How the choice of transmission conductor can reduce greenhouse gas emissions.
What is the scope of the impact?

Complete conversion of the US grid to efficient conductor would eliminate 44 million metric tons of CO₂ due to the reduction of line losses by 20 to 40% compared to ACSR conductors of the same diameter and weight under equal load conditions:

(1) 30% reduction of
(2) 6% line losses typical of ACSR conductor,
(3) saves or adds 71.8 million MWh of power generation,
(4) which at an average of 1.37 pounds of CO₂ per kWh,
(5) results in 44 million metric tons reduction of CO₂ per year, or alternatively,
(6) The effective generation/delivery of 8,199 MW of power for consumers.

### Potential Impact of US Conversion to Efficient Conductors

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Consumption</td>
<td>3,990,000,000,000</td>
<td>kWh</td>
</tr>
<tr>
<td>Transmission Line Losses (6%)</td>
<td>239,400,000,000</td>
<td>kWh</td>
</tr>
<tr>
<td>30% Reduction with ACCC</td>
<td>71,820,000,000</td>
<td>kWh</td>
</tr>
<tr>
<td>MWh Equivalent Savings (Annual)</td>
<td>71,820,000</td>
<td>MWh</td>
</tr>
<tr>
<td>Generation Equivalent Delivered</td>
<td>8,199</td>
<td>MW</td>
</tr>
<tr>
<td>annual economic value @ $50/MWh</td>
<td>$3.591</td>
<td>billion</td>
</tr>
<tr>
<td>US Average CO₂ Emmision</td>
<td>1.372</td>
<td>lbs/kWh</td>
</tr>
<tr>
<td>Annual CO₂ Reduction with ACCC</td>
<td>44,688,000</td>
<td>Metric Tons</td>
</tr>
</tbody>
</table>
Technical aspects of efficiency

- The more aluminum in a conductor the better
- The higher the %IACS of the aluminum the better
- Annealing improves conductivity and resistivity
- Conductivity and Resistivity are correlated
Factors in selecting conductors

• Any given set off towers has limits to weight, diameter, and sag clearance of the conductor whether a new line design or replacement of conductor on existing towers.
  • Weight – impacts tension on towers
  • Tension – limited by towers and crossarms
  • Diameter – mostly impacts wind and ice loads
  • Sag – clearance at temperature (and ice/wind load)
  • Operating amps – establishes expected temperature and sag
• For comparison it is fair to keep upper limits on design factors for towers/conductors.
Reconductoring Kumbotsu - Danagundi Transmission Line

• **Reconductoring: Kumbotsu – Danagundi 132vV T/L**
  - Objective: Deliver 600A while maintaining clearance
  - Large increase could not be handled by ACSR Wolf (400A)

• **Project Requirements (Limitations)**
  - Use existing towers with only maintenance repairs
  - Meet sag requirement of 10 meters (current sag allowance for ACSR Wolf)

• **Project Analysis**
  - Select best performance options from ACSR, ACSS, STACIR, AAAC and ACCC
  - Compare conductor cost based on sizing of capacity and sag requirements
Making a project comparison with CCP™ Software

1. Nine areas for inputs, conductor selection and outputs.
   1. Environment
   2. Line factors/Cost factors
   3. Sag calculation factors
   4. Ice/wind conditions
   5. Conductor selection
   6. Temperature and line loses
   7. Sag and tension results
   8. Visual sag and limits
   9. Efficiency and emissions

2. All yellow cells are inputs, can enter own value or choose from dropdown list

3. Clearly demonstrates how conductor selections impact a project.
In #1, we see that the Kumbotsu – Danagundi transmission line is operating at 400 amps, delivering 91 MW of power, which is the maximum rating for the ACSR Wolf conductor.

