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Prospects for silver demand in ethylene oxide and photovoltaics

A report prepared for The Silver Institute

THE INDEPENDENT AUTHORITY
MINING | METALS | FERTILIZERS

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1. Introduction

Silver is a soft, white and lustrous precious metal which has the highest electrical and thermal conductivity of all metals. It is found in pure form, or more commonly with gold, lead, and zinc. With a history that dates back more than 5,000 years, silver has had valuable uses throughout the ages. Today, it is a common element in jewelry, tableware, and coins and bars. Its thermal and electrical conductivity properties also make it an essential industrial metal.

In 2015, of the 1,170 million ounces (Moz) of physical silver consumed, 589Moz were used for industrial fabrication, equivalent to 50% of total physical demand. Two of the most everyday industrial uses for silver are as a catalyst for the production of ethylene oxide and in photovoltaic (PV) cells (more commonly known as solar panels). Ethylene oxide (EO) is a vital raw material for the production of ethylene glycol, which in turn is used in the production of antifreeze coolants and polyethylene terephthalate (PET); a resin of the polyester family used in fibres for clothing as well as plastic bottles and food containers. These two expanding industries will drive increases in EO capacity and, correspondingly, demand for silver.

On the other hand, the number of solar panel installations is forecasted to rise steadily in the coming years. A combination of carbon emissions legislation, government policies and a decrease in the cost per gigawatt (GW) of electricity generated using PV will increase the number of solar panel and therefore silver demand.

This paper will therefore look into silver demand from the EO and the PV industry separately, and give forecasts on respective silver demand from 2016 to 2020.

2. Ethylene oxide: steady return to growth

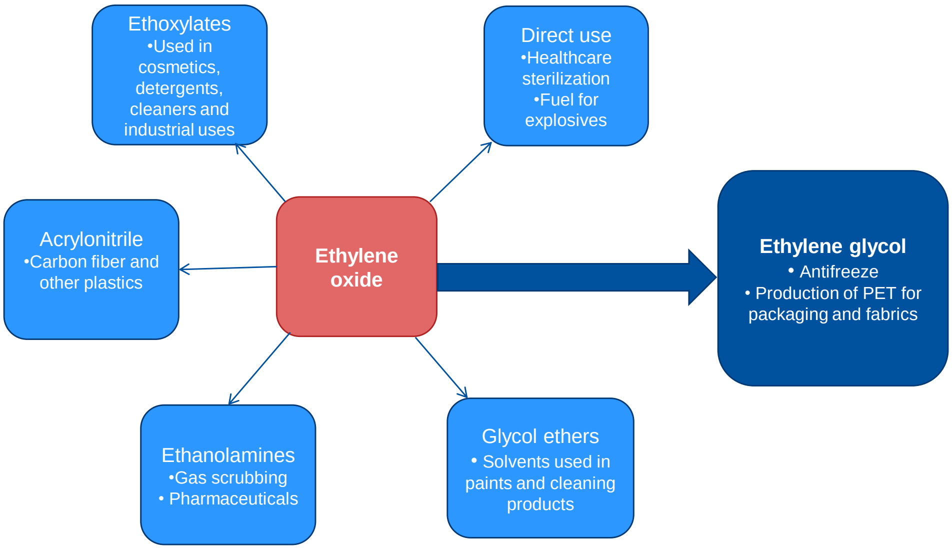
2.1 An introduction

Wherever you turn to look, there will be something in our view that silver has helped to produce. It is no exaggeration to say that ethylene oxide (EO) forms the fabric of the consumer society. Without it we would not have polyurethanes which go into buildings, ships, bedding and furniture; polyesters used for example in clothing and as polyethylene terephthalate (PET – raw material for plastic bottles); softeners (cork, glue, casein and paper); plasticizers; solvents; cosmetics; lubricants; and last but not least, antifreeze in vehicles. The irony is that the production of ubiquitous EO at low enough cost can only happen in the presence of much, much rarer and more expensive silver.

That crucial connection is made because the commercial production of EO uses silver as a chemical catalyst. This means that as ever greater volumes of EO production are required to satisfy a growing downstream industry, more silver will be needed to catalyse this EO production. But also even if EO production were to stabilize, the replacement demand for silver in EO production due to the gradual degradation of the catalyst will continue to be an important source of industrial silver demand.

In this report we will quantify this powerful underlying demand for EO until 2020 and thus the consumption of silver in this application. Currently the EO sector is estimated to be in overcapacity. Our purpose is also to match this against the profile of growing demand to predict the future implications for silver used in EO.

Materials produced using ethylene oxide have an incredibly diverse range of end uses, the most important being antifreeze and PET



2.2 How is silver used in EO?

While commercial EO is produced by a variety of methods, all are variants on direct oxidation, which was firstly developed in 1931 by T.E Lefort and requires silver as the base for the catalyst in oxidation. A catalyst is a substance that facilitates the process of particular chemical reactions. A catalyst itself either does not participate in this chemical reaction, or it is fully retrievable and undergoes no chemical change. That said, catalysts can eventually degrade over time and require replacement.

In effect, one can think of silver-based catalyst as a capital good used to produce EO. As a result, an increase in EO production generated by new consumer demands all around the world will need more silver. But as with any other capital good, there is also a demand for new silver arising from the depreciation after “wear and tear”.

Silver-based catalysts generally have a lifespan of five years, according to research supported by the Silver Institute. They are then recycled at some cost and reused as catalyst in future production. However, as the catalyst is used its efficiency can be compromised in a number of ways. Overheating within the reactors can cause sintering, a process by which the small silver nanoparticles accumulate, reducing the catalysts overall surface area and hence activity. The silver particles themselves can also be ‘masked’ by other chemicals within the system (known as poisoning). Again, this acts to reduce the quantity of silver available to catalyze the reaction, lowering efficiency. Once the catalyst is spent (i.e. its efficiency drops to a level deemed uneconomical), it is removed from the reactor and replaced with fresh material.

Around 10% of silver used in the EO industry is as replacements for deactivated catalysts. Therefore, our forecast combines the growth in silver demand from the EO industry into two parts, new catalysts required by new production capacity, and replacement material required by existing production capacity.

