The Role of Silver in the Green Revolution

Prepared for The Silver Institute

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CRU International

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Executive summary

With its unique conductive and chemical properties, silver is an important industrial metal with integral roles in many electrical and electronic applications. The ongoing revolution in green technologies, driven by the mainstream adoption and exponential growth of new energy vehicles (NEVs) and the continued investment in solar photovoltaic energy, should form an increasingly important part of industrial demand for silver in the future.

This study is intended to inform Silver Institute members and the general public about the critical role silver has played and will continue to play in the ongoing green revolution, both within the electrical generation segment and the transportation and related charging infrastructure segments. It will provide a robust framework for evaluating future changes in silver demand within these two markets, focusing on the key macroeconomic, policy and technological views and changes required to bring about such a revolution.

The key findings of this study are as follows:

- **The cost of installing and providing solar photovoltaic (PV) has fallen rapidly relative to other electrical energy sources over the past two decades, even with factoring out the effects of solar subsidies and taxes/penalties on nonrenewable energy sources. These trends are expected to continue over the medium-term, leading to an ever-increasing share in renewable energy generation and investment, led by both macroeconomic/cost considerations and public policy.**
- **Solar energy uptake will grow most significantly in developing regions during the next decade, led by major policy-driven investments in domestic solar infrastructure within China and India. Solar energy uptake is expected to continue growing strongly within the United States, despite some short-term uncertainty associated with recent tariffs on solar PV imports. Within Europe, solar PV uptake is expected to decelerate through 2030, although renewable energy sources will continue to account for a growing share of regional electricity generation.**
- **Although solar power will account for a growing share of global electricity generation, the amount of silver used per photovoltaic cell is expected to continue declining. Thrifting, which is widely utilized across the full metals spectrum, has already brought the average silver loadings per generated kilowatt hour down to 28.6 grams in 2017, driven mainly by continued advancements in dual printing processes, reductions in wafer thickness and finger width and, to a lesser extent, replacement of silver with other materials like copper. CRU expects silver loadings in solar PV to continue declining through 2030, albeit at a slower pace than during**

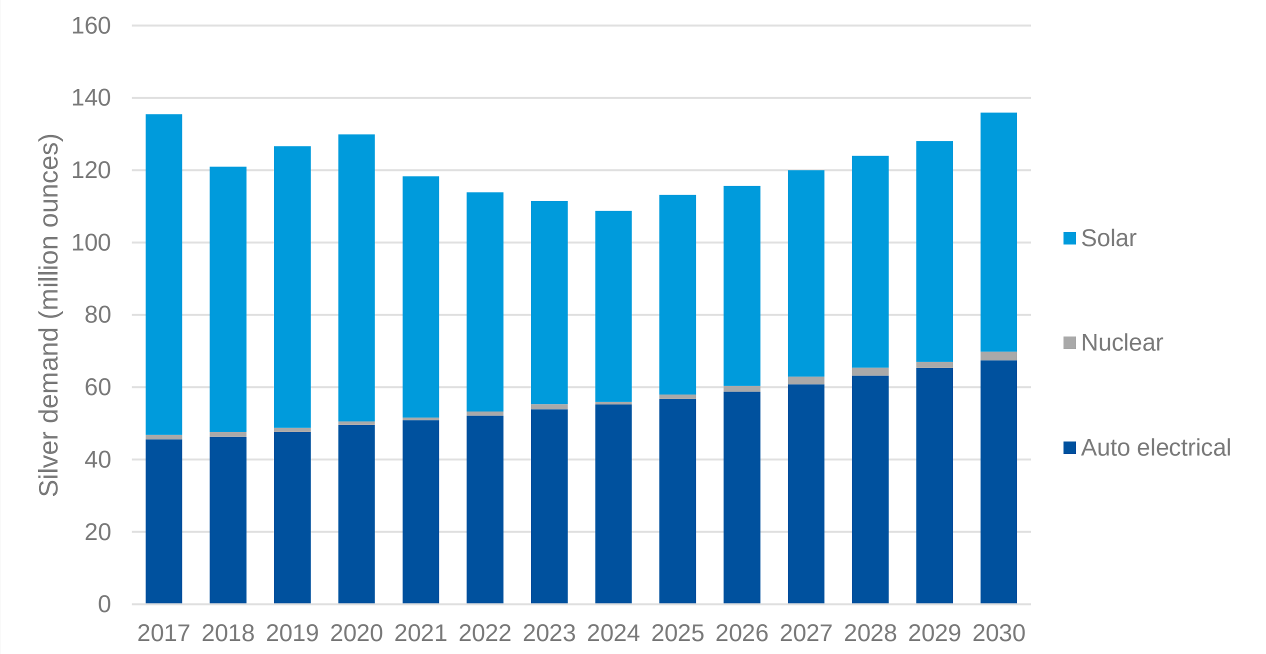
the past 10 years. Moreover, it is important to note that silver's unique conductive properties ensure that substitute materials will not be able to match it in terms of energy output per panel. As a result, the pace of silver thrifting is expected to slow down considerably over the longer term, ensuring that the solar PV market will remain a key vertical for silver use in industrial applications. Ultimately this will lead to short term growth in silver demand in PV from 2018-2020, before thrifting and a reduced amount of PV capacity installed per year causes a decline in demand through the early 2020s, after which we expect demand to return to growth from 2025 onwards.

- **In the transportation sector, spurred on by overwhelming policy support, as well as falling costs and greater understanding of the benefits of electric vehicles, new energy vehicles (NEVs), such as battery electric vehicles, (BEV), and plug-in hybrids (PHEVs) will account for an ever-increasing proportion of global vehicle sales. Based on our electric vehicle model, CRU estimates that BEVs and PHEVs may collectively account for as much as 17% of global car sales while hybrids account for an additional 20% of sales by 2030.**
- **The incremental growth in silver loadings within new energy vehicles will have a meaningful impact on future demand for silver from the automotive segment. Within vehicles, silver is primarily used in electrical contacts, which connect electrical components with one another. The automotive battery market remains a commercially untapped opportunity for silver-zinc batteries. Due to cost pressures, however, current trends indicate that automakers and their suppliers will continue to invest in lithium ion technology with nominal investment in silver-bearing battery materials.**
- **The value proposition of wireless inductive charging ports and stations will increase substantially if the successful development and mainstream adoption of autonomous vehicles succeeds. At the moment, inductive charging for the transportation sector is gaining traction in electric buses used by public transportation agencies, and there are signs that the next major market for this technology will be electric trucks used by regional freight companies. CRU expects the adoption of inductive charging stations by the household market to provide meaningful growth in silver demand only over the long-term, as plug-in charging remains the favored technology for the current generation of EV owners.**
- **Even so, the technology behind inductive power transfer has come forward in leaps and bounds in the past decade, turning a once-impractical technology into a method of transferring power that is convenient, quick and increasingly energy-efficient. This is reflected in its newfound commercialization, with inductive chargers boasting enough technological advancement and consumer convenience to**

generate sales despite their considerable premium. There are clear benefits to the technology that could revolutionize certain areas of the transport sector in terms of both profitability and convenience, but a substantial reduction in price is needed before these areas can be properly explored. If the costs of these technologies do come down substantially, however, the transport sector is sure to bring a silver lining to the long-term shifts in the energy market.

- **In total, CRU estimates the demand for silver in the three key 'green' applications covered in this study to be in the range of 110-140 million ounces each year from 2018 to 2030, with growth in both automotive and solar applications bolstering demand in the longer term, while nuclear provides a much smaller, but nonetheless positive, benefit.**

Figure 1 Demand for silver in 'green' applications covered in this study



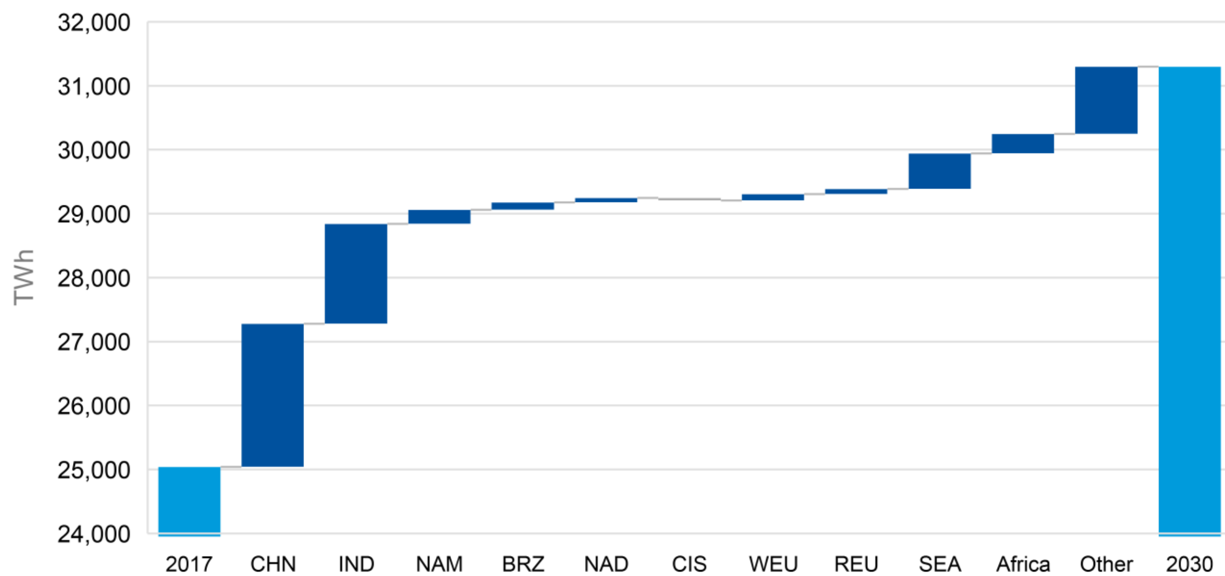
Data: CRU, SI,

*Auto electrical excludes silver consumption in defogging applications (conductive pastes)

1. Power

World electricity consumption reached 25,000 terawatt-hours (TWh) in 2017, growing at an average annualized rate of 3.2% from 2007. Terawatt-hours is a measure of electricity consumption, equal to 1,000,000 megawatt-hours. For reference, the average US household consumes about 11 megawatt-hours per year, according to the US Energy Information Administration. This rate can be expected to slow to 2% to 2030, with global consumption reaching 31,000 TWh in that year. As Figure 2 shows, this slowdown will continue to occur in developed areas, such as Europe, North America and North East Asia, as energy-efficient technologies become more widespread; meanwhile, China will continue its fast-paced growth and will be joined by India, South East Asia and sub-Saharan Africa, as improvements in quality of life and rapid economic growth lead a burgeoning middle class in these areas to not only consume more energy in general, but also rely more on electrical appliances over traditional sources of energy.

Figure 2 Forecast increase in electricity consumption by region



Data: CRU; CHN-China, IND-India, NAM-North America, BRZ-Brazil, NAD-North Asia Developed, CIS-Russia and the CIS region, WEU-Western Europe, REU-Rest of Europe, SEA-Southeast Asia

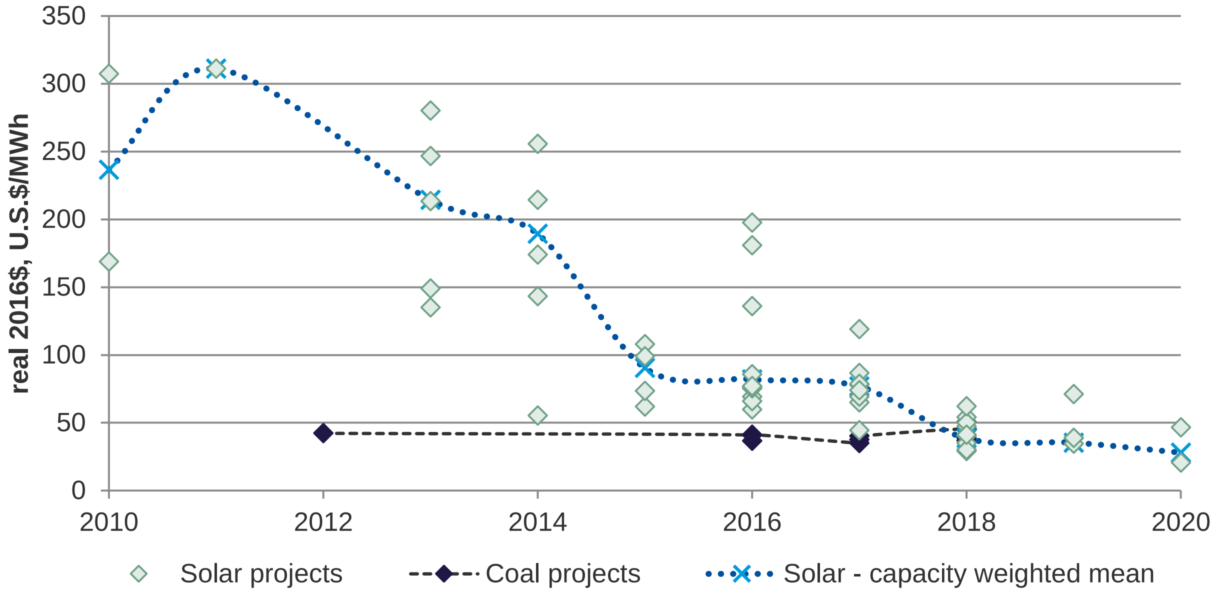
Fossil fuels continue to dominate electric generation in most markets, with coal, oil and gas accounting for around two-thirds of global electricity production in 2017. However, as the issue of pollution grows in significance in the wake of the Paris Agreement, governments are increasingly looking to implement policies encouraging low-carbon sources of power generation, causing demand from these sources to decline. While the Paris Agreement is not the only policy framework that drives shifts in electricity consumption, it is one of the more prominent overarching policies with global significance. There are also numerous noteworthy energy policies at the national level that play a significant role in renewables energy uptake, as outlined in further detail below.

