Goldman Sachs

THE LOW CARBON ECONOMY

Technology in the Driver's Seat

A year on from Paris, markets are focused on near-term headwinds and policy uncertainty for renewable energy with the US election of Donald Trump. Yet in this GS SUSTAIN deep-dive, we argue that LEDs, solar PV, onshore wind and electric vehicles will maintain momentum and are now as much a transformative tech shift as they are a regulatory response to global environmental challenges. Global coal consumption has already peaked, sales of pure combustion engine cars could peak by 2020, and lighting will shift almost exclusively to LEDs sometime in the 2020s. We expect markets for low carbon technologies to remain volatile, but see growing opportunities in the maturing and consolidating LED and wind sectors.

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The following is an excerpt from "The Low Carbon Economy: Technology in the Driver's Seat", published November 28, 2016, 53 pgs. All company references in this excerpt are for illustrative purposes only and should not be interpreted as investment recommendations.

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THE LOW-CARBON TRANSITION in numbers

STEPPING ON THE ACCELERATOR

20.5 million

The number of EVs that IHS expects to be sold globally between now and 2025—almost 10mn cars more than it forecast 12 months ago.

SLOWING DOWN?

2020

The year we expect sales of pure combustion-engine vehicles to peak.

SCALING UP

106 bp

The average annual market-share gain in global electricity generation that we expect for wind and solar combined over the next 10 years.

CUTTING BACK

~5x

The increase in closures of smaller and obsolete coal plants we expect in China between 2015 and 2020, from 4.2GW in 2015 to 22 GW.

MATURATION

2017

The year we expect LED sales to overtake sales of incandescent and fluorescent lighting for the first time.

PHASING OUT

62%

The annual savings of lighting electricity consumption that could be achieved in the US by 2025E, as LEDs reach a significant share of the installed base.

ADDING VALUE

$1,041

The value of the semiconductor content in an EV, 3x the value in a conventional car.

NEW MARKETS

5.4x

The increase in lithium consumption we expect from the autos sector between 2015 and 2020.

SUPPLY-CHAIN EFFECTS

¼

The industries (autos, utilities, capital goods, energy and materials) that could be affected by the transition to a Low Carbon Economy, as a share of global listed equities.

A LOWER-CARBON FUTURE

2.1 GT

The incremental CO_2 emission savings by 2025 that we expect from higher-than-anticipated solar & wind installations and lower-than-anticipated electricity demand growth vs. the IEA's INDC scenario.

The Low Carbon Economy: Technology in the driver's seat

The Low Carbon Economy is now as much a transformative tech shift as it remains a response to global environmental challenges. In our second GS SUSTAIN deep-dive, we continue to explore how a set of four transformative low-carbon technologies – LEDs, solar, wind and electric vehicles (EVs) – are redefining competitive dynamics and growth patterns across our coverage. As the transition gathers pace, the risk markets face is low-carbon tech disruption, not necessarily carbon pricing. Industry dynamics in autos, utilities, capital goods, energy and materials could be meaningfully affected.

A year on from Paris, markets are focused on near-term headwinds…
The prospects of a cyclical downturn in solar and wind, along with growing policy uncertainty in the US and China, have been key contributors to the weak performance of clean-tech stocks in 2016. In solar, overcapacity and large price cuts have led to a sharp correction, marking the third major downturn in a decade. In China, major energy-sector reforms, which include cuts to wind and solar targets, are now underway as the government responds to lower and more energy-efficient growth. Meanwhile, in the US, President-elect Donald Trump's campaign promises included a reversal of the climate policies introduced by his predecessor.

…but the structural shift to low-carbon technologies continues
We expect the core dynamics that drive the expansion of the Low Carbon Economy to be largely unaffected by these cyclical swings and policy shifts. Electric vehicles hit the accelerator in 2016, as carmakers pivoted to fast-track a new generation of long-range EVs, and could deliver a fourth year of 50%+ volume growth. Next year, LEDs will for the first time account for over half of lighting sales, according to our analysts. By 2020, we expect the share of wind and solar in global power generation (c.10%) to exceed today's share of ecommerce in global retail (c.8%), and that of US shale in oil production (c.6%). Meanwhile, thermal coal use has peaked, owing to growing market-share losses in the US and China; and, as EVs and hybrids take share, sales of pure combustion-engine cars could peak in 2020, according to our analysts' forecasts.

The risk markets face is low-carbon tech disruption, not necessarily carbon pricing
As low-carbon technologies continue to spread, there is a need to reconsider *when, where,* and *how* equities will be impacted. We believe carbon footprints – often used to assess 'carbon risk' – provide investors with limited guidance to their exposure. Instead, we focus on how the Low Carbon Economy reconfigures demand patterns and competitive dynamics in complex ways, with parallels to other tech-driven shifts like shale or ecommerce. Industry dynamics in autos, utilities, capital goods, energy and materials could be affected by 2025E– sectors that together account for a quarter of listed equities.

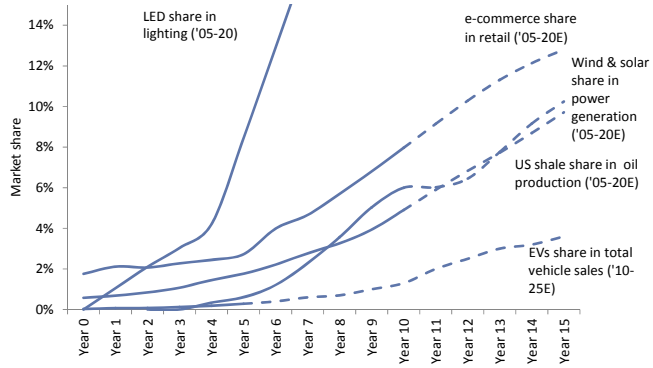
We provide an investing blueprint for the Low Carbon Economy
In this report, we assess how different stages of technology development shape opportunity sets for companies in affected industries. Incumbents typically struggle through a prolonged adjustment period, offering limited upside, even for those that are adapting successfully. Among technology pioneers, long-term winners with sustainable competitive advantages also only begin to emerge once technology transitions start to mature, with the rate of technological change slowing and sectors reconsolidating.

A framework to assess the impact of low-carbon technologies

Core to our thesis is that the Low Carbon Economy is emerging through a series of rapid technology shifts in select, carbon-intensive industries. Such transformative low-carbon technologies are rare; indeed, we believe only four exist today – LEDs, solar PV, onshore wind and electric vehicles. They have emerged where a combination of regulatory pressure, cost reductions and performance improvements create competitive solutions, which are able to gain broad-based market acceptance (see our first deep-dive, *GS SUSTAIN: The Low Carbon Economy*, November 30, 2015).

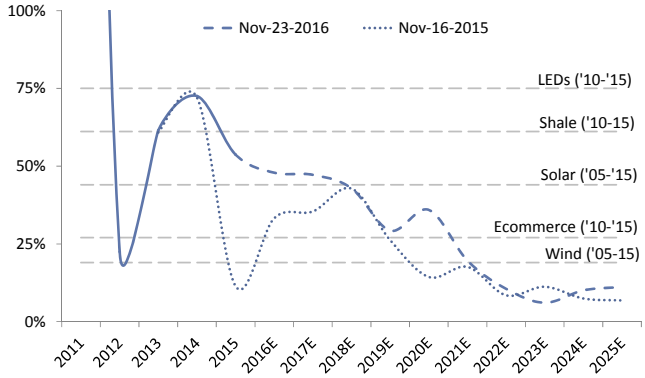
We offer a straightforward framework for investors to assess: a) the different stages through which these technologies gain market acceptance; b) how these stages shape the opportunity set for companies in affected industries; and c) their supply-chain implications.

Exhibit 1: Growth paths for transformative low-carbon technologies are similar to ecommerce and shale oil
Market shares (dotted lines indicate forecasts)



Source: Euromonitor, BCG, IHS, IRENA, BP, Goldman Sachs Global Investment Research.

Exhibit 2: Comparison to other disruptive shifts suggests upside for EV growth vs. mainstream IHS forecasts
EV growth vs. CAGR of technologies around inflection



Source: IHS, Euromonitor, IHS, IRENA, BP, Goldman Sachs Global Investment Research.

***Breakthrough:* EVs (<1% share) are crossing the Rubicon; 50%+ pa vol. growth**

In the breakthrough stage**,** volume growth is very rapid but market share gains and volumes are still small. In **autos**, fully **electric vehicles** are delivering 50%+ annual volume growth but still account for 1% of sales. Despite rapid gains in terms of cost and performance, they are still at a significant disadvantage to incumbent technology. We expect scaling to continue as a new generation of long-range models becomes available to consumers, allowing EVs to reach mid-single-digit market share by 2025.

***Scaling:* Wind & solar (c.5% share); 100+ bp average annual share gains**

In the scaling phase, the technology and business models begin to stabilise. Continued cost reductions and performance improvements make the technology increasingly competitive with incumbent solutions. Installed volumes are still small but now significant and, although growth has slowed somewhat, annual market share gains accelerate. **Wind and solar** now jointly account for c.5% of **power generation,** and we estimate they will gain 106 bp pa market share over 2015-25. In parts of the US, the cost of wind *before* subsidies is now around $40/MWh, or comparable to natural gas.

***Maturation:* LEDs (>40% share) now dominate, with c.800 bp annual share gains**

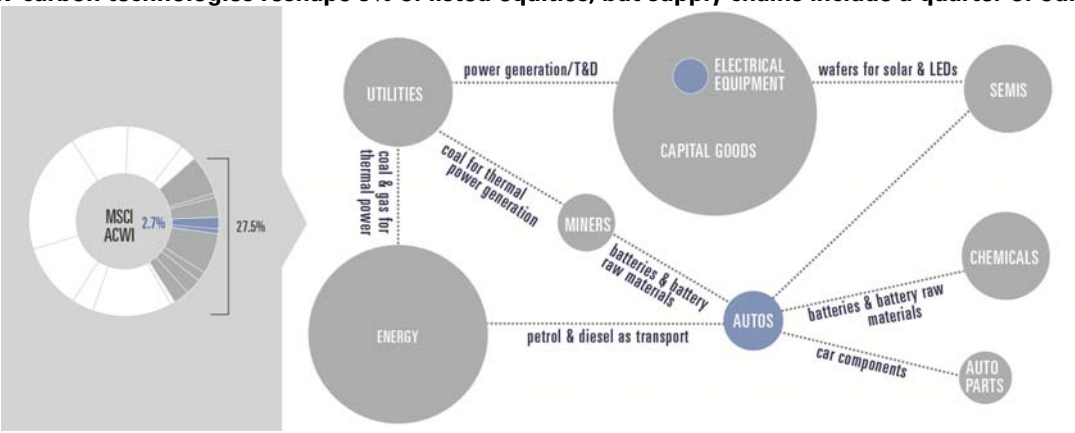
As the technology approaches maturation, it begins to offer significant advantages compared to incumbents. Cost reductions slow, as do volume growth rates. Market shares are large and continue to grow rapidly as incumbent technology is relegated to legacy status. In lighting (c.15-20% of electricity use), LEDs capture c.43% of the market in 2016E, with share gains in the US, for instance, exceeding 1000 bp pa. Short lifespans for legacy

lamps imply that lighting will shift almost exclusively to LEDs sometime in the 2020s, which would mark one of the fastest technology shifts on record.

More than meets the eye: ¼ of equities could be affected by 2025

The technologies that we focus on directly transform only relatively small sectors in our coverage; in terms of GICS® industries, primarily autos and electrical equipment (note that some solar companies are also classified as semiconductor firms or utilities). However, extensive supply chains tie these industries to a much broader set of sectors, comprising roughly a quarter of our coverage. We believe investors should be as vigilant about the implications of low-carbon technologies along these supply chains, as they are in the markets in which they take share.

Exhibit 3: Low-carbon technologies reshape 3% of listed equities, but supply chains include a quarter of our coverage



Source: Datastream, Goldman Sachs Global Investment Research.