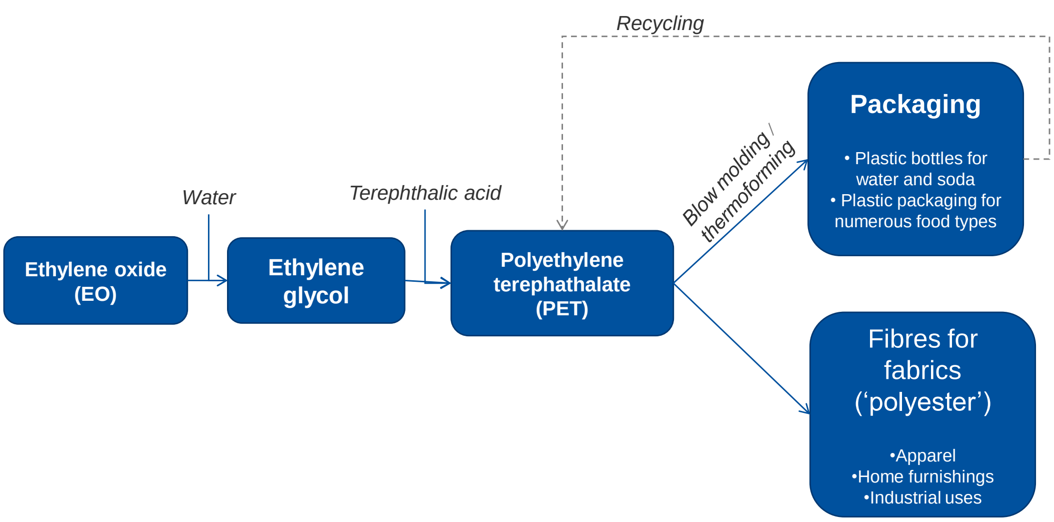
2.2.2 The two forces driving silver EO demand growth

There are two powerful underlying forces expected to drive the demand for silver in EO production. One, PET, is less immediately visible while the other, automotive, comes more easily to mind. But both are set to undergo a transformation of scale and type, especially in emerging consumer nations such as China. CRU estimates that together these two applications currently represent about 60-70% of all silver EO demand.

2.2.2.1. Packaging and the easy life

One of the many important end uses of EO is in the production of PET. This compound is produced by the reaction between ethylene glycol and terephthalic acid, and is used both in the production of fabrics, where it is usually referred to as polyester, and in plastic packaging, where PET or PET resin is the typical nomenclature.

PET is the main derivative product of EO and is used in packaging and textiles



The vast majority of single-serving bottles of water and a large proportion of soda bottles sold worldwide are made from PET plastic. PET is also popular for packaging salad dressings, cooking oil, peanut butter, shampoo, liquid hand soap, mouthwash, and other personal care items. Special grades of PET are used for microwavable or oven-proof food packaging. In general PET packages help the modern consumers save on time, space and weight compared to traditional reusable containers such as glass or porcelain. As higher incomes are associated with denser urban living, it also becomes cheaper to provide PET packaged goods in large scale through retail networks.

Given these advantages, as income levels approach global middle class standards, people are likely to use PET packaging much more frequently, and rely less on non-disposable packaging. The implication is that PET consumption in developing countries will increase faster than their GDP per capita levels. Moreover, all evidence suggests that PET is especially favoured by Chinese customers, who already consume more bottled water compared to people from countries of similar GDP per capita.

Given the steady long term economic and population growth, CRU estimates that the quantity of PET produced will increase continuously with a faster speed and become an important driver for EO demand in the future.

2.2.2.2. Cars, cars and cars

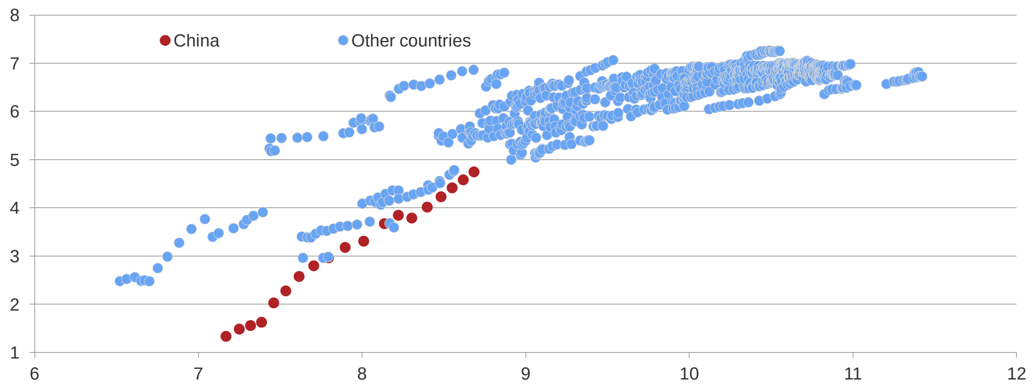
Another key application for EO is to produce antifreeze used in automotives. Waste heat removal from internal combustion engines in autos is typically done by water cooling. However, water in this instance is more typically a water-antifreeze mixture, where the antifreeze reduces the freezing point of the coolant and also increases its boiling point. If the coolant were to either freeze or boil, the engine would fail, so the addition of antifreeze means that engines can operate at a much wider temperature range, both high and low, than if just water were used. Antifreeze is used not just in cars but also commercial vehicles such as buses, trucks and coaches as well as aeroplanes. In addition, ethylene glycol is used as the main component of many de-icing (and anti-icing) fluids used for both aircraft and automobiles in cold weather, however its toxicity means that in some cases alternate fluids are preferred (e.g. propylene glycol for aircraft de-icing).

The important point is that, as antifreeze, EO use depends not on car production or new car sales but more directly on car usage. Thus EO demand expected to rise even after the development of a second hand car market, or a greater recourse to car sharing schemes.

CRU expects that global automotive use is set to increase. Continued economic growth and urbanization in China is set to boost its car population and therefore push auto density in the world's most populated nation towards the higher levels seen in more developed countries. At the same time, we would expect Europe and North America populations to keep using vehicles at high existing rates. Legislative and environmental changes may change the type of car, making it more electric, lighter or even more driverless, but in all events we expect usage to increase. Taking this into account, we estimate that the global car population is expected to increase by 155 million units between 2015 and 2020, exceeding the 1 billion units mark. We would expect a similar pattern for commercial vehicle usage, and therefore higher car usage need not imply less use of other automotives.

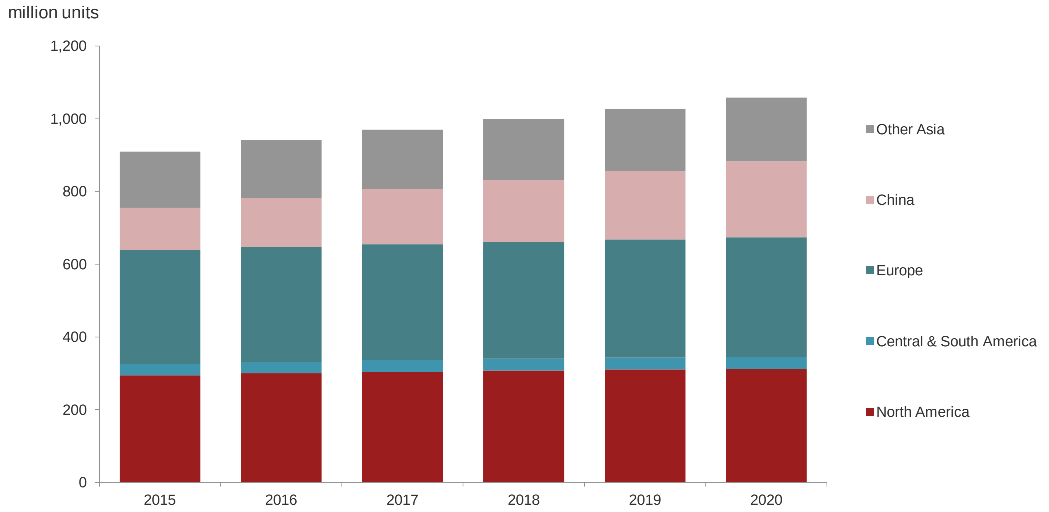
The bright prospects for car use in China

x-axis: ln (GDP/capita)
y-axis: ln (cars/1,000 active population)



Data: CRU.