The degree to which coal cedes market share to other sources will depend greatly upon various regional factors; environmental issues of course offer a raft of great and worthy incentives for the transition from coal to renewables, but the realities of providing cheap and reliable power are often a stronger motivation. Demand for coal may have fallen between 2014 and 2016 in China, for example, but it can be expected to once again rise modestly in the coming years as efficiency gains and a lower demand for domestic heating are counteracted by an increased demand for centralized power.

This is a trend in other developing countries, who are more likely to choose to address their carbon emissions through consolidating coal-fired plant assets, increasing its efficiency, and investing in carbon capture & sequestration (CCS) technology. India is an example of this, with most of the nation’s extravagantly-named Ultra Mega Power Projects (UMPPs) being coal plants, as the country’s rapid growth in baseload power needs has required a great deal of additional coal capacity to quickly and affordably meet demand.

But where renewables once struggled to compete in markets where the priority is the cheap and rapid expansion of an emerging economy’s electric infrastructure, new sources of energy are making headway, thanks to both plummeting costs and rapid lead times. As Figure 3 demonstrates, the global average levelized cost of electricity (LCOE) for new solar project has approached and is surpassing that of an average coal-fired power plant (U.S.$40/MWh – although in nations with large coal reserves or where thermal coal is produced domestically, the LCOE can be as low as U.S.$27-32/MWh). This has sparked interest in developing nations which would once have never considered a move to renewables – indeed, a fair number of Indian UMPPs are solar projects, with the nation expecting to boast total solar capacity of 100 GW by 2022.

Figure 3 Solar and coal plant LCOEs



Data: CRU

The proliferation of renewable sources of energy, then, is far from being the pipe dream it once was – it is now a cost-effective means of energy generation, unfettered by price concerns. This is not to say there will not be challenges, even in the developed world – a comparative dearth of wind and sun in north-east Asia will cause coal demand in Japan and Korea to rise as nuclear plants continue to close in the wake of the Fukushima disaster; varying levels of political support in different regions, will no doubt continue to arise. Despite these roadblocks, the long-term outlook continues to look positive for all carbon-neutral sources of energy.

This low-carbon transition represents an opportunity for growth for two sources of electricity which consume silver: solar photovoltaic (PV) and nuclear energy. The need for silver in the generation of solar energy is widely publicized, and with good reason – the conductive silver paste found on the front and back of most PV cells represents the potential for a substantial increase in global silver demand, although the effects of thrifting pose a perennial risk. Silver finds a further use as a neutron absorber in the rod cluster control assemblies (RCCAs) that are used to regulate the rate of fission in some designs of nuclear reactors, and while the demand is small, not to mention reliant on an energy sector that has faced challenges since the 2011 Fukushima disaster, the global necessity for carbon-neutral energy represents an opportunity for growth that merits a brief exploration.

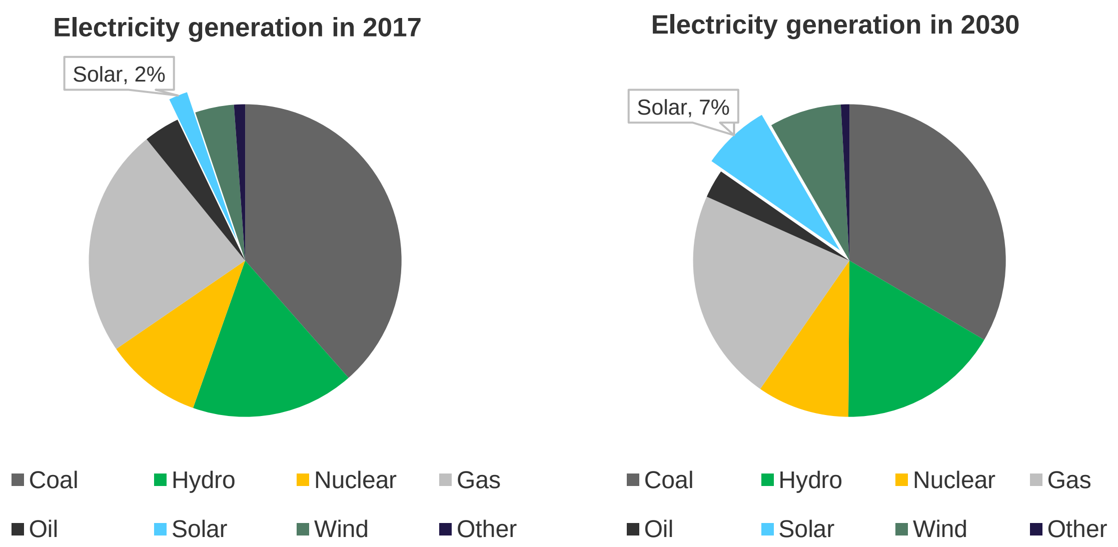
This chapter will therefore chart the recent policy and technological factors that affect both the uptake of solar demand and the degree to which it may translate into silver demand, taking into account the potential adverse effects of both thrifting and increasing cell efficiency; it will then discuss the likelihood of a significant reversal in fortunes for nuclear energy, and whether this will have any substantial effect on silver consumption.

1.1. Solar

This section will review solar photovoltaic (PV) uptake on a regional level, followed by discussion of historical and forecast silver intensities in PV equipment.

Demand for renewables is expected to increase to 4.5 times its current level by 2030, expanding the sector's share of global electricity generation from 6% to 14%, as shown in Figure 4. Given the nature of renewable energy, the ratio of wind to solar demand is dependent upon geographic and climatic factors, meaning solar is unlikely to dominate the renewables sector in the foreseeable future; nonetheless, as solar's cost advantage becomes more pronounced, its share of the renewables sector will increase from 33% to 48% by 2030.

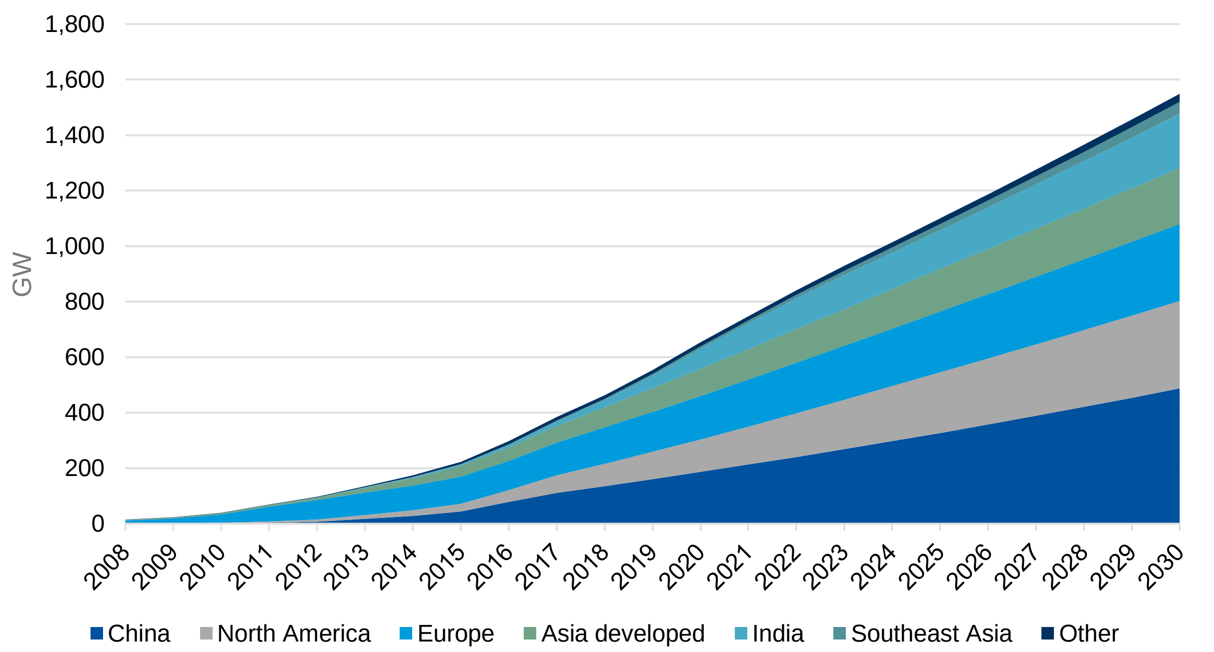
Figure 4 Global electricity generation by type



Data: CRU

As **Figure 4** shows, more than 1,100 GW of additional installed capacity is required to fulfill demand by 2030. Most of the additional solar capacity moving forward is expected to be installed in North America (in particular, the US) and China; these regions account for 22% and 32% of future capacity increases respectively. Other areas that claim high shares of future capacity are India (15%), Europe (14%), and North East Asia (12%). There is a comparative lack of interest in solar power in other parts of the world, often despite favorable climates such as in parts of Africa and South America; this reflects the pervading truth that for many developing countries, coal remains the quickest and often cheapest way to meet the sizeable baseload demand required by a rapidly growing consumer base.

Figure 5 Historical and forecast solar capacity by region, 2006-2030



Data: CRU

1.1.1. China

As the largest market for photovoltaics and world leader for new installations, China shows no signs of stemming its impressive demand for solar power. Spurred on by the twin drivers of economic growth and considerable policy support, Chinese solar capacity is expected to rise to two and a half times its current level of 163GW to 488GW by 2030.

A large part of this rise is simply in response to the energy demands associated with China’s continued development. China’s GDP growth may be expected to slow from 6.9% in 2017 to 2.8%

by 2030 as it continues its transition into a developed nation, but it will nonetheless require significantly more electricity to achieve. China is at the tail end of a major demographic shift from a mostly rural, low-income population to an urbanized, high-income population, and our internal economics team forecasts 70% of the Chinese population will live in cities by 2030; the associated energy demand is expected to increase electricity consumption to 2238 TWh p/y by 2030.

Nonetheless, the fact that PV solar power is predicted to account for 22% of China's additional consumption is testament to the resoluteness of recent energy policy and their reputation for meeting similar targets in the past. Since the introduction of the Golden Sun incentive scheme from 2009-2011, which provided subsidies to PV power generation projects with the aim of increasing installed PV capacity to 500MW, China has favored solar energy as a means to adhere to its goal to keep carbon emission levels at bay despite its increased demand for electricity. The current Five-Year Plan is no exception; CRU estimates they will trounce their goal of 105GW installed solar capacity by 2020 by a resounding 81GW. With the legwork already done in establishing a solar industry – seven of the top ten PV manufacturers by market share are Chinese, representing a total shipped capacity in 2017 of 23GW – all macroeconomic and political factors indicate that China's solar capacity will continue to grow at an impressive rate to reach 488GW by 2030.

1.1.2. North America

North American solar demand is mostly concentrated in the US, which in 2017 installed 22GW of new solar capacity. Indeed, the US has seen a strong rise in solar capacity over the past few years, with various federal policies since 2008 supporting the research and development of solar technology. However, unlike other regions, there is no mandatory nation-wide renewable energy target, although the state of California has pledged to generate half of its electricity from renewable sources by 2030. More recently in May 2018, the State of California announced new policies that require all new housing developments to incorporate solar power by 2020.

