Goldman Sachs | Equity Research

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Global Automobiles

New era in CO2 regulation: EVs to be tested across life cycle, not only on running performance

The following is a redacted version of the original report. See note below for details.

European regulators are opening the door to a new method for evaluating CO2 emissions that would have important implications for the auto industry and for investors positioning for the transition to electric vehicles. By calling for consideration of life cycle assessment (LCA) standards no later than 2023, the European Union is proposing to broaden the review of a vehicle's environmental impact well beyond emissions when the vehicle is operating. LCA takes into account the environmental pressures created by the entirety of a vehicle's life, from the energy used to generate the power to the impact of the manufacturing and recycling of its parts when it is done. This change would dramatically alter how electric vehicles are compared with hybrids and traditional models, and it would introduce a range of new calculations for investors to consider in assessing the competitive landscape.

LCA could highlight unexpected CO2 emissions of electric vehicles

Current regulations focus solely on CO2 emissions when a vehicle is running (tank to wheel), but future regulations will encompass emissions during energy generation (well to tank) and auto manufacturing (manufacturing and recycling). The average sedan powered by an internal combustion engine (ICE) generates 120g/km of CO2 emissions on a tank-to-wheel basis, but from an LCA standpoint this increases to 170-180g/km. While an EV has zero CO2 emissions on a tank-to-wheel basis, we estimate that CO2 emissions average at 100-120g/km on an LCA basis. In other words, if CO2 emissions are measured across a vehicle's life cycle rather than on a tank-to-wheel basis, the CO2 emissions of an ICE vehicle increase by just 50-60g, whereas the emissions of an EV increase by 100-120g. The total CO2 emissions of an EV over its full life cycle vary significantly depending on the sources of power used where the vehicle is manufactured and driven.

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Note: The following is a redacted version of Goldman Sachs Research's report "Global Automobiles: New era in CO2 regulation: EVs to be tested across life cycle, not only on running performance" originally published Dec 5, 2019 (46pgs). All company references in this note are for illustrative purposes only and should not be interpreted as investment recommendations.

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5 KEY IMPLICATIONS
in the LCA era

1

The relative advantage of EVs in meeting climate-change regulations will become **more regionalized** based on disparities in electrification of the power grids, remaining strongest in Europe but decreasing or being pushed back in regions such as Japan. In some conditions, hybrids or traditional internal combustion engine vehicles will compare favorable against EVs when the entire life cycle is examined.

2

The **ability of automakers to address customer demands** for longer range of EVs will be **constrained** by the environmental impact of the larger batteries needed, barring advances in battery technology.

3

The challenge and complexity of optimizing for LCA will play into the **need for consolidation in the auto industry** as larger global companies will have an advantage.

4

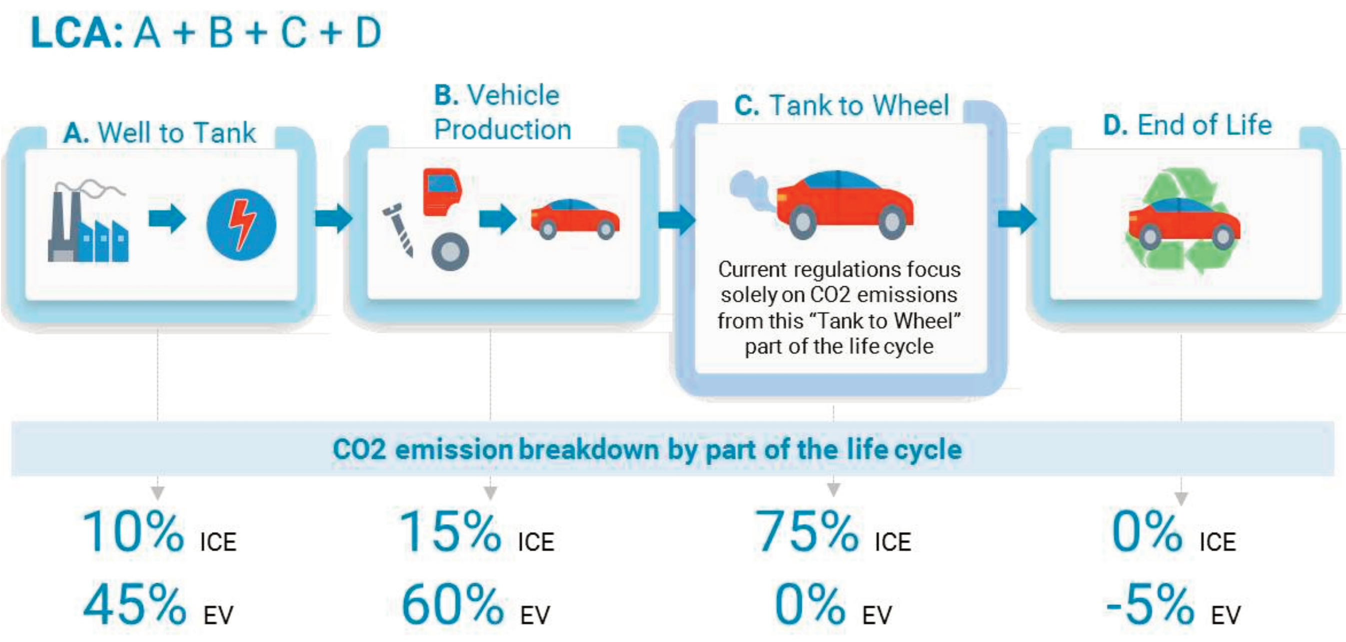
Regional supply chains will become more important and suppliers with energy sources in regions that get a higher percentage of electricity from renewables will have an advantage over those in regions more dependent on fossil fuels.

