



## WHITE PAPER

# Advanced Overhead Conductors: Changing the Value Equation for Utility Transmission Line Upgrade and New Build Projects

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## Section 1

# UTILITY SPEND ON ADVANCED CONDUCTOR ACCELERATING AS ECONOMIC AND OPERATIONAL BENEFITS PROVEN

### 1.1 Introduction

For more than a century, utilities have been building their overhead transmission and sub-transmission (33 kV and higher) networks with traditional aluminum conductor steel reinforced (ACSR) conductor. Today, that age-old practice is shifting and investment in newer advanced conductors is accelerating worldwide.

While advanced conductors still cost more per meter than traditional options, the total cost of ownership—which considers improved efficiency and structural and environmental benefits—is often lower than traditional options. A growing number of utilities today consider advanced conductors to be proven solutions and invaluable tools in their toolbox for transmission line upgrades, rebuilds, and, increasingly, new builds.

This white paper includes an overview of conductor types, categorized as traditional, improved, and advanced conductors. It also includes discussion of the key market drivers leading advanced conductors to displace the traditional and improved conductor types, and a discussion of overhead transmission line project economics for three project types: new lines, rebuilds and reconductors. The final section includes an overview of the market outlook for global investment in overhead transmission projects and conductors.

The many operational benefits of advanced conductors are described in detail; principal among these is the fact that the use of an advanced conductor allows utilities to re-conductor along existing corridors, doubling capacity while making use of existing support infrastructure and rights of way (ROW). Reconductoring projects not only cost roughly half what a new line or a rebuilt line may cost, they can also be executed in a fraction of the time and with fewer regulatory and permitting burdens.

### 1.2 Overhead Conductor Evolution, Categories, and Key Characteristics

In the late 1800s, copper's value made its use within overhead transmission conductors cost-prohibitive. Aluminum made for a relatively cheap, technically comparable alternative. This led to the invention of the AAC (all aluminum conductor). While conductivity was decent, AAC's tensile strength still left a lot to be desired.

In the early 20<sup>th</sup> century a steel core was added for strength and the ACSR conductor was invented. ACSR has been the standard transmission conductor of choice for utilities around the world ever since.

Around the middle of the 20<sup>th</sup> century, improvements were introduced to the original ACSR design. The ACSS, AAAC, ACAR, and TACSR conductors all improved upon ACSR, primarily in terms of capacity. A short time later, the first high temperature low sag advanced conductors were invented. These conductors, including Gap and Invar, could not only raise ampacity but could also maintain relatively high sagging clearances at significantly elevated temperatures.

More recently, high performance advanced conductors were introduced to the market. These conductors, using strong, lightweight composite cores, not only greatly reduce thermal sag but also increase line efficiency and length between structures, resist cyclic load fatigue, maintain self-dampening characteristics, and much more. This class of the most advanced conductors include ACCR, ACCC, ACFR, LoSag, and C7.

Table 1-1 summarizes the major categories of traditional, improved, and advanced conductors described here, and lists example vendors.

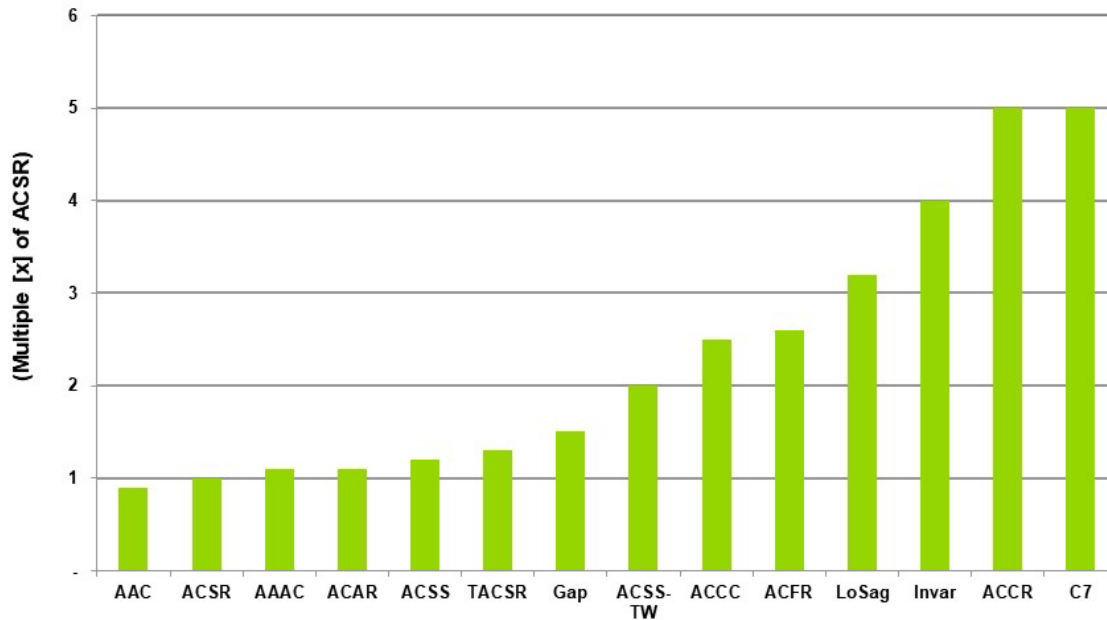
**Table 1-1. Traditional, Improved, and Advanced Overhead Transmission Conductors**