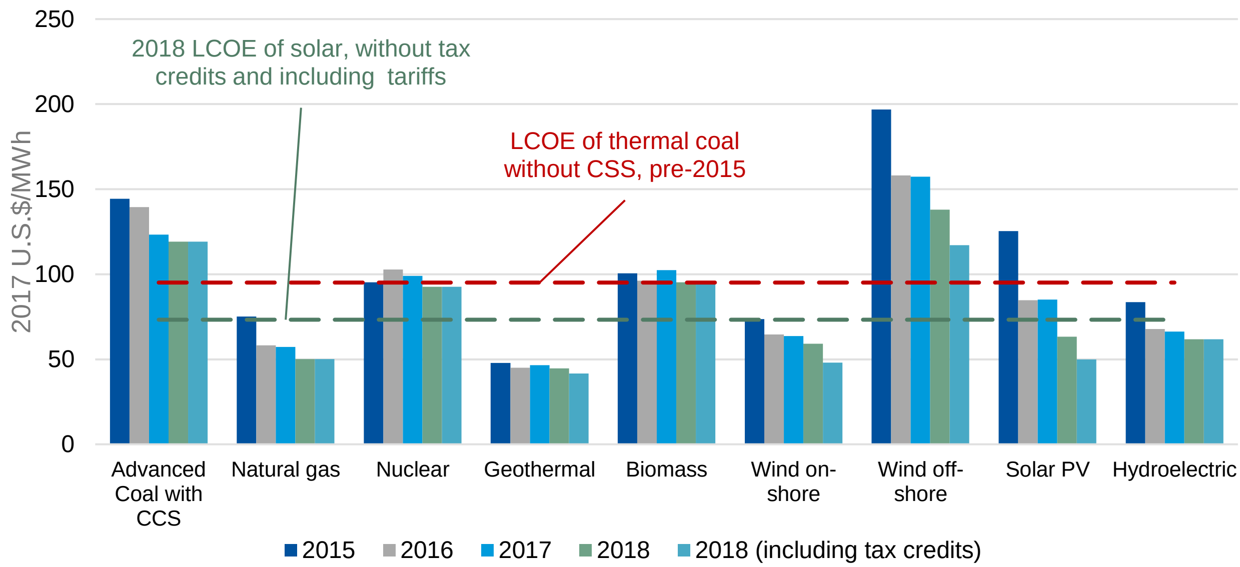
The inauguration of Donald Trump as president in 2017 may have spelled a shift in energy policy, but it remains to be seen what effect this will have. There has been some concern over whether Trump's much-publicized support for coal power generation may affect solar uptake, be it through a fall in demand following the US's withdrawal from the Paris Agreement in 2020 or the possibility of cutting solar subsidies in favor of investment into carbon storage research.

So far, the largest effect the Trump presidency has had on the solar industry came in January 2018, when the introduction of 30% tariffs on PV panels threatened to increase consumer prices and slow the previously rapid uptake of solar power. This has caused a great deal of consternation within the market; many analysts have revised down their figures for new installed capacity by as much as 15% through to 2021, and the American panel manufacturer SunPower, who make the majority of its panels abroad, have predicted an annual loss of U.S.$50m from the move.

It remains to be seen how much of an effect this tariff will have on American solar uptake. A similar tariff brought in by the EU in 2013 had little effect on installation growth which is already declining in that region, but US installers and consumers face a greater challenge now than their counterparts in the EU did in 2013: the market share of imports in the US today is 80% compared to 33% in the EU in 2013, and the European solar industry was at the time much more mature in comparison to China than the US is now.

In any case the tariffs have caused a shake-up in the market as domestic solar installation companies scramble to ensure a tariff-free supply: the Chinese manufacturer JinkoSolar, for example, has announced the construction of a factory in Florida, while SunPower has applied for an exemption and acquired SolarWorld Americas, a rival with a greater manufacturing capacity in the US. It will no doubt take a few years for the market to settle, during which time solar uptake may be negatively impacted, but these tariffs are unlikely to affect the growth rate of the solar industry in the long term. Solar power still has the perennial and conclusive advantage of rapidly falling costs, a fact that even the fossil friendly current Republican administration has recognized, pledging U.S.$105 million to the development of solar technologies and their integration into the grid in April 2018.

Figure 6 Estimated LCOE for new generation resources, 2015-2018



Data: U.S. Energy Information Administration

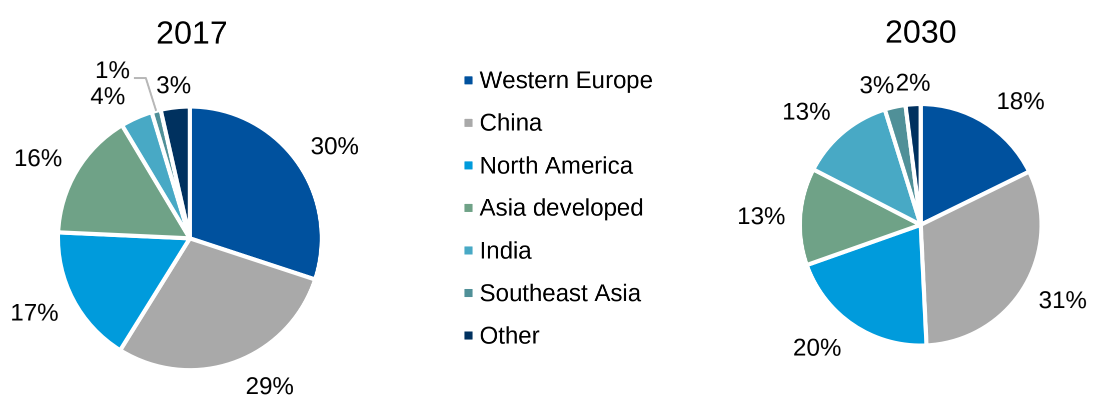
As **Figure 5** demonstrates, the average estimated levelized cost of electricity (LCOE) of new solar projects in the US is far below new coal projects and on a parity with natural gas when tax credits are taken into account. Coal's relative costliness may be due to a reinterpretation of the Clean Air Act §111b, which in 2015 required coal plants to have carbon capture & sequestering (CCS) technologies, but current solar costs have proven to be lower even than historical coal costs in real terms, with the LCOE of coal without these requirements still being 33% more expensive than solar power, even when tax credits are removed and a particularly pessimistic price adjustment for the new tariff is taken into account. It is worth keeping in mind that the likelihood of the current US government removing CCS requirements from new coal projects is particularly low, given existing policy momentum, Trump's campaign rhetoric on 'clean coal' and subsequent investments made by the Department of Energy into the technology.

1.1.3. Europe

The member states of the European Union (EU) continue to make strides towards meeting their target of fulfilling at least 20% of its total energy needs with renewables by 2020 and 27% by 2030. Although CRU believes it will be a close call whether the 2020 target is met, our estimates show that the 2030 target will be comfortably exceeded, with the bloc achieving a renewable share of 30% by this time. This would seem to corroborate a recent (February 2018) report from the International Renewable Energy Agency (IRENA) stating that a new target of 34% by 2030 would be technically feasible, and it is possible that the goalposts may be moved forward even further in this timeframe.

However, much of the groundwork for this increase has already been laid, with Europe already boasting total renewables capacity of 280GW, of which solar accounts for 116GW. Given the fundamentally intermittent nature of both wind and solar, there is currently a limit to the extent to which a grid can rely on renewables without risking gaps in coverage; moreover, for many northern European nations, wind remains the better option for power generation. Because of this, Europe is likely to lose its position as the world leader in solar capacity (as a proportion of its total energy generation) sometime in the next year, although solar capacity is expected to continue growing an annualized 11% to 275 GW by 2030.

Figure 7 Share of solar capacity by region, 2017 and 2030



Data: CRU

1.1.4. India

India smashed its original target of 20 GW installed solar capacity by 2022, achieving it four years ahead of schedule in 2018. These plans have since been revised, with the Indian government now aiming for a total of 100GW installed capacity by 2022. This may be an ambitious target, but it is nonetheless achievable, with CRU predicting that installed capacity will in fact surpass 100GW by a modest but not inconsiderable margin. In addition to this, there is a large-scale initiative to develop off-grid solar energy for rural and impoverished areas. Though most applications in this area, such as water heaters and solar cookers (appliances that cook or heat food using the thermal energy from directed sunlight), will rely on concentrated solar power (CSP), some will require small PV cells, such as lanterns and streetlights in areas with low accessibility.

There are few limits to the potential growth of India's solar industry moving forward. The current Prime Minister, Narendra Modi, has demonstrated a commitment to solar power both at home and abroad, and is the chief architect of the International Solar Alliance (ISA), an association of 121 countries that seeks to further the exploitation of solar energy in nations that lie between the Tropic of Cancer and the Tropic of Capricorn.

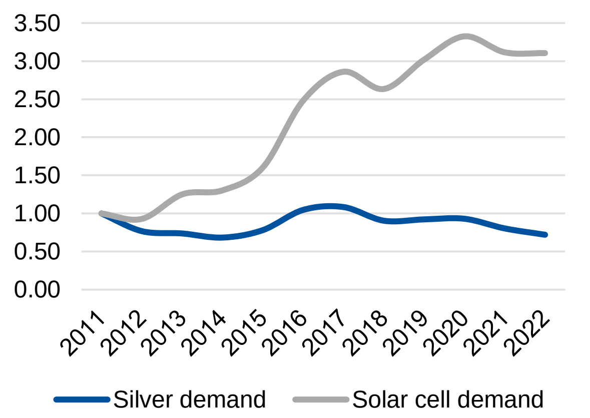
Alongside such favorable international and policy support, the Indian solar industry has a considerable advantage conferred by the twin drivers of high levels of solar energy insolation and perhaps the largest potential consumer base worldwide. Total annualized electricity demand is expected to almost double from 2017 to 2030 from 1,625 TWh to 3,187 TWh as connection to the national grid becomes the norm in the nation's growing urban areas; moreover, the majority of the country's landmass receives an average annual solar irradiance of over 1900 kWh/m^2, meaning solar power can be delivered more cheaply as less solar capacity is needed for the same amount of power. Off the back of this, solar power has become highly cost-competitive, with some new projects in 2017 being auctioned for as low as ₹ 2.44/kWh – significantly cheaper than the average LCOE of coal in the region.

We therefore expect installed solar capacity to rise to almost ten times its current level by 2030, to 196 GW. Half of this is assumed to come as a direct result of Modi's commitment to reach a capacity of 100 GW by 2022; in the absence of any evidence for further policy after this point, growth is expected to be somewhat slower from 2022 to 2030, although there is a distinct possibility that policy support may remain, and solar uptake may be higher than forecast from 2022 onwards.

1.1.5. Silver demand in PVs

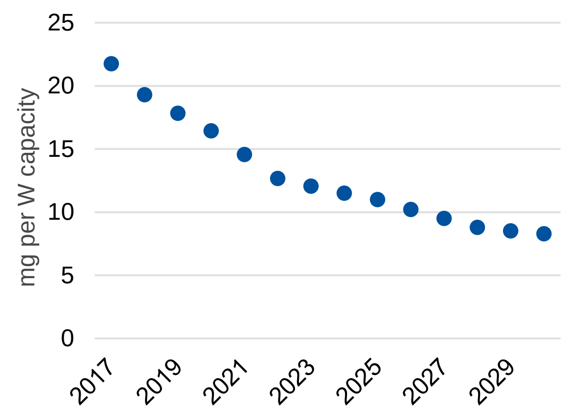
The threat of thrifting in PVs has loomed over suppliers since the industry was in its nascence, causing demand for silver within the solar industry to rise at a considerably slower pace than PV demand. As Figure 8 shows, this trend is only set to persist as manufacturers continue to reduce the silver content of their panels as a cost saving measure. However, the rate of silver reduction is beginning to slow; having fallen from 400mg to 130mg per cell between 2009 and 2016, CRU forecasts silver content to begin levelling out at 65mg around 2028. With average cell output expected to rise from 4.7 watts in 2018 to 6.0 watts by 2030, continued thrifting amounts to roughly 10.5mg of silver required per watt of generation capacity by 2030. In Figure 10 below, we have indexed total demand for solar cells (as measured by number of cells) to silver demand from the solar PV market (as measured by mg of silver per cell) starting from a base year of 2011. Although the gap widened considerably from 2012 to 2017 in line with thrifting trends, we expect this gap to widen at a much slower pace during the latter half of our forecast as the performance/efficiency losses from using less silver begin to outweigh the benefits of lower manufacturing costs.