5

The argument for **hybrids** as an effective solution in the medium term will become more dependent on **regional factors** and **the ability of hybrids to increase their thermal efficiency.**

Exhibit 1: LCA takes a holistic view of CO2 emissions

CO2 life cycle for automobiles (image of mid-size sedan)



Source: Goldman Sachs Global Investment Research

LCA captures CO2 emissions across the whole life of a vehicle

Life cycle assessment overview

LCA measures the environmental burden across the whole life cycle of a car, from production to driving and ultimately recycling parts of the vehicle. According to a document published by the European Commission on April 2019, the Commission should no later than 2023 evaluate the possibility of developing a common Union methodology for the assessment and the consistent data reporting of the full life-cycle CO2 emissions of such vehicles placed on the Union market. The Commission should adopt follow-up measures, including, where appropriate, legislative proposals. Automakers currently provide each vehicle's CO2 emissions on a tank-to-wheel basis, but if the European Union adopts the LCA approach, this would reveal the environmental impact of a vehicle across its life cycle, including the production of the vehicle itself and its fuel source, the vehicle scrapping process, as well as the potential to reduce environmental impact by recycling parts of the vehicle at the end of its life.

Current challenges posed by LCA

The International Organization of Standardization introduces standards specific to LCA as part of its family of standards on environmental management. At this stage, it is difficult to anticipate exactly how the introduction of LCA standards could affect the way potential buyers compare vehicles. LCA covers not only CO2 emissions, but also other factors that determine the total environmental impact of a vehicle, including acidification, eutrophication caused by runoff from land and water, and the use of abiotic resources. In this report, we look primarily at the climate change aspect of LCA — specifically, CO2 and other greenhouse gas emissions — and we consider how the introduction of an LCA framework could change the fuel economy of vehicles.

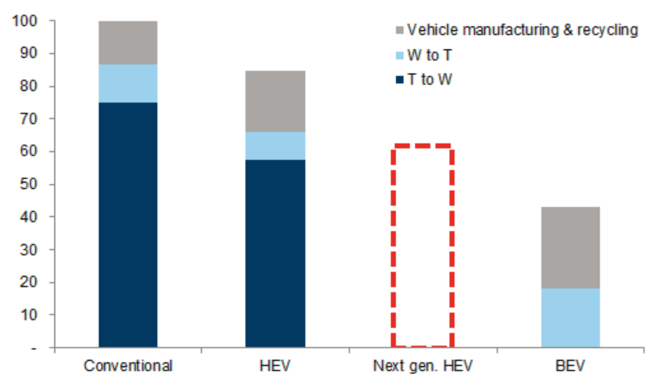
LCA could highlight unexpected CO2 emissions of electric vehicles

The average sedan powered by an internal combustion engine (ICE) generates 120g/km of CO2 emissions on a tank-to-wheel basis, but from an LCA standpoint this increases to 170-180g/km. While an EV has zero CO2 emissions on a tank-to-wheel basis, we estimate that CO2 emissions average at 100-120g/km on an LCA basis. In other words, if CO2 emissions are measured across a vehicle's life cycle rather than on a tank-to-wheel basis, the CO2 emissions of an ICE vehicle increase by just 50-60g, whereas the emissions of an EV increase by 100-120g. The total CO2 emissions of an EV over its full life cycle vary significantly depending on the sources of power used where the vehicle is manufactured and driven. In Europe, for example, where clean energy sources such as nuclear power and hydro power are relatively widespread, EVs still compare favorably with other types of vehicles if CO2 emissions are measured from an LCA standpoint. However, in Japan and other markets outside Europe, where fossil fuels such as crude oil and coal are still the main sources of energy, EVs are less attractive in terms of the overall scope for reducing environmental impact.

Another variable is how total driving distance is calculated

CO2 emissions measured on an LCA basis vary widely depending not only on a country's energy mix but also on how a vehicle's average driving life is defined. In Europe, the assumption is that EVs have an average driving life of 180,000 km, compared to 110,000 km in Japan. Therefore, the CO2 emissions of EVs compare more favorably in Europe, where the cars are expected to be driven over a longer total distance. We compare Europe and Japan in Exhibits 2 and 3, taking the above definitions into account.

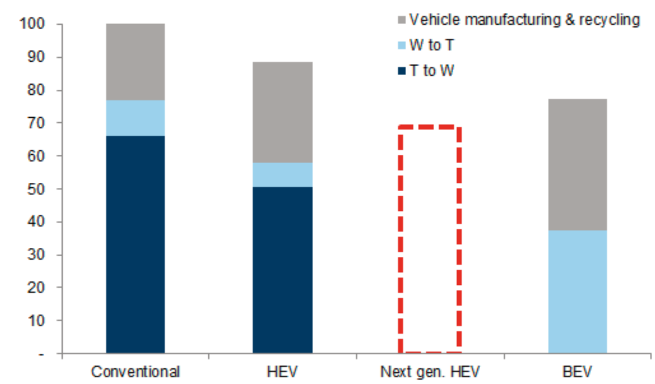
Exhibit 2: EVs come out on top in Europe
CO2 emissions measured on an LCA basis in Europe (assuming emissions of 100 for ICE vehicles)



Based on Europe's projected energy mix in 2030, CO2 intensity includes power transmission loss

Source: Toyota Motor presentation at the 2019 Vienna Motor Symposium

Exhibit 3: Next-generation hybrid vehicles may provide a solution
CO2 emissions measured on an LCA basis in Japan (assuming emissions of 100 for ICE vehicles)