World car population set to increase



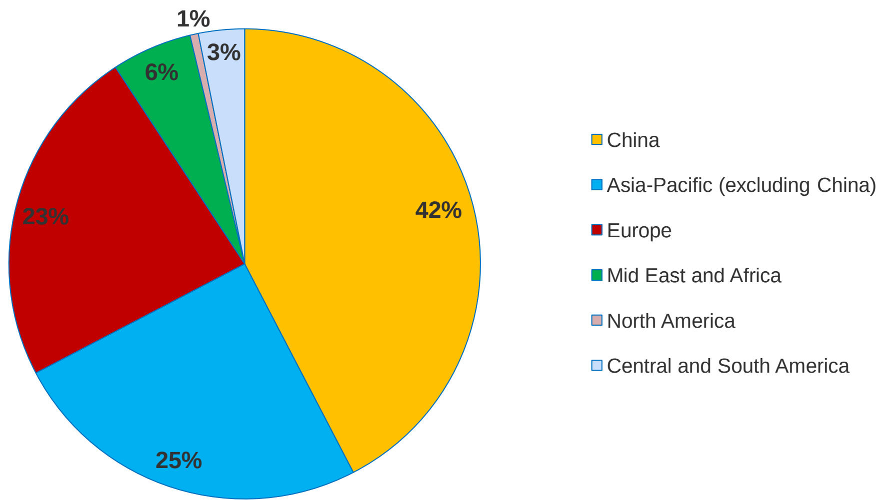
Data: LMC Automotive, OE, CRU.

Thus the combined pull of PET packaging and automotives will boost underlying growth in EO consumption towards 2020. However it is also important to understand what will drive the pattern of silver EO demand growth in intermediate years, and this story is taken up in the next section.

2.2.3 Silver EO consumption in the intervening years

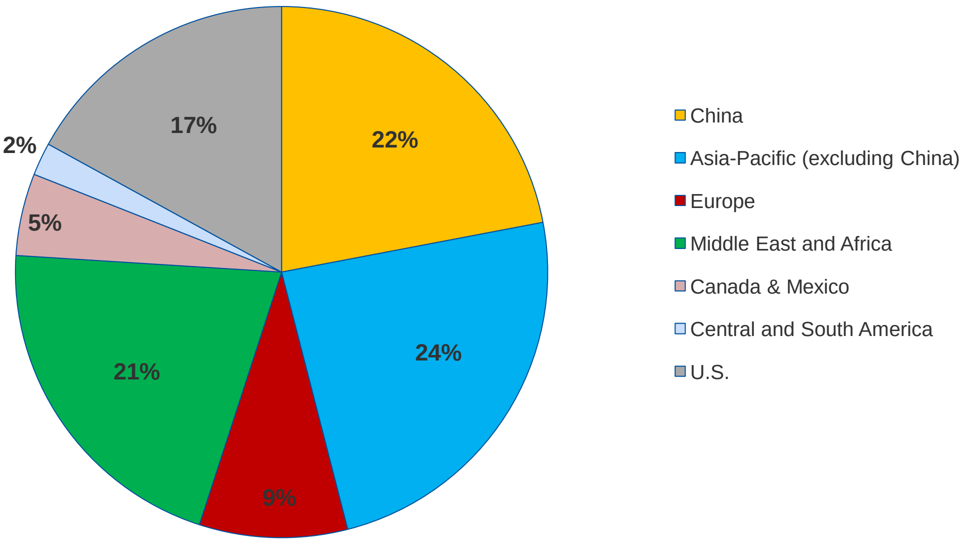
According to data from the Silver Institute, silver consumed from the EO industry more than doubled in 2015, from 5 Moz to 10.2 Moz. CRU estimates that most of this spectacular increase was triggered by the installation of new EO production capacity and most of that happened in China. While Europe and Asia-Pacific experienced double digit growth in production, China's capacity growth has been the most spectacular. China alone accounted for 42% of new capacity added in 2015. Our estimated capacity for the production of EO in 2015 was 30.9 million tonnes.

China represented 42% of the worldwide EO capacity increase in 2015



Data: CRU

China (22%) and U.S. (17%) will have the most EO capacity in 2020



Data: CRU

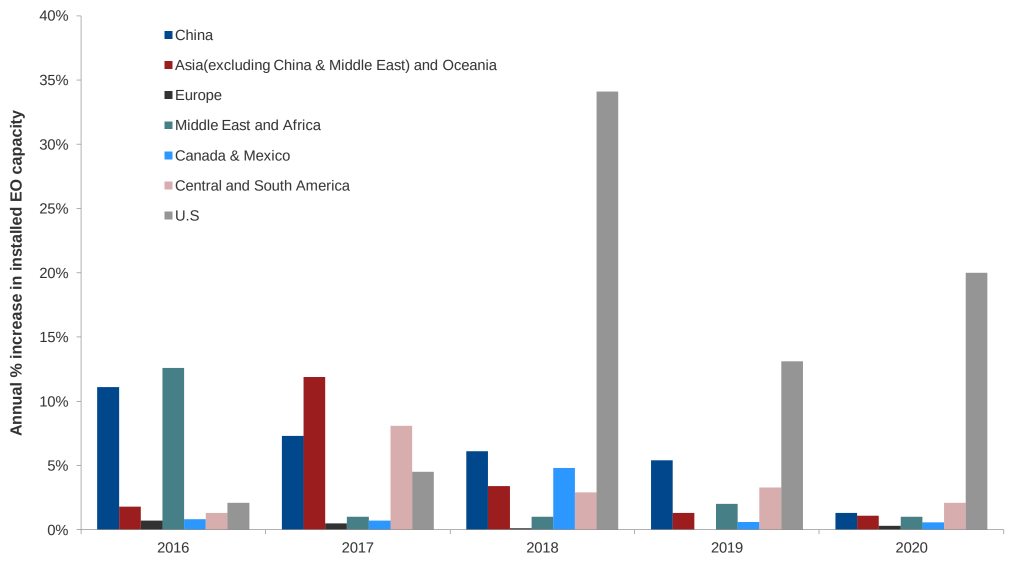
However, this significant increase in EO capacity and production with no immediate increase in consumption from downstream industries has left the Chinese market severely oversupplied. At this point it is important to recognize that any overproduction of EO in China is unlikely to be exported. EO is difficult to transport and for this reason there can be large price disparities between countries and even within different regions of China. EO trade is only a tiny share of its production around the globe. Thus the building of excess capacity in China has resulted in low capacity utilisation, rather than higher exports as we have seen in many other Chinese industries. We estimate that Chinese EO capacity utilisation has fallen dramatically from a high in 2011 at about 90% to about 60% now in 2016. Part of the reason for this capacity overhang is that the lead time for a new EO plant is around 3-5 years, and prices were very high at that point in the past.