<b>Traditional Overhead Conductor Types</b>	<b>Abbr.</b>	<b>Vendor Examples</b>
Aluminum Conductor Steel Reinforced	ACSR	Most major conductor vendors
All Aluminum Conductor	AAC	Most major conductor vendors
<b>Improved Overhead Conductor Types</b>	<b>Abbr.</b>	<b>Vendor Examples</b>
Aluminum Conductor Aluminum Reinforced	ACAR	Some major conductor vendors
Aluminum Conductor Steel Supported	ACSS	Most major conductor vendors
All Aluminum Alloy Conductor	AAAC	Most major conductor vendors
Thermal Resistant Aluminum Conductor Galvanized Steel Reinforced	TACSR	Most major conductor vendors
<b>Advanced Overhead Conductor Types</b>	<b>Abbr.</b>	<b>Vendor Examples</b>
Invar	N/A	Wiretec, J-Power Systems, and others
Gap	N/A	J-Power Systems, ZTT Cable (China), LS Cable, and others
ACCR Conductor	N/A	3M (core only, one known supplier)
ACCC® Conductor	N/A	CTC Global (core only, ~25 suppliers)
ACFR Conductor	N/A	Tokyo Rope (core only, three known suppliers)
C7™	N/A	Southwire (core now provided by Tokyo Rope [as of September 2018])
LoSag™	N/A	Nexans
Other	ZFCC, ACMCC	Various Chinese replication composite core suppliers

(Source: Navigant Research)

Chart 1-1 shows conductor types ranked by price as a multiple of ACSR, from lowest to highest. Many of the advanced conductors available today offer similar capacity improvements—but increasingly factors such as efficiency, resiliency, weight, and sag are also important considerations in the utility decision-making process.

**Chart 1-1. Relative Cost for Overhead Conductors**



(Source: Navigant Research)

### 1.3 Market Drivers for Advanced Conductors: Not Just about Price Anymore

Advanced conductors offer varying degrees of capacity increase, sag reduction, and improved efficiency versus ACSR conductor in exchange for price premiums. The global market for advanced transmission conductors is expanding—Navigant Research projects annual investment to quintuple over the next decade—and is driven by several critical market drivers.

In mature markets, such as North America and Europe, market drivers for advanced conductors include aging infrastructure, a need for higher transmission capacity to support load growth, the need to interconnect new renewable generation sites, and growing difficulties of accessing new or widened ROWs.

In emerging markets, these drivers for advanced conductors are also prevalent. And while new electrification and new interconnections often use more traditional (and initially less costly) conductors for overhead lines, the operational benefits of advanced conductors increasingly are weighed in these decisions as well. Utilities are becoming more adept at considering all factors in determining the best solution for a given set of technical and economic requirements. For example, in Bangladesh, CTC Global’s patented ACCC®

conductor has become the de facto standard in an aggressive national electrification upgrade project.