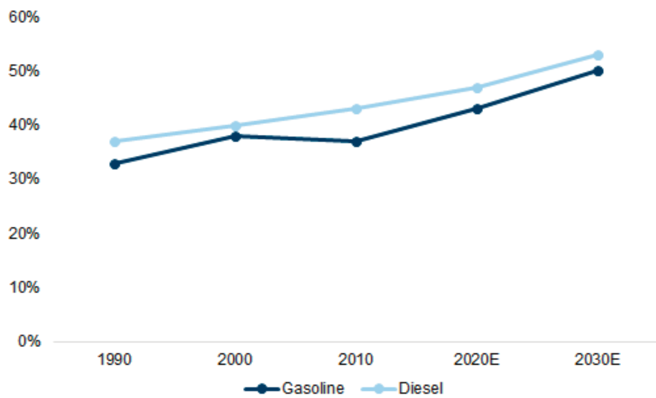
Based on Japan's projected energy mix in 2030, CO2 intensity includes power transmission loss

Source: Toyota Motor presentation at the 2019 Vienna Motor Symposium

Further advances in technology essential for HEVs to retain their edge

HEVs, which tend to be more profitable for automakers, could see their competitive advantage threatened if LCA is widely adopted. Current HEVs could become much larger emitters of CO2 than EVs especially in Europe, where clean energy proliferates. In countries with low reliance on nuclear power, such as Japan, however, automakers have already achieved CO2 emissions in HEVs on par with those of EVs. Moreover, if next-generation HEV technology advances that automakers are currently working on are realized, HEVs could beat EVs in terms of CO2 emissions based on LCA standards. There are significant challenges to overcome, including in the areas of advanced heat management, extreme insulation, ultra-lean burn, and laser ignition, but we think the fact that automakers, especially Japanese automakers, are aiming to boost engine thermal efficiency to 50% from just over 40% is significant.

Exhibit 4: Good prospects for increased engine efficiency
Engine thermal efficiency

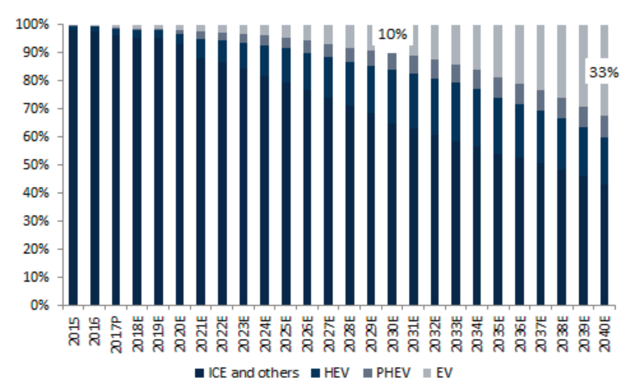


Source: Goldman Sachs Global Investment Research

Next 10 years to be the HEV era, followed by the EV era

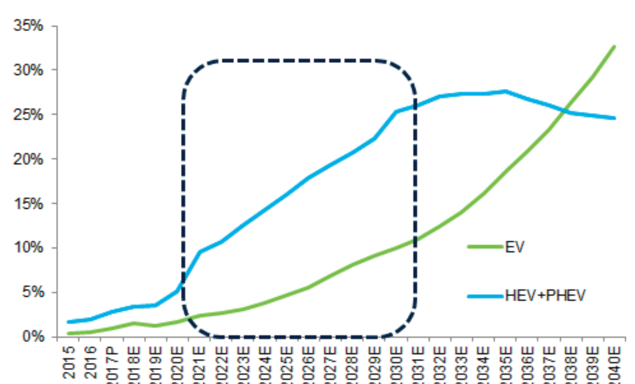
China is gradually introducing tougher new energy vehicle (NEV) regulations and vehicle emission standards and the EU will tighten CO2 emission standards from 2020. Automakers are implementing electrification strategies to minimize the impact of tighter regulations. Governments are gradually shifting from electric vehicle (EV) policies to electrified vehicle policies as a more realistic solution to reducing CO2 emissions because of battery prices, driving ranges, charging infrastructure, and other hurdles to establishing a mass market for EVs. For at least the next 10 years, we believe hybrid systems will be the main form of vehicle electrification adopted by automakers to meet stricter environmental regulations being introduced around the world (expected over 2025-2030). However, after that we foresee significant progress in electrification, supported by the introduction of LCA, changes in the structure of power sources underpinned by the Paris Agreement, and lower battery prices. We expect EVs to account for only 10% of sales in 2030, but expect the weighting to rise to 33% by 2040. We think HEV and EV sales will trade places in 2037.

Exhibit 5: We foresee rapid growth in EVs through 2040
Global powertrain forecasts



Source: IHS Global Insight, Goldman Sachs Global Investment Research

Exhibit 6: EVs and HEVs likely to trade places in 2037
Electrification forecasts through 2040