However, China remains the biggest producer of polyester fibre in the world, contributing to about 70% of the world's production of that material. Polyester fibre requires monoethylene glycol (MEG), a downstream product of EO. China's demand for MEG due to its enormous polyester fibre production far exceeds its domestic supply and it consequently imports a lot of MEG. Investors' attention to this disparity between supply and demand is exacerbated by record low prices for EO caused by the oversupply. As a result, with time demand will increase to gradually absorb the excess supply, and result in another round of expansions in EO production capacity. We predict that existing building programs will result in continued increases in EO capacity in China in 2016 and 2017, but expect limited increases beyond that due to the inevitable drag of oversupply. Investment will finally start to recover again after 2020, rescued by underlying demand growth.

A similar trend is also likely to occur in the Middle East, South Asia, Africa and South America, where a significant increase in capacity will take place in the next two years, then remain roughly at the same level of capacity as the investment and utilisation recovers. These regions all feature average annual growth rates within 3% to 4% range, but will enjoy much higher growth after 2020. European EO capacity is expected to see little change across the forecast period.

These short term slowdowns in EO capacity building are expected to be overshadowed by the powerful trajectory of the industry in the United States. The U.S. is forecasted to take over the mantle from China as the largest builder of new EO capacity from 2018. One piece of evidence comes from existing plans for building plants, but on the demand side growth for EO in the United States is also likely to remain strong, based on automotive use. The expansion of EO in the United States is also favoured by the low cost of gas and oil. These fuels are a key component in the production costs of upstream industries for EO and therefore the U.S. shale boom has made EO operations profitable even under the low realised sales prices. We therefore expect an astonishing 14% average annual growth in U.S. EO capacity from 2016 to 2020.

The U.S. takes over from China in EO capacity growth from 2016 to 2020



Data: CRU

2.2.3.1. How does EO capacity growth translate into silver demand?

Each time new EO capacity is put in place, silver is needed to be purchased for the catalyst. Thus capacity additions matter directly for silver demand. As that capacity is used over time, the silver catalyst is eventually recycled and replaced. Hence, while new capacity matters for new demand, production matters for replacement demand.

To translate these numbers into silver demand, we need to take a stance on the intensity of silver use within EO production, both in terms of silver used for new EO capacity as well as replacement demand when the catalyst is recycled. Our estimates suggest that we can be confident that silver intensity will not fall in the following five years. Based on the past investment plans of BASF, Shell and the Dow Chemical Company, CRU estimates that silver intensity for EO production in new plants is not very different to past vintages and is similar across different companies. Neither do we think that there are new technologies that are about to emerge from the shadows and reduce silver intensity.

Using a silver replacement intensity estimated from typical catalyst lifespan and adjusting for an impurity ratio, we can further obtain an estimate of replacement demand based on EO production. We estimate that the replacement demand for EO silver is just over 1Moz/yr, though that will increase slowly in future decades.

Consequently, we can predict that the silver demand from the EO industry will drop from the overinflated 2015 high of 10.2 Moz to around 5.9 Moz in 2016 and 2017. At that point, there is a recovery in 2018 thanks to the rapid growth in EO capacity in the U.S. By 2020, silver demand has steadied again at around 5.5 Moz, and our estimates are for silver EO demand to keep steadily increasing towards 2030.

Table 2.3. Silver EO consumption (Moz)

	2016	2017	2018	2019	2020
China	2.1	1.7	1.6	1.5	0.7
Asia-Pacific (excluding China)	0.7	2.7	1.2	0.7	0.7
Europe	0.2	0.2	0.2	0.2	0.2
Middle East and Africa	2.5	0.5	0.5	0.8	0.6
U.S.	0.3	0.5	3.4	1.9	3.2
Canada & Mexico	0.1	0.1	0.3	0.1	0.1
Central & South America	0.0	0.2	0.1	0.1	0.1
World	**5.9**	**5.9**	**7.2**	**5.2**	**5.5**

Data: CRU

2.3 Summing up: slowdown and recovery in Silver EO demand

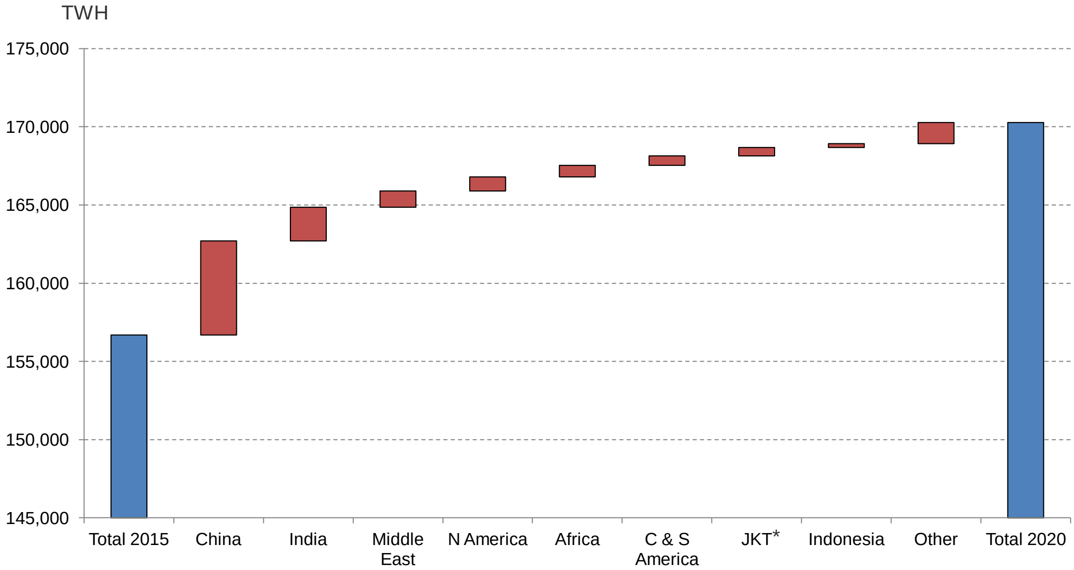
Most shoppers of silver jewellery will be unaware that the rare metal they are buying also plays a key role in making their bedding or in keeping their car running. Yet silver demand for EO production is an important prospect for the industry. In this chapter, we highlighted that the extremely rapid development of EO capacity in 2015 especially in China. This will act as a head wind against future capacity growth and thus hold back silver EO demand for the next few years. Nonetheless the underlying demand for EO is buoyant, and in the separate U.S. market there is scope to increase capacity. Hence, we would expect this to only be a temporary slump, and we should see the early shoots of recovery before 2020.

3. Photovoltaic demand for silver: solar panels picking up speed

3.1 Introduction

In 2016, the world is on track to consume 159,829 terawatt-hours (TWh) of primary energy, of which around 15% as electricity. By 2020, this is expected to surpass 170,000 TWh, driven principally by China and India.