In #2, we see the minimum up-rating target of 600 amps (137 MW) which will be the basis for conductor selection and performance comparison.
**Baseline capacity of ACSR Wolf**

**CTC GLOBAL**

### Conductor information

<table>
<thead>
<tr>
<th>Type</th>
<th>ACSR</th>
<th>Conductor #1</th>
<th>Conductor #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (mm² Al - Code Word)</td>
<td>158.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Aluminum Area (mm²)</td>
<td>18.130</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>69</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rated Strength (kN)</td>
<td>726.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Weight (kg/km)</td>
<td>0.17875</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DC Resistance at 20°C (ohms/km)</td>
<td>0.18285</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>AC Resistance at 25°C (ohms/km)</td>
<td>0.21885</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>AC Resistance at 75°C (ohms/km)</td>
<td>0.21885</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

### Conductors per phase
- 1 Circuit: 1 Conductor
- 70°C Ampacity: 416 A
- 75°C Ampacity: 443 A
- 100°C Ampacity: 577 A

### Line Loss (Based on Inputted Peaking Operating Amps Value)
- Steady-State Temperature (°C) at Peak Ampacity: 68°C
- Resistance at Peak Operating Amps (ohm/km): 0.21353
- First Year Line Losses (MWh): 4,682

### Environmental Input
- 1023.6 W/m² Sun Radiation
- 35°C Ambient Temp.
- 0.61 m/s Wind
- 100 m Elevation
- 0.5 Solar Absorptivity
- 0.5 Emissivity
- 90° Wind Angle
- 0° Azimuth of Line (NS=0, EW=90°)
- February Month
- 15 Day of Month
- 12 Time (24 hrs.)
- Clear Atmosphere

### Load and Generation Cost Assumptions
- 400 Peak Operating Amps
- 70% Load Factor
- 52% Loss Factor
- 3 Phases/Circuit
- 50 Cost of Energy Generation ($/MWh)
- 0.200 CO₂ ($/kg/kWh)
- 0% Load Increase/Year

**ACSR Wolf is the basis for current capacity and limitations of the transmission line**
ACSR Wolf establishes sag/tension limitations

<table>
<thead>
<tr>
<th>Conductor information</th>
<th>Base Conductor</th>
<th>Conductor #1</th>
<th>Conductor #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type: ACSR</td>
<td>Select Type</td>
<td>Select Type</td>
<td></td>
</tr>
<tr>
<td>Size (mm² Al - Code Word): 158 - WOLD</td>
<td>0 - Select Size</td>
<td>0 - Select Size</td>
<td></td>
</tr>
</tbody>
</table>

**Initial Sag and Tension:**
- % RTS: 20.0%
- Sag at Initial Sagging Temperature (m): 7.90
- Initial Tension at Sagging Temperature (kN): 13.8

**Sag/Tension at Above Stringing Temperature:**
- Temp(°C): 68
- Sag at Peak Operating Amps (m): 3.34
- Tension (kN): 11.7

**Sag at Rated Operating Temperature:**
- Temp(°C): 75
- Sag (m): 3.61
- Tension (kN): 11.4

**Sag at Maximum Temperature:**
- Temp(°C): 100
- Sag (m): 10.50
- Tension (kN): 10.4

**Temperature at Maximum Allowable Sag:**
- Max. Temp(°C): 86
- Sag (m): 10.01
- Tension (kN): 10.9
- Ampacity (A): 511

**Wind / Ice or Cold Temperature Sag/Tension:**
- Sag (m): 8.44
- Tension (kN): 18.0

ACSR Wolf establishes the limits for installation tensile loads on the towers and the maximum sag of the conductors.
Mapping conductors within limitations

Tension needed to meet sag clearance (13.8kN = 1.4MT)

Because the towers were built for ACSR Wolf, we must only consider comparison of conductors that are very close to its weight and diameter, and can be installed to meet the ground clearance.

ACSR Wolf
158.1 mm² aluminum
18.13 mm diameter
726 kg/km
13.8 kN installed tension

However, since ACSR Wolf cannot meet 600 amps, we will use these parameters to look at larger ACSR conductor.