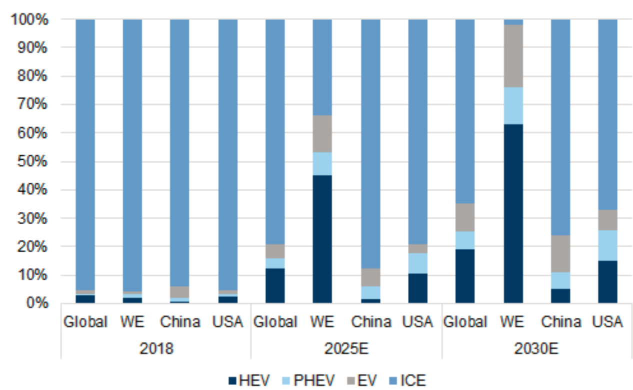


Source: IHS Global Insight, Goldman Sachs Global Investment Research

Significant regional disparities in electrification

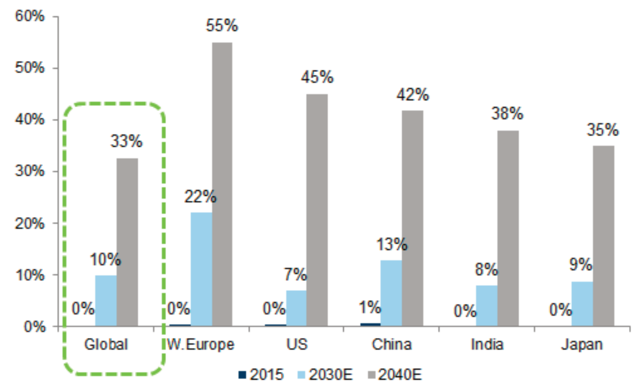
There will likely be major differences between countries and regions in terms of the pace of electrification. We think EV proliferation will not be consumer-led through 2030. Our forecasts are based on the minimum volume automakers have to sell to meet regulations. Accordingly, we think electrification will make far greater progress in Europe, which has the world's tightest CO2 emission rules, than in other countries. We expect the sales weighting of EVs in Europe to reach 22% in 2030, due partly to the adoption of LCA, and think it will likely be far higher than in other regions. Looking further ahead to 2040, however, we think EV sales in other regions will likely catch up with those in Europe due to lower battery prices (falling to $100/kWh or lower) and the spread of clean energy.

Exhibit 7: Europe set to take the lead in the shift to EVs
Powertrain forecasts by region



Source: Goldman Sachs Global Investment Research

Exhibit 8: Other countries likely to catch up with Europe by 2040
EV sales weighting



Source: Global Insight, Goldman Sachs Global Investment Research

Paris Agreement likely to have significant impact

Challenging targets

The Paris Agreement is an international treaty on climate change control that was concluded by numerous countries at the 2015 United National Climate Change Conference (COP21) in Paris and went into force the following year. The common target is to keep the increase in the average global temperature in 21st century to less than 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C.

Countries not moving forward in unison

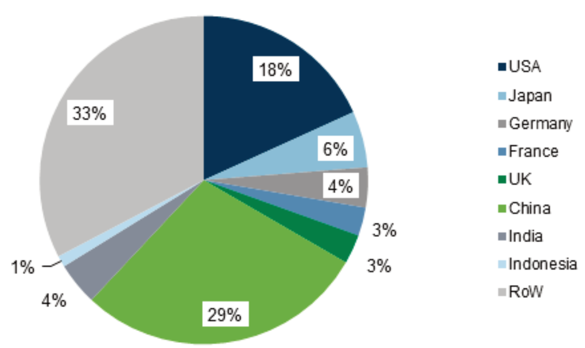
Signatory countries agreed to set interim (2030) targets and were asked to submit long-term targets by 2020. As of now, only fewer than 10 out of more than 180 countries have submitted long-term targets. More long-term target announcements from other countries are expected. The US has announced its withdrawal from the Paris Agreement.

Heavy burden for automakers

China, the world's largest auto market, has only set 2030 targets, while the US, the world's second largest auto market, has announced to withdraw from the Paris Agreement. This makes it harder for automakers to formulate business plans.

Exhibit 9: Waiting for 2050 target announcements
Countries' CO2 emission reduction targets and weightings in global auto demand

Each Country's Target	
Developed Countries	
USA	Cutting more than 80% CO2 by 2050 vs. 2005 (Obama Administration). President Trump announced to quit the agreement on Nov. 2020
Japan	Cutting 80% CO2 by 2050 vs. 2013.
EU	Cutting 80-95%/75%/more than 80% CO2 in Germany/France/UK by 2050 vs. 1990.
Developing Countries	
China	Cutting 60-65% CO2 per GDP by 2030 vs. 2005.
India	Cutting 33-35% CO2 per GDP by 2030 vs. 2005.
Indonesia	Cutting 29% CO2 by 2030 vs. BAU (business as usual). Cutting at most 41% CO2 based on the international support.



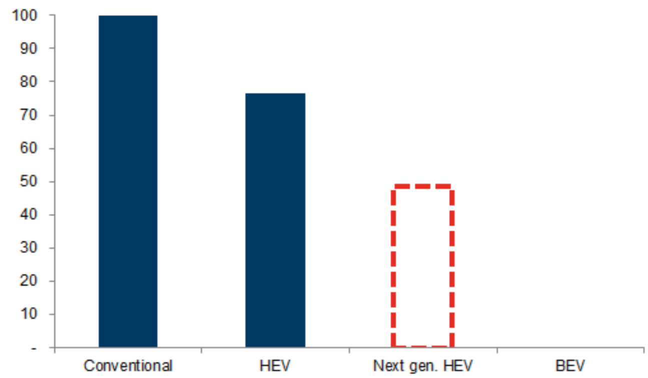
Source: Ministry of Economy, Trade and Industry, IHS Global Insight

Tank to wheel: We expect existing rules to remain in place, turning point should come in 2020

Pillar of existing CO2 emission rules; EVs the best solution

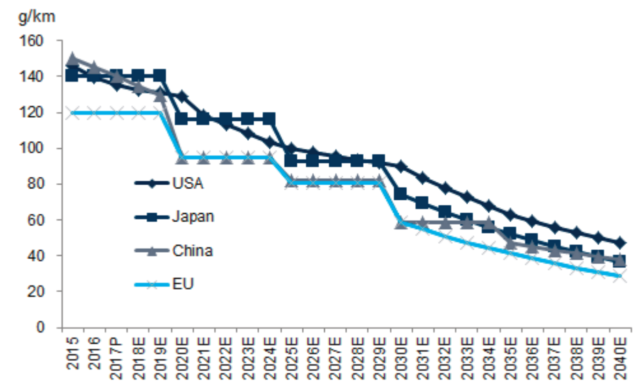
Existing CO2 emission rules are all on a tank-to-wheel basis, which means they cover only CO2 emitted when vehicle engines are running. As they take no account of the environmental impact of vehicle/fuel production, they regard EVs as zero CO2 emission vehicles, and naturally position them as superior to existing vehicles, including hybrids. Despite their poor profitability, automakers are trying to increase their sales of EVs to comply with 2020-2021 European CO2 emission rules (95 g/km, tank to wheel).