China and India will drive up energy consumption from 2016 to 2020



Data: CRU

*Japan, Korea and Taiwan

The electricity that the world consumes is generated from a variety of sources. Oil, coal and gas have historically accounted for around 90% of global power production. As pollution and carbon emissions have become significant global problems, and technological advances have rendered other sources of energy commercially viable, the fuel mix is rapidly changing. Renewable sources of energy are predicted to grow the fastest, at the expense of growth from traditional sources, as their costs continue to fall, enhanced by governments' policies and subsidy support.

The increase in renewable sources of energy, especially solar power, will lead to an increasing demand for silver. Silver is consumed in the manufacturing of solar panels for the photovoltaic (PV) generation of power from the sun's energy. A high silver content layer is pasted on the front side of a silicon solar cell, as well as a lower silver content layer on the rear side.

In 2015, PV's demand for silver amounted to 77.6 Moz, a substantial increase of 23% compared to 2014. This application accounts for around 13% of industrial demand of silver.

In this chapter, we will firstly discuss the impact of recent policy changes on the composition of energy generation. Based on these findings, we will forecast the trend in photovoltaic growth from 2016 to 2020. We will finally discuss prospective changes in the amount of silver consumed in each solar panels, and show that the 'thrifting' in PV (i.e. a decrease in silver intensity per GW) is fully offset by increases in PV manufacturing as a whole.

3.2 Renewable energy sources set to benefit from carbon emission policies

In December 2015, the Paris Climate Conference brought together world leaders to chart a way forward on tackling global warming and curbing greenhouse gas emissions. Many countries announced plans and gave pledges to restrict carbon emissions ahead of the conference. The Paris agreement requires wealthy countries to collectively deliver $100bn per year by 2020 and more in later years to help poor countries cut emissions and adapt to climate change. It also established a new reporting and monitoring system, which requires all countries to submit voluntary emissions-cutting plans every five years from 2020. The final agreement aims to keep global temperature increase "well below" 2°C compared to pre-industrial levels, and commits participating countries to "pursue efforts" to limit warming to only 1.5°C. So far, the Paris climate agreement has been signed by 177 countries.

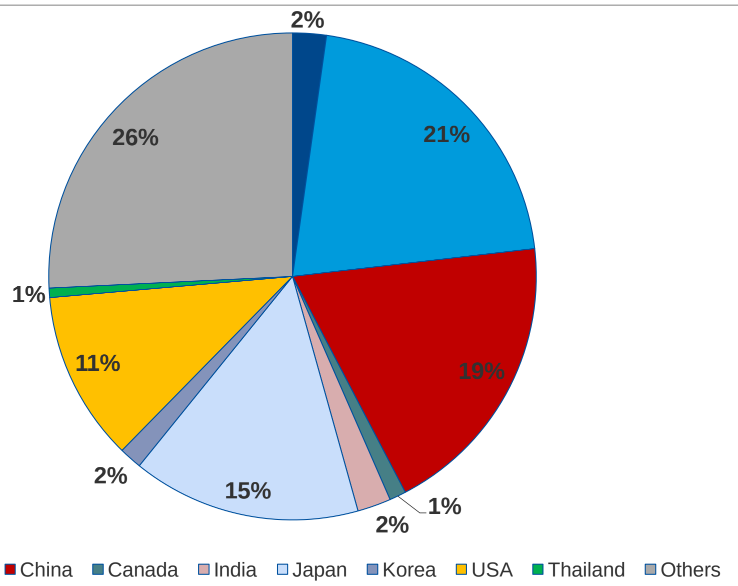
However, given that fossil fuel power plants are comparatively efficient, the coal price low, and that any mining sector unemployment may cause political pressures, it is politically challenging to fully achieve the CO_2 emissions targets set by the Paris agreement. However, it will still have profound impact on composition of electricity generation, and on the growth in PV share.

3.2.1 Europe leads in cutting CO_2 emissions and adopting renewables

In October 2014, leaders of the 28 European Union (EU) nations endorsed a binding target to cut greenhouse gas emissions by 40% from 1990 levels by 2030. In July 2015, the European Commission presented a new legislative proposal to revise the EU Emission Trading System (ETS) post-2020, requiring the overall number of emission allowances to be reduced by 2.2% per year from 2021 onwards, representing acceleration in emission cuts from the current rate of 1.7% per year.

According to CRU's estimation, the EU's CO_2 emissions are currently approximately 14% lower than a decade ago. If CO_2 emissions targets are to be met, a further 22% reduction will be required by 2030. Consequently all EU countries have invested heavily in the research and development of affordable renewable energy. At present, the EU has the largest installed solar panel capacity in the world, with 21% of the global total. In addition, many European countries have committed to further investment in lower carbon energy generation capacity that will drive a strong fall in emissions. For example, the UK is turning to gas and nuclear power, and pledges to invest more in PV capacity.

The world's installed capacities of PV in 2015 concentrated in EU, China, Japan and the U.S



Meanwhile, the European Commission is now seeking to tighten up emission allowances granted through the ETS scheme. This includes the withdrawal of a total of 900 million emission allowances[1] during the 2014-2016 period and a likely expansion of the withdrawal programme in the future.

On the other hand, other countries in the EU have made decisions that suggest coal will remain a significant fuel in power generation. Germany's recent pledge to phase out nuclear power, for example, is likely to mean a continued reliance on coal until at least 2030. Therefore, we expect EU energy demand and emissions to fall, but not sufficiently to meet designated targets.

Based on these findings, we believe there will be an increase in the share of electricity generation from wind turbines and solar power, from 13% in 2016 to 15% in 2020, and further

[1] One allowance gives the holder the right to emit one tonne of CO_2 or the equivalent amount of nitrous oxide or PFCs

to 21% in 2030, while coal's share of power generation is forecast to fall from 13% in 2016 to 10% by 2020.

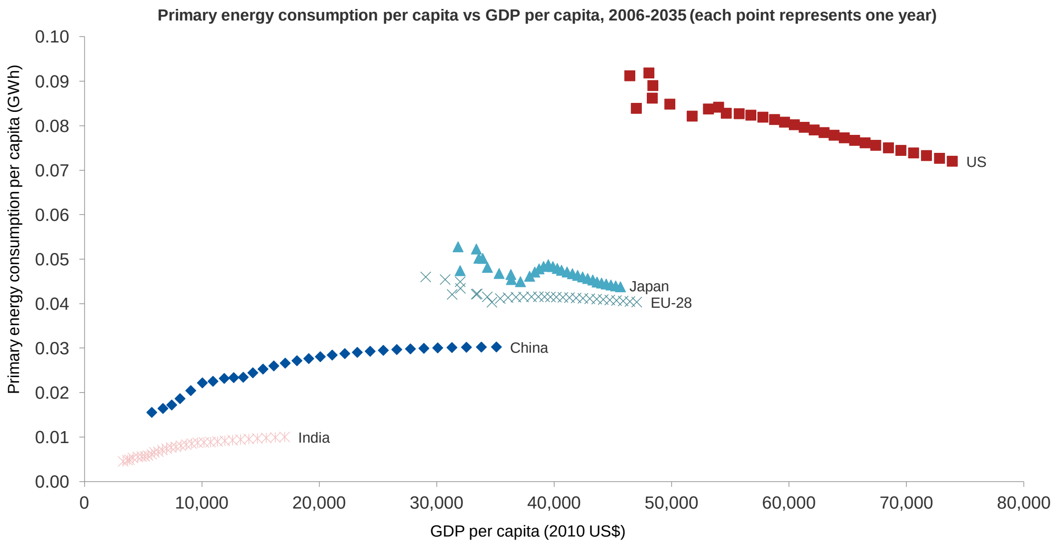
3.2.2 Chinese emission controls favour renewables