Figure 8 Indexed demand for PV cells and silver in solar PV



Data: CRU, SI. Index shows changes relative to 2011, which is marked as 1.00 on the chart

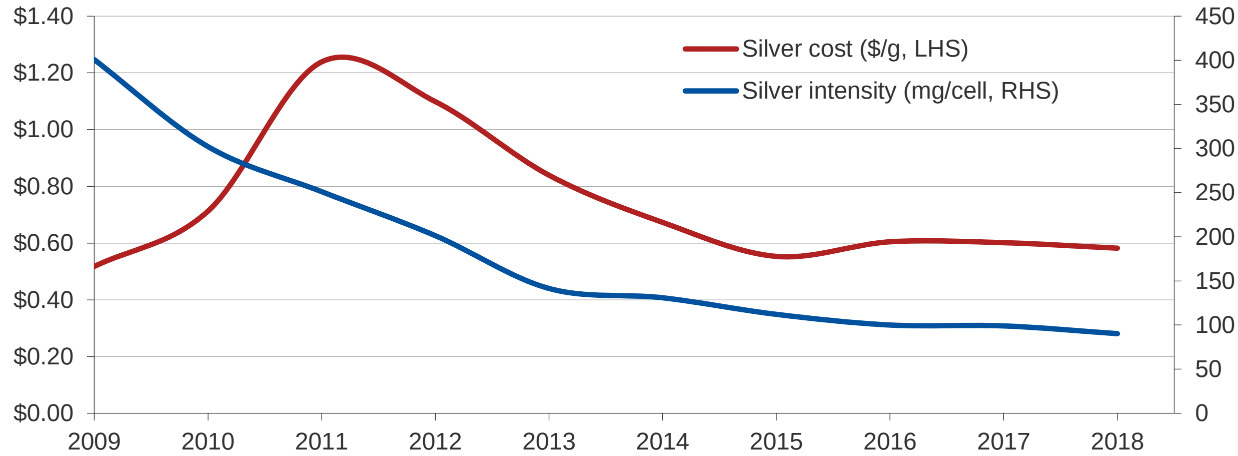
Figure 9 Forecast silver consumption per generation capacity



Data: CRU, ITRPV, SI

The main driver for this thrifting is the price of silver; when it more than doubled between 2009 and 2011, the amount of silver in the average PV cell halved from 4.0g to 2.5g. The rate of thrifting then halved between 2012 and 2017 as the price of silver fell from U.S.$31 to U.S.$17 per ounce. CRU forecasts show the price of silver is unlikely to rebound to the record-high levels reached in 2011, playing a role in the decelerating rate at which thrifting is expected to continue. Nonetheless, the fact that manufacturers continue to reduce their silver loadings is symptomatic of a highly competitive market in which prices are consistently being driven down. Thrifting continues to be spurred on by new manufacturing processes, such as dual printing, where the fingers and busbars of a PV cell are printed separately, allowing busbars to be printed with a paste with a lower silver content it is also made possible by the reduction of finger widths. Furthermore, it is important to note that thrifting and material substitution is a trend that is not inherently unique to silver but is rather present across the full commodities market; Downstream manufacturers constantly strive to lower raw material costs, whether it is related to aluminum substitution for copper in cable and wiring or plastics substitution for tinplate in food container production. It bears repeating that silver has remarkable electroconductive qualities unmatched by other metals, and there is a physical limit on the ability of solar PV manufacturers to continue reducing silver loadings before performance and efficiency losses begin to outweigh whatever benefits are achieved from lower raw material costs.

Figure 10 The price of silver relative to silver intensity in photovoltaic cells



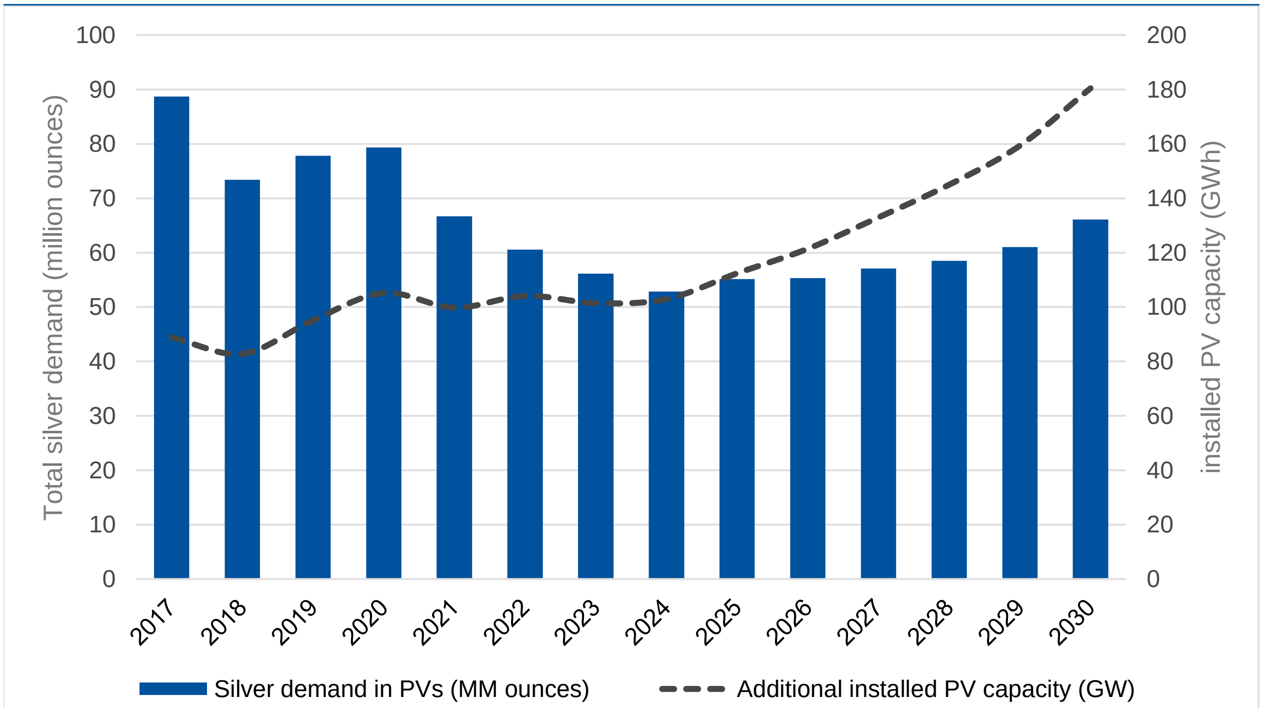
CRU, ITRPV

As in other applications, there is also a modest risk that silver may be substituted with less expensive materials, such as copper. However, substitute materials have had difficulty competing. Silver has the lowest electrical resistance among all metals at standard temperatures, meaning its substitutes cannot hope to match it in terms of energy output per panel; the savings made in substitution may therefore be offset by the increased number of panels needed to match capacity. Moreover, due to technical hurdles, such as the reduced adhesiveness of front pastes containing high amounts of copper or aluminum, non-silver PVs tend to be less reliable and have shorter lifespans, meaning they are some way off in terms of commercial development and are unlikely to gain significant market share between now and 2030 as the broader market heads toward more compact and efficient solar panel equipment.

However, efficiency gains are expected to prolong the downward trend of silver loadings per watt of capacity, which may prove to be enough to tip silver demand in the PV sector into a period of deceleration in the coming years. The amount of solar energy that the average panel can convert into electricity currently stands at about 19%, up from 17% last year; some market leaders, such as SunPower in the US, are reporting efficiencies for commercially available cells of up to 22%. With this in mind, CRU believes average efficiency may rise to 25% by 2030, meaning a reduction in the number of panels needed to produce the same amount of energy of 24%.

These two factors – thrifting and efficiency increases – may decrease silver loadings enough that it would take a significant increase in solar capacity's growth rate to keep silver demand from slipping – an increase that the industry as it currently stands will not be able to deliver in the long term. Increased demand from policy support in India will buoy silver demand, keeping it at a stable level until the end of the decade, and the rate of solar uptake will continue to grow at a not inconsiderable pace, only slowing past 2030; however, as volumes increase the need for both increased efficiency and decreased cost will continue to drive silver demand per GW down until 2028. With this in mind, CRU believes that 2017 represented a probable peak for silver demand in the PV industry, but a deceleration in thrifting and continued additions to solar generation capacity will continue to support silver consumption, particularly in the longer term. We expect annual silver demand in PV cells to range around 70-80 million ounces in the next few years, before declining to approximately 50-55 million ounces in the mid-2020s. We expect that it will then return to growth, reaching 66 million ounces by 2030.

Figure 11 Forecast demand for silver in PV cells



Data: CRU

1.2. Nuclear power

While silver has relatively well-known uses in solar power and industrial catalyst applications, an often overlooked application for silver is nuclear power, where silver is used in combination with other metals to produce control rods for nuclear reactors. This section with first outline our market outlook for global and regional nuclear generation informed by recent developments and policy announcements, followed by commentary on current and anticipated applications for silver in nuclear power generation.

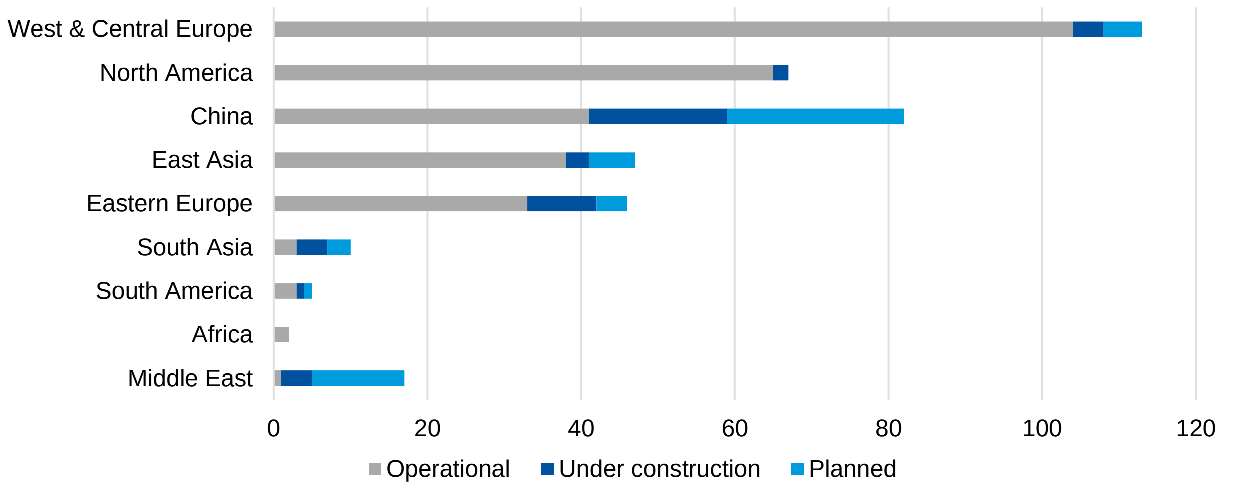
The 2011 Fukushima Daiichi disaster was a substantial blow to the global proliferation of commercial nuclear energy, which the Japanese government to immediately suspend all nuclear operations and encouraged other countries with nuclear power capabilities to reassess their reliance on nuclear energy. While Japan has since reopened only 6 of the country's 53 reactors, and resumed construction on two more in Oma and Shimane, both public opinion and prevailing policy remain strongly anti-nuclear, and the country is unlikely to see installed nuclear capacity rise to anything near pre-2011 levels.

A similar withdrawal of public support, and resultant policy changes, have materialized in a number of developed nations following Fukushima. Germany, Belgium and Switzerland – where a ban on the construction of new reactors has even been enshrined in the Constitution – have all announced plans to phase out nuclear power fully in the wake of Fukushima, and France, the largest producer and traditionally most stalwart proponent of nuclear power, passed the Energy Transition for Green Growth bill in October 2014, setting a target of lowering nuclear contribution to electricity supply to 50% in 2025 from its current level of 75%. These announcements perhaps signal the beginnings of a greater trend away from nuclear and towards renewables in these regions.

Elsewhere in the developed world, however, governments have begun to look more favorably on nuclear power. In the US, for example, Donald Trump has voiced strong support for nuclear energy; this may be yet to materialize as policy, but there is a chance that he may seek to reverse the fortunes of American nuclear power after the financial collapse of Westinghouse (a historically-significant global supplier and contractor of nuclear power plant technology and infrastructure) last year.