Weight (726 kg/km)
ACSR Bear meets amps target but weighs 66% more

ACSR Bear can just meet the increased 600 operating amps and 800 amp target with a weight increase of 66%. (1,213 vs 726)
ACSR Bear cannot be installed on current towers

ACSR Bear greatly exceed the constraint on installed tension and maximum allowable sag
Mapping conductors within limitations

Tension needed to meet sag clearance

ACSR Wolf
158.1 mm² aluminum
18.13 mm diameter
726 kg/km
13.8 kN installed tension

ACSR Bear
264.5 mm² aluminum
23.45 mm diameter
1,213 kg/km (167%)
25.1 kN installed tension (182%)

ACSR Bear is far too heavy to be installed within the limits of the towers, so we must consider HTLS conductors.
ACSS conductors meet performance target

### Conductor Information

<table>
<thead>
<tr>
<th>Type</th>
<th>Base Conductor</th>
<th>Conductor #1</th>
<th>Conductor #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>ACSR</td>
<td>ACSS/Thunder</td>
<td>ACSS</td>
</tr>
<tr>
<td>Size (mm² Al - Code Word):</td>
<td>158.1</td>
<td>171.5</td>
<td>170.5</td>
</tr>
<tr>
<td>Diameter (mm):</td>
<td>18.130</td>
<td>15.602</td>
<td>18.821</td>
</tr>
<tr>
<td>Rated Strength (kN):</td>
<td>69</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>Weight (kg/km):</td>
<td>726.0</td>
<td>783.2</td>
<td>783.2</td>
</tr>
</tbody>
</table>

#### DC Resistance at 20°C (ohms/km): 0.17875 (ACSS/Thunder) 0.18010 (ACSS) 0.18010 (ACSS)

#### AC Resistance at 25°C (ohms/km): 0.24325 (ACSS/Thunder) 0.18630 (ACSS) 0.18630 (ACSS)

#### AC Resistance at 75°C (ohms/km): 0.21311 (ACSS/Thunder) 0.21311 (ACSS) 0.21311 (ACSS)

### Load and Generation Cost Assumptions

- **ACSR 158 - WOLD**
  - Reduces First Year CO₂ Generated by (MT): -72
  - Reduces First Year Line Losses by (MWh): -401
  - Reduces First Year Line Losses by (%): -14%
  - Line Loss Savings per meter of Conductor ($/m): -1.32
  - Reduces 30 year line loss by ($) -1,189,054

- **ACSS 158 - WOLD**
  - Reduces 30 year CO₂ generation by (MT): -4,756

**ACSS/TW Oriole and ACSS Oriole meet capacity requirements with only slightly higher weight than ACSR Wolf**
Sag/tension limits ACSS/TW to 600 amp target

<table>
<thead>
<tr>
<th>Sag/Tension at Above Stringing Temperature:</th>
<th>Sag at Peak Operating Amps</th>
<th>Sag at Rated Operating Temperature</th>
<th>Sag at Maximum Temperature</th>
<th>Temperature at Maximum Allowable Sag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp(°C)</td>
<td>105</td>
<td>99</td>
<td>97</td>
<td>86</td>
</tr>
<tr>
<td>Sag (m)</td>
<td>10.64</td>
<td>10.02</td>
<td>10.55</td>
<td>10.01</td>
</tr>
<tr>
<td>Tension (kN)</td>
<td>10.3</td>
<td>11.7</td>
<td>11.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Sag (m)</td>
<td>7.90</td>
<td>7.45</td>
<td>8.13</td>
<td>10.01</td>
</tr>
<tr>
<td>Tension (kN)</td>
<td>13.8</td>
<td>15.8</td>
<td>14.5</td>
<td>11.7</td>
</tr>
</tbody>
</table>

ACSS/TW Oriole and ACSS Oriole are sag limited, even when the installed tension exceeds the criteria by 15%.
Mapping conductors within limitations

Tension needed to meet sag clearance

ACSR Wolf
- 158.1 mm² aluminum
- 18.13 mm diameter
- 726 kg/km
- 13.8 kN installed tension

ACSS/TW Oriole
- 170.5 mm² aluminum
- 17.6 mm diameter
- 783 kg/km (108%)
- 15.8 kN installed tension (115%)

