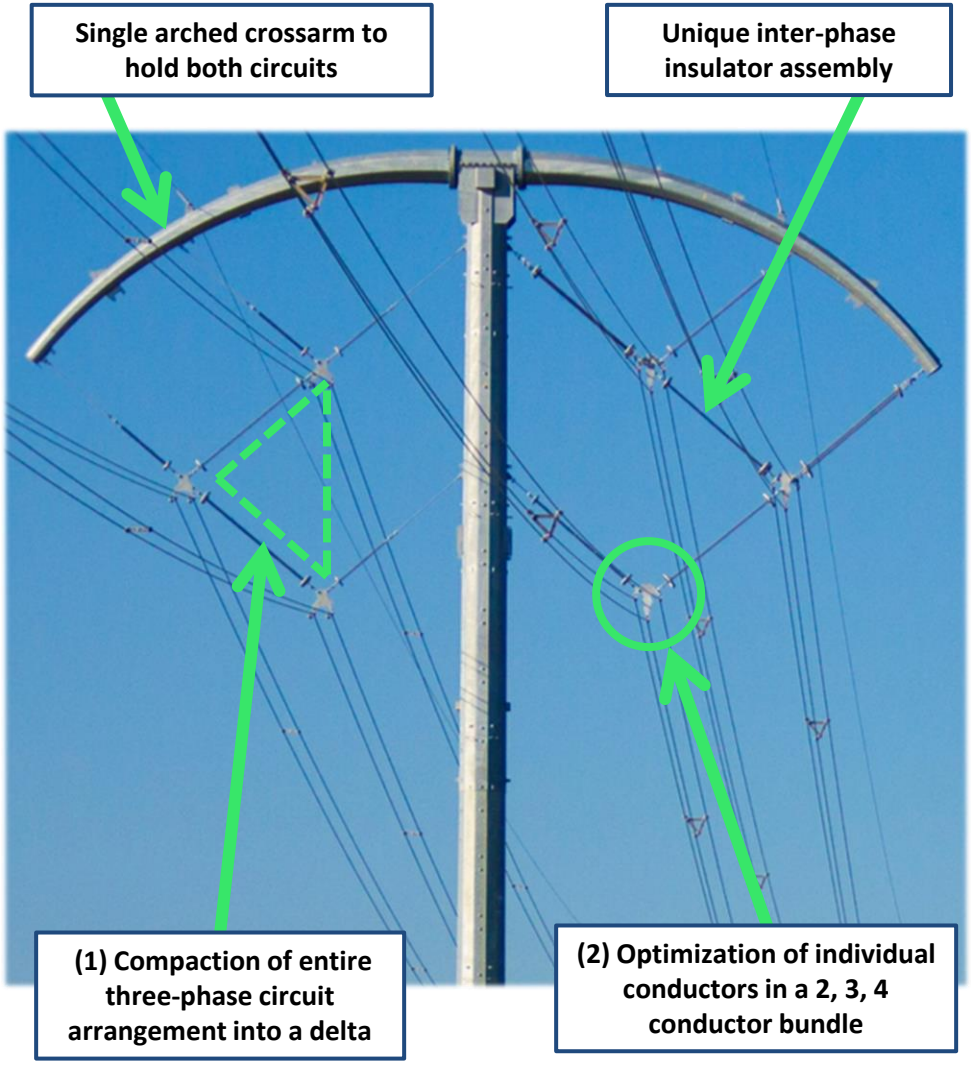
Electrical

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

BOLD®

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**



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BOLD ADVANTAGE – THE MATH

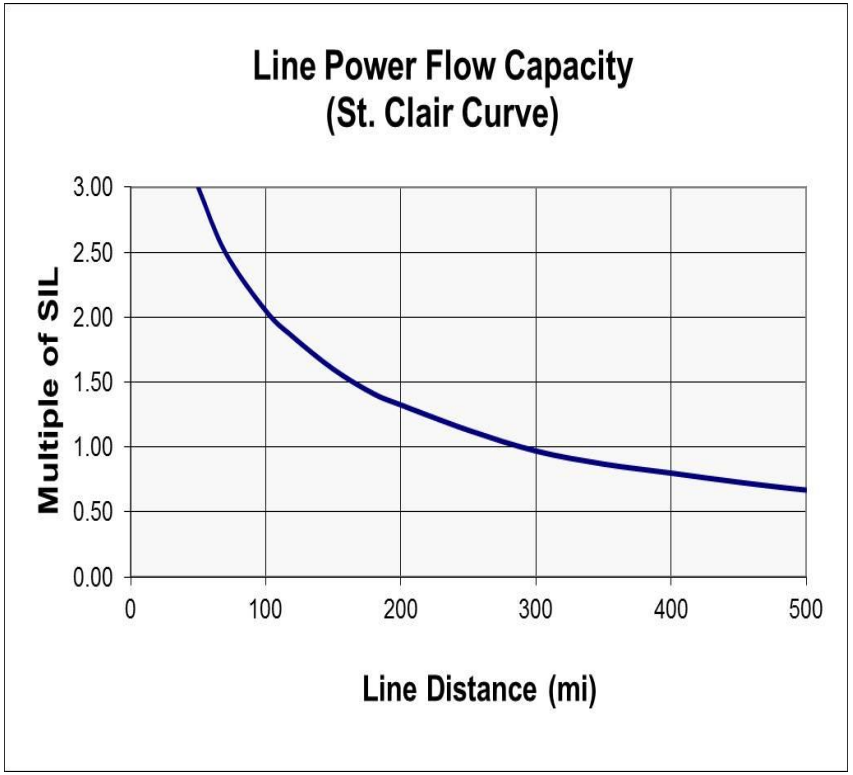
- Surge Impedance changes with $\sqrt{L^{+}/C^{+}}$ (ohm)
  - $\boldsymbol{L^{+}} \approx \frac{\mu_o}{2\pi} \boldsymbol{ln}\left(\frac{\boldsymbol{d_{eq}}}{\boldsymbol{R_{eq}}}\right) = 0.3219\ \boldsymbol{ln}\left(\frac{\boldsymbol{d_{eq}}}{\boldsymbol{R_{eq}}}\right) mH/mi$
  - $\boldsymbol{C^{+}} \approx {}^{2\pi\epsilon_o}\Big/_{\boldsymbol{ln}\left(\frac{\boldsymbol{d_{eq}}}{\boldsymbol{R_{eq}}}\right)} = {}^{89.41}\Big/_{\boldsymbol{ln}\left(\frac{\boldsymbol{d_{eq}}}{\boldsymbol{R_{eq}}}\right)} nF/mi$
  - $\boldsymbol{Z^{+}} \approx 60\ \boldsymbol{ln}\left(\frac{\boldsymbol{d_{eq}}}{\boldsymbol{R_{eq}}}\right)\ \Omega$
  - 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)***
    - $d_{ab}, d_{bc}, d_{ca} = Phase\ spacings\ (ft)$
    - $N = Number\ of\ subconductors\ per\ phase$
    - $r = Subconductor\ radius\ (ft)$
    - $R = Subconductor\ bundle\ radius\ (ft)$

L, Z decrease; C increases with:

- Closer phase spacing
- More sub-conductors
- Larger bundle diameter
- Larger conductor diameter