Knock-on effects along supply chains amplify impacts

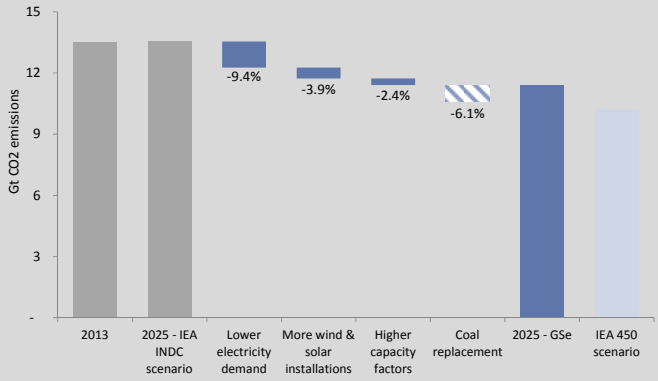
- **Utilities (3.4% of MSCI ACWI)** have been under regulatory pressure to rapidly shift to renewables. Wind and solar have not. We see thermal assets as the biggest losers, with T&D businesses and renewable assets as winners.
- In **Energy (7.2% of MSCI ACWI)**, coal use has peaked and producers are under pressure as share losses continue. For oil, we expect tangible demand implications only once EVs begin to scale post-2020. In the absence of cheap and scalable grid storage, gas remains a potential winner from the low-carbon transition.
- In **Materials (5.2% of MSCI ACWI)**, chemicals companies that supply battery raw materials (including lithium, graphite and cobalt), stand to benefit. Miners with coal exposure are also affected by declining coal demand.
- **Cap goods (7.2% of MSCI ACWI)** companies include the winners on solar, wind and LEDs. However, with utilities and energy among the key verticals for the sector, growth patterns for many cap goods companies could be affected by the low-carbon transition.

Low-carbon technology could deliver a CO_2 peak in c.2020; not yet enough for a '2°C' pathway

Low-carbon technologies could begin to shift emission pathways earlier than is commonly assumed. We expect power-sector emissions to be almost 16% lower by 2025 than mainstream models suggest. This mainly reflects higher wind and solar penetration, and lower electricity consumption growth – with China's slower and less energy-intensive growth and LED savings as key contributors. This could mean that overall energy-related emissions peak around 2020 – rather than continue to increase gradually over the next decade as mainstream modelling, like the IEA's INDC scenario suggests (which assumes that countries honour their Paris commitments). However, by themselves, such savings would not yet be sufficient to put the world on a '2°C' pathway.

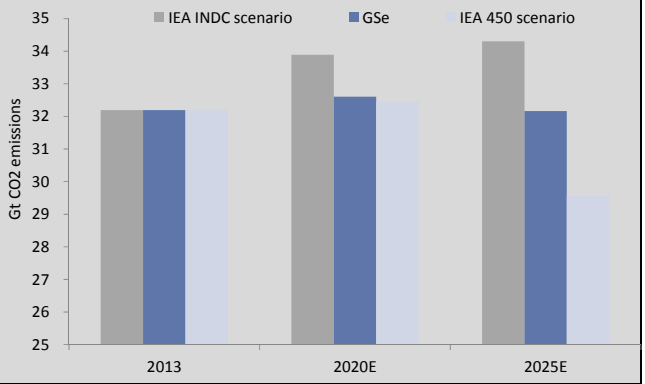
Given their lack of scale, electric vehicles are unlikely to deliver large-scale emission savings over the next decade, even if they continue to see rapid growth. With over 1 bn cars, even a very rapid adoption path would not significantly impact total oil consumption or emissions in the sector, although it could contribute to slowing growth towards the middle of the next decade.

Exhibit 4: Power sector emissions could be more than 15% lower by 2025 than mainstream scenarios suggest
The IEA's INDC scenario modified with our forecasts



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 5: Global emissions could peak around 2020, but for now to remain above a '2˚C scenario'
Emissions in the IEA's INDC/450 scenarios vs. our estimates



Source: IEA, Goldman Sachs Global Investment Research

Carbon footprints offer limited guidance on the exposure to transformative low-carbon technologies

Although now widely used by investors as a gauge for 'carbon risk', we believe that corporate carbon footprints offer a poor guide to threats and opportunities connected to technology shifts discussed in this report. With limited prospects for economy-wide pricing of emissions, some of the most carbon-intensive sectors (e.g. construction materials or airlines) currently face little threat from transformative technologies. Even in sectors where low carbon technologies are taking share, we believe carbon intensities rarely offer meaningful insight to the competitive threat individual companies are facing.

Three shifts in 2016 to shape the Low Carbon Economy 2017-20E

Three shifts in 2016 to shape the Low Carbon Economy 2017-20E

A year on from Paris, we take stock and identify three key shifts that are set to shape the Low Carbon Economy going forward. These are: 1) the *potential beginnings of a market breakthrough for EVs*; 2) the transition to *slower, less energy-intensive growth in China*; and 3) *changing political currents in the wake of the US elections*. While markets are focused heavily on the latter, we believe the implications of the Trump Administration on the core dynamics that drive the adoption of key low-carbon technologies should not be overestimated.

2016 has been a busy year for the Low Carbon Economy, with developments largely following a familiar pattern we laid out in our November 2015 report (*GS SUSTAIN: The Low Carbon Economy,* November 30, 2015).

- **Technologies and market adoption surprised on the upside.** The new GM Bolt offers the same battery size and 8% more range than a Tesla Model S60, but costs 40% less. EVs are on track for the fourth year of 50%+ volume growth; solar module costs are down 16% YTD.
- **Clean-tech stocks have been volatile and, with few exceptions, have surprised on the downside.** Our solar coverage is down 32.0% YTD, while lithium miners rallied. Wind did well through much of the year but corrected sharply on a softer 2017 outlook and negative sentiment on the US elections (wind coverage -10.2% YTD).
- **The regulatory environment has remained as fragmented and volatile as ever.** Wind/solar tax credits were extended in the US with rare bipartisan support, while Germany decided to abolish its famous feed-in-tariffs. India confirmed plans to double its ambitious 2022 solar target; in China, wind/solar targets were cut 16/27%. South Korea boosted incentives for EVs, while the Netherlands (plug-ins accounted for c.10% of 2015 sales) scaled them back.

We look beyond the noise and focus on three major developments that are likely to shape the Low Carbon Economy over the next three to five years.

EV breakthrough begins to take shape, focus on potential for leapfrogging hybrids; supply-chain implications

Electric vehicles continue to see rapid volume growth, with 2016 shaping up as the fourth year running with 50%+ growth for pure EVs. Compared to last year, we now have much greater confidence that the key elements for a disruptive shift to electric drivetrains in autos are in place.

Key indications are:

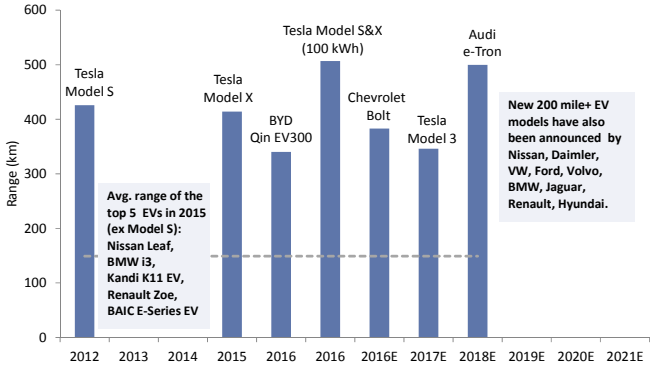
a) **Accelerating cost reductions and performance improvements:** Battery ranges continue to get longer, while prices continue to drop rapidly. For example, the new GM Bolt at below $40k offers a slightly longer range than an entry-level Tesla Model S60;

b) **Growing regulatory focus on grid-connected vehicles:** signs that regulators are shifting to incentivising grid-connected vehicles (e.g. New Energy Vehicle (NEV) credit system being introduced in China, new subsidies in Germany).

c) **Signs of growing market acceptance:** We see 372k pre-orders for the Tesla Model 3 and commitments from the majority of incumbents to bring new, long-range models to market in 2018-2021 as key signals.

However, given growth off a low base, we do not expect EVs to begin to scale rapidly before 2020. A new generation of long-range EVs that is becoming available – including e.g. the GM Bolt (2016E), Tesla Model 3 (2017E) and Audi e-tron (2018E) – will be key to establishing broad consumer acceptance of electric drivetrains. These models offer consumers more than double the driving range compared to models of the previous generation (such as the BMW i3 or Nissan Leaf). Assuming rapid volume growth continues, the market share for EVs is nonetheless set to remain in the low-single digits by 2020E (1.3% on our auto team's forecast; <5% even if EV volumes were able to maintain their 50%+ 3-year trailing CAGR).

Exhibit 6: In 2016, major carmakers have announced new long-range EV models to be introduced before 2021
Announced long-range EV launches and their range



Source: Company data, Goldman Sachs Global Investment Research.

Post 2020, the margins of uncertainty for the growth path of EVs become very large. This is due to a combination of: a) uncertainty about the consumer response to a new generation of long-range EVs; b) limited visibility on the pace of further cost reductions and performance improvements in batteries (including potential shift to post li-ion technology); and c) the lack of clarity on how regulatory frameworks for the autos sector will develop. If battery technologies continue to deliver, we also see growing potential for EVs to 'leapfrog' hybrids, similar to how LEDs leapfrogged compact fluorescent lamps (CFLs) in lighting.

The supply-chain implications of EVs (e.g. for petroleum demand or battery raw materials) will become increasingly visible, even if we do not expect transformative impacts before 2020. Our chemicals analysts expect the autos sector to consume 24% of total lithium output by 2020 (up from c.7% in 2015). Modelling by our oils analysts expects EVs to reduce 2020 oil demand by just 178 basis points in China and by only c.25 bp in the US. If EVs were to begin to scale rapidly, implications could be substantial. Recent modelling by Statoil suggests that, if EV penetration were to increase rapidly, global oil demand could peak as early as the mid-2020s.

China's slower, less energy-intensive growth to accelerate transition, but a near-term headwind for wind/solar

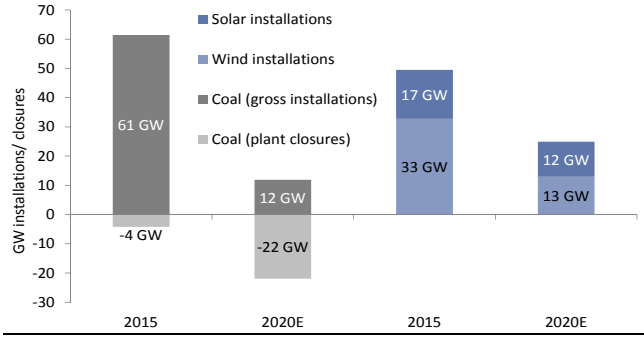
China's slowing and less energy-intensive growth could accelerate the transition to a Low Carbon Economy. Our analysts estimate out to 2030 that China will be able to sustain 5% GDP growth pa, with just 1% primary energy demand. According to their estimates, the total energy demand of the world's second-largest economy and largest carbon emitter will be 5% below current government forecasts already by 2020.

As a result of lower energy-demand growth, China's appetite for fossil fuels set to taper. Our analysts believe that China's thermal coal consumption has already peaked in 2014. They expect closures of smaller and obsolete coal plants to increase fivefold between

2015 and 2020, and new coal installations to decline by 80% over the same timeframe, as planned capacity is shelved or cancelled. Meanwhile, China's oil and gas demand will continue to expand, but likely at a much slower pace. For gas, our analysts estimate that consumption by 2020 will be 21% below the government's 350 bcm target. For gasoline, they believe lower car sales, fewer miles driven and a higher NEV share will result in a gradual flattening of demand (1.8% CAGR in 2020-25E vs. 5.6% in 2015-20E and 9.4% in 2010-15).

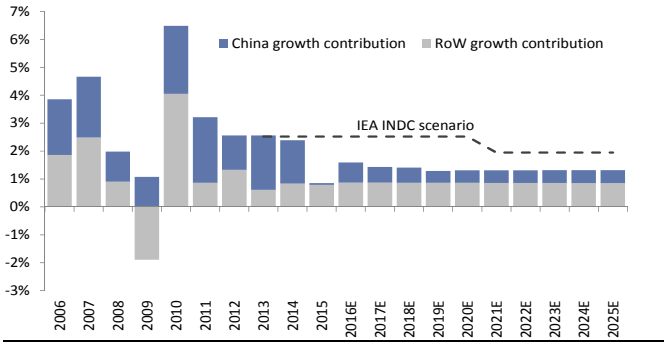
Overcapacity and slowing demand also significant negatives for Chinese wind and solar volumes, even as share gains accelerate. We expect renewables to gain market share *faster* than anticipated, with the wind/solar share in power generation more than doubling to 9% in 2020E vs. 4% in 2015. However, as the government is moving to curb overcapacity, our analysts expect combined wind and solar installations to drop from their 2015 peak by almost half to c.25GW in 2020. We see this already playing out in the government's 13th Five-Year Plan for the power sector (2016-20), which was released on November 7 and which lowers 2020 cumulative installation targets for wind and solar by 16% and 27%, respectively.