ACSR Bear
- 264.5 mm²

Weight
Mapping conductors within limitations

Tension needed to meet sag clearance

- **ACSR Wolf**
  - 158.1 mm² aluminum
  - 18.1 mm diameter
  - 726 kg/km
  - 13.8 kN installed tension
- **ACSR Bear**
  - 264.5 mm²
- **ACSS/TW Oriole**
  - 170.5 mm²
- **AAAC Sycamore**
  - 303.3 mm² aluminum
  - 22.6 mm diameter (125%)
  - 835 kg/km (115%)
  - 16.0 kN installed tension (116%)
- **AAAC Poplar**
  - 239.5 mm² aluminum
  - 20.1 mm diameter (111%)
  - 659 kg/km (91%)
  - 13.8 kN installed tension (100%)
Mapping conductors within limitations

Tension needed to meet sag clearance

- **ACSR Wolf**
  - 158.1 mm² aluminum
  - 18.13 mm diameter
  - 726 kg/km
  - 13.8 kN installed tension

- **STACIR (invar) 160**
  - 159.3 mm² aluminum
  - 18.2 mm diameter
  - 706.8 kg/km (97%)
  - 14.0 kN installed tension (101%)

- **ACSS/TW Oriole**
  - 170.5 mm²

- **AAAC Sycamore**
  - 303.3 mm²

- **AAAC Poplar**
  - 239.5 mm²

- **ACSR Bear**
  - 264.5 mm²
Mapping conductors within limitations

Tension needed to meet sag clearance

ACSR Bear
- 264.5 mm²

ACSS/TW Oriole
- 170.5 mm²

AAAC Sycamore
- 303.3 mm²

ACSR Wolf
- 158.1 mm² aluminum
- 18.13 mm diameter
- 726 kg/km
- 13.8 kN installed tension

ACCC® Oriole
- 222.3 mm² aluminum
- 18.8 mm diameter (104%)
- 689 kg/km (95%)
- 13.8 kN installed tension (100%)

STACIR (invar) 160
- 159.3 mm²

AAAC Poplar
- 239.5 mm²
Mapping conductors within limitations

Tension needed to meet sag clearance

STACIR (invar) 160
159.3 mm²

ACSS/TW Oriole
170.5 mm²

ACSR Wolf
158.1 mm² aluminum
18.13 mm diameter
726 kg/km
13.8 kN installed tension

ACCC® Oriole
222.3 mm² aluminum
18.8 mm diameter (104%)
689 kg/km (95%)
13.8 kN installed tension (100%)

AAAC Poplar
239.5 mm²

Weight
Mapping conductors within limitations

Tension needed to meet sag clearance

ACSS/TW Oriole
- 170.5 mm² aluminum
- 17.6 mm diameter
- 783 kg/km (108%)
- 15.8 kN installed tension (115%)

ACCC® Oriole
- 222.3 mm² aluminum
- 18.8 mm diameter (104%)
- 689 kg/km (95%)
- 13.8 kN installed tension (100%)

AAAC Poplar
- 239.5 mm² aluminum
- 20.1 mm diameter (111%)
- 659 kg/km (91%)
- 13.8 kN installed tension (100%)

STACIR (invar) 160
- 159.3 mm² aluminum
- 18.2 mm diameter
- 706.8 kg/km (97%)
- 14.0 kN installed tension (101%)
### Relative conductivity CO2 generation

<table>
<thead>
<tr>
<th></th>
<th>ACSR</th>
<th>STACIR</th>
<th>ACSS/TW</th>
<th>AAAC</th>
<th>ACCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Area mm²</td>
<td>158.1</td>
<td>159.3</td>
<td>170.5</td>
<td>239.5</td>
<td>222.3</td>
</tr>
<tr>
<td>%IACS</td>
<td>61.20%</td>
<td>60%</td>
<td>63%</td>
<td>52.50%</td>
<td>63%</td>
</tr>
<tr>
<td>Relative conductivity</td>
<td>97</td>
<td>96</td>
<td>107</td>
<td>126</td>
<td>140</td>
</tr>
<tr>
<td>Resistance at 600 amps (ohm/km)</td>
<td>0.2407</td>
<td>0.2259</td>
<td>0.2116</td>
<td>0.1739</td>
<td>0.1578</td>
</tr>
<tr>
<td>Annual line losses (MWh)</td>
<td>6,548</td>
<td>6,146</td>
<td>5,755</td>
<td>4,713</td>
<td>4,293</td>
</tr>
<tr>
<td>CO2 Generated (MT)</td>
<td>1,310</td>
<td>1,229</td>
<td>1,151</td>
<td>943</td>
<td>859</td>
</tr>
<tr>
<td>Reduced CO2 versus ACSR (MT)</td>
<td>0</td>
<td>80</td>
<td>159</td>
<td>367</td>
<td>451</td>
</tr>
<tr>
<td>Reduced CO2 per KM (MT)</td>
<td>0</td>
<td>8</td>
<td>16</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>% Reduction CO2 Generation</td>
<td>0%</td>
<td>6%</td>
<td>12%</td>
<td>28%</td>
<td>34%</td>
</tr>
</tbody>
</table>