Conductors included in the advanced category, however, do not all carry the same value and merit. While Gap and Invar can run at elevated temperatures without sagging, efficiency is not a benefit. This is due to their heavier steel cores, which restrict their ability to increase aluminum content without a weight penalty. Newer composite core conductors benefit from a much lighter, high strength core, increased aluminum content, and—thus—greater efficiency.

Table 1-2 compares traditional, improved, and advanced conductors in terms of capacity (relative to ACSR), their ability to withstand high temperatures, to reduce sag, improved efficiency, and installed base worldwide.

**Table 1-2. Performance Characteristics of Common Traditional, Improved, and Advanced Overhead Conductors**

Traditional	Capacity (xACSR)	High Temp	Low Sag	Efficient*	>5,000 km Installed
ACSR	1	×	×	×	✓
AAC	1	×	×	✓	✓
<b>Improved</b>					
ACAR	1.2	×	×	✓	✓
ACSS	2	✓	×	×	✓
AAAC	1.2	×	×	✓	✓
TACSR	2	✓	×	×	✓
<b>Advanced</b>					
Invar	2	✓	✓	×	✓
Gap	2	✓	✓	×	✓
ACCR	2	✓	✓	✓	×
ACCC®	2	✓	✓	✓	✓
ACFR	2	✓	✓	✓	×
C7™	2	✓	✓	✓	×
LoSag™	2	✓	✓	✓	×

\* Defined as >25% improvement in line losses.

Source: Navigant Research)

## 1.4 Advanced Conductors Change the Value Equation for Utilities

The challenges faced by utilities today cannot all be met by traditional steel core conductor in the transmission grid. It is no longer just about initial project cost. Rather, it is about:

- Providing reliable, efficient, and environmentally friendly power to more customers in a more competitive market.
- Providing uninterrupted power to urban centers where populations and load are growing rapidly.
- Bringing electricity to un- and under-served populations in support of economic development and citizen prosperity.
- Connecting new, often remote, distributed generation sites to urban centers, and about bringing that power through increasingly crowded geographies.
- Getting the most out of expensive and increasingly difficult to obtain ROWs.
- Maintaining adequate power supply when coal and nuclear plants are retired.
- Preparing for N-1 and N-2 conditions and preventing costly cascading power outages.

In short, the status quo—the traditional ACSR conductor, in use now for more than a century—no longer serves all the needs of utilities, nor their customer base. In response, the market has evolved and several types of advanced conductors are now available with varying levels of success in the field and demonstrated benefits to the utilities who deploy them.

This white paper describes the economic and operational benefits of advanced conductors. Principal among these is the fact that the use of an advanced conductor allows utilities to re-conductor along existing corridors, doubling capacity with the use of existing support infrastructure. Reconductoring projects not only cost roughly half of what a new line or a rebuilt line may cost, they can be executed in a fraction of the time and with fewer regulatory and permitting burdens.

A new line built with an advanced conductor may require narrower ROW and will not require as tall or as many structures thanks to dramatically less thermal line sag. These new lines can provide enhanced capacity to accommodate and optimize difficult-to-forecast load growth in emerging markets and provide a far more resilient network.

As more utilities open design to advanced conductors, the adoption rate will accelerate. ACSR will maintain the lion share of the market, but the shift to advanced conductors has begun. Advanced conductors turn traditional transmission line project economics on their head, resulting in project solutions that not only cost less, but also offer substantial benefits in terms of grid resiliency, efficiency, safety, and construction time.

## Section 2

### ADVANCED CONDUCTORS GIVE UTILITIES ATTRACTIVE NEW LINE AND UPGRADE PROJECT OPTIONS

#### 2.1 Overhead Transmission Project Types and Economics

Whether a new transmission line is being built—or whether an existing line is rebuilt or reconducted for greater capacity—overhead transmission line projects are costly and time consuming. The following sections describe the three project types included in this analysis and break down the costs and economic considerations for each.

##### 2.1.1 New Line Build

Building new transmission lines is complex, takes anywhere from 5-15 years, and always requires substantial investment. This is especially true on longer projects or any projects that cross state, country, or other jurisdictional boundaries. Total project costs may range from under \$200,000/km to over \$2 million/km, depending on the location and voltage.

The cost of the conductor is a relatively small percentage of the overall project cost in a new transmission line project. That said, there are important considerations beyond cost—the conductor capacity, thermal sag propensity, conductor weight, span length, efficiency, and more. When these factors are evaluated, advanced conductors often meet increasingly complex utility requirements at a lower total cost over the long-term.