Exhibit 7: As the government moves to curb overcapacity, coal is being hit the hardest.
China coal, wind and solar capacity installations/removals in 2015 and 2020E



Source: CEC, China Wind Energy Association, National Bureau of Statistics, Goldman Sachs Global Investment Research.

Exhibit 8: 10-year avg. global electricity demand growth to halve as China's growth contribution tapers
Global electricity demand growth with the contribution from China and the rest of the world shown separately



Source: BP, IEA, Goldman Sachs Global Investment Research.

Meanwhile, a new regulatory framework is likely to further boost EV sales in China. Our analysts expect new regulations on New Energy Vehicle (NEV) quotas and Corporate Average Fuel Consumption (CAFC) for car makers to be finalised in 2016. Draft regulations published in September would require automakers to improve average fuel efficiency by more than a quarter by 2020. Separately, starting in 2018, automakers would be required to produce increased minimum numbers of EVs and PHEVs (12% of production by 2020, or 2x our current forecast). A credit system modelled on California's ZEV regulation is planned to connect these schemes, offering non-compliant carmakers the ability to purchase credits from those exceeding their quotas.

As China's role as primary global energy demand driver is waning, in our view, investors should be mindful of the global repercussions. Solar, for example, is likely to see the first year-on-year drop in global installations for over a decade, as China contracts. As Chinese volumes normalise, we expect the focus to shift to other EMs as key drivers of global growth for 2017-2020. In renewables, domestic producers would bear the brunt of volume declines, given foreign companies' limited role in China's wind and solar sector. However, we expect increasing competitive pressures and heightened outward M&A potential (particularly in wind), as Chinese companies seek a foothold abroad to escape a shrinking domestic market.

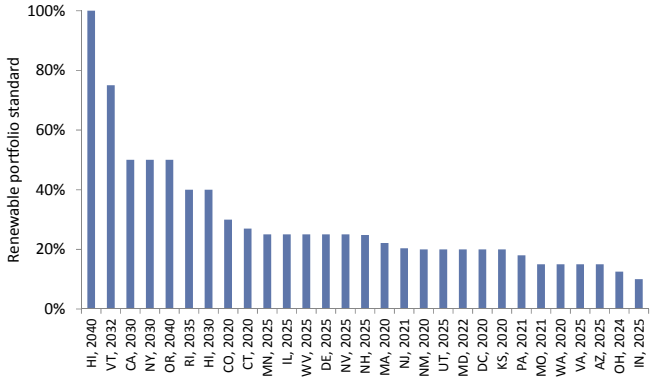
Changed US policy landscape an incremental negative, but unlikely to alter core dynamics

A number of clean-tech stocks corrected sharply following the victory of Donald Trump in the US Presidential Elections. We believe this reflected market concerns over the President Elect's campaign promises to reverse the climate policies of his predecessor, including US participation in the recently ratified Paris Agreement and the Clean Power Plan, which is currently under litigation.

While the US regulatory landscape remains unchanged for now, we see this as negative on sentiment, adding a source of incremental downside risk for global volume growth in low-carbon technologies. Nonetheless, we do not believe that this shift will materially affect the overall dynamics that drive market-share gains for these technologies.

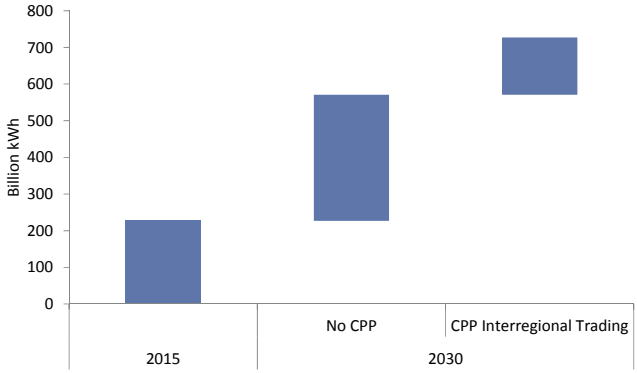
- **We expect innovation and global markets, rather than politics, to continue to be the primary driver for the growth in low-carbon technologies.** In our view, prices for batteries and solar panels will continue to drop, and global market-share gains will continue for wind, solar, EVs and LEDs, regardless of who occupies the White House.
- **The fragmented patchwork of sector-by-sector, country-by-country regulation mitigates the impact of policy shifts in individual countries, even in a key market like the US.** Policy reversals have been quite common (the UK and Australia offer recent examples). While they are a key source for volatility, they generally do not shift the overall growth trajectory of the Low Carbon Economy.
- **Some US policies, including Renewable Portfolio Standards (RPS) and federal tax credits for wind and solar, appear less likely to change.** During his campaign, President-elect Trump did not suggest any plans for changes to the tax credits, which were extended earlier this year for five years with bipartisan support. The most stringent renewable standards are set at the state level, putting them out of reach of the federal government. In California and New York, for example, utilities are now required to have a 50% renewables share by 2030.

Exhibit 9: Majority of US states have portfolio standards requiring high renewables shares in power generation
Renewable portfolio standard of US states



Source: NYISO, Goldman Sachs Global Investment Research.

Exhibit 10: US solar and wind power generation could reduce to 2.5x current output vs. 3.2x by 2030
EIA modelling of Clean Power Plan (CPP) impact on power generation from wind and solar



Source: EIA, Goldman Sachs Global Investment Research.

We believe markets will focus on three key areas:

1) **The Clean Power Plan (CPP), which we believe could be most vulnerable to a repeal**. Near-term implications would likely be limited, but this could be a negative for post-2020 wind and solar volumes given the current plan's timeframe for

implementation. EIA modelling suggests that dismantling the CPP could reduce 2030 US solar and wind power generation to 2.5x of the current output vs 3.2x. This would remain sensitive to post-2020 federal policy, as well as the evolution of state-level renewable obligations.

2) **The mid-term review of the CAFE standards in 2017, which is shaping up as the first litmus test for the Trump Administration's stance on low-carbon technologies.** The outcome of the review of the fuel-efficiency standards will be crucial to determine the federal government's willingness to exert pressure on carmakers to reduce emissions of conventional vehicles. It may also signal to what extent the Trump Administration is willing to support EV development (e.g. by extending generous tax breaks that are set to expire as EV volumes ramp up). We note that state-level restrictions, e.g. in the largest car market of the US, California, will continue to be a key feature of the regulatory landscape here as well.

3) **The Paris Agreement, from which Trump has announced plans to withdraw.** The likelihood, timelines and tangible consequences of such a move remain difficult to assess at this point. We note that national contributions to emission cuts under the Paris agreement are essentially voluntary and that the treaty does not contain an enforcement mechanism *(GS SUSTAIN: The Low Carbon Economy-Key Takeaways from the Paris Agreement,* December 15, 2015). However, we believe that any actual moves towards a withdrawal from the treaty would be a significant negative on sentiment and could reduce upside risk for low-carbon technologies from future policy measures.

Breakthrough-Scaling-Maturation: Rethinking the low-carbon transition

Breakthrough-Scaling-Maturation: Rethinking the low-carbon transition

The impact of the Low Carbon Economy is often considered in terms of potential carbon pricing, and carbon footprints are frequently used to assess the exposure of individual companies. However, important elements of the low-carbon transition could continue to proceed, even as substantial economy-wide carbon pricing remains a distant prospect. This can create complacency about the risks and opportunities connected to rapidly growing, transformative, low-carbon technologies that are the focus of our work. This section offers a basic conceptual framework to assess how solar PV, onshore wind, LEDs and electric vehicles are likely to affect the industries in which they are gaining market share.

Focus on transformative low-carbon technology, not carbon pricing

We believe that the Low Carbon Economy is now emerging in select, carbon-intensive industries, where a combination of regulatory pressure, rapid cost reductions and performance improvements creates competitive technologies that are able to gain broad-based market acceptance. Such technologies are relatively rare. Indeed, we believe only four exist today: LEDs, solar PV, onshore wind and electric vehicles (for a detailed discussion, see *GS SUSTAIN: The Low Carbon Economy*, November 30, 2015).

Like other technology shifts, the introduction of these low-carbon technologies can be considered in a succession of stages. We offer a straightforward three-step framework that can help to assess how these technologies gain market acceptance and how they shape the opportunity set for companies in affected industries through these stages.[1]

Exhibit 11: A basic framework for analysing the growth in low-carbon technologies

	Breakthrough →	Scaling →	Maturation
Technology	EV, Solar PV, Onshore wind, LEDs		
Market share	Very small, modest gains	Single digits, growing rapidly	Substantial with continued rapid gains
Growth	Very rapid	High	Slower
Pace of technological change	Very high	Beginning to slow	Incremental
Competitiveness	Cost & performance not yet comparable to incumbent technology	Cost & performance begins to approach incumbent technology	Significant cost & performance advantages vs incumbent technology
Market Structure	Consolidated & dominated by incumbents	Fragmented as new entrants take share	Re-consolidating as winners take share

Source: Goldman Sachs Global Investment Research.

Breakthrough

In the Breakthrough stage, volume growth is very rapid but overall volumes and market-share gains are still very small. The technology experiences step-changes in terms of cost

[1] We note that there is extensive academic literature discussing more sophisticated models of technological change and diffusion. See, e.g., P. A. Geroski, *Models of Technology Diffusion* in Research Policy (2000) 29(4/5), 603–625; or B.H. Hall *Innovation and Diffusion*, in Fagerberg et al (eds.), Handbook of Innovation, Oxford University Press, 2004.

and performance, but is still at a significant disadvantage compared to incumbent technology; also, companies are still experimenting with different business models.

In **autos**, **electric vehicles** still account for less than 1% of sales, but are on track to deliver the fourth consecutive year of 50%+ volume growth. We expect rapid scaling to continue as a new generation of advanced long-range EVs becomes available to consumers. Future growth rates remain subject to large margins of uncertainty, but continued scaling could allow EVs to reach mid-single-digit market share by 2025.

Scaling

In the scaling phase, the technology and business models begin to stabilise. With continued cost reductions and performance improvements, the technology becomes more competitive with incumbent solutions. Volumes are still small but now significant, and, although growth has slowed somewhat, annual market-share gains are now sizable.

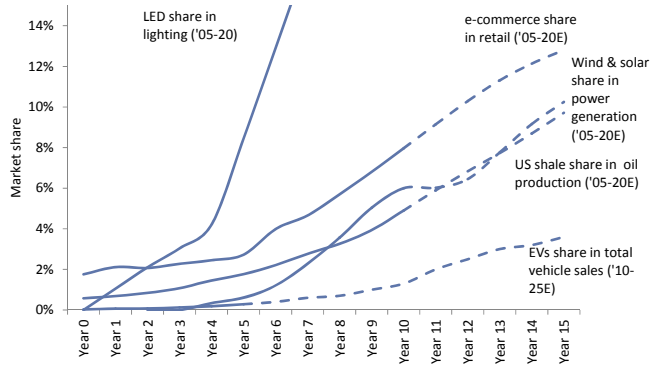
With almost $200 bn spent globally on **onshore wind and solar PV** installations in 2015, they accounted for almost half of total spending on **power generation equipment** – and >9x the investment in nuclear; >6x the investment in gas; and >2.5x the investment in coal-fired power generation. This drives accelerating market share gains. By 2020, we expect the share of wind and solar in global electricity generation (c.10%) to exceed today's share of ecommerce in global retail (c.8%), and that of US shale in global oil production (c.6%).

Maturation

As the technology approaches maturation, it begins to offer significant cost and performance advantages compared to incumbent technology. Cost reductions and performance improvements slow, as do volume growth rates. Market shares are large and continue to grow rapidly as incumbent technology is relegated to legacy status.

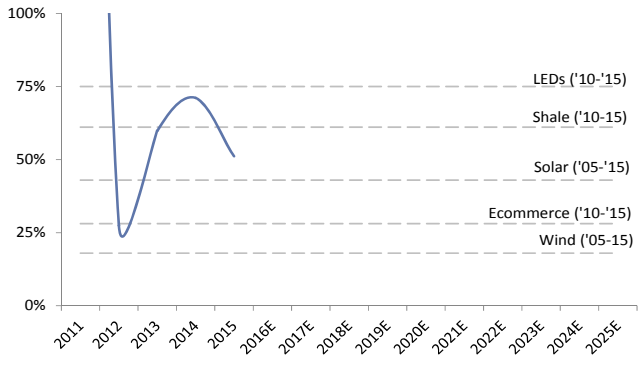
In **lighting** (which accounts for 15-20% of global electricity consumption), high-performing, long-lasting and increasingly cheap **LEDs** are set to account for c.43% of the global lighting market in 2016E and have relegated other lamps to the status of fast-disappearing legacy technologies. Annual market share gains in the US, where detailed data is available, exceed 1000 basis points. Short lifespans on legacy lamps imply that lighting globally will shift almost exclusively to LEDs sometime in the 2020s, marking one of the fastest technology shifts in human history.