BOLD leverages these principles

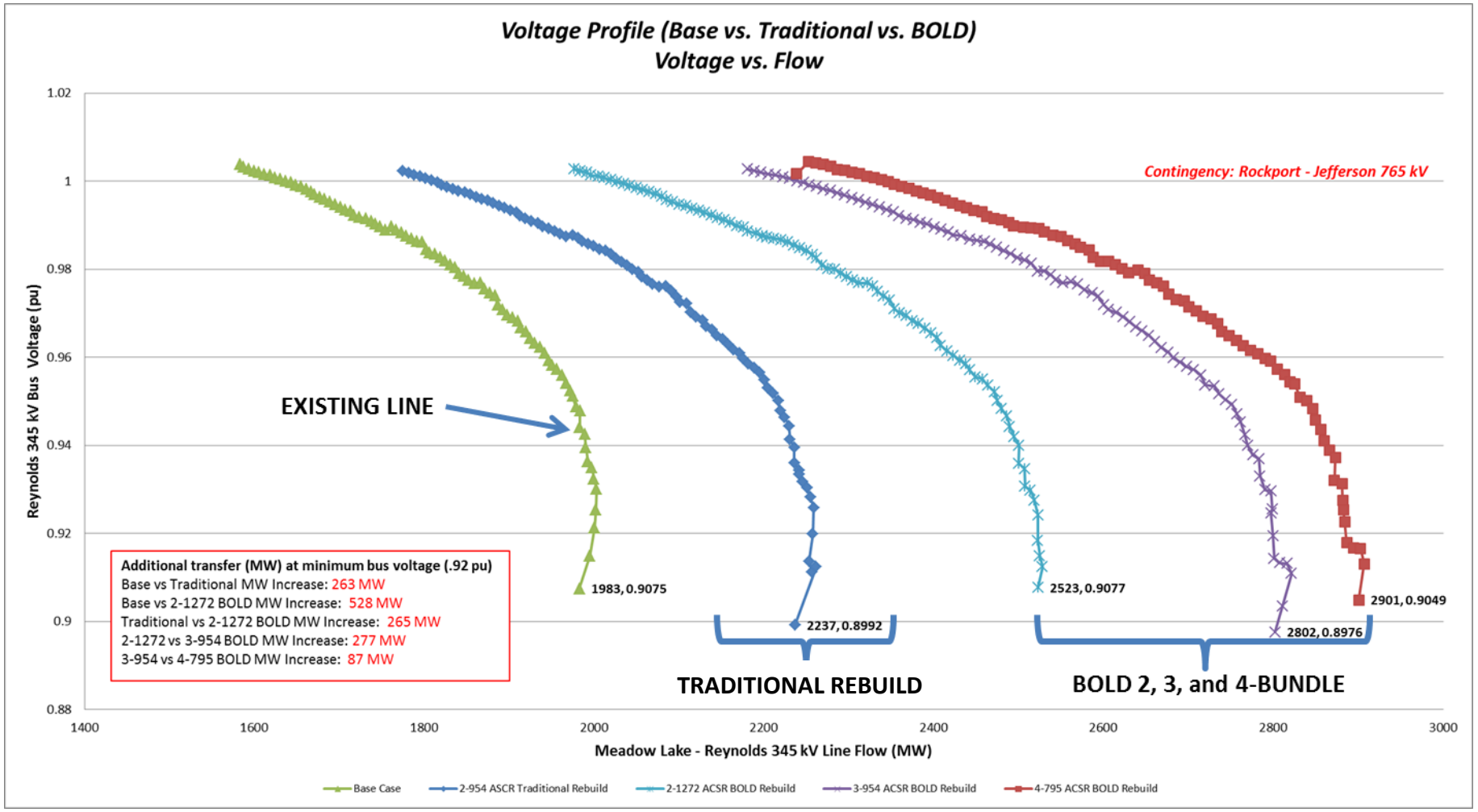
LINE LOADABILITY BASED ON:
SURGE IMPEDANCE LOADING (SIL)



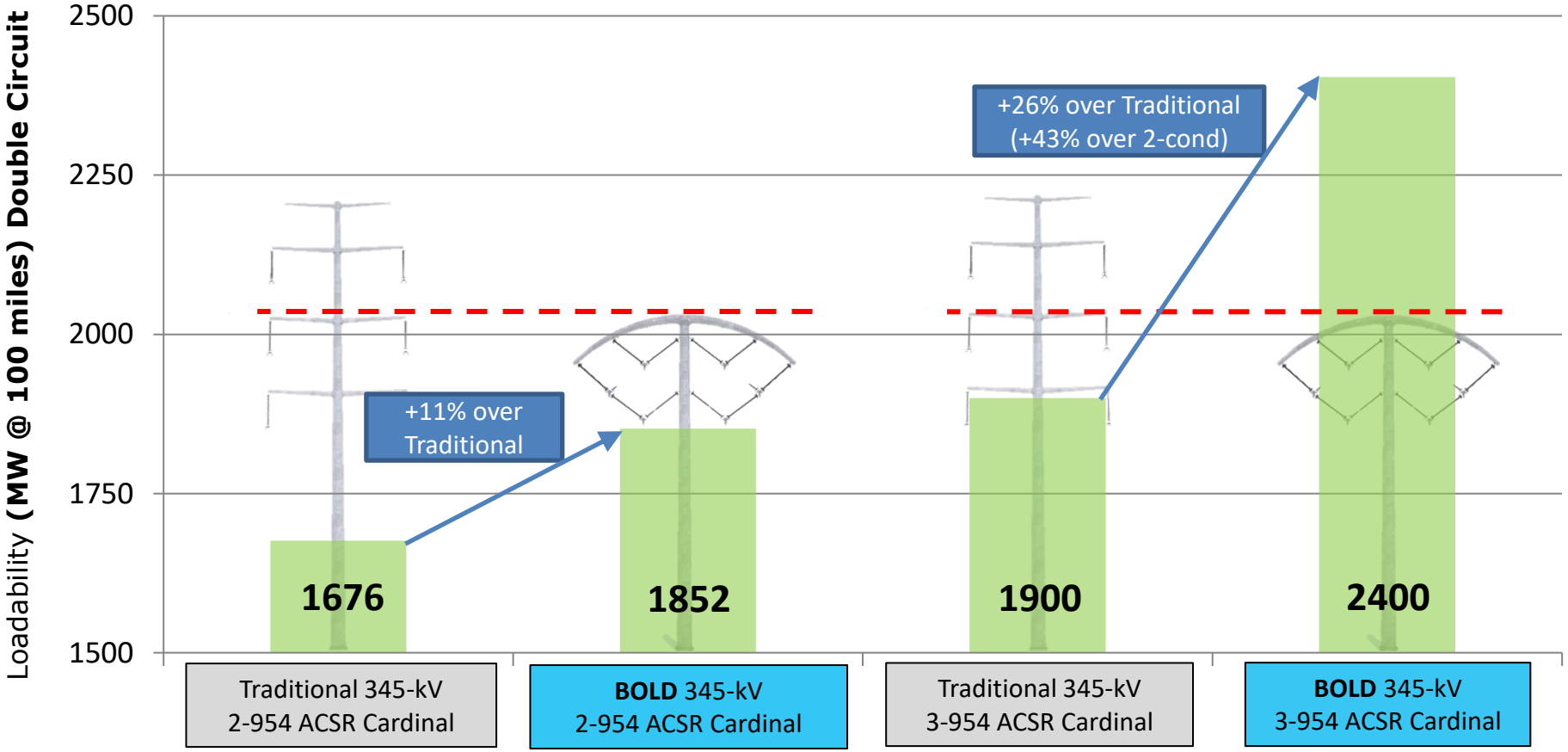
The St. Clair Curve represents a transmission line's power delivery capability over distance without reactive compensation.