In a new line build project, labor/construction costs will unquestionably be the most significant portion of overall project cost—typically about half. The costs in acquiring ROWs is also a substantial expense depending on location (in those places where it is still possible to acquire new ROWs). Conductor and associated hardware can range from 6% to nearly 20% of total new line project costs.

##### 2.1.2 Rebuild

A rebuild project typically occurs where the existing line capacity no longer meets the load demand to where the transmission line delivers power and where the infrastructure is old and no longer meets reliability requirements, which is significant in the US and other developed markets. This is a rip and replace scenario and is much costlier than a reconductor project. That said, a rebuild strategy may be selected due to utility financial incentives. In places where utilities operate under a regulated rate of return financial model, they may choose to rebuild a line because regulators will allow for project inclusion in the utility's rate case. Essentially, these projects—and the regulated return on investment—will be funded by ratepayers. In some regions, regulators are increasingly pushing back on this strategy, as the benefits of reconductoring become better understood.

If a utility does rebuild an existing line, it will incur substantial expense in removing and replacing some or all existing support structures and lines. For example, Southern California Edison recently reported that the removal of existing 230 kV transmission lines and structures alone could cost \$714,000-\$948,000 per mile.

Where the load growth is notable—in emerging Asia Pacific markets, for example—utilities increasingly evaluate advanced conductors for rebuild projects. ACSS variations are also popular where line losses are not of major concern.

### 2.1.3 Reconductor

As an attractive alternative to the high costs of transmission line rebuilds, utilities are increasingly reconductoring. Due to their low thermal sagging properties, using advanced conductors allows utilities to use existing infrastructure and ROWs to double capacity.

In comparison to a new line or rebuild project, a reconductor project will generally cost significantly less. Reconductor products typically range in price from under \$200,000/km to \$1 million/km, despite the higher cost of the advanced conductors typically used.

Notably, reconductor projects may also be done through a utility's maintenance budget; regulatory approval may not be required. In cases where a rebuild project has been turned down by the regulator, more and more utilities are deciding that the economics of reconductoring are attractive enough—when combined with other project benefits—to merit moving ahead through their operating budgets. The cost of the conductor and associated hardware is a substantial portion (roughly half) of the overall cost in a reconductor project.

## 2.2 Capacity, Efficiency, Resilience, and More Outweigh Upfront Costs

At the end of the day, total project cost and benefits must be considered when selecting an overhead transmission conductor. While the nominal cost per meter for advanced conductor is higher than it is for traditional ACSR, the overall economic and operational equation may prove more appealing.

In Section 3, the operational benefits of advanced conductor are explained in detail and numerous case studies are provided.



## Section 3

# MARKET DRIVERS POINT TO GROWING USE OF ADVANCED CONDUCTOR IN OVERHEAD TRANSMISSION PROJECTS

### 3.1 Cost Is No Longer the Deciding Factor in Transmission Conductor Choice

As noted in Section 1, there are numerous factors driving increased interest in the use of advanced conductors for both upgrade and new transmission line projects.

When it comes to upgrading an existing line, the higher capacity, reduced thermal sag, improved efficiency and resilience, and other advantages make advanced composite core conductors an attractive choice for new line and rebuild projects in a growing number of markets.

- **Higher Capacity:** Load growth, particularly in densely populated/high population growth regions, is a primary driver for transmission line upgrades and the selection of an advanced conductor. Another major driver is to improve grid reliability. For instance, in the US, growing demand may represent a second-tier concern, while shifting generation resources and/or reliability and resilience concerns may be primary drivers. Advanced conductors, including the composite core options as well as Gap and Invar conductor types, allow utilities to substantially increase capacity (2x), often with the added benefit of using existing structures and ROWs.
- **Smaller ROWs:** The acquisition of ROWs for new lines has become extremely difficult in many parts of the world. Urbanization (by 2050, 68% of the global population will reside in a city according to the UN) and high population growth in emerging markets make building new transmission lines in urban areas complicated and expensive—and the trend toward city living (and accompanying higher land prices) will only make this more challenging in coming years. In mature markets, getting approval for building a new line and acquiring the necessary ROW has become difficult, time consuming, and expensive—if possible at all. Increasingly, it is not only more economically attractive to re-conductor an existing circuit for higher capacity, but it also may be the only option. The time to complete the project is also reduced substantially when re-conductoring versus a new line with new ROWs.
- **Reduced Sag:** One of the key features of advanced conductors is their ability to tolerate a higher operating temperature with much less thermal sag. When too many amps are run through a power line, maybe because an adjacent line goes down and flow is redirected, that line overheats. An overheated line may sag to the point that it touches trees or underbuilt lines, creating the potential for cascading outages, fires, and extreme risk to the population.