On the whole, however, developed countries remain ambivalent over nuclear power, with many opting for other non-fossil fuel energy sources like wind power or solar to meet Paris Agreement targets. Developing countries, however, are poised to embrace it, with especially strong growth in nuclear capacity seen in China, which alone accounts for 38% of all pressurized water reactors (PWRs) currently in construction and 43% of all planned PWRs. Other regions with high uptake are the rest of Asia, which accounts for 18% of under construction and 17% of planned PWRs, the Middle East, which claims 9% and 23% respectively of under construction and planned PWRs, and Eastern Europe, which is accounts for 20% and 8% respectively.

Figure 12 Number of PWR reactors by region

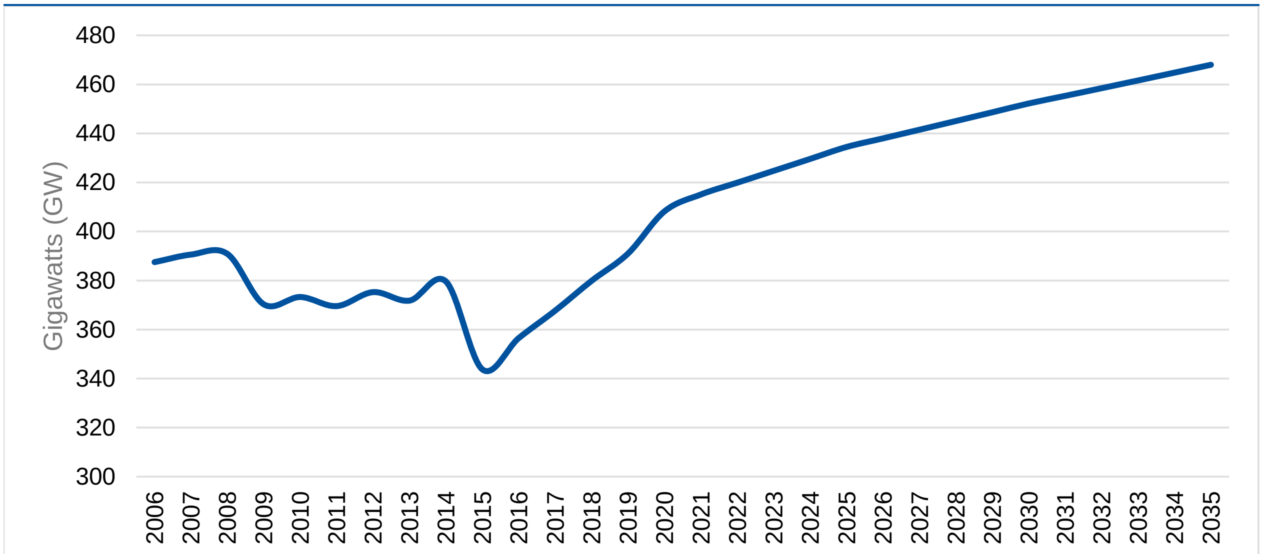


Data: World Nuclear Association

For nations such as China, India and Pakistan, nuclear energy offers a way to seek to grow and develop with a limited carbon footprint; the potential energy capacity that nuclear power can offer means that these nations can provide for a large and growing population while curbing air pollution levels. Several other are also in the planning stage of nuclear development, especially in the Middle East: Turkey, Jordan, and Saudi Arabia, as well as Indonesia and Vietnam, are planning to make their first forays into nuclear energy in the coming years.

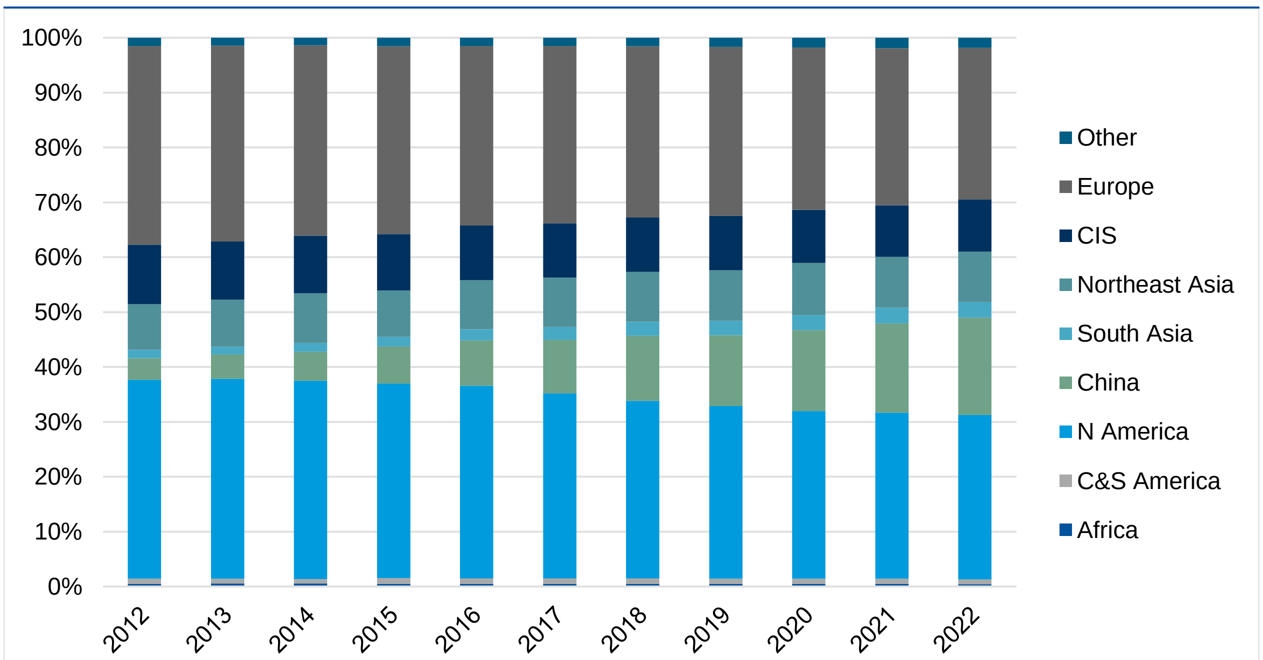
Despite current opposition, CRU expects nuclear capacity to reverse its recent decline and to return to a steady growth globally over the coming years; although ageing reactors in the West are increasingly being replaced with natural gas or renewable sources, or even having their lifespans extended by up to 100 years in some cases, the harnessing of nuclear power for commercial energy production remains a matter of national prestige for developing countries.

Figure 13 Global nuclear capacity



Data: CRU

Figure 14 Total nuclear power generation capacity by region



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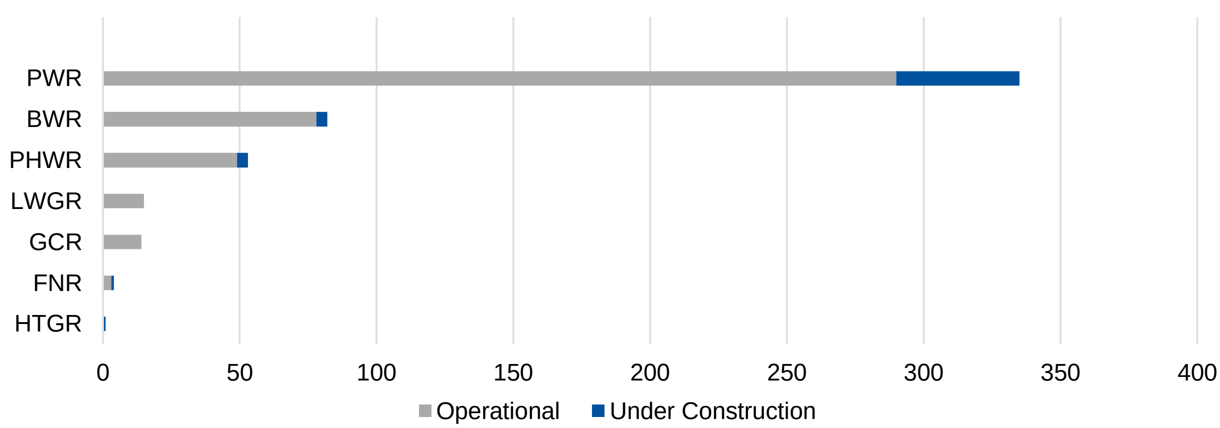
1.2.1. Silver demand in RCCAs

Silver demand in the nuclear sector is largely limited to its use in control rods. The rod cluster control assemblies (RCCAs) are inserted into the reactor to control the rate of fission, and as such must be made of a material which is: capable of absorbing neutrons without undergoing nuclear fission itself, has a high mechanical strength, and is resistant to corrosion. Common elements used include cadmium, boron, carbon, cobalt, silver, hafnium, gadolinium and europium.

The two most common materials used are boron carbide and an alloy which is 80% silver, 15% indium and 5% cadmium (Ag-In-Cd). The material used largely depends on reactor design, with most designs favoring the use of boron carbide, including pressurized heavy water reactors (PHWRs), gas-cooled reactors (GCRs), boiling water reactors (BWRs) and light water graphite reactors (LWGRs). Typically, Ag-In-Cd rods are found in pressurized water reactors (PWRs).

However, PWRs make up the clear majority of commercial reactors globally, accounting for 64% of operational reactors and 84% of those under construction in 2017. Other designs tend to be more regional variants, with PHWRs being favored in Canada, GCRs almost exclusively in the U.K, BWRs in the U.S, Taiwan and Japan, and LWGRs – of which the most famous is Chernobyl 4 – in ex-Warsaw Pact nations. Because of this, the majority of RCCAs – especially those under construction for use in new reactors – are 80% silver by weight, potentially representing a respectable chunk of future silver demand, should global policy call for a widespread uptake of nuclear power.

Figure 15 Global number of reactors by design



Data: CRU

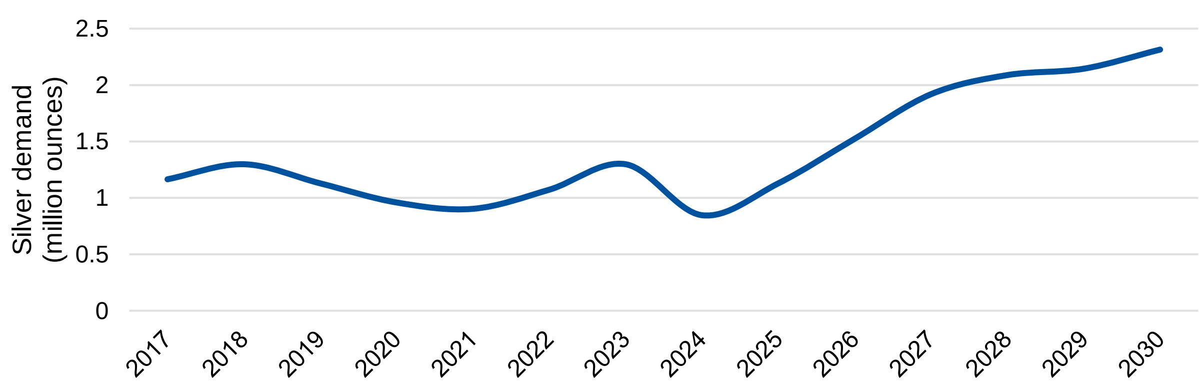
1.2.2. Drawbacks for silver demand

Nonetheless, however strong the global pipeline for nuclear capacity may be, there is no guarantee that this will translate into a noteworthy rise in silver demand, not only because each reactor uses only a small amount of silver, but because an RCCA has a low rate of replacement, since it catalyzes nuclear reactions rather than being consumed in the reaction. Therefore, the driver of silver demand in this sector is the continued addition of new nuclear capacity, as existing facilities will only have minimal ongoing silver demand once constructed.

The average silver content in a reactor can vary widely with nuclear generation capacity, which can be anywhere between 0.3GWe (Chashma, Pakistan) and 1.66GWe (Taishan, China); however, the average capacity is 1GW, and more than 56% of PWR reactors are between 900 and 1.2GWe in capacity, utilizing an average per reactor of 40 RCCAs containing 20 individual rods. This amounts to roughly 71 thousand ounces of Ag-In-Cd, or 56 thousand ounces of silver.

Moreover, one of the advantages to using Ag-In-Cd rods over relatively inexpensive BC_4 is their durability. Even though Ag-In-Cd rods are liable to some degradation over time – mainly due to cracks in the cladding caused by swelling from the absorption of neutrons – they are not designed to be 'used up', nor is it often necessary to replace them. Estimates put their lifetimes at 14 years in a control bank and 22 years in a shutdown bank. Even assuming a high silver demand scenario in which all PWRs replace all rods every 14 years, the annual silver consumption of the commercial nuclear industry would have represented 1.2 million ounces of global annual silver demand, doubling to 2.3 million ounces in 2030. This is also ignoring the occurrence of thrifting: some new Stage IV reactors are being equipped with control rods that are boron carbide for the top 60% of their length and Ag-In-Cd for the bottom 40%.