Exhibit 10: EVs are the most logical choice under current rules
Tank-to-wheel CO2 emissions (LCA emissions of existing vehicles = 100)



Source: Toyota Motor presentation at the 2019 Vienna Motor Symposium, Data compiled by Goldman Sachs Global Investment Research

Exhibit 11: European rules are the strictest
CO2 emission regulations for certain countries/regions



Source: US Department of Transportation, European Commission, Ministry of Industry and Information Technology, Ministry of Land, Infrastructure, Transport and Tourism, Goldman Sachs Global Investment Research

European CO2 emission rules are very strict

In 2018, the average CO2 emission in the European car industry was 121g/km. This is well above (by 26g/km) the 2020-2021 target of 95g/km, exposing many automakers to risk of fines (NEDC standards). In general, the challenge posed by the 2020-2021 European CO2 rules is made even harder due to the following three points.

1. The decline in sales weighting of diesel vehicles since the Dieselgate scandal at Volkswagen in 2015 (fuel consumption is generally around 10% lower in diesel vehicles than in gasoline-fueled vehicles)
2. Growth in sales weightings of SUVs and other large vehicles, which is driving up CO2 emissions by maker
3. Discussion of the introduction of the Worldwide Harmonised Light Vehicles Test Procedure (WLTP), which will make achievement of CO2 emissions targets even harder

The decline in sales weighting for diesel vehicles, in particular, is obviously having a major impact on the auto industry. Achieving the 2020-2021 CO2 emissions targets has become difficult for many automakers since the Dieselgate scandal at Volkswagen in

2015. However, due to sluggish sales since 2015 of diesel vehicles, which are roughly 10% more fuel efficient than gasoline vehicles, improvement in fuel consumption, which had been trending around 3% annually, has come to a standstill.

CO2 costs will be a major issue in 2020

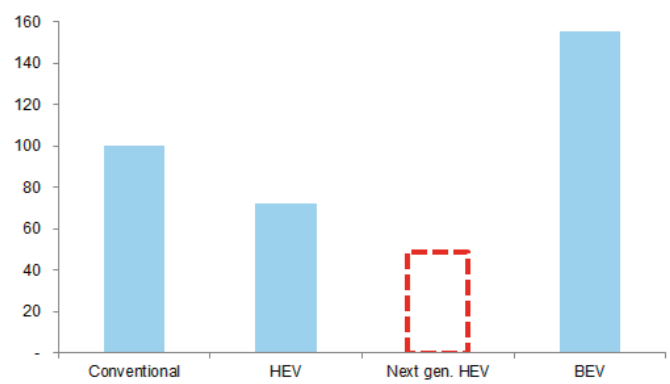
The EU will tighten its CO2 emission standard to 95g/km in 2020. If the target is not met, a penalty will be applied using the following formula: €95 for each g/km of the target exceeded multiplied by vehicle sales volume in the EU. Depending on sales volume, CO2 penalties could range from several tens of billions of yen to several hundred billion yen. We believe many automakers will expand their EV sales volume at a loss to minimize any potential CO2 penalties. However, merely shifting the impact from penalties to unprofitable sales will not reverse the increase in CO2 costs.

Well to tank: Adding fuel CO2 emissions

Adding new CO2 emissions

With the application of LCA, it will become necessary to include CO2 emitted over the entire life cycle in consumption assessments, from well to tank—i.e., from the fuel production to the vehicle fuel tank. In the case of EVs, total CO2 emissions will have to be assessed from the power generation/battery charging stage through driving using electricity. With fuel cell vehicles (FCVs), the total includes CO2 emitted as a result of hydrogen production, transportation, and storage, and operation of the vehicle on hydrogen. EVs, which have an edge on a tank-to-wheel basis, produce nearly twice as much CO2 as ICEs and HEVs on a well-to-tank calculation.

Exhibit 12: Electricity generation produces more CO2 than gasoline in the production/transportation process
Well-to-tank CO2 emissions (LCA emissions of existing vehicles = 100)



Source: Toyota Motor presentation at the 2019 Vienna Motor Symposium, Data compiled by Goldman Sachs Global Investment Research

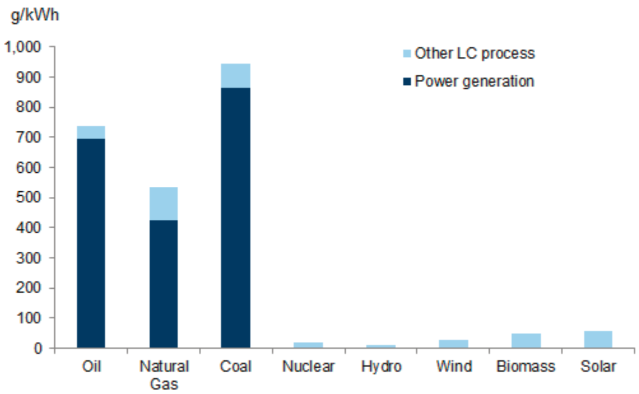
Well to tank CO2 emissions vary widely depending on power source

Since CO2 emissions vary widely depending on power source, EVs' well to tank fuel consumption also varies depending on where they are used. Examination of CO2 emissions per kWh by power source reveals that hydro, nuclear, and wind power have much smaller environmental loads, while oil/gas-fired thermal power have much larger loads, with coal-fired thermal power having the highest CO2 emissions.