EXAMPLE

Meadow Lake – Reynolds 345-kV

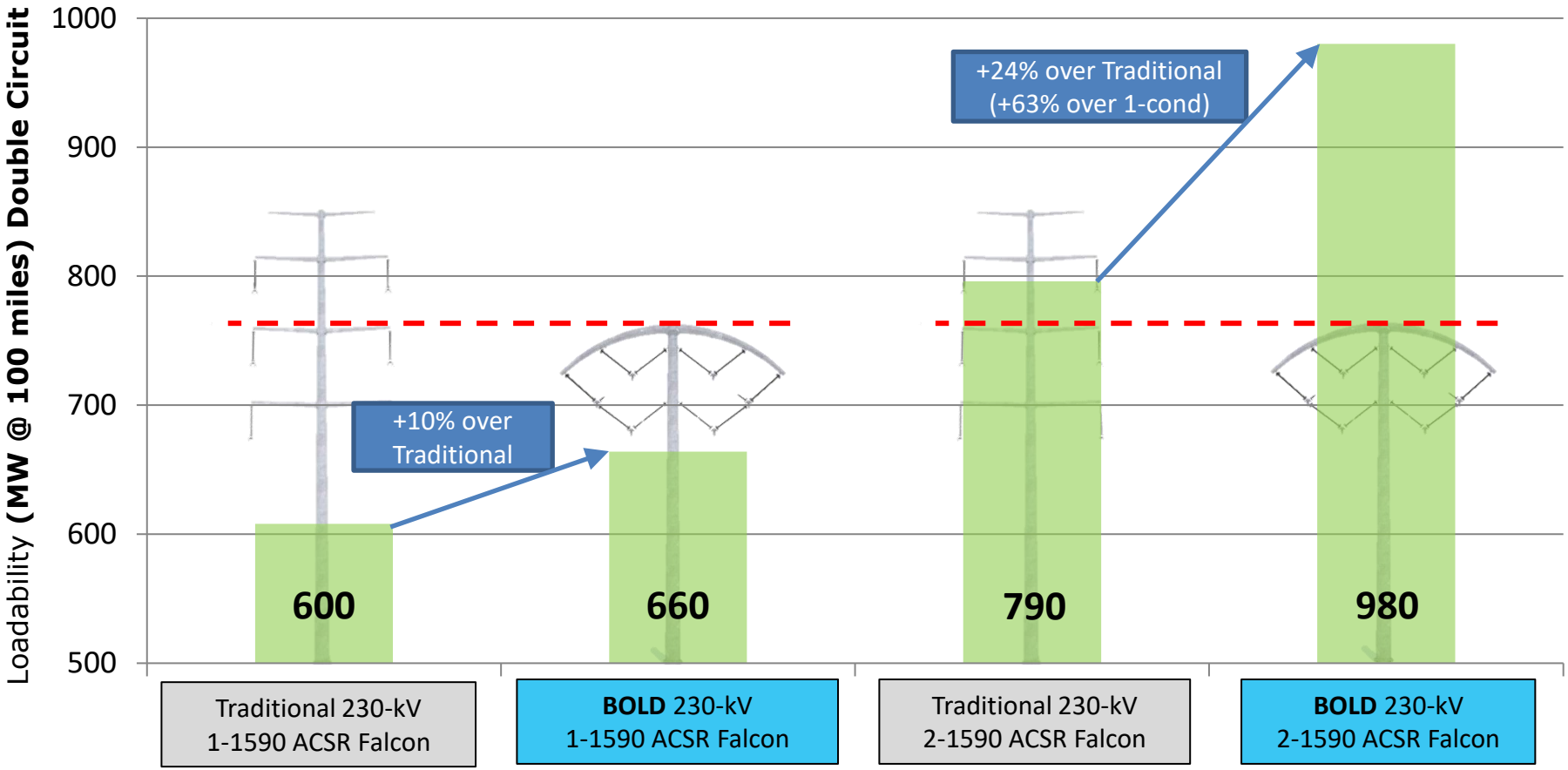


Higher Capacity – 345 kV



(Values are approximate)

Higher Capacity – 230 kV



(Values are approximate)

BOLD®

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

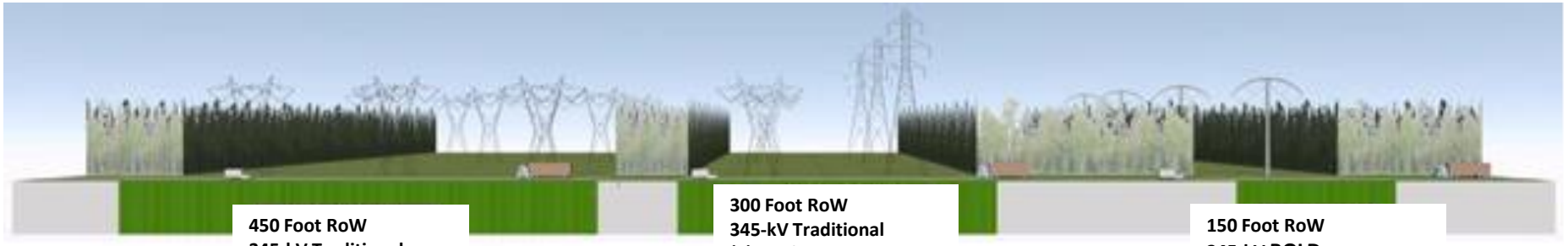
175’ ROW

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

450’

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

300’

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

150’

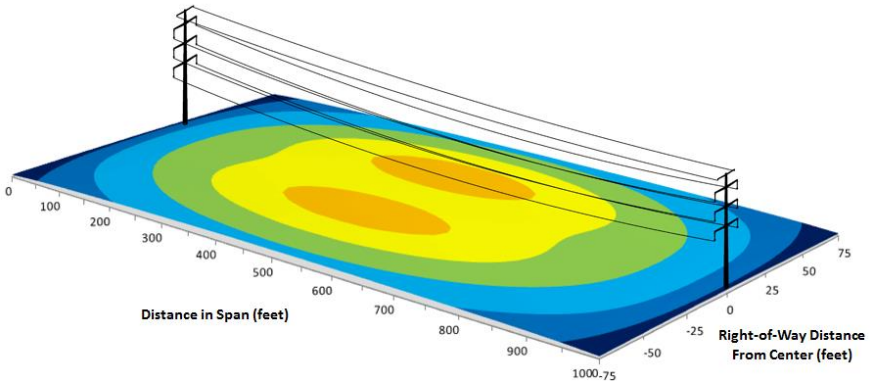
One **BOLD** 345-kV double-circuit line can deliver the same power carrying capacity as three traditional 345-kV single- circuit lines creating a smaller environmental footprint of roughly 1/3 by comparison

BOLD®

Magnetic Field Mitigation

Traditional 345-kV

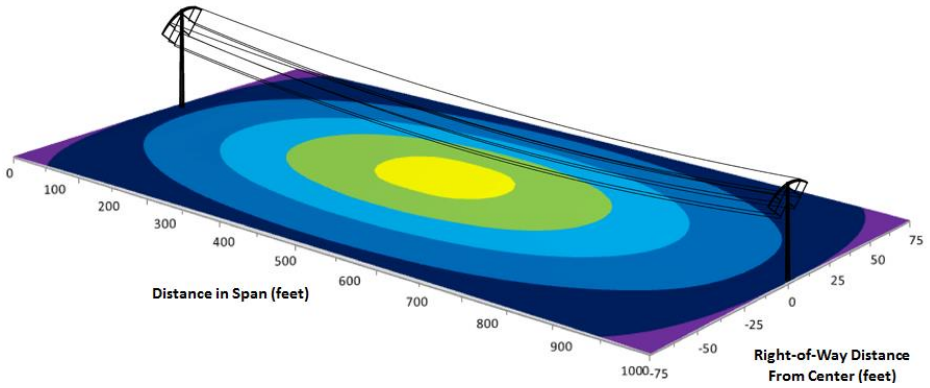
Magnetic Field Profile @1000MVA Per Circuit
Traditional 345-kV 2-Falcon 25.5ft Phase Spacing 18" Bundle Diameter
Super Bundle Arrangement (A-B-C / A-B-C)