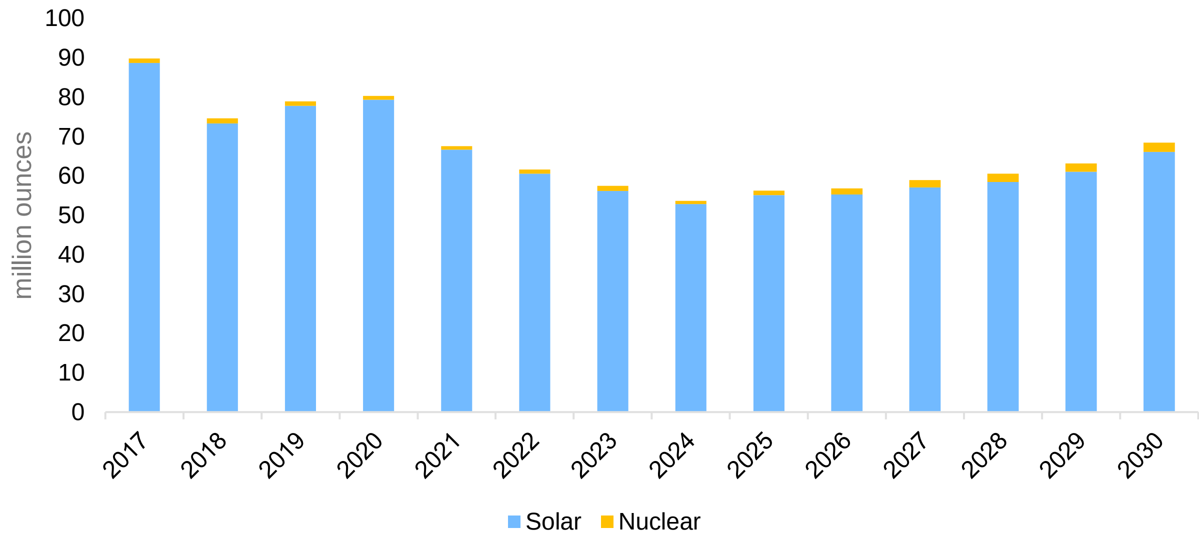
Figure 16 Global annual silver demand in commercial nuclear energy



Data: CRU

The role of nuclear power in the green revolution will therefore have a limited effect on total industrial silver demand; even in an optimistic scenario, where silver demand doubles from 1.2 million ounces to 2.3 million ounces per year by 2030, nuclear energy would still represent less than 1% of industrial silver demand.

Figure 17 Total silver demand in the solar and nuclear sectors



Data: CRU

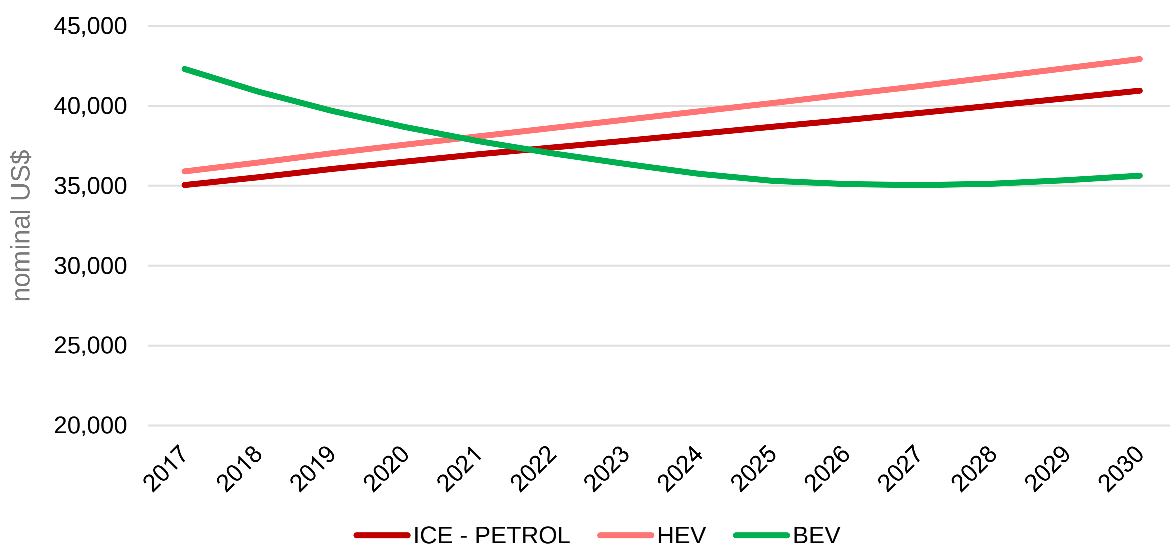
2. Transportation and related infrastructure

A pervading theme of both the green revolution and international development in general is how energy is being consumed increasingly in the form of electricity. Where families in now-developed areas once burnt coal for heating, cooked on wood stoves, and lit their homes with gas lamps, they now fulfill most of their energy needs through electricity with only certain needs being met via natural gas or propane; likewise, developing areas will come to rely less on these traditional sources and more on electricity in the coming decades. This transition has been key to pollution control from the very beginnings of environmental policy; a cornerstone of the UK's 1956 Clean Air Act, for example, was the banning of coal fires for residential heating in urban areas in favor of the introduction of the hot water convection radiators seen today.

One area of consumption that has resisted this transition thus far, however, has been transport. The electrification of the transport sector has always faced the fundamental problem that a physical connection to a grid compromises a machine's mobility, with solutions traditionally only being in place in cases where the mode of transport in question travels along a fixed route – for example, trains, trams and trolleybuses. This has left the internal combustion engine (ICE) – a century-and-a-half old technology – with no viable alternative, especially for private modes of transport where consumers expect full mobility.

Although other sectors, such as communication, have solved this issue with the use of batteries for electricity storage, the sheer amount of energy involved in travelling by car has traditionally been beyond the scalability of lithium-ion battery technology. However, newer generations of battery material technology (e.g. the types of metals or materials used to create the cathode components of the battery) have come with increased power densities and rapidly plummeting costs, meaning electric cars are now able to not only fulfill the needs of most car owners, but also compete in price with traditional ICEs. The diagram includes our view on the total cost of ownership[1] for three types of vehicles sold within North America: a traditional gasoline-powered vehicle, conventional hybrid (HEV) and a battery-powered electric (BEV). BEVs represent a significant upfront cost but have lower maintenance and charging expenses over the lifetime of the vehicle. We believe that perceptions of the total cost of ownership are one of the key drivers of electric vehicle adoption by both the household and commercial markets.

Figure 18 Forecast total cost of ownership for BEVs vs ICEs within North America

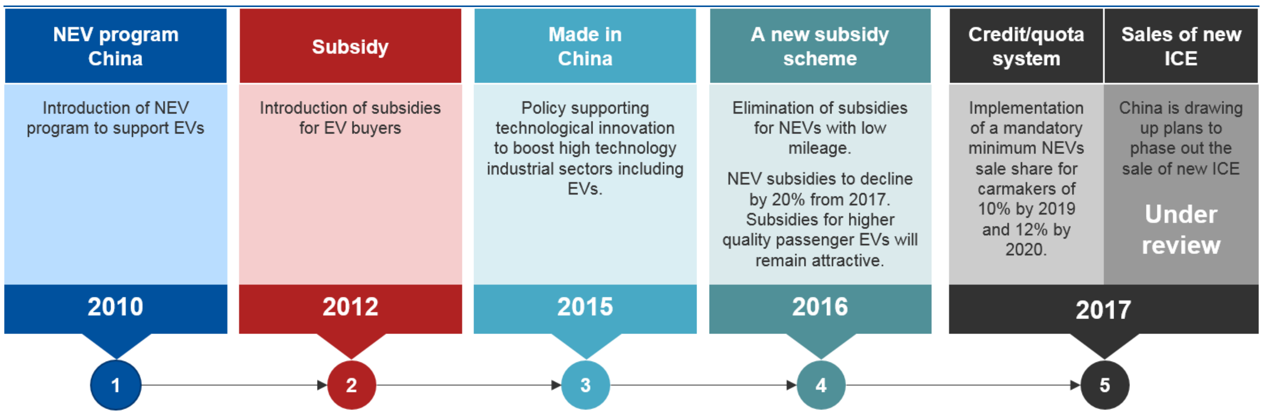


Data: CRU, *Includes the effects of subsidies and weighted-average costs of initial capital investment, maintenance costs and costs of electricity and/or gasoline consumption. Data only for North America.

[1] Total cost of ownership includes initial purchase price, plus fuel costs, plus maintenance costs, over the full lifespan of a vehicle

Recognizing this as an opportunity to curb pollution in urban areas, governments across the globe have included policies that favor the uptake of electric vehicles (EVs) into their broader strategies to tackle climate change. China, the largest car market in the world, has introduced a series of policies on the issue which have gradually moved from incentivizing consumers to buy electric to punishing manufacturers who fail to offer EV models.

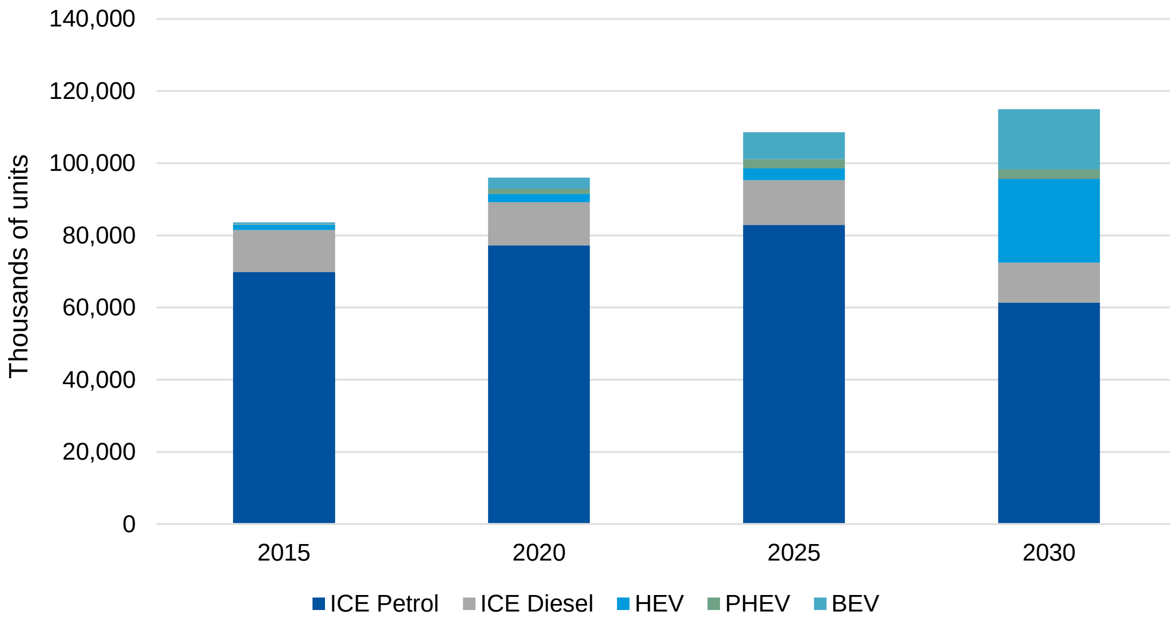
Figure 19 Chinese EV policy



The logical conclusion of this gradual policy change is an effective ban on the sale of new ICEs. A few years ago, such a prospect would have been deemed outlandish; however, China would be merely joining a host of other nations that have already made the commitment to phase out the purchase of ICEs by a certain date, including Norway (2025), Germany, India and the Netherlands (all 2030), the UK and France (2040), and seven U.S states (2050).

Spurred on by this overwhelming policy support, as well as falling costs and greater understanding of the benefits of electric vehicles, new energy vehicles (NEVs), such as battery electric vehicles, (BEV), and plug-in hybrids (PHEVs) will account for an ever-increasing proportion of global vehicle sales. CRU estimates that by 2030, NEVs may account for as much as 17% of global car sales, with hybrids accounting for an extra 20%.

Figure 20 Total global light-duty vehicle demand by powertrain



Data: CRU

This uptake is likely to bolster the pre-existing trend of increasing silver consumption in the automotive industry. Silver's high electrical and thermal conductivity and resistance to corrosion make it an ideal material for use in electronics, and as cars demand more and more electricity to fulfill certain on-board functions, so too does the industry demand an increasing amount of silver for the manufacture of electrical contacts and motor control switches.