All nations seeking to shift to clean energy

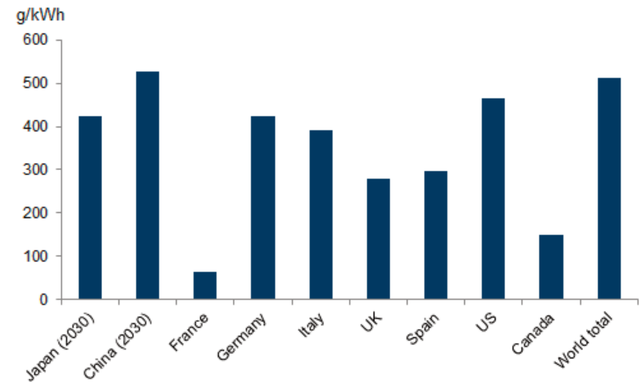
Energy policy will play a greater role in the debate surrounding LCA standards. From an LCA standpoint, Japan will be limited in its capacity to reduce EV CO2 emissions without restarting nuclear power operations. Europe, which has been promoting a rapid shift to EVs and where nuclear power is a major power source, achieved CO2 emissions of 34g/km for EVs on a well to wheel basis in 2015 (vs. 59g/km in Japan). This compares with 5g/km in France, showing a significant disparity in EV emissions. In contrast, CO2 emissions are very high (82g/km in 2015) in China, where coal accounts for a large share of power production (around 70%). In order to make EVs true eco-friendly vehicles and combat the worsening issue of global warming, the need for a change in power mix is an issue that will likely be addressed in many nations.

Exhibit 13: Environmental load of EVs varies widely depending on power mix
CO2 emissions per kWh by power source



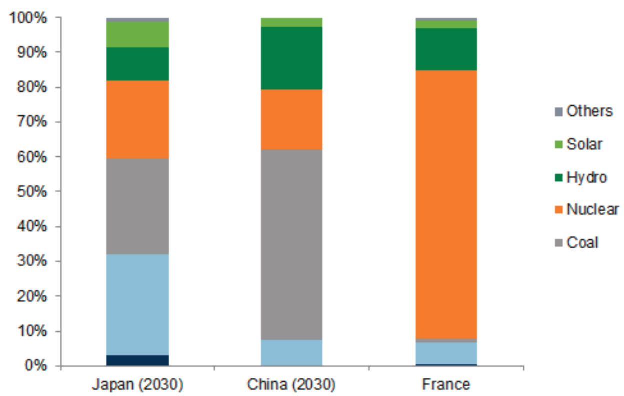
Source: CRIEPI

Exhibit 14: Environmental load varies by region
CO2 emissions during power generation per kWh by region



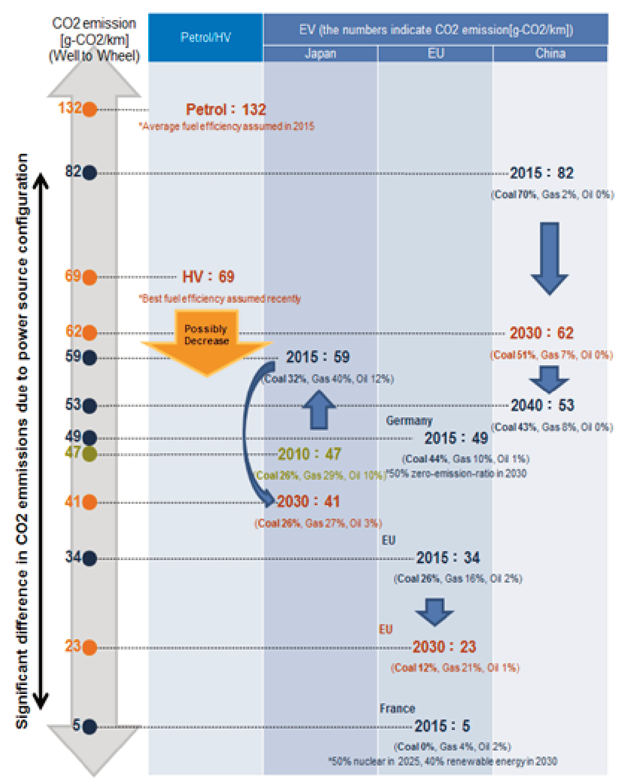
Source: BP, IEA, Thomson Reuters, Ministry of Economy, Trade and Industry

Exhibit 15: EV has advantage in France
Power supply mix in Japan, China, France



Source: BP, IEA, Ministry of Economy, Trade and Industry

Exhibit 16: Environmental impact of EV penetration varies widely depending on power mix
Power mix by country/region and well to wheel emissions



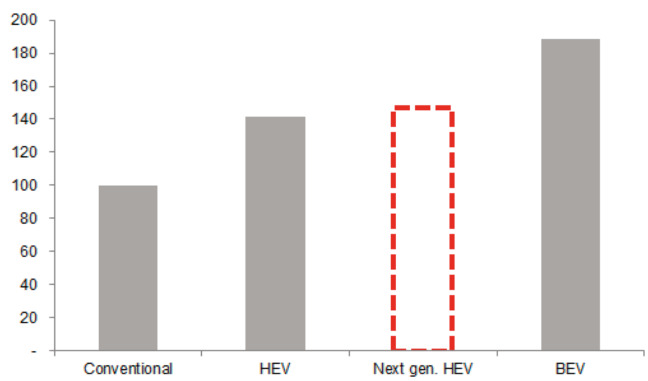
Source: Ministry of Economy, Trade and Industry

Manufacturing and recycling: CO2 emissions from auto/battery production also targeted