Exhibit 12: Transformative low-carbon technologies have seen very rapid global market share gains
Market shares of different disruptive technologies (dotted lines indicate forecasts)



Source: Euromonitor, BCG, IHS, IRENA, BP, Goldman Sachs Global Investment Research.

Exhibit 13: What's the right CAGR for EVs going forward?
5-year CAGR of different disruptive technologies around inflection points vs. EV growth rates



Source: Euromonitor, BCG, IHS, IRENA, BP, Goldman Sachs Global Investment Research.

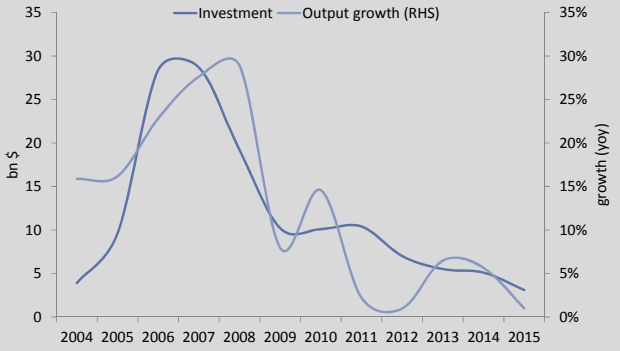
Alternative low-carbon technologies face growing risk of marginalisation

As the above-discussed, low-carbon technologies rapidly gain scale and see rapid cost reductions and performance improvements, other alternative low-carbon technologies face growing risks of marginalisation. In lighting, compact fluorescent lamps (**CFLs**) are rapidly losing market share to LEDs, which are significantly more energy efficient, have much longer life times and whose price premiums have dropped significantly. As LEDs gain popularity, producers have shifted away from CFLs, with GE, for example, announcing that it would cease production by the end of the year.

In power generation, several early-stage, low-carbon technologies are at risk of losing access subsidies, as solar PV and onshore wind offer governments cheap and scalable low-carbon power. Heavy investment and high volume growth could allow them to sideline potential competitors, such as **concentrated solar power** or **carbon capture and storage (CCS).** For example, a coalition of major oil and gas companies recently announced a major initiative to invest $1 bn over 10 years to develop CCS technology. In comparison, this is less than was invested on average every two days in solar and wind projects in 2015.

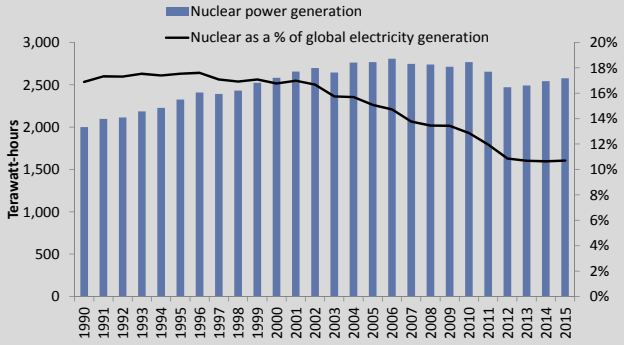
In autos, rapid growth of long-range, fully electric vehicles could similarly threaten low-carbon competitors such as **biofuels**, **fuel cell vehicles**, and potentially even **hybrids**. If battery technology continues to improve rapidly, these technologies could face a challenging combination of declining regulatory support and loss of interest from carmakers. We believe the recent move by carmakers to emphasise long-range EVs in their alternative drivetrain strategies is indicative of this shift. Ironically, EVs were sidelined in a similar fashion by combustion engines in the early 20th century.

Exhibit 14: In biofuels, production has dropped sharply as oil prices and policy support declined
Investment in new biofuel capacity and growth rate in global production, 2004-15



Source: OECD, FAO, UNEP, Goldman Sachs Global Investment Research.

Exhibit 15: The market share of nuclear power has declined since the 1990s
Nuclear power generation; nuclear share of global electricity generation.



Source: BP, Goldman Sachs Global Investment Research.

Meanwhile, **battery-based grid storage is perhaps the closest candidate to emerge as the next transformational low-carbon technology, given it is highly complementary to the technologies we discuss in our report.** However, volumes are still very low. In the US, which accounts for roughly half of all incremental global energy storage added, a little over 200MW were installed in 2015. This is only a fraction of the over 1,000GW of generation capacity on the US utility grid.

Transformational low-carbon technologies diffuse at different speeds

The pace at which technologies proceed through these phases depends on a variety of factors. In the first instance, this includes the **pace of cost reductions and performance improvements**, and the **degree of regulatory support** in key markets. However, **asset life, capital intensity, and system-switching costs** (such as the need to develop supporting infrastructure) are also important to determining the pace of the transition. For example, the extremely rapid adoption of LEDs (short asset life, low capital intensity, negligible system-switching costs) and the more gradual diffusion of wind and solar (long asset life, high capital intensity, significant system-switching costs) can be explained this way.

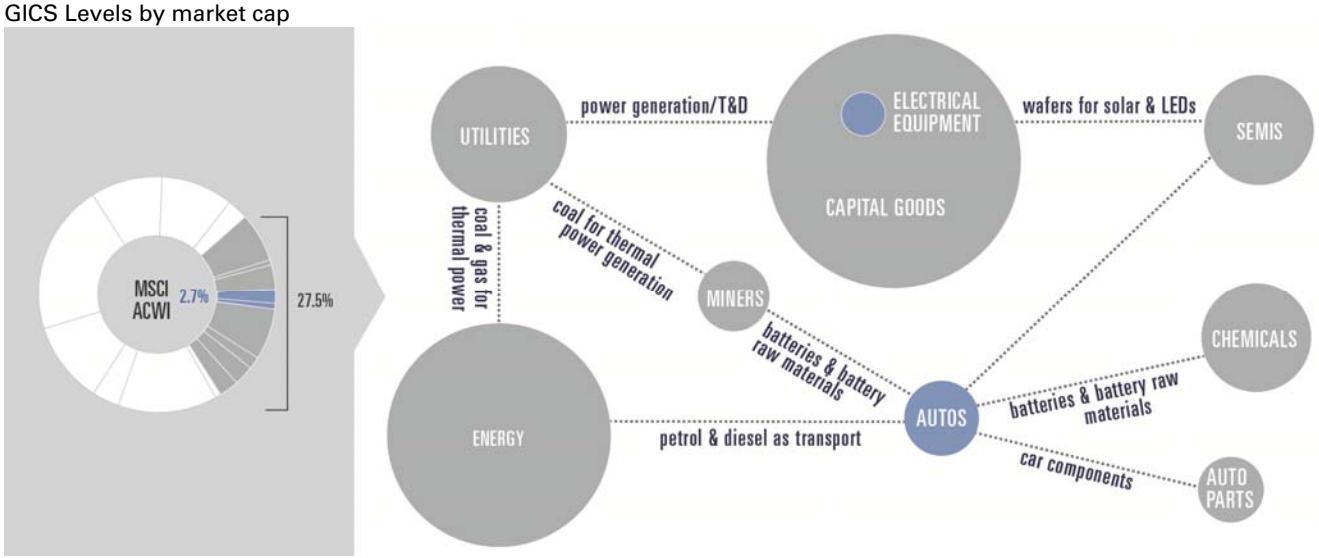
While we focus heavily on technology and market dynamics, their interplay with regulatory developments continues to be central to the Low Carbon Economy. Regulatory pressure and incentives are key to catalysing investment in low-carbon technologies and to accelerate their adoption. However, we emphasise that key regulation will be determined

country by country, sector by sector, and may be volatile in nature. Meanwhile, we expect carbon pricing to remain one policy instrument among many, applying only selectively and imposing relatively modest price levels (for an in-depth discussion of how regulation shapes the Low Carbon Economy, see *GS SUSTAIN: The Low Carbon Economy,* November 30, 2015).

When and where?

- **Where? We expect the Low Carbon Economy to impact sectors highly unevenly**, rather than in proportion to their carbon emissions. We believe markets will respond where low-carbon technologies attain meaningful market share and begin to reshape earnings and returns patterns. In carbon-intensive industries where transformative technologies are lacking, like airlines or construction materials, risks for now are likely to remain incremental, and mainly regulatory and reputational in nature.

Exhibit 16: Low-carbon technologies reshape sectors accounting for just 3% of listed equities, but supply chains amplify their impact across our coverage
GICS Levels by market cap



Source: Datastream, Goldman Sachs Global Investment Research.

- **When? We expect the Low Carbon Economy to reshape global markets earlier than commonly anticipated.** We see realignments already underway, with the biggest market dislocations occurring over the course of the next 5-10 years, as low-carbon technologies take share in lighting, power generation and autos. As these technologies continue to scale and their impacts spread along supply chains, we believe that autos, utilities, capital goods, energy and materials could be meaningfully affected by 2025– sectors that together account for a quarter of listed equities.
- **How? The key risks incumbents face are new entrants with transformative technology and business models**, in our view, not a gradual increase in compliance costs. Industries where risks from low-carbon technologies loom large, like autos and oil, can learn from others like lighting, utilities and coal, where they have already manifested.

Technology could deliver CO2 peak c. 2020, not yet enough for 2°C

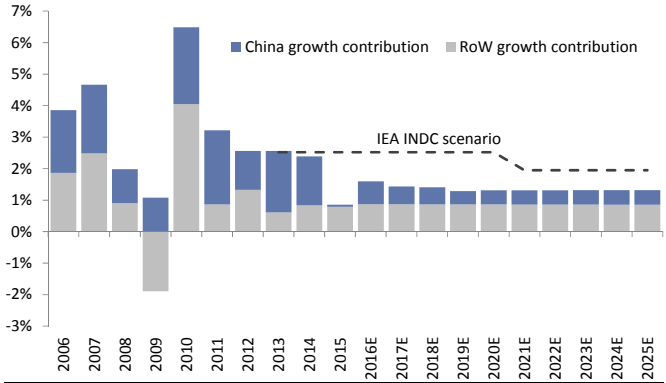
Technology could deliver CO_2 peak c.2020, not yet enough for 2°C

Low-carbon technologies could begin to shift emission pathways earlier than is commonly assumed. We expect power-sector emissions to be more than 15% lower by 2025 than mainstream models suggest. This is mainly due to higher wind and solar penetration and lower electricity consumption growth, with China's lower and less energy-intensive growth and LED savings as key contributors. This could mean that overall energy-related emissions peak around 2020, rather than continue to increase gradually over the next decade as mainstream modelling suggests. However, by themselves, such savings would not yet be sufficient to put the world on a '2°C' pathway, in our view. Even if they continue to see rapid growth, we do not yet believe electric vehicles will deliver large-scale emission savings over the next decade given their lack of scale.

In the long run, the low-carbon technologies discussed in this report could reduce fossil-fuel consumption and carbon emissions significantly. Indeed, if solar power, onshore wind and electric vehicles were to largely replace incumbent technology, thermal coal consumption (currently over 3.9 bn tonnes per annum) would virtually disappear, as would approximately a third of global oil consumption (assuming light-duty vehicles account for about half of transport emissions), which is used to power light-duty vehicles. We estimate this would equate to saving roughly 13.5 Gt of CO2e p.a., or c.42% of today's global energy-related emissions. Fossil-fuel use under such a scenario would be limited to industrial applications (such as coal for steel making, oil used for plastics, natural gas for chemicals), some forms of transport (such as aircraft), as well as gas for power generation as backup for renewables (at least in the absence of cheap and scalable grid storage).