- **Resiliency and Reliability:** Increasingly violent storm activity is evident around the world, as are warmer temperatures. When planning new lines, utilities must consider their transmission network’s ability to withstand these storms and heat—or ice load during the winter in colder climates. Corrosive air environments (seaside or due to chemicals used in agricultural or industrial regions) are also a consideration.
- **Reduced Line Losses:** Utilities, particularly those in developing markets with high load growth, are working harder to reduce line losses in order to have the lowest cost of electricity and to defer (or eliminate) the need to build new generation. Several advanced conductors with lighter weight composite cores offer considerably higher efficiency compared to the traditional or improved types of conductor. In the American Electric Power (AEP) case study below, not only did the utility double its line capacity, it reduced line losses by 30%. Higher efficiency not only means the potential to defer the construction of expensive peaking plants, it also reduces operating costs (fuel consumption) for the utility. In emerging markets like Bangladesh, Panama, Chile, Kenya, India, and Indonesia, the efficiency benefits of advanced conductors are now driving utilities (with regulatory support) to opt for advanced conductors.

### 3.1.1 Case Study: Higher Capacity

In 2016, AEP won the Edison Electric Institute Transmission award for the largest ever successful live line reconductor project to date. The challenge was to upgrade the existing transmission line without shutting down power to customers. The 240-circuit mile, 345 kV ACCC reconductor project not only doubled the capacity of the line to support peak load demand, it also reduced line losses by over 300,000 MWh per year, freeing up 28 MW of generation. Additionally, the utility was able to save over 200,000 metric tons of CO<sub>2</sub> per year, the equivalent of removing 34,000 cars from the road. The project was completed 8 months ahead of schedule, and provided the additional capacity needed without service interruption.

### 3.1.2 Case Study: Restricted Clearance

Allegheny Power installed 3M’s ACCR to upgrade a 138 kV line linking the Bedington and Nipetown substations along Interstate 81 in West Virginia. The 138 kV line shares structures with three other lines for most of its length, including two underbuilt 12 kV lines, and had a flow of 2,200 amps and expected peak temperature of 200°C. The 1.7-mile upgrade boosted transmission capacity without risk of contact with the underbuilt lines.

### 3.1.3 Case Study: Resilience – High Heat and Wind

In 2018, Southern California Edison saw the need for a significant improvement in reliability (N-1 conditions) in Palm Springs, California. This area’s climate is hot and arid with frequent strong winds. The ACCC conductor was chosen for its reduced thermal sag properties and its self-dampening characteristics. The 38 km, 115 kV line was energized ahead of schedule, with virtually no environmental impact on protected wildlife.

### **3.2 Traditional, Improved, or Advanced?**

When it comes to selecting an overhead conductor, there is more to the equation than upfront cost. As the case studies and market drivers demonstrate, the choice of an advanced conductor brings a multitude of benefits that increasingly outweigh the nominal cost of advanced conductors versus traditional or improved selections.

Navigant Research believes that the tendency of utilities to re-conductor, rather than rebuild, for higher capacity or other environmental and reliability needs will grow markedly over the next decade. Furthermore, advanced conductors have begun to displace the use of traditional or improved conductor types previously favored.

Section 4 presents the market outlook for global transmission investment for overhead conductors (broadly) and for advanced conductors (specifically).