The outlook for silver demand in the transportation sector looks even brighter when it is taken into consideration that the related infrastructure needed to facilitate a widespread proliferation of BEVs and PHEVs may also require large amounts of silver. A potential gamechanger for transport markets is the use of inductively coupled power transfer (ICPT) technology to wirelessly charge vehicles through the use of silver-plated induction coils.

This chapter will evaluate the increasing use of silver contacts and address both the economic and technologic viability of ICPT's use in BEV charging infrastructure. These two areas both have the potential to greatly impact silver demand in the coming decades.

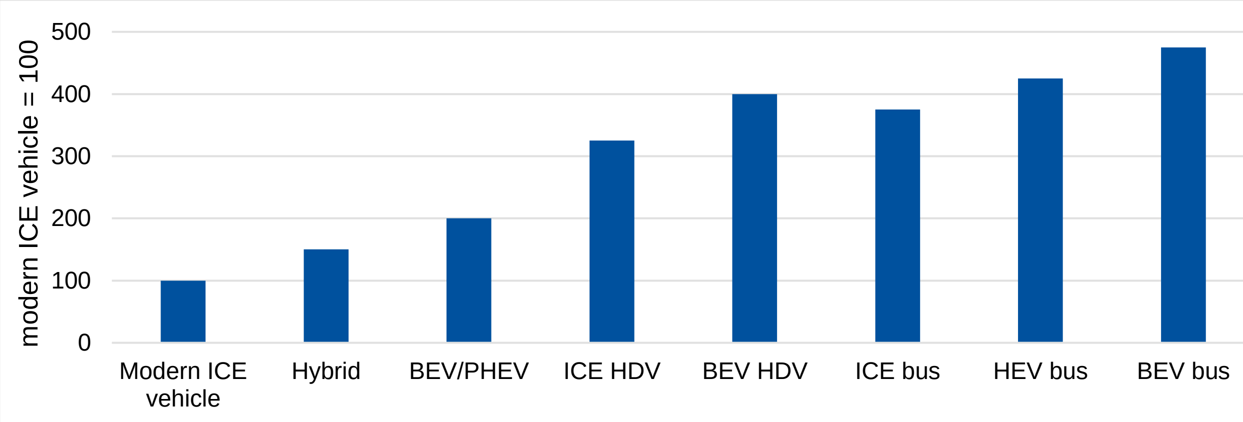
2.1. Silver in electrical contacts

Silver has been a ubiquitous presence in all cars since the propagation of electric starter motors and headlamps in the 1920s. Since then, electrical power has superseded other forms of energy in the fulfillment of more and more functions over time; from the introduction of electric switches to replace crank-handled window controls to the proliferation of onboard diagnostic computers and entertainment systems, the increasing sophistication of automotive technology has required larger and larger silver loadings.

The modern car therefore already relies much more heavily on electricity than it used to; where an average car once relied on electrical power for only the starter, engine control unit, lighting system, and a few other minor functions, even the most basic modern ICE cars use the vehicle's onboard battery system for a host of different functions, such as anti-lock braking systems, traction control, vent control, and safety systems. With the rise of new energy vehicles (NEVs), the size and complexity of the average car's electrical system will only grow, as fully electric powertrains and related features such as regenerative braking become the norm.

It is difficult to put a number on the exact silver content of the average car, especially given the wide range of vehicles available on the global market, representing a plethora of different price ranges and applications. An average ICE car may have as many as 40 individual contacts, while a high-range model with extra features will have up to 50. A hybrid car would contain a greater amount still, while a top-of-the-line NEV could have as much as double the amount of an average ICE car. Trucks and buses, given their use of additional features such as modular door control, additional brake and stability controls, and trailer connections, have an even higher number of contacts. In addition, electric vehicles use copper busbars (often plated with silver or silver alloys) to connect battery modules or cells components in series or parallel, inverters and converters with silver-plated connectors, and various other components with silver-plated or silver-alloy contacts that are not found in traditional ICE vehicles.

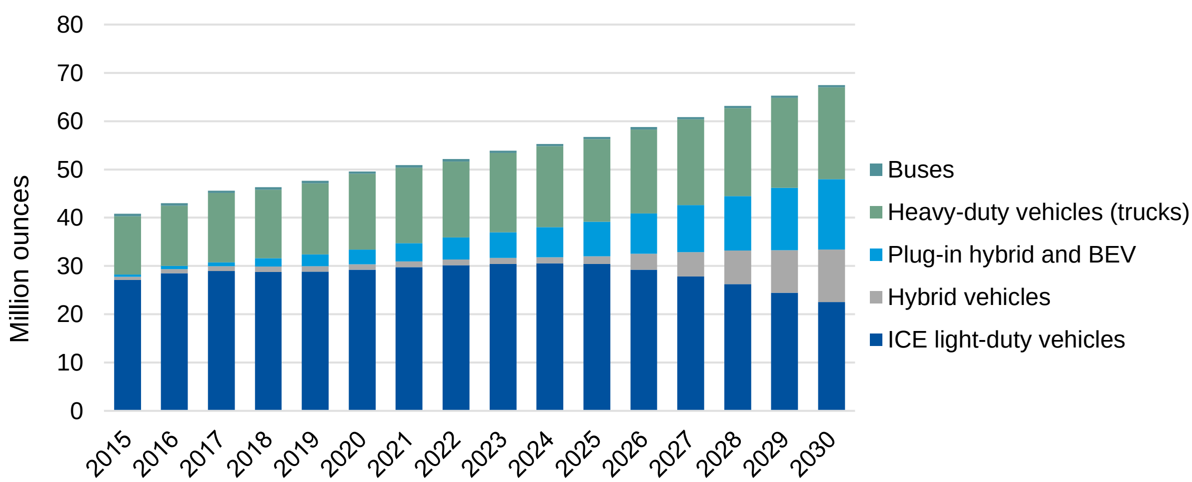
Figure 21 Comparative silver use in automotive by powertrain type



CRU, *excludes silver conductive pastes typically used in defogging/deicing applications; figures used in this chart are indexed values with a typical internal combustion engine vehicle (gasoline) as the base case

While the average silver use in each electrical contact or component is generally tiny, when summed across the myriad electric components currently installed in vehicles, the aggregate silver demand is significant. Automotive sales numbers are expected to rise overall, with CRU predicting global annual sales to be 26% higher than current levels by 2030, facilitated by higher incomes in developing regions. The continued electrification of automobiles, however – and not just in NEVs, but in all new cars – will cause silver demand to rise at a faster rate than this, reaching 148% of current levels by 2030. This implies that the approximate silver demand in electrical automotive applications will reach almost 70 million ounces in 2030, up from around 45 million ounces in 2017.

Figure 22 Estimated silver consumption in auto electrical by powertrain type



Data: CRU, SI, *excludes silver consumption in defogging applications (conductive pastes)

2.2. Inductively coupled power transfer

ICPT works by passing a current through a coiled wire, creating an electromagnetic field that in turn induces a current into another coil. The electrical intensity of the field can be enhanced by using copper wire as the transmitting coil, while silver plating the receiving coil can reduce resistance and so further improve the efficiency of the transfer.

Research into the technology's use in wireless charging was first undertaken in earnest in 2006, although working models had been created before; the technology is therefore already commercially available and increasingly common, especially for the smaller-scale application of high-end mobile phone chargers. For electric vehicles, however, the technology is still rather niche, with commercially available options for domestic wireless chargers only offered by third parties, such as Plugless Power, although major car manufacturers such as Kia and BMW have tested prototypes.

Although there are some problems associated with scaling inductive chargers to the level needed for BEVs, such as losses in efficiency and the need to precisely align the transmitting coil and receiving coil, these concerns have been greatly reduced as the technology matures. Efficiencies have improved from 40% in 2007 to 90% in 2016, and a series-parallel configuration on the receiving coil has been shown to charge with less precise alignments that would be typical in actual use.

Current charging infrastructure can be broken down by power rating into three 'tiers', as shown in Table 1. These tiers vary significantly in application, with consumers typically having widely different habits in their day-to-day use. Because of this, it is worth briefly considering each tier separately when discerning how inductive charging technology might disrupt traditional charging markets.

Table 1 Overview of plug-in charging technology

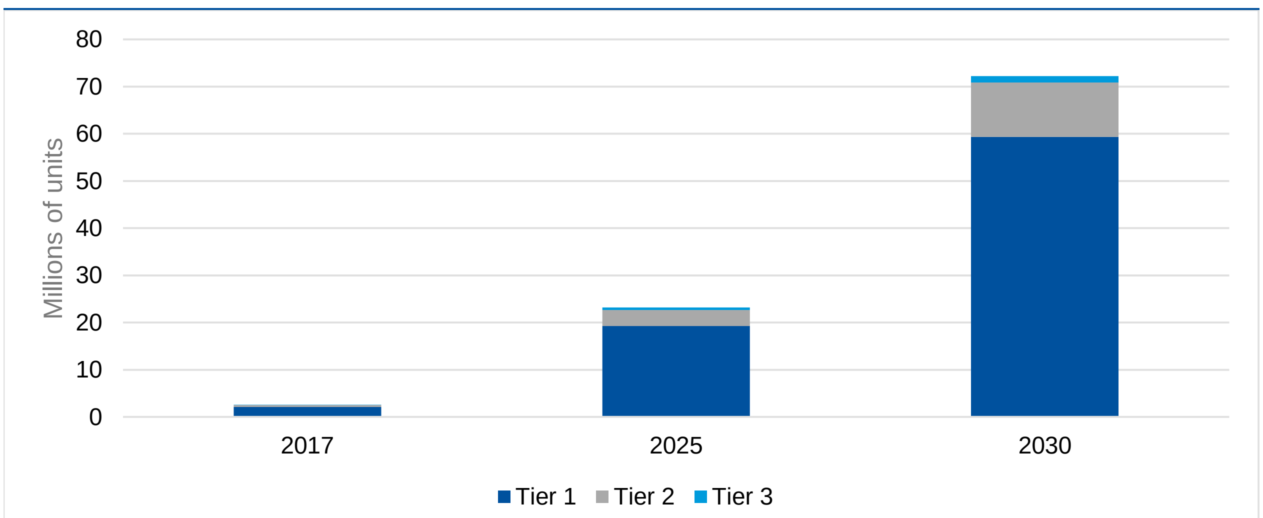
Classification	Tier	Current	Power	Public/ private	Setting	Charging time	Silver intensity of an equivalent ICPT*
Slow charger	1	AC	≤ 3.7 kW	Private	Home	6-12 hours	27.1g
	2		> 3.7 kW, ≤ 22 kW	Semi-public	Workplace On-street residential Apartment car parks	2-6 hours	71.0g
				Public	Public charging stations On-street non-residential Shopping centers Public car parks Hotels Airports Leisure centers		
Fast charger	3	DC	> 22 kW, < 200 kW	Public	Public charging stations	15-45 minutes	Not available

Data: CRU, ORNL, Plugless Power
* Estimates based off an assumed plating thickness of 4 microns.

2.2.1. Tier 1 – domestic chargers

As Figure 23 demonstrates, the clear majority of EV chargers, both now and in the future, are found in private garages and driveways. These low-wattage domestic chargers will continue to account for more than 80% of all charging points throughout the 2020s and represent a potential silver demand of 10.2 million ounces by 2030.

Figure 23 Global number of chargers by tier



Data: CRU

ICPT chargers are already commercially available within this tier, with a number of manufacturers producing models that are able to compete with traditional domestic chargers in terms of technical specifications. Plugless, for example, a market leader in inductive charging in the US, produces two models which can boast a continuous power output of 3.3kW and 7.2kW respectively. A similar market leader in plug-in charging infrastructure, Pod Point, offers models with similarly rated power outputs of 3.6 kW and 7 kW, as well as a 22kW model sold at a premium.

Without further technological advances, there are few selling points to motivate a consumer to choose wireless charging in this category. The usual benefits of wireless charging do not apply to cars in the domestic context; though the owner of a wireless phone charger may find it helpful to be able to intermittently use the phone with ease while it is charging, by its very nature a car is rarely in use while parked. The convenience of owning a wireless charger is therefore limited to a few small benefits: they don’t pose a trip a shock hazard, and a consumer does not need to remember to plug and unplug their vehicle, or expend a few moments doing so. A domestic wireless charger would therefore have to be competitive in terms of price to have gain any noteworthy market share over traditional plug-in chargers. If this is to be done, however, significant reductions in cost will have to be made: the current price of a Plugless 3.6 kW charger, U.S.$5999, is more than 10 times the cost of a similarly rated plug-in charger. That being said, the technology is not without potential in the domestic market, and the benefits of hands-free charging are more likely to be felt when autonomous driving (or at least self-parking vehicles) become more conventional. In a future where an owner can hail his own vehicle and send it home when done, or otherwise park automatically, removing the need to plug in a charger manually becomes a much greater convenience.