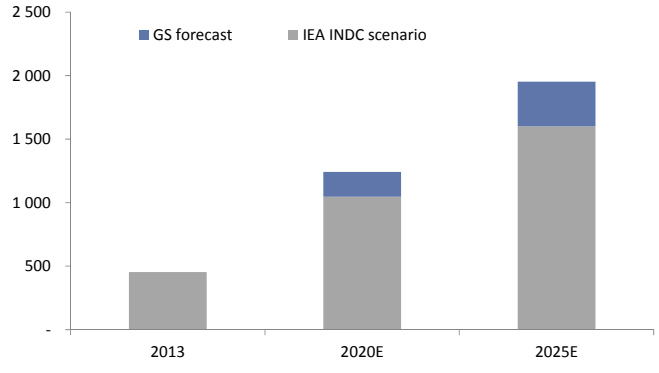
Such large-scale shifts in energy consumption would take at least until the middle of this century, on our estimates, putting them well beyond mainstream investment horizons. Assuming the current pattern of large annual share losses for coal-fired power generation continues in the US and China (averaging -15.4%/-18.0% bp for 2010-2020E), thermal coal consumption in these countries would cease by 2039 and 2055, respectively. Assuming electric vehicles were able to maintain a 50% growth CAGR indefinitely (vs. 55% for 2013-2016E), the last new combustion-engine car would be sold in 2029, and it then would take at least another decade for the existing global stock of combustion engines to have been largely replaced. Under more realistic assumptions, such shifts are likely to take considerably longer.

Exhibit 17: We forecast lower energy demand growth out to 2025, with slower China demand a key contributor…
Global electricity demand growth with the contribution from China and the rest of the world shown separately



Source: BP, IEA, Goldman Sachs Global Investment Research.

Exhibit 18: …and we see more wind and solar capacity additions than implied by the INDC scenario
Installed solar and wind capacity (GW); IEA and GS forecast

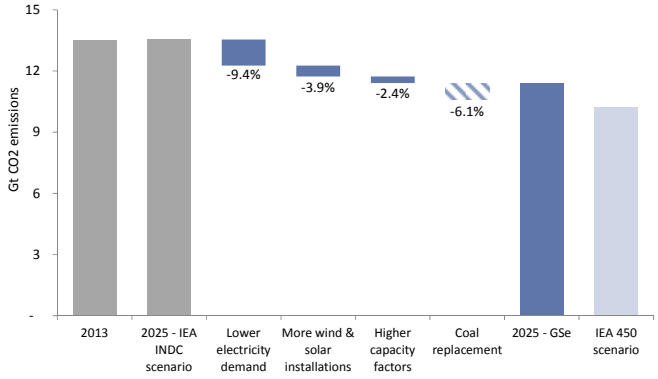


Source: IEA, Goldman Sachs Global Investment Research.

Nonetheless, transformative low-carbon technologies are set to deliver meaningful near-term emissions savings, particularly in the power sector. Compared to the IEA INDC scenario (which assumes countries meet their national Paris commitments), we expect lower demand growth, higher wind and solar installation, and more efficient turbines and panels to deliver 15.8% lower emissions from power generation.

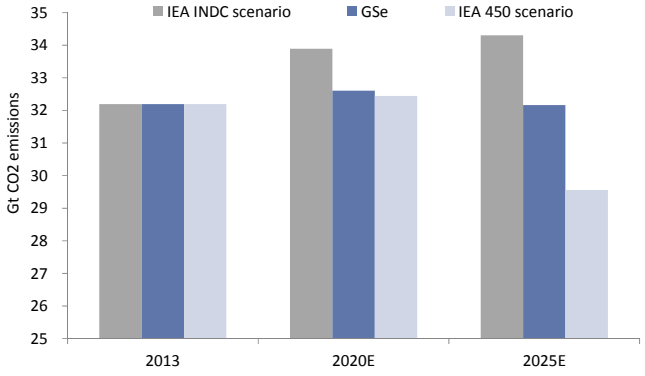
Policy choices will remain critical. Our calculations assume that wind and solar will take market share from other forms of power generation in proportion to their share of the power mix. If all market-share gains come exclusively at the expense of coal, we estimate additional savings of 6.1% could be realised.

Exhibit 19: Power-sector emissions could be more than 15% lower by 2025 than mainstream scenarios suggest
The IEA's INDC scenario modified with our forecasts



Source: IEA, Goldman Sachs Global Investment Research

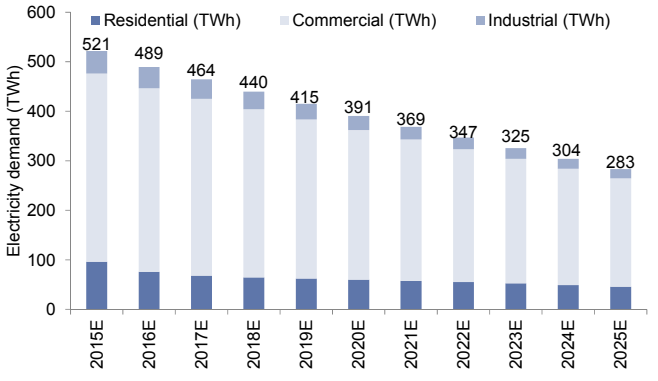
Exhibit 20: Global emissions could peak around 2020, but for now remain above a '2˚C scenario'
Emissions in the IEA's INDC/450 scenarios vs. our estimates



Source: IEA, Goldman Sachs Global Investment Research

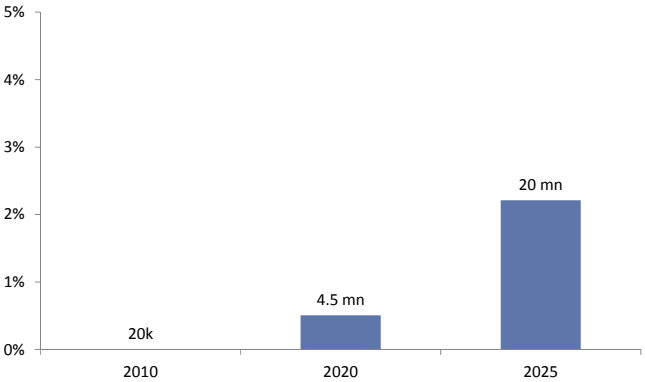
LEDs make an important contribution to lower electricity demand growth. Given lighting accounts for 15-20% of global electricity consumption and LEDs can cut consumption by half compared to the incumbent mix, rapid LED penetration has important implications for demand. In the US alone, our analysts estimate that LEDs could reduce total power demand by 4% by 2020, compared to the base case for demand growth.

Exhibit 21: 25% reduction in power demand by 2020 from LEDs under base case
US lighting power demand by segment



Source: Goldman Sachs Global Investment Research.

Exhibit 22: Given an installed base of 1 bn cars, EVs have a limited impact in the near term
Installed vehicle fleet vs. share of EVs



Source: IHS, OICA, Goldman Sachs Global Investment Research.

Electric vehicles could become a major contributor to emissions savings, but not before the mid-2020s, in our opinion. Given the large number of cars (c.1 bn vehicles globally) even a very rapid adoption path would not significantly impact total oil consumption or emissions in the sector, even if it could contribute to slowing growth.

EVs are crossing the Rubicon: 2016 could signal the breakthrough

EVs are crossing the Rubicon: 2016 could signal the breakthrough

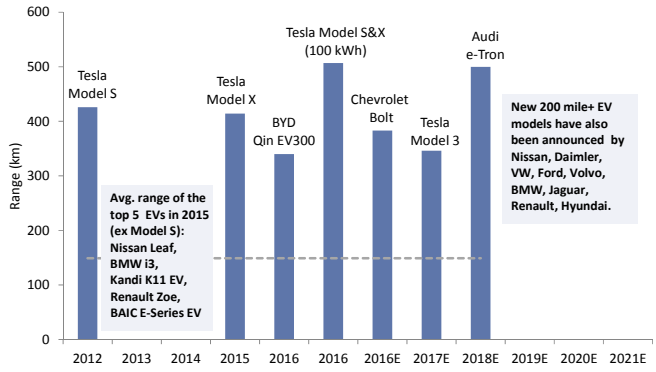
2016 could mark the breakthrough year for electric vehicles, even if the technology for now remains more promise than reality. Pure EVs are on track to deliver the fourth year running of 50%+ volume growth, but they still account for only about 1 in 200 cars sold globally. We expect volumes and battery technology to continue to surprise to the upside, as regulators and carmakers are rethinking the market potential and timelines for EVs. In our view, the technology will not begin to scale before 2020, but it is already transforming the competitive landscape for auto OEMs and suppliers.

Rapid volume growth for pure EVs continues

Year-to-date sales numbers indicate that 2016 is on track to deliver the fourth consecutive year of 50%+ volume growth for pure electric vehicles. In the first nine months of this year, grid-connected vehicle deliveries increased by 54% year-on-year. China, the largest EV market globally, remains the most important contributor to growth, with sales in grid-connected vehicles more than doubling compared to the first three quarters of 2015.

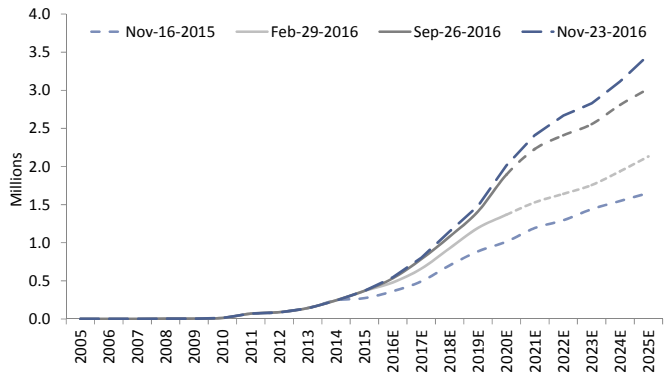
Growth forecasts have seen material upwards revisions over the course of 2016, despite persistent uncertainties around future EV adoption rates. Over the past year, for instance, data-provider IHS has upgraded its cumulative EV volume forecast out to 2025 by 93%. Our autos analysts now forecast a 32% CAGR for EVs for the next 10 years, and in April they revised the probability of a 'transformative' growth scenario up to 35% (vs. 25% previously). In such a scenario, annual deliveries of pure EVs could be as high as six million by 2025.

Exhibit 23: In 2016, major carmakers have announced new long-range EV models to be introduced before 2021
Announced long-range EV launches and their range



Source: Company information, Goldman Sachs Global Investment Research.

Exhibit 24: IHS upgraded its cumulative 10-year EV forecast by c.10 million vehicles over the last 12 months
IHSs 'pure' EV engine forecasts since November 2015



Source: IHS, Company data, Goldman Sachs Global Investment Research.

A pivot by major carmakers to fast-tracking new long-range models has contributed to more bullish market views. More than half a dozen carmakers announced new plans for fully electric models with ranges exceeding 200 miles by 2021 or earlier. This includes the Chevrolet Bolt (planned launch at the end of 2016), the Model 3 (planned for the end of 2017) and the Audi e-tron (planned for 2018). A growing number of automakers are now targeting a significant share of their annual sales to be EVs (e.g. 25% of VW's annual sales are targeted to be electrified by 2025).

Announcements from the Paris Auto Show (October 1-16, 2016)

"We're now flipping the switch, we're ready for the launch of an electric product offensive that will cover all vehicle segments, from the compact to the luxury class."

Dieter Zetsche, Daimler CEO

"We're all facing a legislative framework around the world which is going in one direction and almost converging on the same spot. Within the mix of vehicles for the foreseeable future, you will need to have a good proportion of zero-emission vehicles."

Ian Robertson, BMW Board of Management

"Competitors are now in phase one on their electric strategy, while we're entering phase two. We're already well on our way to electrifying the core portfolio, using powertrain technology from BMW i."

Harald Krueger, BMW CEO

"I think that it is very clear that individual mobility is moving toward carbon-neutral. It is a major milestone for us (the Opel Ampera-e) for our transformation on the long-term horizon to become an all-electric company."

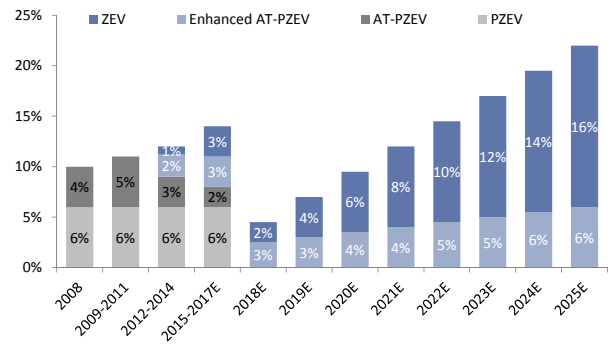
Karl-Thomas Neumann, President of GM Europe

Feedback loops to accelerate EV growth; we focus on the leapfrogging risk for hybrids

We believe rapid progress in battery technologies and increasing regulatory focus on zero-emission vehicles could create potential for EVs to 'leapfrog' hybrids. In contrast, mainstream forecasts assume that vehicle electrification will play out gradually, with hybrids and plug-in hybrids dominating in the mid term and coexisting with EVs in the long term. We see potential parallels to the lighting market. Here, LEDs replaced compact fluorescent lamps (CFL) at a much faster rate than expected, owing to a combination of lukewarm support for CFLs from consumers and regulators on the one hand, and rapid performance improvements and cost reductions in LEDs on the other.