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)

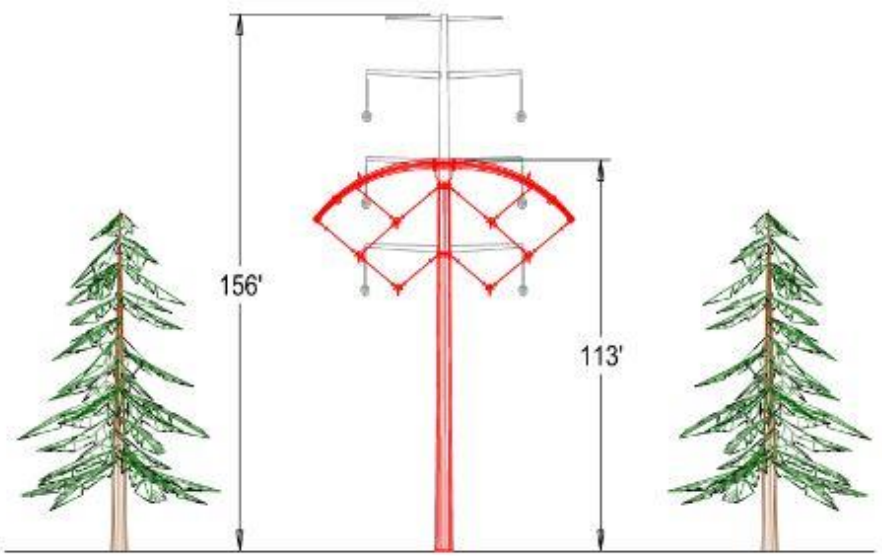
0-30 | 30-60 | 60-90 | 90-120 | 120-150 | 150-180 | 180-210 | 210-240 | 240-270 | 270-300

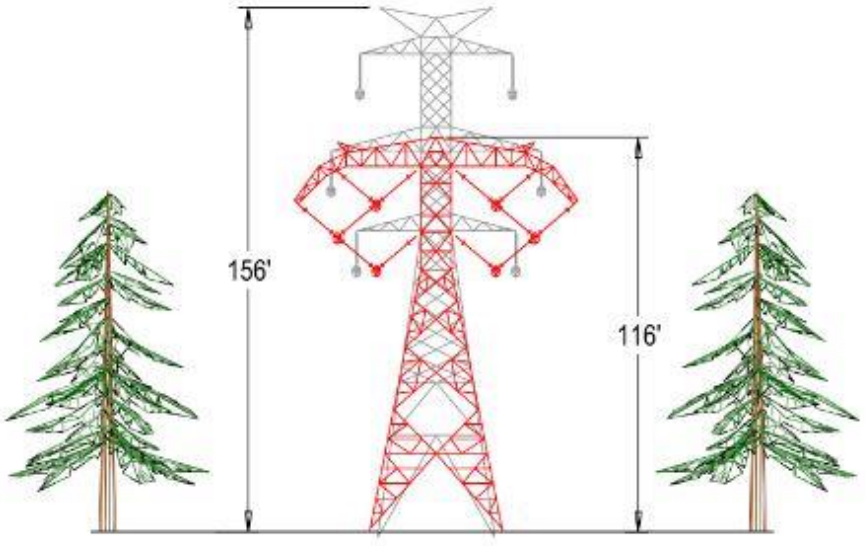
1000’ Span Lengths

BOLD reduces Magnetic Field values by up to 50%!