## Section 4

# UTILITY INVESTMENT IN ADVANCED CONDUCTORS WILL INCREASE NEARLY FIVEFOLD THROUGH 2027

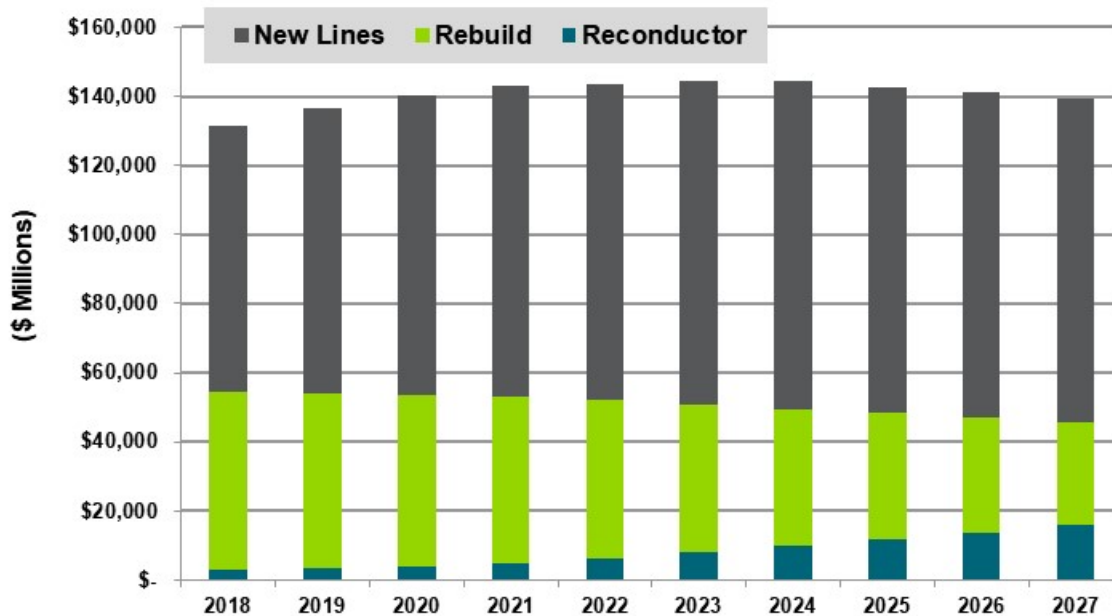
### 4.1 Utility Overhead Transmission Investment Outlook

In 2018, Navigant Research estimates that more than \$131 billion will be invested by utilities worldwide in new or upgrade (collectively, rebuild or reconductor) transmission network projects. By 2027, the annual investment in overhead transmission infrastructure will likely grow to \$139.2 billion, for a nearly 0.6% average annual growth rate. Note that the market peaks in 2024 at \$144.5 billion, after which several aggressive programs in Asia (India, China, others) will slow.

Where costly rebuild projects have been more common in the past, going forward, the attractive economics of reconductor projects are expected to make this type of upgrade project, using advanced conductors, far more prevalent. Chart 4-1 shows projected project investment by new line, rebuild and reconductor project spend.

Of the \$131 billion in total project investment in 2018, the overall market for overhead conductors in all categories is estimated at nearly \$17 billion in 2018; this is expected to grow at 2.4% through 2027, to nearly \$21 billion.

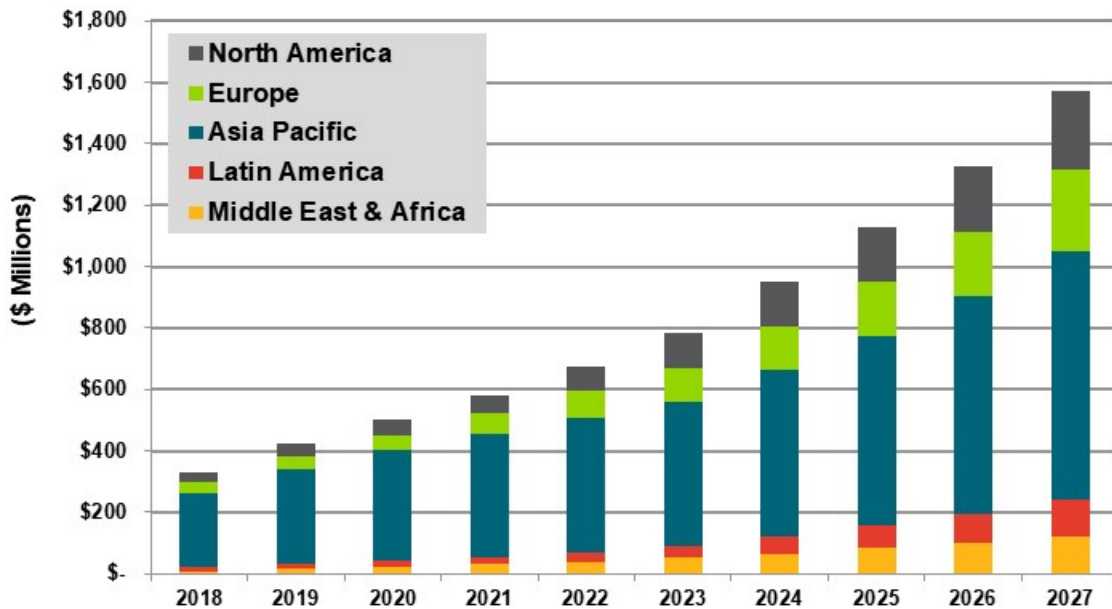
**Chart 4-1. Overhead Line Project Investment, New, Rebuild, Reconductor, World Markets: 2018-2027**