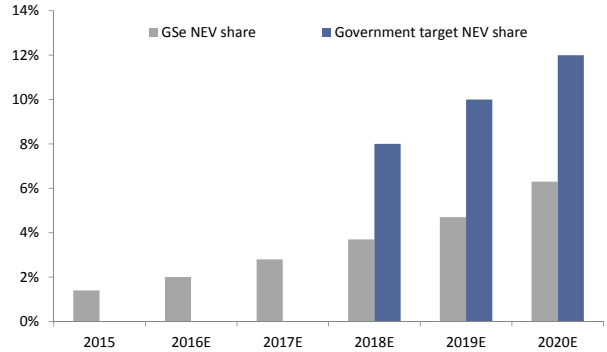
We expect regulators to focus increasingly on incentivising zero-emission vehicles as EV technology continues to improve. We see this reflected in recent regulatory reforms in a number of countries. In China, draft regulations were introduced in September that would require new energy vehicles (NEVs) to account for at least 8% of carmakers' annual production by 2018. This would increase to 12% by 2020, 2x our current forecast. These policies mirror California's credit system, where non-plug-in hybrids will no longer qualify as zero-emission vehicles (ZEV) from 2018 onwards. Germany also announced a €4k grant specifically targeting EVs, as well as additional funding for charging stations. Similar schemes already exist, for instance, in the US, UK and France.

Exhibit 25: In the US, regulation is increasingly supportive of a shift towards grid-connected vehicles…
California ZEV regulation schedule



Source: CEPA, Goldman Sachs Global Investment Research.

Exhibit 26: …and similar policies have been drafted in China
NEV share of total output



Source: MIIT, Goldman Sachs Global Investment Research.

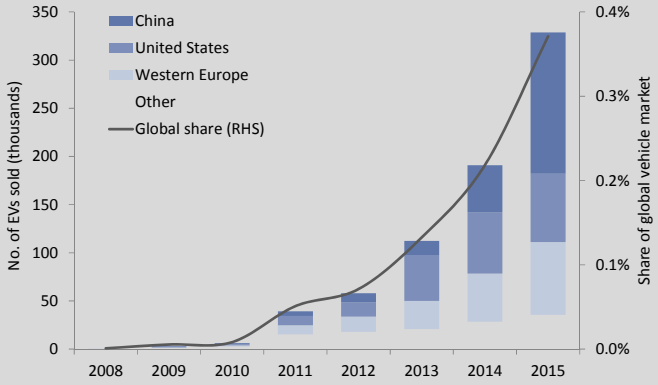
Intensifying investment in battery technologies could accelerate performance improvements and cost reductions for EVs. We believe battery technologies are already surprising on the upside, with the new GM Bolt (below $40k), for example, offering a slightly longer range than an entry-level Tesla Model S60. Faster volume growth, increasing competitive pressures and accelerating investment could contribute to a further acceleration in cost reductions and performance improvements. Automakers have also promised to significantly increase their EV investment, with Daimler stating that it would invest more than half of its €14.5bn R&D budget over the next two years on 'green' technologies. Ford has stated it will invest $4.5 bn in electrified vehicle solutions by 2020.

In China, EVs are accelerating

Strong regulatory support has made China, currently the world's largest car market, also the largest and fastest-growing market for EVs. With 146k pure EVs sold in China in 2015, it is now double the size of the next-largest EV market, the US with 71k.

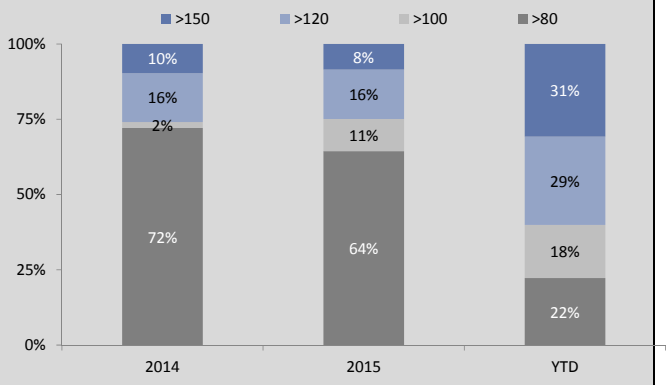
As it seeks ways to reduce fuel consumption growth and air pollution, China has created some of the strongest incentives for a rapid shift to electric vehicles. Draft regulations were introduced in September that would require new energy vehicles (NEVs) to account for at least 8% of carmakers' annual production by 2018. This would increase to 12% by 2020, or 2x our current forecast. Regulations in major Chinese cities also increasingly favour grid-connected vehicles. Beijing has cut its annual licence plate quota from 800k in 2010 to just 150k in 2016, leaving applicants with less than a 1% chance per month of winning the number-plate lottery. In February, the municipal government extended its 150k quota to 2018, and doubled the share of the quota reserved for grid-connected vehicles to 60k, creating significant incentives for consumers to consider EVs and plug-in hybrids.

Exhibit 27: Most recently, China has been the largest contributor to rapid EV growth
'Pure' electric vehicle sales (thousands) by region vs. global market penetration



Source: IEA, Goldman Sachs Global Investment Research.

Exhibit 28: Although coming from a low base, Chinese EVs are rapidly improving their performance
Split of top-20 EV sales in China by max. speed (kmh)



Source: EV-Sales Blogspot, Goldman Sachs Global Investment Research.

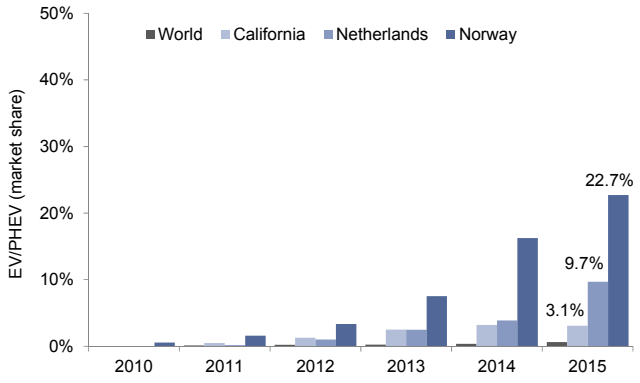
The Chinese EV market is dominated by domestic companies, with a significant technology gap to global leaders. However, performance is improving rapidly. In 2014, almost 3/4 of EVs had a top speed below 100 km/h among China's 20 best-selling grid-connected vehicle models. Year to date, 60% have a top speed of 120 km/h or more, with the share of cars with a top speed higher than 150 km/h having more than tripled.

Transition to remain volatile; regulation to drive a boom/bust pattern

We expect EV growth to remain volatile at the breakthrough stage, as shifting regulatory incentives potentially shape a boom-and-bust pattern in individual markets. Particularly generous incentives have already created high-penetration jurisdictions, e.g. Norway and the Netherlands, where market shares of grid-connected

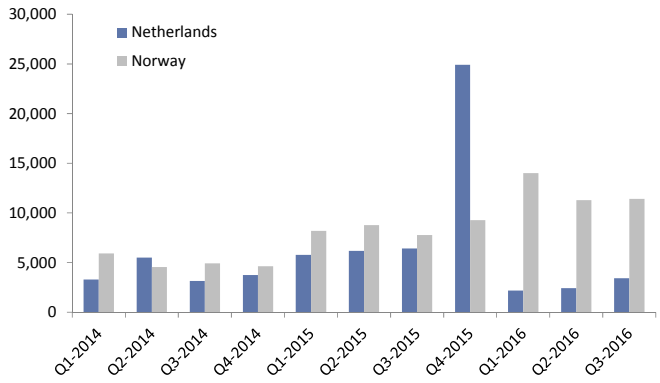
vehicles reached 22.7% and 9.7%, respectively, in 2015. However, as regulatory incentives evolve, we expect volatile growth rates. In the Netherlands, for instance, PHEV incentives were halved from 2016 onwards, driving rapid growth rates in the quarters leading up to the New Year. In the aftermath of this boom, PHEV sales collapsed. A boom/bust pattern has been typical for the expansion of early-stage, low-carbon technologies.

Exhibit 29: Select high-penetration markets are emerging as a result of additional regulatory incentives…
Grid-connected vehicles as a proportion of overall vehicle sales



Source: IHS, IEA, CNCDA, Goldman Sachs Global Investment Research.

Exhibit 30: …but we expect boom/bust periods similar to what we have seen in wind and solar
Netherlands' and Norway's quarterly EV sales



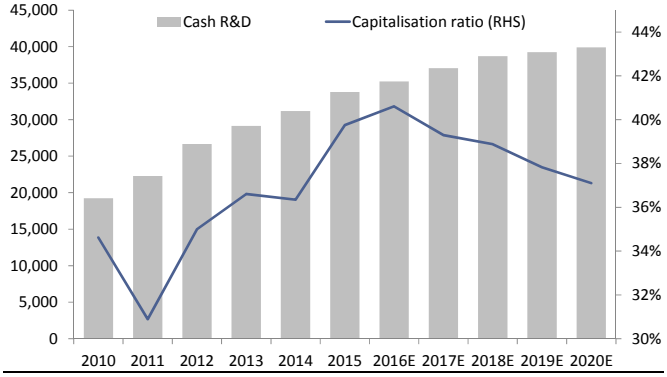
Source: EV-Sales Blogspot, Goldman Sachs Global Investment Research.

We expect a challenging transition for the auto sector

The returns of auto OEMs may come under pressure as R&D intensifies. Our European autos analysts expect R&D spending as a share of sales to increase from 5.1% to 5.7% between 2015-20, with alternative drivetrain technology now accounting for the largest part of OEM patent spending. However, the payoff for these investments remains uncertain, forcing OEMs to expense a growing share of R&D spending, and contributing to sequential declines in returns (they forecast aggregate return on invested capital to decline from 7.8% in 2016 to 7% by 2021).

Beyond the pressure on returns, carmakers could also face increasing risk from new entrants to the market, as barriers to entry decline, owing to a mechanically similar powertrain and less capital-intensive vehicle construction. Our analysts estimate that the number of parts in an EV is only two-thirds of the content in a gasoline car. As a result, the ability to coordinate and integrate production across several fronts, which is a key strength of conventional automakers, may be less important.

Exhibit 31: R&D spending to intensify while returns on investment become incrementally more uncertain
Cash R&D (€ bn) vs. capitalisation ratio for European carmakers



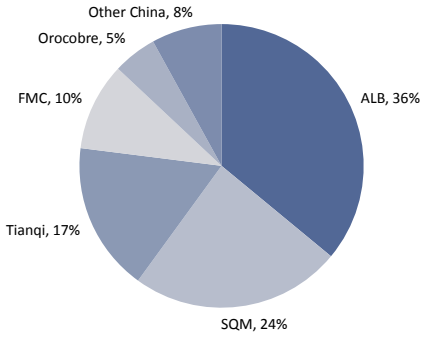
Source: Company data, Goldman Sachs Global Investment Research.

Suppliers likely to face demand pressure and more competition. As the EV renders a whole range of combustion-engine-related content obsolete (such as engines, fuel tanks, alternators, exhaust systems, injection systems etc.), auto suppliers are likely to see significant parts of their revenues at risk. Suppliers are investing in battery management to substitute some of the lost revenues, but it is not yet clear how much value they will be able to retain while the new technology also opens the door for new competitors. Battery companies, such as Samsung SDI, LG Chem and Panasonic, are increasingly forcing their way into carmakers' supplier chains.

To meet increased demand from EVs will require a rapid production capacity expansion for batteries and raw materials. Benchmark Mineral Intelligence expects battery-production capacity to increase by more than 5x by 2020, with the lion's share of the expansion meant to supply electric vehicles. We see potential for significant competitive pressures and cost reductions during this period, similar to what we have seen in the solar industry. The EV battery industry is currently dominated by five key players from South Korea, Japan and China. As companies invest in different battery chemistries and partner with different car manufacturers, there is still limited visibility as to who will be the leading battery manufacturer going forward.