BOLD®

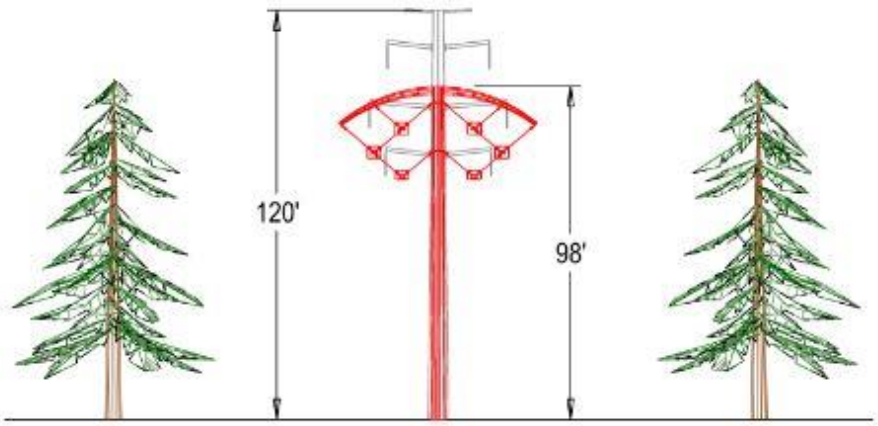
Structure Comparison – 345 kV

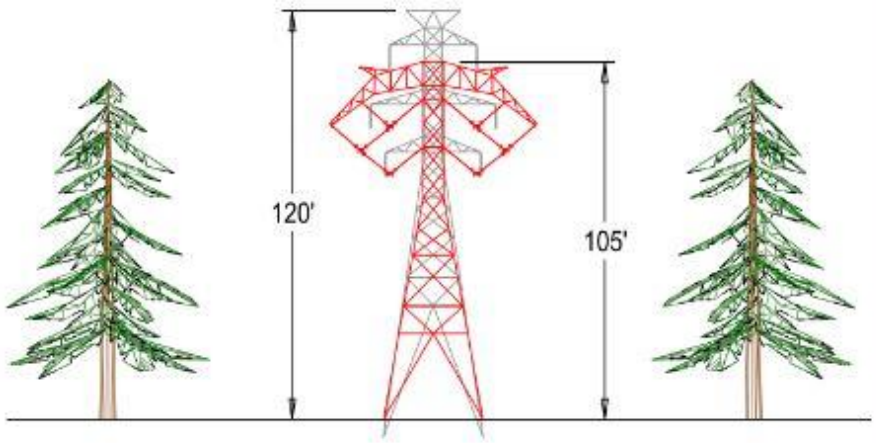




1000’ Span Lengths

Structure Comparison – 230 kV





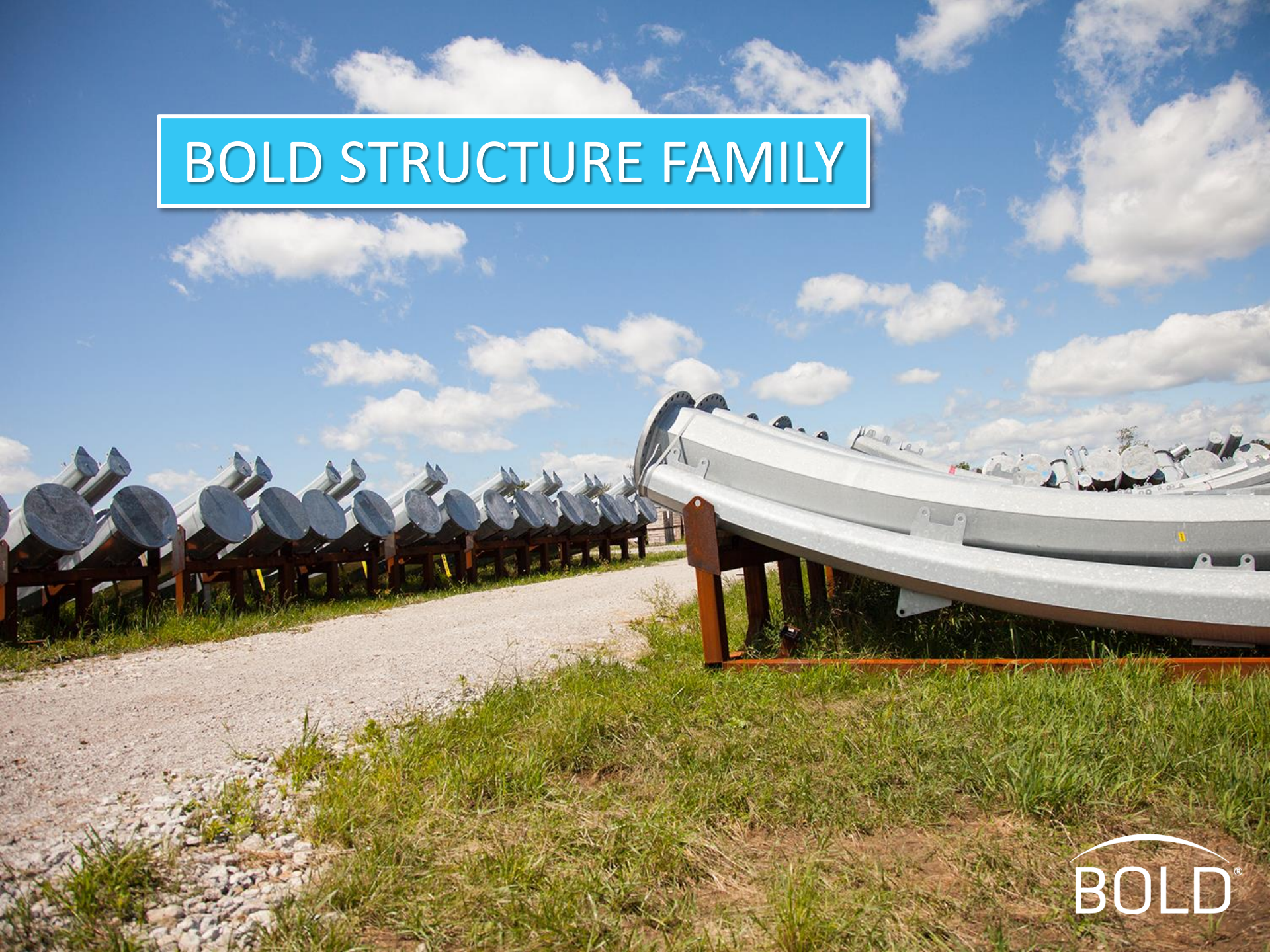
1000’ Span Lengths

BOLD Reduces Avian Interaction*

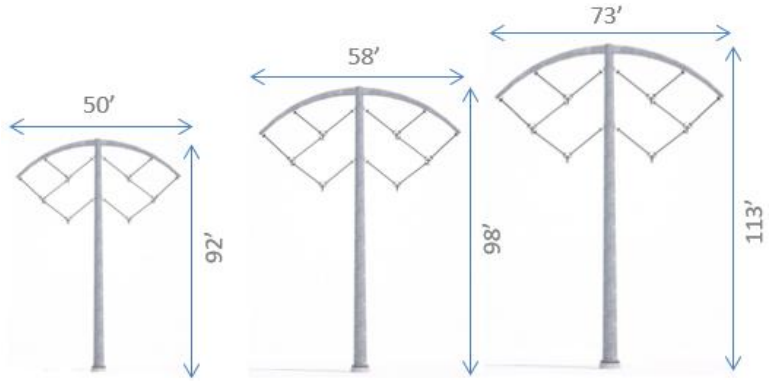
- **Nesting**
  - **BOLD** eliminates cavity nests and should minimize corvid and raptor stick nests due to the unique arch-shaped cross member.
- **Collision**
  - **BOLD** has design elements to reduce collision risk
- **Feces**
  - **BOLD** should reduce pollution outages by limiting perching and creating a barrier; it may also reduce streamer outages.
- **Predation Management**
  - **BOLD** may minimize avian predation on sensitive species by reducing nesting on transmission structures.
- **Electrocution**
  - **BOLD** can be implemented as eagle friendly

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

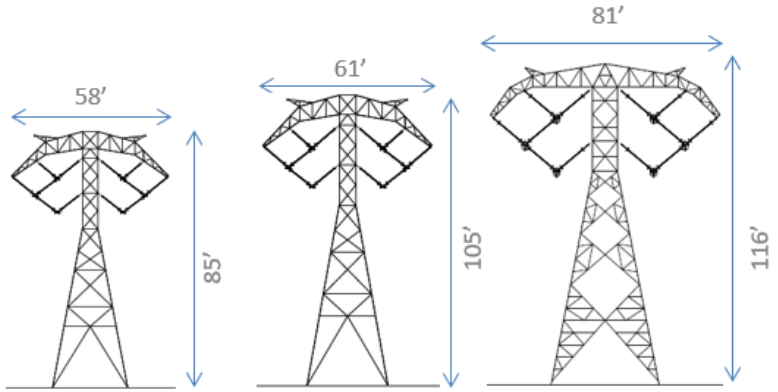
BOLD®


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

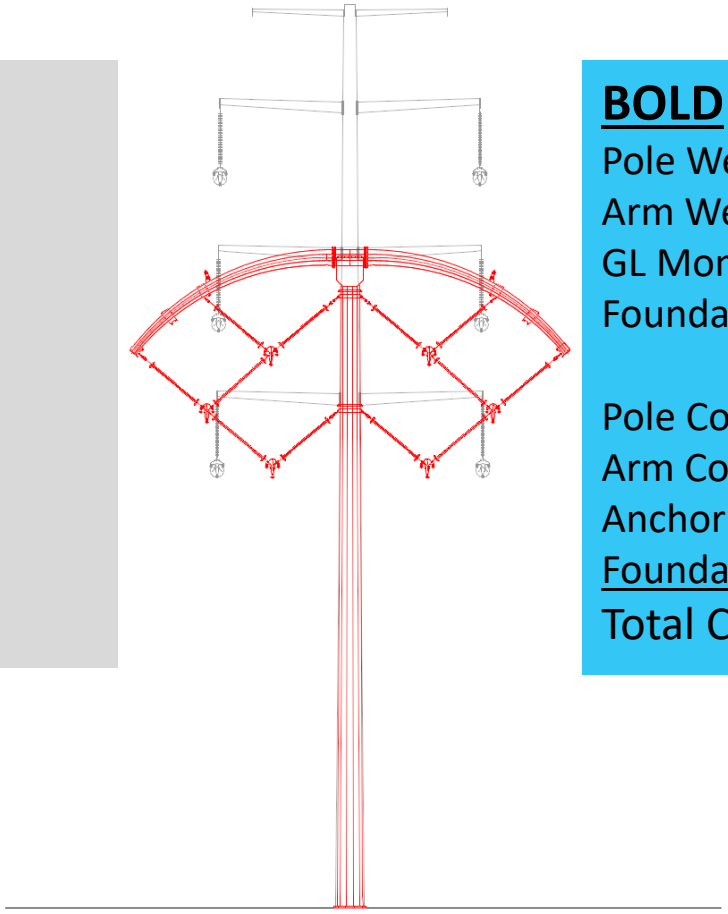
BOLD is the optimal design for cost and impedance.