For the next two decades, China will face both growing energy demand and strict restrictions on emissions. On the one hand, increasing income levels and the urbanisation process dictate higher per capita energy consumption. Chinese GDP per capita is currently around $13,500 and this figure is forecast to rise to $36,000 by 2035. Historical data for other countries suggest that primary energy consumption per capita peaks and starts to fall once GDP per capita reaches this level. Therefore, energy demand is very likely to keep growing strongly, albeit at a less ferocious pace than seen previously.

Despite this growing energy demand, if China abides by its agreed targets, current carbon emissions levels need to remain constant until 2030. To achieve this, the increasing demand for electricity will have to be largely satisfied by clean energy sources and renewables. China has demonstrated the capacity for substantial investment in these forms of energy generation – solar panel installed capacity has grown by an astonishing annual average of 136% since 2011; China is now the country with the largest installed PV capacity. Given China's growing energy demand and determination to support renewables, this growth in solar panels is expected to continue, though the pace may slow.

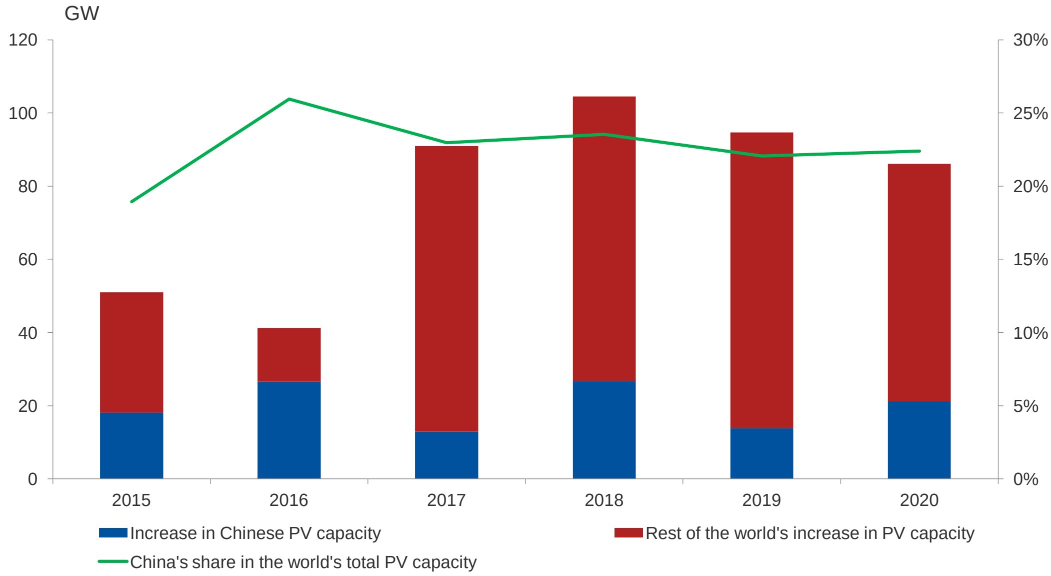
CRU estimates that China's CO_2 emissions target will be achieved. China's energy demand peaks in the early 2030s, while electricity generation continues to grow. We expect the coal share of electricity generation in China to fall from 71% in 2015 to 65% in 2020, and 51% in 2030. This proportional decrease in coal power generation is mainly driven by the increase in PV capacity and wind turbines. Together, these are expected to increase from 4% of total power generation in China at present, to 10% in 2020. Given the enormous installed capacity of electricity generation in China, this relatively small proportional increase actually constitutes a significant 101.3 GW in absolute terms. As a result, China contributes to 24% of the world's PV capacity growth from 2016 to 2020.

China's energy consumption per capita is significantly lower than historical comparables, leaving upside for renewables



Data: CRU

PV capacity continues to increase in China, and stays a main driver for the world's growth



Data: CRU

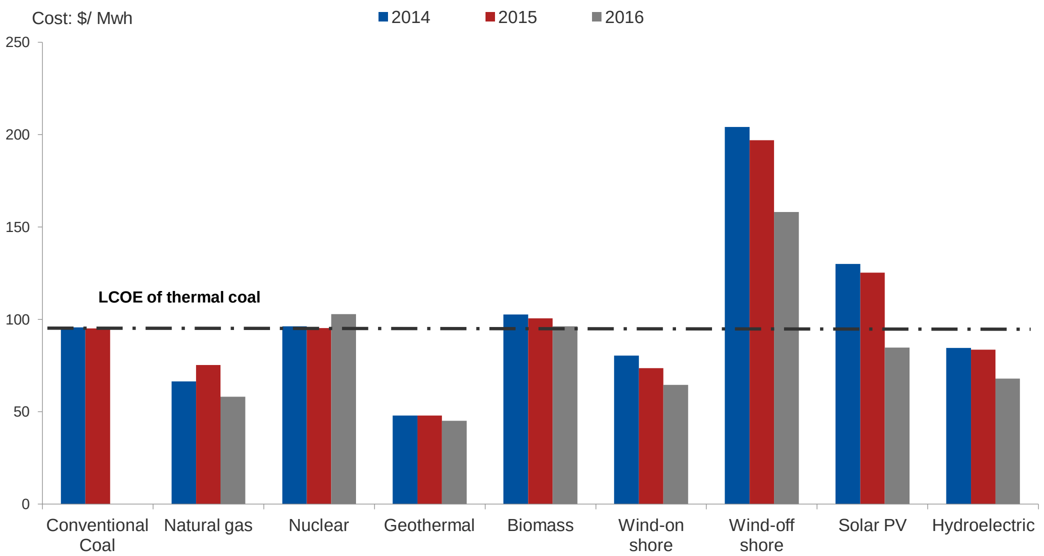
3.2.3 Increase in economic viability of PV will result in its growing share in U.S. power generation

Both GDP and energy consumption per capita in the U.S. are amongst the highest in the world. As is typical of mature economies, energy consumption per capita has peaked and has been falling at a rate of 0.5% per year since 2010. During the period 2016-2025, energy consumption per capita is forecast to fall slightly more rapidly, at a rate of 0.7% per year, as greater efficiency savings are made.