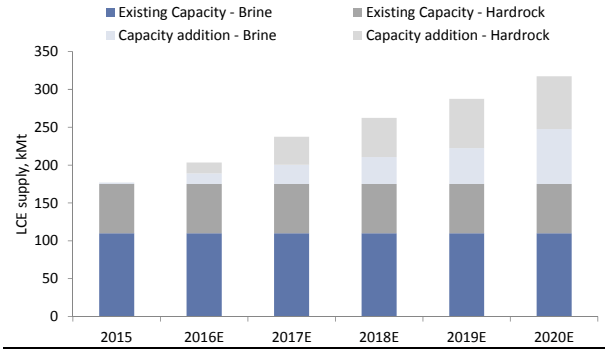
Rapidly increasing demand for batteries requires a significant expansion in lithium production capacity. Our analysts expect the global lithium supply to expand at a 12% CAGR through to 2020, enough to fuel the demand created by batteries during this period. As part of this expansion, lithium from hardrock sources (generally more expensive than brine lithium) is expected to take a greater share of the added capacity.

Exhibit 32: Albemarle is the leading global lithium franchise by market share
Lithium market share, 2015



Source: SQM, Goldman Sachs Global Investment Research.

Exhibit 33: Capacity addition from hardrock to be equal to brine's by 2020
Lithium supply from brine & hardrock sources



Source: Company data, Goldman Sachs Global Investment Research.

Wind and solar are now scaling at a similar pace to ecommerce

Wind and solar are now scaling at a similar pace to ecommerce

After a record-breaking 2015, annual wind and solar installations are likely to face a cyclical downswing in 2017/18, as volumes in China contract and growth in the US remains sluggish as the ITC/PTC extension has stretched deployment timelines. Nonetheless, we expect installations to average almost 120GW pa for 2015-2020. Over the next decade, we expect the global installed base and market share of wind and solar to triple, while we forecast global electricity supply from wind and solar to overtake nuclear by 2020 and hydro by 2025.

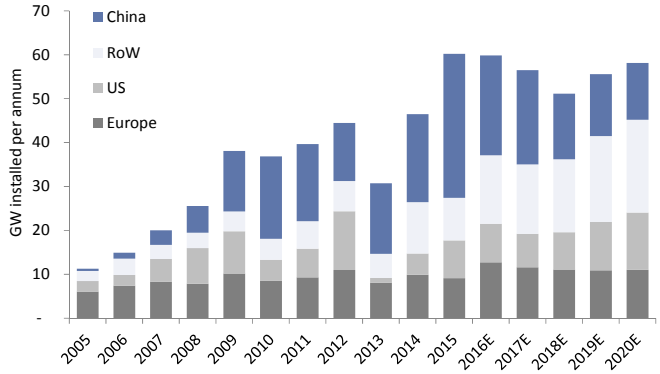
Another bust (2017/18), another boom (2019/20): Installations remain volatile

After three consecutive years of booming volume growth, wind and solar installations face a challenging near term in 2017/18E. From an estimated peak of 122GW in 2016, we expect installations to decline sequentially by -6%/-2% over the next two years. China, by far the most significant growth driver over the last eight years, is seeing a significant contraction, as policy makers are looking to cut overcapacity. In the US, we expect volumes to be weaker over the next two years as PTC/ITC extensions allow for installations to be pushed into subsequent years.

However, 2019 and 2020 could see another boom, as Chinese volumes begin to bottom and US tax credits near expiry. We expect US volumes to recover ahead of the tax credit expiry in 2020 and to contribute almost 27GW to global installations (35% more than in 2016E). Also, emerging economies other than China are likely to have scaled to a level at which they become a significant driver of global installations (43% of installations in 2020E). At that point, we believe China's share of installations will have normalised.

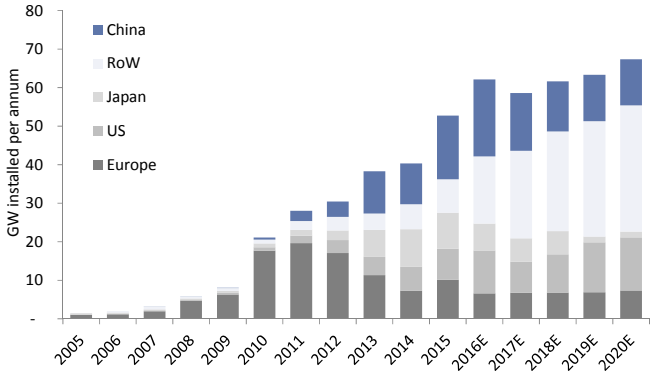
Such a boom/bust pattern would continue to pose significant challenges for wind-turbine makers and solar-panel manufacturers. We expect falling demand and rising overcapacity to intensify competitive pressures. This is likely to be most apparent in China, where we expect installations of wind and solar to fall by 50% between 2015 and 2020. This could result in further competitive pressure abroad, as Chinese wind-turbine manufacturers turn more aggressively to exports to make up for declining demand at home.

Exhibit 34: Both global wind and solar installations…
Annual onshore wind installations by region, 2005-2020E



Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Exhibit 35: …are expected to see a challenging near term Annual solar PV installations by region, 2005-2020E



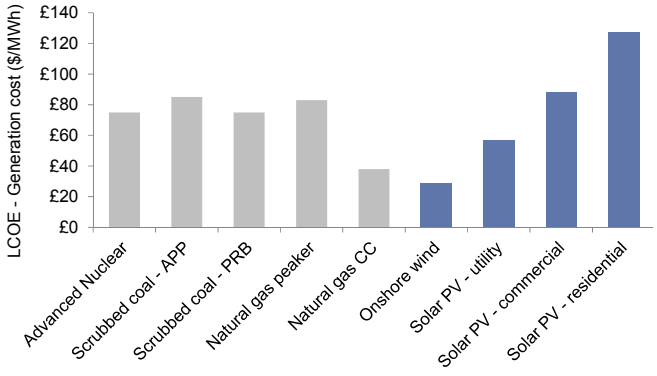
Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Cost declines to accelerate as competitive pressures remain intense

As cost declines continue to surprise on the upside, wind and solar are becoming increasingly competitive with incumbent power generation. With the benefit of tax credits, wind is now already the cheapest form of adding new power-generation capacity in the US, and utility-scale solar provides an increasingly competitive all-in cost that is almost on par with gas and other fossil-fuel alternatives. In select emerging markets, renewables are even cheaper, with solar now being installed for as little as 1$/W, according to industry feedback.

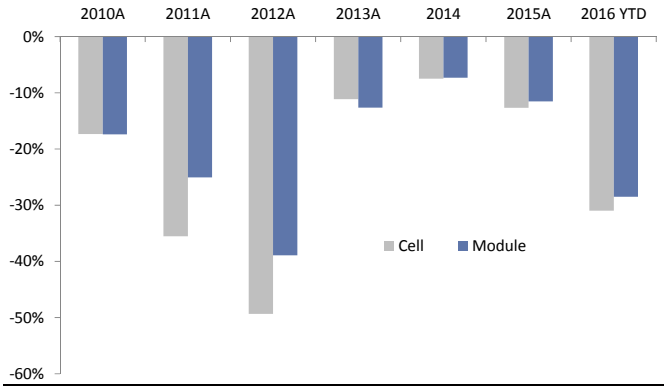
Growing overcapacity and rising competitive pressures are likely to accelerate cost declines in both wind and solar. This is particularly apparent in solar, where YTD solar prices for cells and modules have declined sharply (31% and 29%, respectively) and our analysts expect downwards pressure to persist into 2017.

Exhibit 36: With subsidies, wind is now by far the cheapest form of adding new power-generation capacity in the US
US levelised cost of energy by power source



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 37: Solar cell and module ASPs are down the most ytd since 2012
Annual price declines for solar cells and modules

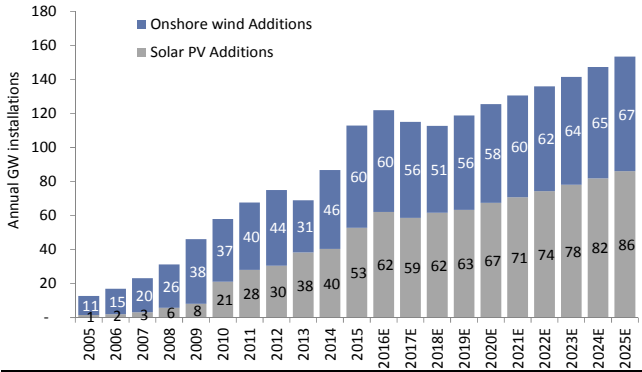


Source: LBNL, Goldman Sachs Global Investment Research.

Looking through the cycle: At 100+ GW annual run-rate, installed solar/wind base to triple by 2025

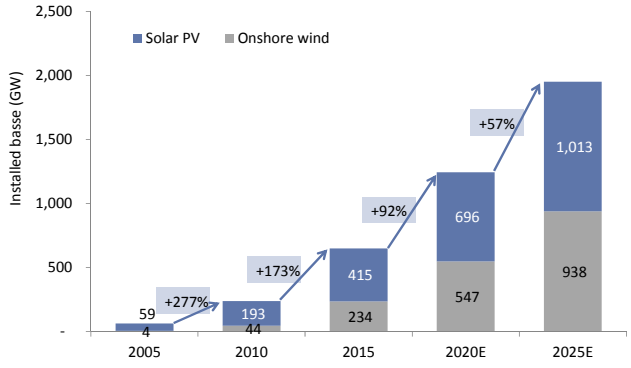
Despite the volatility we expect to see in annual installations, we believe the rapid scaling of the installed base of onshore wind and solar PV is set to continue. With combined annual installations averaging around 119GW over the next decade, we expect the installed capacity to have almost doubled by 2020E, and tripled by 2025E vs. 2015.

Exhibit 38: Installations continue at 100+ GW pa…
Annual onshore wind and solar PV installations, 2005-25E



Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Exhibit 39: …we expect the installed base of wind and solar to grow 3x by 2025 vs 2015
Installed base for onshore wind and solar PV (GW)



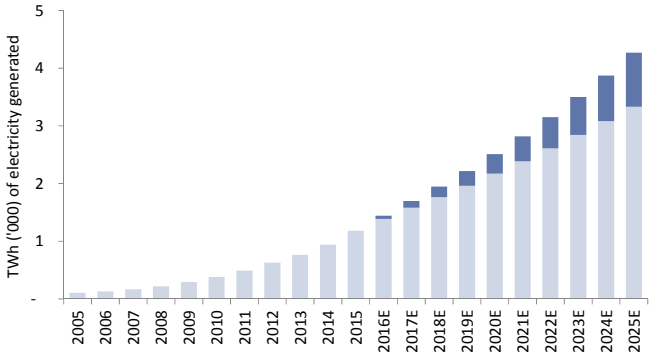
Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Electricity supply to grow >4x, matching nuclear by 2020E and overtaking hydro by 2025E

We estimate the electricity harvested from wind and solar will grow at an even faster rate than the installed base from which it is generated. Continued performance improvements of wind turbines and solar panels should make new installations significantly more productive (we forecast capacity factors of new wind/solar installations to improve from 30%/18% in 2015 to 35%/25% by 2025).

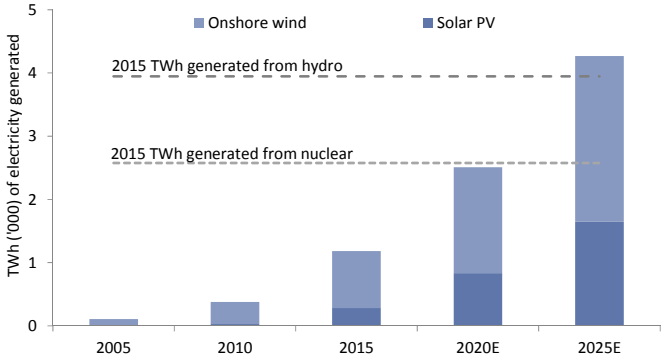
Our forecasts imply that, by 2020, wind and solar will generate almost as much electricity as nuclear does today, and overtake hydro by 2025. Our volume and capacity-factor forecasts imply that electricity generated from wind and solar grows to over 2.5k TWh by 2020 and more than 4k TWh by 2025 (compared to global power generation of 23.5k TWh today). This is 11x more than they generated in 2010 (0.38k TWh).