BOLD®

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

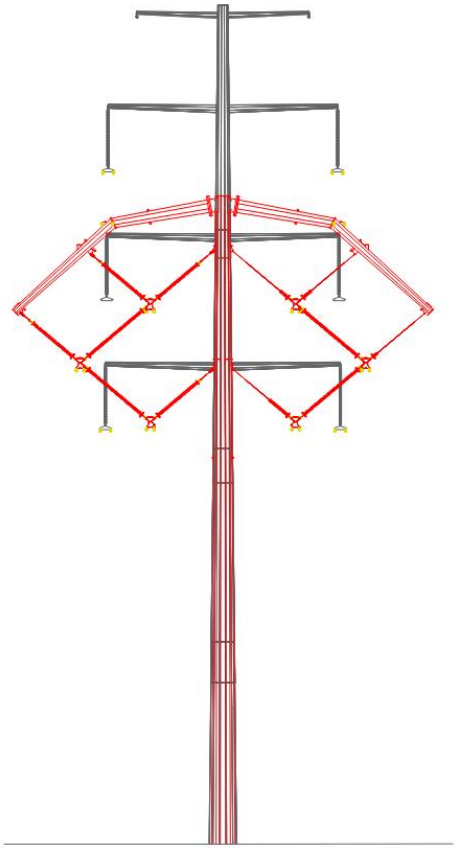
2-1590 ACSR Falcon

BOLD®

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’