A technology such as this will always need to prove its added benefits are worth its inflated price, and although it is currently hard to justify, inductive charging may well have greater potential as time goes on. Prices are likely to drop should economies of scale be achieved, and a greater acceptance of self-parking vehicles could boost the value of having a wireless charging system; as the gap between price and added benefit narrows, wireless charging becomes more likely to make inroads into the market. Just as the electric vehicle market oversaw the price of lithium-ion battery production more than halving from 2010 to 2017, CRU expects the price of inductive charging to drop as well.

2.2.2. Tier 2 – public slow chargers

The most powerful inductive charger tested but not yet commercially available has a rating of 20kW and an efficiency of 90%, which is comparable to slow chargers currently available on urban streets and in car parks. This was achieved by the U.S Department of Energy in 2016, and though the technology is still in its nascence, it demonstrates that inductive charging can be used for public applications.

It is somewhat easier to see how inductive charging may become the norm in this sector. Use would no doubt be more intermittent, with drivers ‘topping up’ in hour-long sessions while running errands. The charger could be fully integrated into a premium parking space, with the cost of electricity factored into the cost of parking, reducing the risk of vandalism or accidents. The capital cost would be shouldered by local councils or business owners, keen to support the technology either as a matter of policy or as a selling point.

Though not as prevalent as Tier 1 chargers, representing 15% of the charger market by numbers, an inductive charger would nevertheless require greater silver loadings to enable a larger power rating, therefore representing as much as 7.1 million ounces of silver p/a by 2030. And although the costs would undoubtedly be much higher than plug-in chargers here as in the Tier 1 market, there are likely to be commercial organizations who would be willing to shoulder the cost in return for the prestige that being an early adopter of new technology can confer. For this reason, as well as the greater perceived benefits of this sector, it is likely that any great push towards reaching economies of scale will be sparked by demand here.

2.2.3. Tier 3 – fast chargers and future in-road chargers

Tier 3 plug-in chargers have a power rating of over 200 kW, allowing them to fully charge an EV in 15 minutes. This makes them an essential part of any large-scale charging infrastructure as they allow a car to travel long distances with a minimal amount of time spent on charging.

Even though there are inductive chargers currently able to transmit 200 kW of power, they are not yet suited for use on cars. The intensity of the charging coil’s magnetic field is dependent on the coil’s radius and the number of turns, meaning the power capacity of a charging coil is limited by its size, and, the degree to which the receiving coil can capture the transferred energy is dependent on it being an optimal size in relation to the transmitting coil; because of this, it is not currently possible to make a 200 kW charger with a receiving coil small enough to fit onto an average passenger car. However, inductive charging technology lends itself to an application that would fulfill the same purpose of extending an electric car’s range: electrified roads, whereby a series of lower-power inductive chargers buried underneath a road would allow a car to charge while driving. This application is one that showcases best the advantage that inductive charging can offer over traditional plug-in charging – by removing the need for the vehicle to stop while charging, an inductive road effectively extends a vehicle’s range indefinitely.

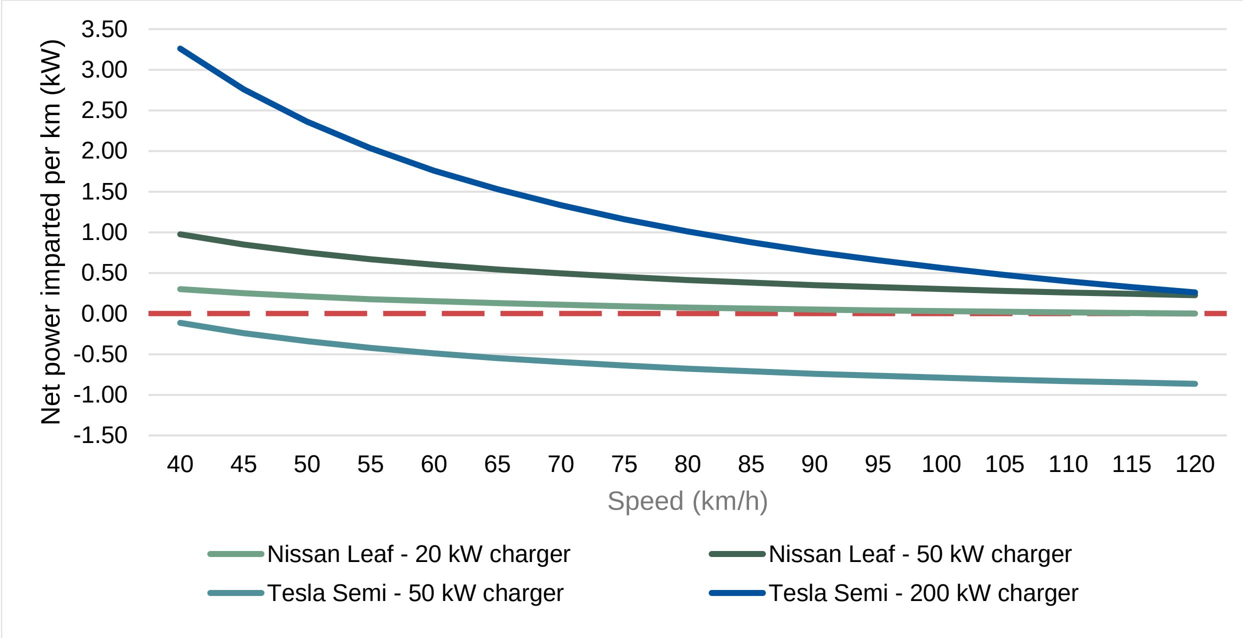
This prospect has some extensive and important implications for the transport sector. Even the longest-ranged electric car, travelling at 80 km/h, must spend 30 minutes charging at a fast charger for every 7 hours driven. Cutting out the need to charge would therefore reduce long-distance journey times by 7% - a huge efficiency gain, and one that is particularly useful when applied to heavy-duty freight vehicles. Indeed, when paired with autonomous vehicle technology, it creates the possibility of a vehicle that can drive for days without stopping, and whose range is only limited by its own resistance to wear.

The connection to the freight sector is key as it is an industry governed almost entirely by the twin needs to keep costs down and freight volume up. Therefore, unlike tiers 1 and 2, the successful penetration of ICPT into this sector is reliant not on it competing in cost with plug-in chargers, but on whether its potential is enough to not only enable the use of battery technology in heavy trucks, but also to offer savings in efficiency that outweigh initial costs of installation. This is a question currently being studied by many government bodies, such as the U.S Department of Energy (US DoE) and the European Commission's FABRIC project ("**f**e**a**si**b**ility analysis and development of on-**r**oad charg**i**ng solutions for future electric vehi**c**les").

There are still a number of issues that make this kind of application commercially unfeasible – the most pressing being the efficiency and speed with which an in-road charger could currently power a vehicle. Coils often require a precise alignment to impart charge, and while some designs of in-road charger currently utilize large, meters-long rectangular coils which effectively extend the amount of space in which a receiving coil would be induced, the high speeds at which vehicles travel along long-distance motorways mitigate this advantage by limiting the amount of time spent over each individual coil.

Consequently, current technology is only efficient enough for a small passenger vehicle with an energy efficiency of 15 kWh/100km to maintain its charge travelling at any speed. Figure 24 shows charging rates for chargers of various power ratings covering a kilometer of road, demonstrating how the current highest rated charging technology (20 kW) can maintain a car's charge up to 120 km/h. This is consistent with test results from both the USDE and FABRIC. Should the USDE's target of a 50 kW in-road charger be achieved, it would represent a significant gain for passenger vehicles; however, it would still not be enough to power a Tesla semi-truck at its current predicted efficiency of 124 kWh/100km (<2 kWh/mi) – although a road with a rating of 200 kW, for which a Tesla truck would be able to accommodate a sufficiently large receiver coil, would be able to impart a momentous amount of charge.

Figure 24 Estimated charging rates for various charger power ratings



Data: CRU, USDE

The limiting factor, then, is that the technology is not yet significantly advanced to be feasible in the area it would most benefit. Moreover, the sheer amount of infrastructure needed to facilitate this level of charging makes it currently uneconomical for use on passenger vehicles. As it stands, two in every three kilometers of road would need to be electrified to maintain the charge of a car travelling at 80 km/h; even if the USDE achieves its target of 50 kW, EVs will require a 25% electrified road to maintain charge. In order to compete with a Tier 3 fast charger, this technology must be able to extend a vehicle's range by the same amount – that is, double it. In a Nissan Leaf with a range of 270 km, this would require a total of 180 km of 20 kW road or 70 km of 50 kW road.

The drawback of such a build is immediately apparent. Not only would such a road require a monumental upheaval of current transport infrastructure, requiring the rebuilding of large stretches of some of the world's busiest roads; it would also incur significant capital costs. The cost of installing a single Tier 3 charging station is estimated to be U.S.$15,000; assuming a bank of 12 chargers is needed at a busy motorway charging station, the final cost of U.S.$180,000 is still significantly lower than the cost of an in-road inductively coupled power transfer system at approximately U.S.$350,000/mile. Despite the high costs, a few municipalities have announced the rollout of in-road power transfer systems, most of which were publicly funded. For example, Sweden recently inaugurated its first 'electric road', a 1.2 mile stretch of highway from Stockholm to a regional airport that charges users for the quantity of electricity consumed while moving. Although the total cost exceeded U.S.$2 million, the proof of concept showed that public regulators can devise a way to charge users for electricity while on the move, similar to automated tolls on many interstates.

That being said, in commercial freight and public transport sectors, the potential benefits of in-road charging may thoroughly outweigh the costs, especially should prices come down. In these industries, high-power inductive charging has a dual advantage, dealing with both vehicles large enough to mount high-power receiver coils onto and industries where maintaining speed and efficiency is key to cost reductions. The maximum potential benefit may only be realized when autonomous driving is taken into account: a vehicle which could effectively travel indefinitely, without needing to stop for either refueling or for the needs of a driver, would truly revolutionize the trucking industry by slashing both the time needed to move freight and the time between contracts.

For the public transport industry, high-powered inductive chargers are already a reality, with Momentum Dynamics being commissioned to install a 200kW system in Wenatchee, Washington in April 2018 for the city's public battery-electric bus fleet. As mentioned earlier, these fast-charging systems are currently most amenable to the electric bus market, where the long-term benefits of providing opportunistic charging for vehicles on predetermined daily routes overweighs initial capital investment costs. This will likely be joined by further installations elsewhere, as the benefit of cutting out the need for midday charges may prove to be enough of a draw for public transit operators.

It will be a while before this technology becomes cost-effective enough for governments to consider mainstream implementation; nonetheless, the potential growth in demand for silver in this sector is huge. As such, a system would require not only a widespread infrastructure but also high-power coils requiring greater silver loadings.

2.2.4. Inductive charging conclusions

The technology behind inductive power transfer has come forward in leaps and bounds in the past decade, turning a once-impractical technology into a method of transferring power that is quick, efficient, and easy. This is reflected in its newfound commercialization, with inductive chargers carrying enough of a sense of technological advancement and consumer convenience to generate sales despite their considerable premium at present.

For some, ICPT chargers for automotive applications remain an expensive gimmick, but it would not be the first time an oft-disparaged technology became successful. There are some definite benefits to the technology which could revolutionize certain areas of the transport sector in terms of both profitability and convenience, but a substantial reduction in price is needed before these areas can be properly explored. If prices do plummet, however, the transport sector could well provide a silver lining when set against a lack of growth in silver consumption in the energy sector.

Conclusions

As this report demonstrates, silver has played and will continue to play an integral role in the future viability of green energy generation and mobility. Although thrifting in solar photovoltaic cell manufacturing may present headwinds for industrial silver demand in renewables generation, the potential for greater silver consumption in the rapidly growing electric vehicle market offers new market opportunities for industrial silver use. In particular, the growing need for power-efficient, high-voltage wiring harnesses in battery electric vehicles and a gradually rising interest in wireless charging technology and infrastructure present significant potential for silver consumption. Ultimately, as the world increasingly transitions from an energy market dominated by nonrenewable combustibles to one powered by cleaner electricity, silver's unique electrical and mechanical properties will broaden the precious metal's already wide range of green technology applications.

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