- With all other design conditions the same on this short (10km) 132kv line, conductor choices can reduce CO2 generation by 6 to 34%, versus an overloaded ACSR Wolf.
Bigger lines equals bigger results

120 Circuit Mile AEP Project Example

345 kV Line – Replace ACSR with ACCC

- Increased line capacity by 75% with 625 amp emergency reserve
- Reduced line losses by 30%
- Line loss reduction saves 141,580 MWh / year (= $7.1M @ $50/MWh)

- Emission reductions saves 57,798 Metric Tons CO2 / year
  - This equates to removing over 12,000 cars from the road
  - Line loss reduction also frees up over 16 MW of generation

Notes:
Double bundled conductor. Load factor Assumption = 34%
US National Average CO2 = 1.372#/ kWh. (1 car = 4.75 MT CO2 / year)
## Regional Impact in South East Asia

- 18 million MT reduction of CO2 every year

<table>
<thead>
<tr>
<th>Country</th>
<th>MWh/Year*</th>
<th>CO2 MMT**</th>
<th>5% losses (MWh)</th>
<th>30% saving</th>
<th>CO2 reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>216,200,000</td>
<td>477 MMT</td>
<td>10,810,000</td>
<td>3,243,000</td>
<td>7.2 MMT</td>
</tr>
<tr>
<td>Thailand</td>
<td>164,800,000</td>
<td>258 MMT</td>
<td>8,240,000</td>
<td>2,472,000</td>
<td>3.9 MMT</td>
</tr>
<tr>
<td>Malaysia</td>
<td>131,600,000</td>
<td>216 MMT</td>
<td>6,580,000</td>
<td>1,974,000</td>
<td>3.2 MMT</td>
</tr>
<tr>
<td>Vietnam</td>
<td>157,480,000</td>
<td>146 MMT</td>
<td>7,874,000</td>
<td>2,362,200</td>
<td>2.2 MMT</td>
</tr>
<tr>
<td>Philippines</td>
<td>76,000,000</td>
<td>87 MMT</td>
<td>3,800,000</td>
<td>1,140,000</td>
<td>1.3 MMT</td>
</tr>
<tr>
<td>Myanmar</td>
<td>7,144,000</td>
<td>13 MMT</td>
<td>357,200</td>
<td>107,160</td>
<td>0.2 MMT</td>
</tr>
<tr>
<td>Cambodia</td>
<td>991,000</td>
<td>5 MMT</td>
<td>49,550</td>
<td>14,865</td>
<td>0.1 MMT</td>
</tr>
<tr>
<td>Laos</td>
<td>12,240,000</td>
<td>3 MMT</td>
<td>612,000</td>
<td>183,600</td>
<td>0.05 MMT</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>766,455,000</strong></td>
<td><strong>1,205 MMT</strong></td>
<td><strong>38,322,750</strong></td>
<td><strong>11,496,825</strong></td>
<td><strong>18 MMT</strong></td>
</tr>
</tbody>
</table>

** Source: Enerdata 2013
1-2% lower GHG generation

- Using or changing to efficient conductors reduces line losses by 1 – 2 % and CO2 generation by the same amount.
- Renewable generation benefits through 1-2% more delivered power.
- Better efficiency and better return on capital projects go hand in hand (it is not double counting), so efficiency also generates more profitability for minimal capital cost increase.