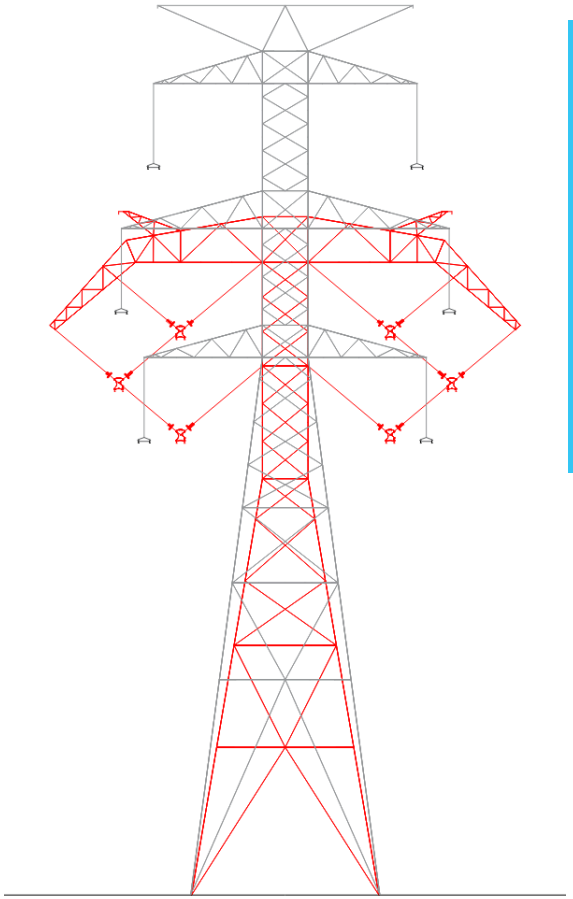
NESC Medium

BOLD®

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

BOLD®


BENEFITS
BOLD®

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

Higher Capacity

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Increased Efficiency

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

Mitigates EMF Effects

- Up to 50%

BOLD®

BOLD Benefits Summary

Higher Capacity

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

Increased Efficiency

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

Mitigates EMF Effects

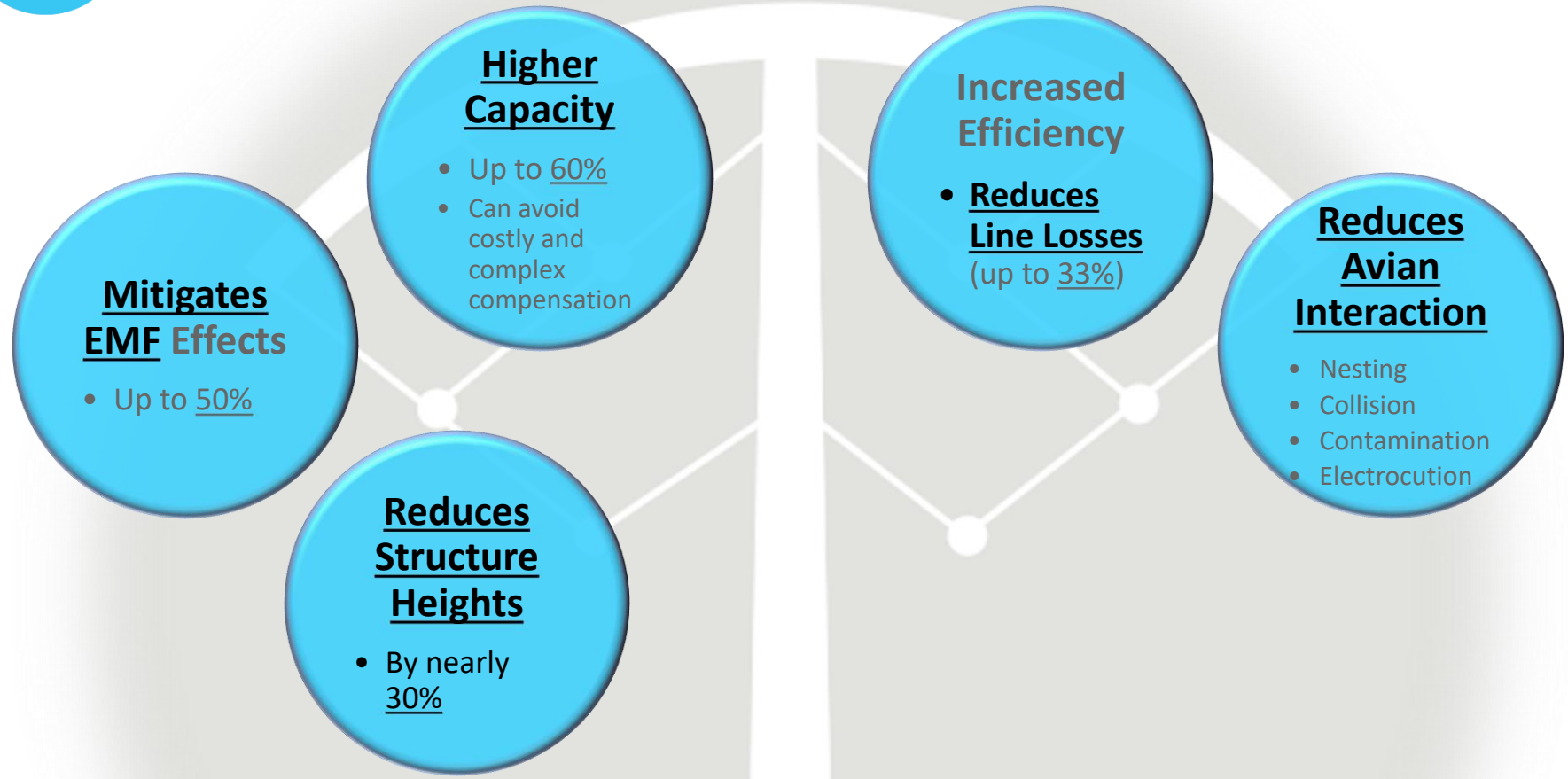