Exhibit 40: Performance improvements of new installations add almost 1k TWh of electricity by 2025E
Electricity generation (TWh) from wind and solar



Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Exhibit 41: Electricity generated from wind and solar to grow more than 4x by 2025E.
Electricity generation (TWh) from wind and solar



Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Capacity-factor improvements add to volume growth

Gradual performance improvements for wind turbines and solar panels make an often overlooked contribution to cost competitiveness and electricity generation. We expect the average global capacity factor for new installations to continue to improve every year by 50 bp to 35% for onshore wind; and by 70 bp pa to 25% for solar PV. This means that the average wind turbine and solar panel installed in 2025 would respectively generate 19% and 45% more electricity than those installed today. This compares to c.80 and 100 bp respectively between 2010-2015. In the US and select emerging economies, the average capacity factor for onshore wind exceeded 40% in 2014 and for solar 29%. As the share of China (where capacity factors are much lower on average) in annual installations declines, we estimate that the global mix-shift alone will contribute 110 bp in total improvements by 2020. We expect a host of factors, such as tracking devices in utility-scale solar, repowering in wind, reduced downtime, better siting, and reduced curtailment, to be additional contributors.

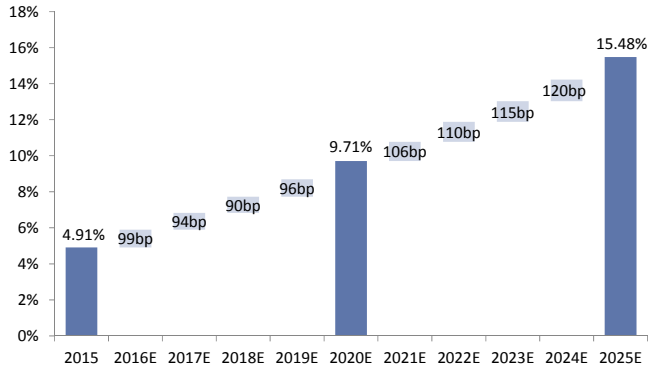
2015-25E market share gains average 106 bp a year

We expect wind and solar together to gain on average 106 bp of market share per annum, comparable to ecommerce. By 2025, we expect their market share to reach 15.5% based on our volume and capacity forecasts. This is more than 3x the market share they had in 2015 (4.9%).

We expect a slowdown in global electricity-demand growth to provide an incremental tailwind to market share gains. We forecast demand growing at a 1.36% CAGR between 2015-25, less than half of the 2.76% CAGR of the previous ten years. We believe China, which contributed 55% on average to global electricity demand growth over the last ten

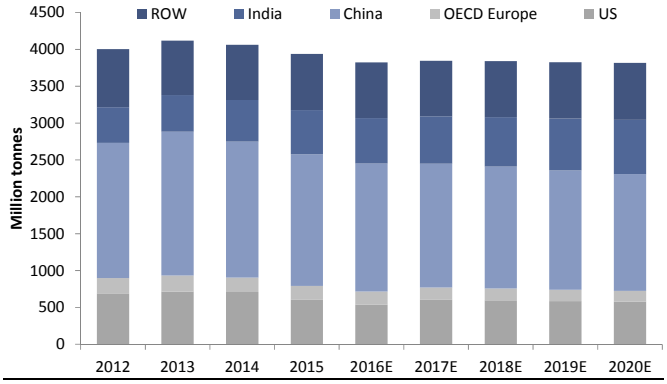
years, will be the largest contributor to this slowdown. Our analysts forecast Chinese electricity demand to grow by a 2.2% CAGR over the next five years vs. an 8.8% CAGR between 2005-15. While electric vehicles may eventually become a tailwind for electricity demand post 2020, in the near term the large-scale savings from LEDs are likely to dominate.

Exhibit 42: We expect annual market share gains for solar and wind of 106 basis points out to 2025 on average
Estimated market-share gains of onshore wind and solar PV, 2015-25E



Source: IEA, IRENA BP, Goldman Sachs Global Investment Research.

Exhibit 43: Global coal use for electricity generation may have peaked in 2013
Thermal coal consumption by region, 2012-20E



Source: IEA, McCloskey, Goldman Sachs Global Investment Research.

Coal rapidly losing market share to renewables and gas in China and the US

As wind and solar scale, they begin to shift power-market dynamics across major economies. In China and the US, coal-fired power generation is rapidly losing market share (-18%/-15% between 2010-20E respectively), while natural gas and renewables are taking a greater share of the overall market. Our analysts forecast that global coal use for electricity generation may have peaked in 2013 and in China only a year later.

Battery-based grid storage could offer an attractive low-carbon alternative, but the technology still remains in its early stages. While grid storage has strong potential, on a large scale it is still ten years away and remains a niche market to date. The US deployed a little over 200MW in energy storage for the grid in 2015, accounting for roughly half of all incremental global energy storage added in the year. This is only a fraction of the over 1,000GW of generation capacity on the US utility grid.

In the absence of large-scale, low-cost grid storage, gas could be a beneficiary of increased renewables penetration. The intermittent nature of renewable energy is disrupting the traditional division of labour in power generation, whereby large coal plants provide a steady supply of electricity, while gas plants adjust their output in line with fluctuations in the load. As gas is competitive in both base load and flexible generation, our analysts see it as a structural beneficiary from this new environment.

In high-penetration markets, such as Europe, regulators may move to incentivise the provision of gas-based backup capacity to guarantee grid stability. Our analysts anticipate a more widespread introduction of availability subsidies (e.g. capacity payments) to ensure the existence of backup power and the security of supply.

As LEDs are maturing we are moving to the next leg in lighting

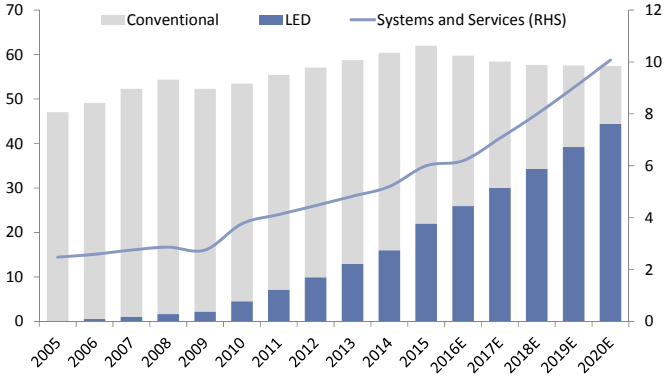
As LEDs are maturing we are moving to the next leg in lighting

As LEDs are going mainstream, companies such as Philips Lighting and Acuity Brands have begun to explore the full potential of the semiconductor technology for intelligent lighting solutions. Although their development is still in the early stages, sensor-enhanced and networked LEDs could become the infrastructure backbone not only for the Internet of Things, but also the connected home.

First low-carbon technology to approach maturation

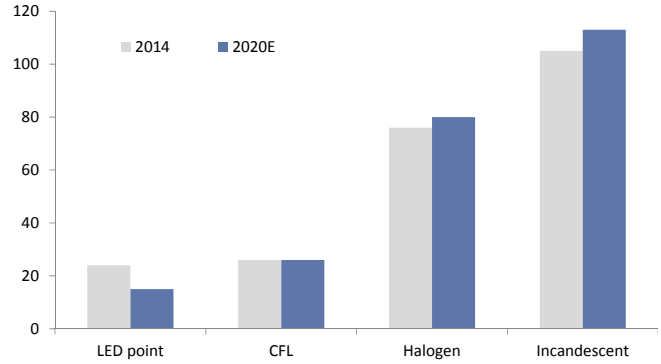
LED lighting is the first low-carbon technology to near maturation as it continues to grow rapidly and relegates former incumbent technologies to a legacy status. After an average annual growth rate of c.30% over the past five years, our analysts expect LEDs to capture more than 43% of the global lighting market this year. By 2020E, LEDs could reach a market share of more than ¾ by 2020E and approach full penetration in the early 2020s. Besides aggressive policy support, LEDs' rapid adoption rates are founded on continued cost and performance improvements that place the technology at an increasing advantage vs. incumbent technologies. Already in 2014, LEDs had the lowest total operating cost, and this is expected to decline by a further 38% until 2020 (according to BCG). Given the very short replacement cycles of legacy lamps, LEDs are likely to have replaced the installed lighting base well before 2030, making it potentially one of the fastest technology shifts in human history.

Exhibit 44: LEDs to overtake conventional lighting technologies as the market leader by 2017E
Global market for conventional and LED lighting technology; market fore Systems and Services (€ bn)



Source: BCG, McCloskey, Goldman Sachs Global Investment Research.

Exhibit 45: Already the cheapest lighting technology in 2014, LEDs to see a further 38% cost decline by 2020
Total cost of operating ($ per 15,000 hours) by lighting technology



Source: BCG, Goldman Sachs Global Investment Research.

Opportunities from intelligent lighting shift into focus

The semiconductor-based technology's key attributes make it a natural infrastructure backbone of the Internet of Things. Beyond delivering light more efficiently and at a fraction of the cost compared to other lighting technologies, LEDs have the added benefits of being easily controlled, networked and embedded with sensors. These attributes make LEDs a key enabler of a continuously growing set of IoT opportunities. Indoor location technology, for instance, relies on sensor-embedded LEDs that allow retailers to understand foot traffic, manage sales-rep head count and collect data on customers in a similar manner that they can online.

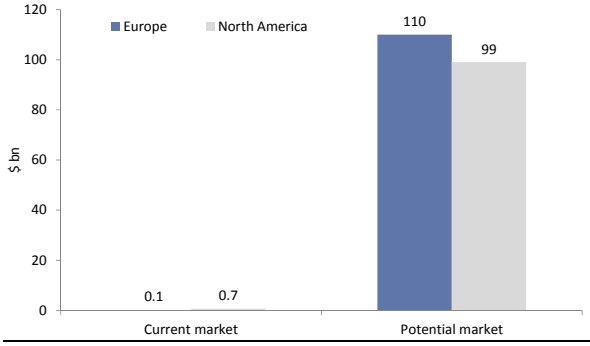
In a maturing growth environment, the opportunities from intelligent lighting solutions and new business models (lighting as a service) are increasingly moving into focus. While still in the early stages, they are emerging as key differentiating factors for lighting OEMs. Higher-value networked devices and IoT applications are increasingly determining companies' ability to consolidate market shares, improve margins and achieve sustainable returns on capital. Adding increasing customer value to their product offering

allows lighting companies to maintain and increase pricing (according to Acuity, it is adding roughly 20% to the price of new fixtures). At the same time, it creates a recurring revenue opportunity as the company can charge monthly fees for monitoring and analysing the data (roughly 10% of the incremental cost).

Home automation offers a long-term growth opportunity

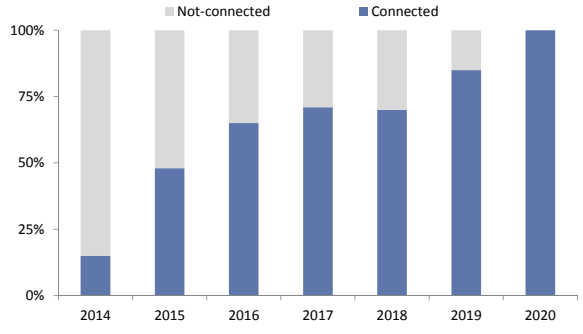
We expect LED lighting to play an integral role in the long-term growth theme of home automation. Lighting plays a key role in broader home-entertainment systems, which can often integrate various home systems such as security, lighting and climate control. Already today, lighting forms the second biggest part of the home automation installed base in North America and the biggest in Europe. While the current market for overall lighting controls is still small (c.US$700 mn in North America and c.US$110 mn in Europe, according to BSRIA), our analysts expect the revenue opportunity to increase significantly over the long term, with a potential addressable market of c.$200 bn. This assumes the full penetration of the current housing stock of c.400 mn in Europe and the US, with an average price of $500 for a lighting control system).

Exhibit 46: The potential market for lighting controls assuming 100% penetration is very significant Current and potential lighting controls market



Source: BSRIA Home Study 2013.

Exhibit 47: The penetration of connected lighting is expected to increase
Connected home lighting systems market



Source: Philips Lighting internal analysis.

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Reg AC

We, Jaakko Kooroshy, Justus Schirmacher and Gaurav Tandon, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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Disclosures

Coverage group(s) of stocks by primary analyst(s)

Brian Lee, CFA: America-Clean Energy, America-Solar Energy. Daniela Costa: Europe-Machinery & Elec Equip. Franklin Chow, CFA: A-share Energy, A-share Utilities, China Energy, China Utilities. Michael Lapides: America-Diversified Utilities, America-Independent Power Producers, America-Regulated Utilities. Stefan Burgstaller: Europe-Autos & Auto Parts. Alberto Gandolfi: Europe-Utilities. Manuel Losa: Europe-Utilities.

A-share Energy: China Petroleum & Chemical (A), PetroChina (A).

A-share Utilities: China Yangtze Power, Datang International Power (A), Huadian Power International (A), Huaneng Power International (A).

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