CO2 emissions from EV production twice that of ICE vehicle production

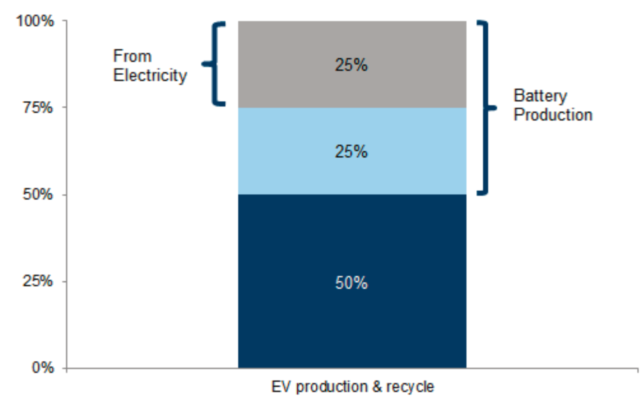
LCA standards take into account CO2 emissions from auto production and recycling. Reports by Volkswagen and Mazda put the life cycle CO2 emissions from EV production at roughly 12,000kg, twice the 6,000kg from ICE vehicle production. The main reason for this disparity is CO2 emissions from battery production, which accounts for roughly half of the environmental load of EV production. While there are differences stemming from the power mix, electricity usage (for aluminum smelting, sintering process for active materials) accounts for roughly half of the environmental load of battery production.

Exhibit 17: Battery production process has high environmental load in EV production
CO2 emissions from vehicle production/recycling (LCA emissions of conventional vehicle=100)



Source: Toyota Motor presentation at the 2019 Vienna Motor Symposium, Data compiled by Goldman Sachs Global Investment Research

Exhibit 18: CO2 emissions from battery production account for roughly half of emissions from EV production
Breakdown of CO2 emissions from EV production



Source: compiled by Goldman Sachs Global Investment Research

Environmental load of battery production varies widely by region

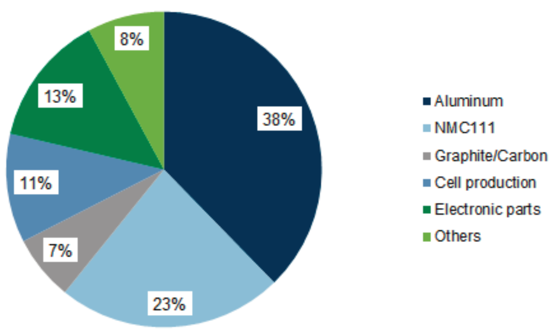
While CO2 emissions from battery production vary widely depending on the region of procurement and production, a report by The International Council on Clean Transportation (ICCT) states that an estimated 56-494kg of CO2 is emitted per 1kWh of battery production (approximately 1,700-15,000kg for a 30kWh battery), a very broad range. CO2 emissions from the production of a NMC111 lithium ion battery, for example, breaks down into 40% from electrode production (mainly rare earth) and a little under 20% each from cell production and aluminum smelting. This is because the production process for cathodes/anode involves sintering active materials at over 1000° C. Aluminum has been nicknamed "canned electricity" for the volume of electricity involved in its production.

Battery production based in Asia

However, this estimate is based on electricity usage in North America, and actual conditions may differ as most battery production is based in Japan, South Korea, and

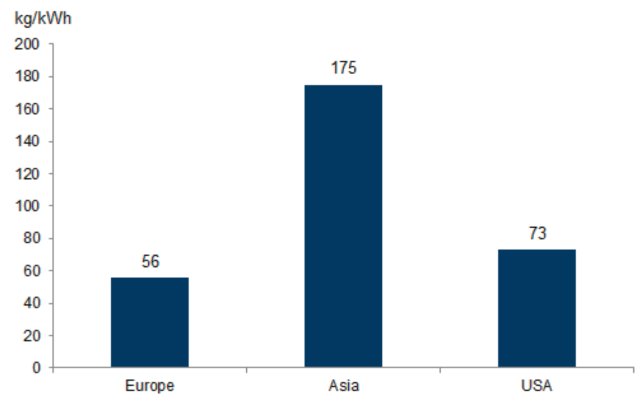
China (the big five automotive lithium ion battery makers are Panasonic, LG Chemical, Samsung SDI, CATL, and BYD). Since the smelting of aluminum ("canned electricity"), in particular, involves the consumption of roughly 13-15kWh of electricity per kg, the environmental load of smelting varies widely depending on the power mix of the region where it occurs. Aluminum-related processes account for a large part of electricity volume usage for battery production. In addition, the bulk of aluminum smelting takes place in China, which relies heavily on coal thermal energy. Thus, we estimate that aluminum smelting may account for as much as 30% of the environmental load of battery production.

Exhibit 19: Aluminum and cathodes account for most of electricity consumption in battery production
Breakdown of electricity consumption in NMC111 battery production



Source: Qiang et al. 2019, "Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications"

Exhibit 20: Batteries made in Asia have high CO2 load
CO2 emissions from battery production per kWh by region



Source: ICCT

Move towards limiting battery capacity has begun

According to the ICCT summary, most batteries are currently made in Asia and their production results in around 175 kg of CO2 emissions per kWh of capacity. A simple calculation therefore implies that 30 kWh batteries generate about 5,000 kg of CO2 and that 60 kWh batteries, which are needed to achieve the 500 km range consumers want, generate more than 10,000 kg of CO2. Considering that the LCA approach puts total ICE vehicle CO2 emissions at around 30,000 kg and total emissions for an EV with a 40 kWh battery at roughly 20,000 kg (assuming a 200,000 km lifespan, EU power source configuration), it is clear that LCA-based emissions worsen significantly as battery capacity increases. It is very interesting that battery capacity is 36 kWh and range is just over 200 km for the mass-production EVs announced by Mazda (MX-30) and Honda (Honda e). We see this as an optimization for LCA, as well as a temporary solution before lowering battery costs.