- Up to 50%

Reduces Avian Interaction

- Nesting
- Collision
- Contamination
- Electrocution

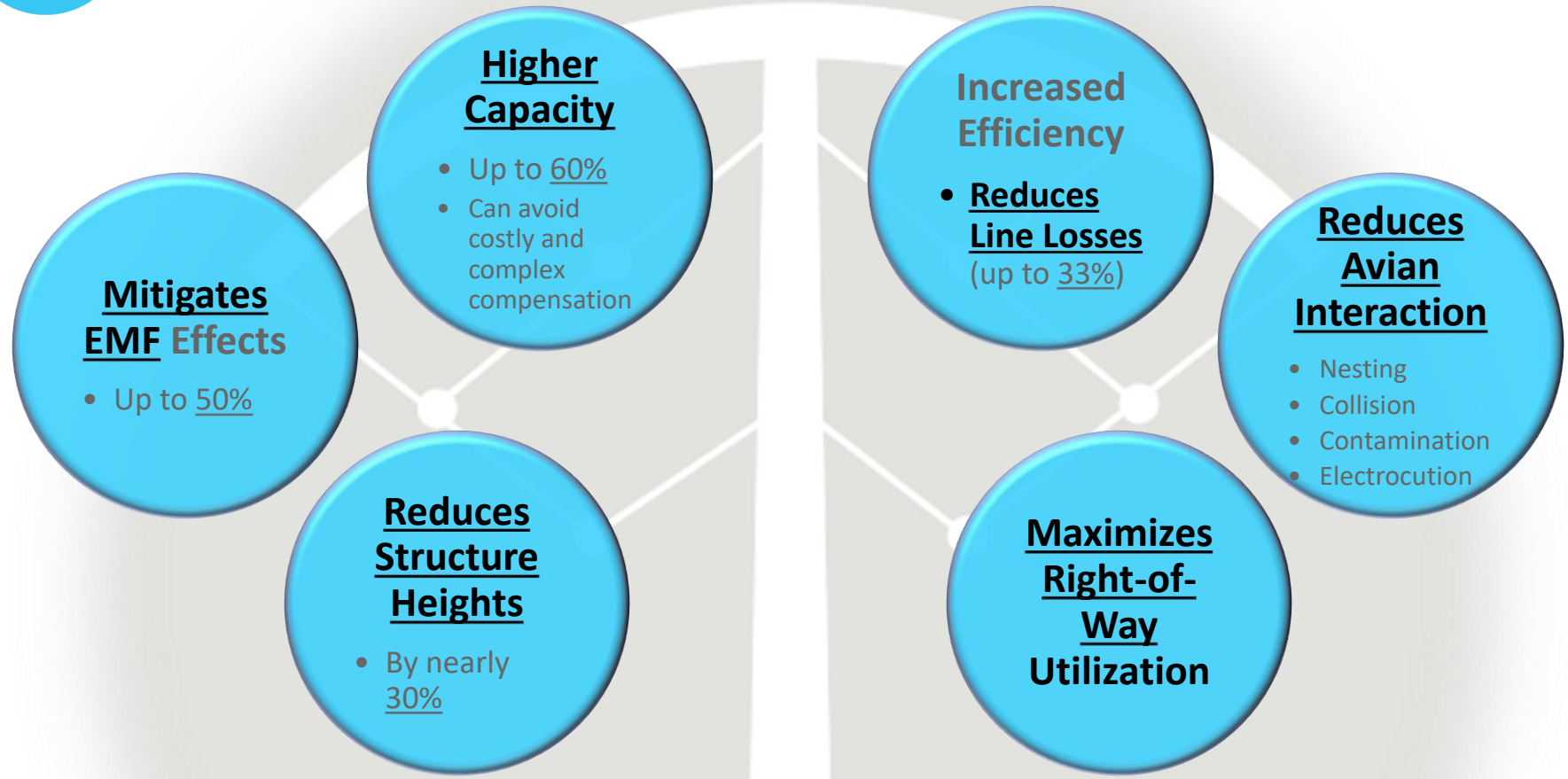
BOLD®

BOLD Benefits Summary



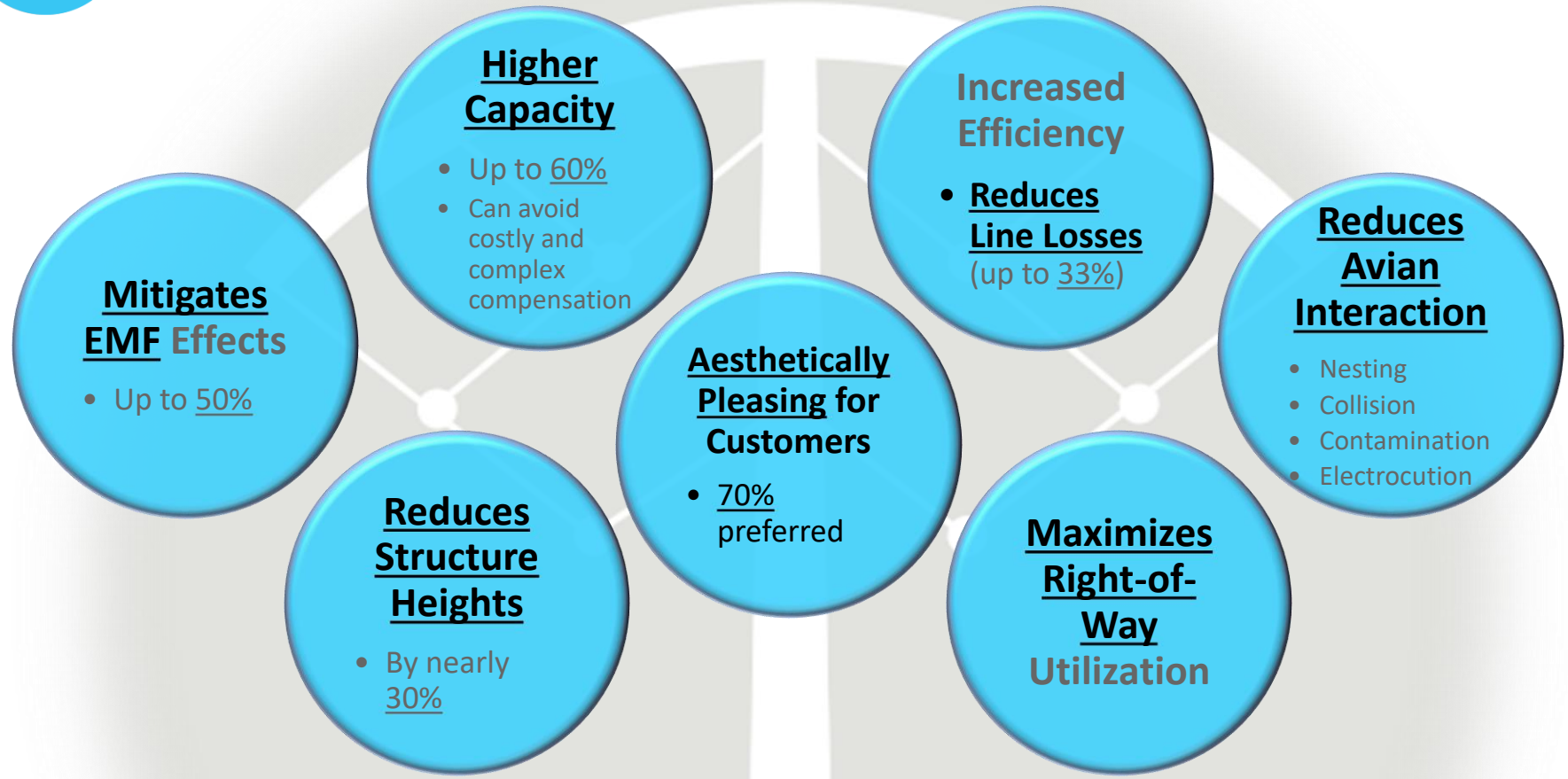
BOLD®

BOLD Benefits Summary

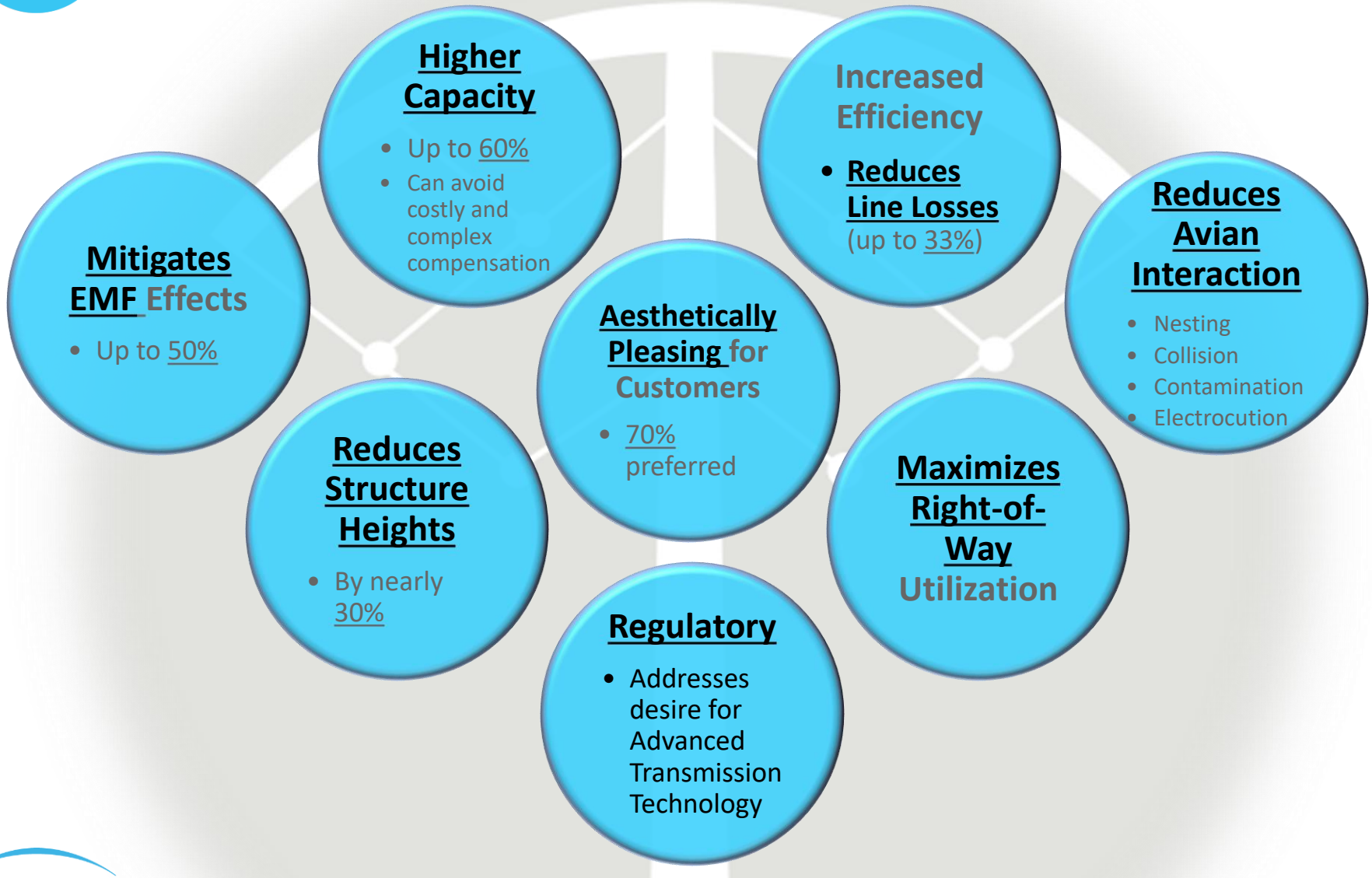


BOLD®

BOLD Benefits Summary

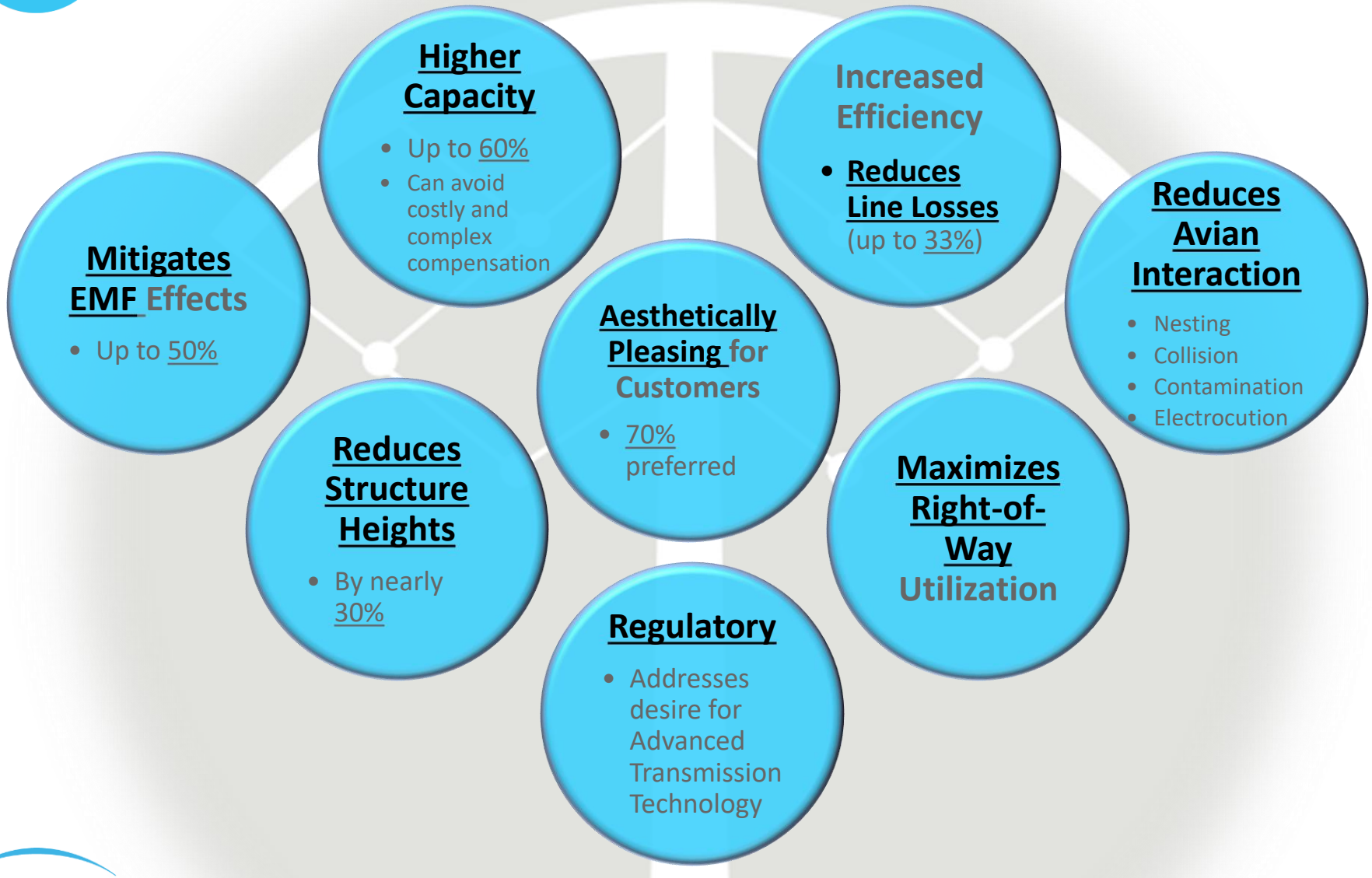


BOLD Benefits Summary



BOLD®

BOLD Benefits Summary



Cost Competitive!

BOLD®

BOLD®

Efficiency never looked so good.®

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

Thank You!

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