This trend, along with the well-publicised fall in coal-fired electricity generation, has caused a notable average annual fall of 0.7% in CO_2 emissions since 2010. In the long-term, we expect emissions will continue to decline in the U.S., however, the CO_2 emission target set by the Paris Agreement remains very challenging. The coal share of electricity generation needs to fall to effectively zero and be entirely replaced by renewable or nuclear power plants to achieve this ambitious target.

One potential driver of this prospective sea change is the increasing economic competitiveness of renewables. The U.S. Department of Energy collects data on the cost of adding new electricity generation capacity based on different fuel types. Recently, it also starts to account for government taxes, subsidies and credit costs. This cost index is called the Levelized Cost of Energy (LCOE) and published annually. The LCOE of PV electricity generation has seen significant decreases in recent years, and has moved from being the second highest cost form of power generation (after off-shore wind) to being below that of coal and nuclear power.

Solar PV's cost has decreased below that of thermal coal and become much more economically attractive



Data: US Department of Energy

However, the all-replacement scenario seems unlikely. The abundant reserves of relatively low cost natural gas reserves in the U.S. have significantly increased the attractiveness of this source of power generation, and natural gas fired power plants are likely to remain a substantial proportion of the generation mix in the U.S.. It is also unlikely that all solid fossil fuel plants will get replaced, due to political unwillingness in committing to entirely replace coal with renewables. Therefore, the U.S. is unlikely to achieve its CO_2 emission target, but it will still have a significant shift towards renewables such as photovoltaic electricity generation.

In the U.S., we therefore expect an increase in the share of electricity generation from renewables from 7% in 2016 to 11% in 2020 and a fall in coal's share of the power mix from 34% to 29% during the same time period.

3.2.4 Growth in energy demand in India leads to growth in quantity of PV

Energy requirements in India are predicted to expand more than in any other country over the next twenty years. GDP and energy consumption per capita are currently extremely low and India's extremely large, young and increasingly educated population is expected to drive GDP growth of 6% per year for the next twenty years. Energy consumption per capita is expected to rapidly grow hand in hand with this economic development.

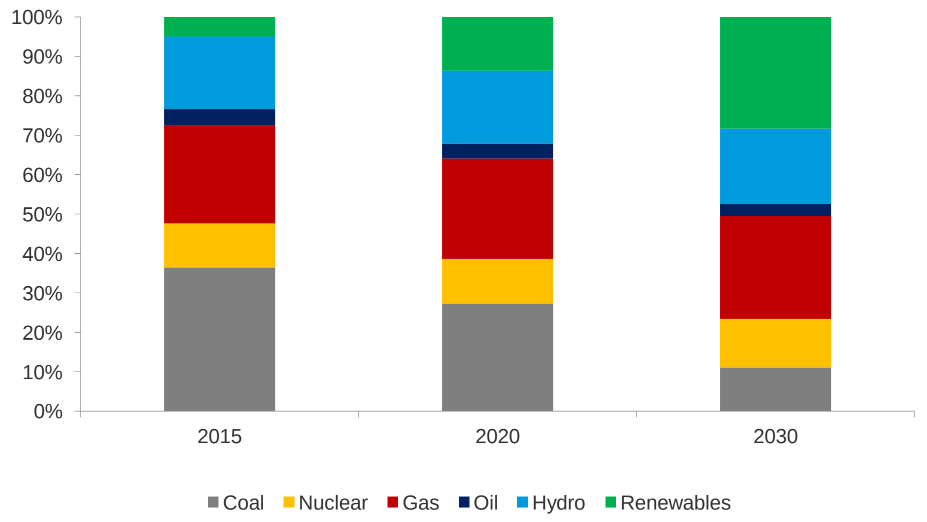
Despite the fact that thermal coal currently dominates domestic power generation, accounting for around 69% of output, investments in renewable energy, particularly solar power, have surged in recent years. Installed capacity of PV in India grew by 72% in 2015 alone; it now surpasses Belgium, Germany and other major PV producers. Even if the share of solar power in electricity generation remains the same, the sheer volume of growth in energy consumption would lead to a significant growth in PVs.

We expect that India will be the most significant energy growth market in the years ahead, with an average annual growth rate of 5% from 2016 to 2020. This will be accompanied by an increase in the share of electricity generation from renewables from 4% in 2016 to 6% in 2020, then reaching 11% in 2030. These two factors combined will deliver strong growth solar panel consumption.

3.3 As renewables grow, so does installed PV

Based on these findings, we believe that the share of renewables in the world's electricity generation will increase, as shown in the graph below

Share of renewables in installed capacity of global electricity generation grows steadily from 2015 to 2030



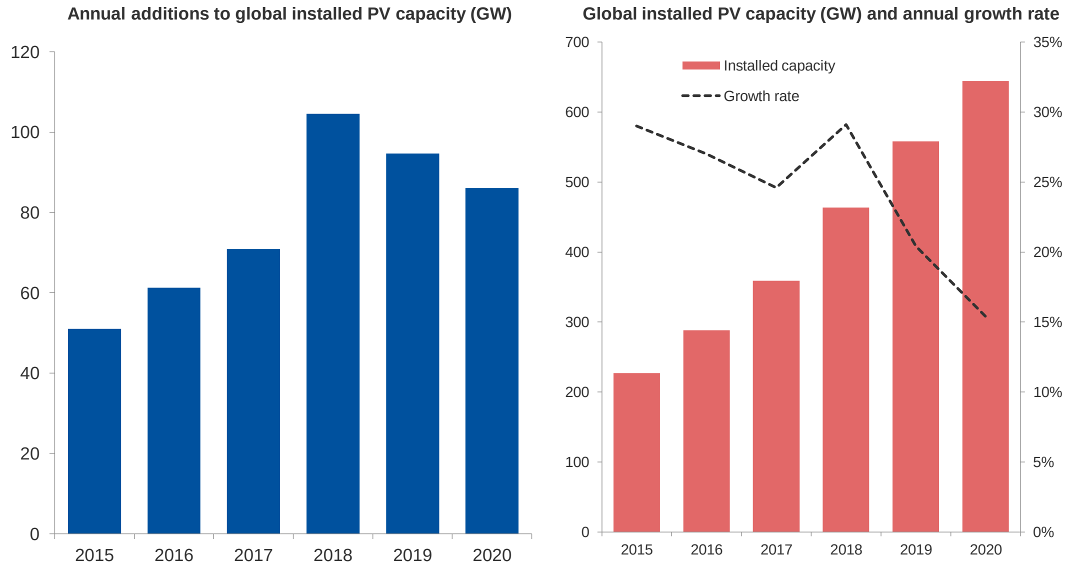
Data: CRU

Based on these findings, we believe that the share of thermal coal in global electricity generation will decrease from the current 35% to 26% in 2020, and further to 11% in 2030. Meanwhile, renewables enjoy a significant growth from the current 5% to 13% in 2020, and further to 27% in 2030. Other lower carbon energy sources like nuclear and gas will increase steadily in coming years. Furthermore, we believe that PV is slightly preferred over wind turbines, the other main component of renewable energy source. Referring back to the previous graph showing levelized cost of energy, we can see that, although on-shore wind turbines have extremely low costs (and are thus very competitive), off-shore wind turbines are the most expensive source of electricity. Therefore, we believe that PVs are economically preferred over off-shore wind turbines.