(Source: Navigant Research)

Of the overall overhead conductor market, the advanced conductors considered in this study—Gap, Invar, ACCC, ACCR, ACFR, LoSag, C7, and others—are expected to grow their share of the global market from 2% to 7.5% over the next decade. Investment in advanced conductor worldwide is set to climb at 19% annually through 2027, from \$331 million to nearly \$1.6 billion.

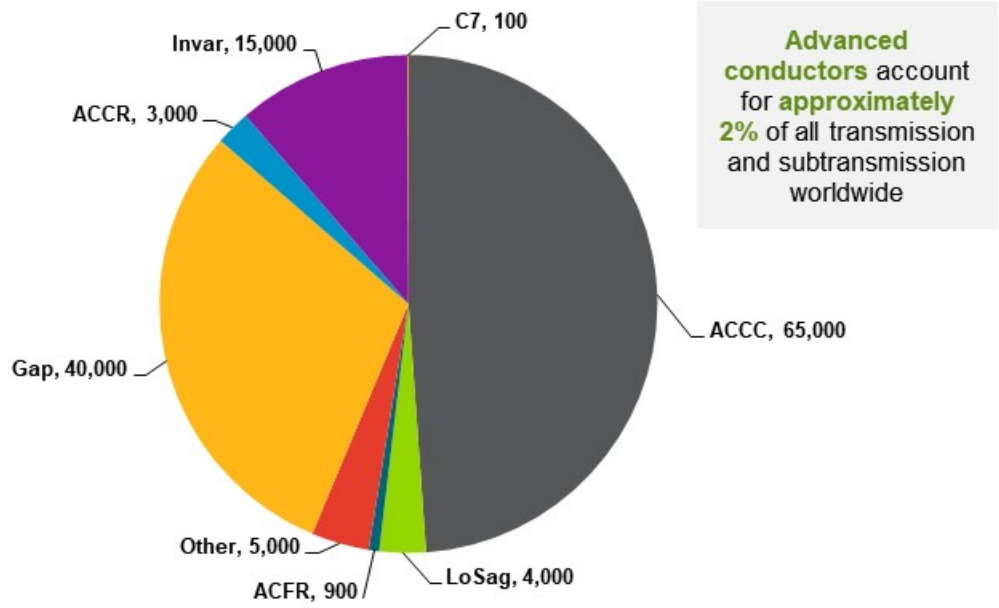
**Chart 4-2. Advanced Overhead Transmission Conductor Revenue by Region, World Markets: 2018-2027**



(Source: Navigant Research)

Among the advanced conductors included here, CTC Global’s ACCC product is the market leader by a good margin. With an estimated 65,000 km installed worldwide and more than 600 projects under its belt, CTC Global has demonstrable support from utilities and regulators in every region mentioned. While some competitive offerings are expected to gain share as their project counts grow—and assuming the conductors perform as expected—ACCC’s head start in this rapidly growing space should allow it to remain a leading technology in coming years.

**Chart 4-3. Estimated Installed Kilometers of Advanced Overhead Conductors: 2018**



(Source: Navigant Research)

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