Given on-shore wind turbines significant existing installed capacity, we believe that all "easily utilisable" on-shore locations for wind turbines are already occupied. Less favoured locations for on-shore wind turbines will inevitably increase the levelized cost of electricity, and therefore make it less attractive compared to PVs. It will gradually concede its leading role in renewables generation with its share declining from the current 55% to 40%.

Therefore, we believe that the economic viability and better adaptability over location choices make PV the spearhead of the growth in renewables. The following graph shows our forecast of annual additions to global installed PV capacity. We predict that the installed capacity of PV will reach 644 GW in 2020, with an average annual growth rate of 23%. This will give a strong boost to silver demand from the industry.

The world's installed Capacity of PV panels increases significantly during 2016-2020



Data: CRU, IEA

3.4 Despite thrifting, silver demand grows

Despite the rapid growth in installed capacity of PV in the last five years, its demand for silver did not increase with the same speed. This is caused by cost saving efforts of PV manufacturing firms. Prices for PV cells have empirically followed Swanson's law, which states that every doubling in installed capacity of PV leads to a roughly 20% decrease in price. Historical data show that PV panel price on average falls at an annual speed of 12.5%. The decrease in price and heat in competition compel manufacturers in constant search of cost saving methods. Silver accounts for 15-25% of the total manufacturing cost of PV panels, and therefore it has become a main focus in cost reduction.

The amount of silver needed per watt has consequently decreased substantially (called "thrifting") over the past 10 years with the amount of silver used in solar cells declining by average annual rate of 7%. Bullish silver markets and high prices, as witnessed in 2011, further incentivise these thrifting practices: currently, approximately 120 milligrams of silver are required to produce an average solar cell, down from roughly 200 milligrams in 2011. It's worth noting that the silver price is the main driver behind thrifting. During 2008-2011 when the silver price remained at a low level, there was no significant thrifting in PV panels. In fact, silver intensity slightly increased. However, when the silver price increased by 65% in 2011, silver usage decreased by 40% in that year, from 123kg/MW to 73kg/MW. The reduction in the silver price since 2013 has reduced thrifting incentives and slowed the pace of silver intensity reductions. As CRU expects that silver price is unlikely to again reach as high a level as in

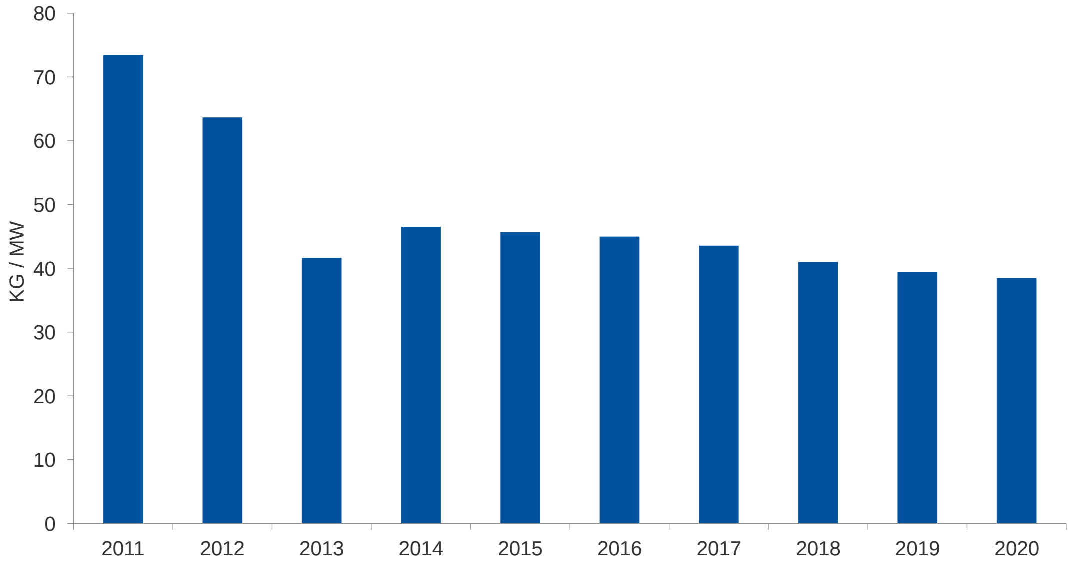
2011, we do not expect the incentive to arise that might lead to a substantial decrease in silver intensity in PV as well.

Nonetheless, research continues into reducing silver requirements in PV panels. Researchers are working on developing new coating technologies like ink-jet and by finding cheaper substitutes to silver, such as copper and nickel phosphide. While there is potential for new metals and technologies to continue to make inroads in the PV space, there are a number of challenges and hurdles. Amongst all metals, silver has the lowest resistivity, which means less electricity is wasted in transmission. Substitute materials have difficulties competing against silver on this basis. Generally, PV panels using copper have solar power delivery efficiency around 13%, that is, 13% of solar energy absorbed by these solar panels is eventually transferred into electricity in the grid. This rate could be even lower in PV panels using other substituting materials partially due to higher resistivity. PV panels using silver, however, have efficiency generally above 15% with an average over 17%. Some may even achieve efficiency over 20%. A lower efficiency requires more number of panels installed as compensations in order to produce the same amount of electricity. Higher number of PV panels can offset the cheap unit cost of using substituting materials, making these technologies not necessarily more attractive.

Moreover, the question of adhesion strength, a significant factor in determining the lifetime of cells, has also made it more difficult to substitute silver with metals like tin, due to the insufficient adhesion problems. Shorter lifetime means more frequent replacement of existing PV panels, and mitigates the benefit of cheaper raw material costs, making alternative technologies less attractive. Adopting substitute metals also involves higher capital costs. For example, the standard metallization and co-firing steps in solar panel manufacturing cannot be used with copper. This means additional processing steps are required, which in turn involve costly facility upgrades and additional production risks.

As a result of these combined effects, we expect on average a 3.7% annual average decrease in silver usage out to 2020, leading to 8kg less in silver consumption for every 1 MW capacity of PV added, compared to 2015 levels.

Silver intensity of usage per PV cell gradually decreases from 2016 to 2020



Data: CRU

However, the decrease in silver usage does not necessarily lead to a decrease in total silver consumption from the PV industry. The predicted significant increase in PV capacity discussed previously will more than offset the negative effect of thrifting. According to our medium term forecast, silver consumption from the PV industry peaks in 2018 at 148Moz, which is almost double the level seen in 2015 (80Moz). It slightly decreases in 2019 and 2020 as global PV capacity additions – where silver in PV is predominately is consumed – are expected to be cyclically lower in those years than in 2018. On average, we expect that the PV industry will consume 114Moz of silver annually during the next five years. Beyond 2020, PV capacity is expected to continue strong growth, and CRU expects that silver demand from this end use sector will certainly increase.

Increased demand for silver in PV expected over next five years, with consumption in 2018 particularly strong