Exhibit 21: Honda/Mazda batteries only 36 kWh
Comparison of EV models

	Price	Battery Size (kWh)	WLTP Range (km)
VW ID.3 Standard Range	30,000 €	45.0	330
VW ID.3 Mid Range	< 40,000 €	58.0	420
VW ID.3 Long Range	> 40,000 €	77.0	550
Honda e	29,660 €	35.5	220
Honda e Advance	32,160 €	35.5	220
Mazda MX-30	33,990 €	35.5	200
Tesla Model 3	60,390 €	75.0	530
Nissan Leaf	36,800 €	40.0	270

Source: Company data, Goldman Sachs Global Investment Research

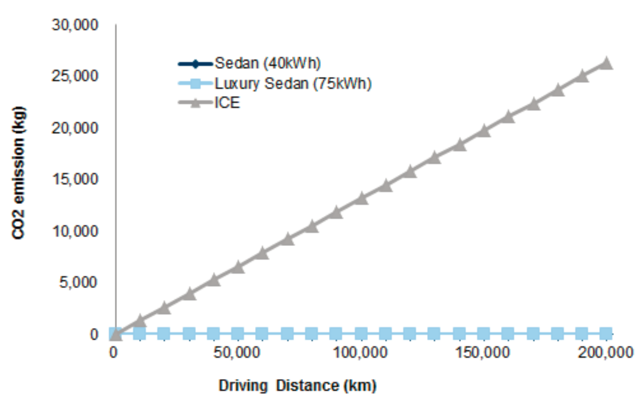
EVs would clearly be superior, even on an LCA basis, if battery performance improved

EVs would clearly be superior on an LCA basis provided further improvement is made in EV battery energy density and cycle count. Based on current battery performance/European power generation mix, a sedan with a 40 kWh battery has to drive at least 70,000 km to become more environmentally friendly than existing cars. A luxury sedan with nearly double the battery capacity (75 kWh) would likewise have to drive at least 150,000 km to result in less life cycle CO2 emissions than a conventional car.

Battery warranty length important also

If a battery is replaced before reaching the end of its life cycle, this adds 6,000 kg (assuming 30-40 kWh battery) of CO2 emissions from an LCA perspective and presents a headwind for EVs. The Nissan Leaf's battery has an 8-year 160,000 km warranty, but we think that warranty periods for upcoming EVs (in developed and emerging economies) merit utmost caution. According to ICCT recent study, battery recycling could potentially reduce CO_2 by 4-10% based on LCA standard. We believe this could be an interesting topic how to utilize used automotive batteries in the future.

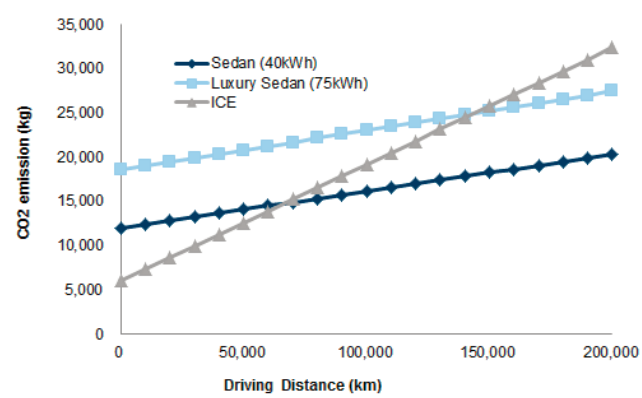
Exhibit 22: EVs clear winner under current assessment criteria, but...
Tank to wheel: Relationship between distance travelled and CO2 emissions



Sedan is totally overlapping with Luxury Sedan

Source: Auto Catalog, Data compiled by Goldman Sachs Global Investment Research

Exhibit 23: LCA: The larger the battery, the worse the emissions
LCA: Relationship between distance travelled and CO2 emissions



Source: Company data, BP, Auto Catalog, Data compiled by Goldman Sachs Global Investment Research

China primary energy mix: Low carbon challenge

30% of global CO2 emission

China contributes to nearly 30% of the annual global CO2 emission of nearly 30Gt, according to IEA. Much of the reason is its high fossil fuel content in the current energy mix (more than 80%). China has come a long-way in fixing its air pollution issues (mostly Sox, Nox, and PMs) since 2013, and is committed to improve its energy mix thus reduction of carbon emission in the longer run. This is reflected in its commitment with the Paris Agreement, as well as its official document of "Revolutionary strategy for energy production and consumption", where NDRC highlighted China's long-term energy plan.

On 3 September 2016, China ratified the Paris Agreement and submitted its NDC to the UNFCCC, with four major targets for 2030E:

- CO2 emissions to reach peak by 2030, or earlier if possible;
- Increase the share of non-fossil energy sources in the total primary energy supply to around 20% by 2030E;
- Lower the carbon intensity of GDP by 60% to 65% below 2005 levels by 2030;
- Increase the forest stock volume by around 4.5 billion cubic metres, compared to 2005 levels.

Among measures to implement enhanced actions on climate change, China also listed the following elements: 1) Increase the share of natural gas in the total primary energy supply to around 10% by 2020; 2) Proposed reductions in the production of HCFC22 (35% below 2010 levels by 2020 and 67.5% by 2025); and 3) "Controlling" HFC23 production by 2020.

On a consistent basis, NDRC also issues 2020-2050E targets that aim to increase the weight of non-fossil fuel in primary energy from the current 14%, to 20% by 2030E, and to more than 50% by 2050E.

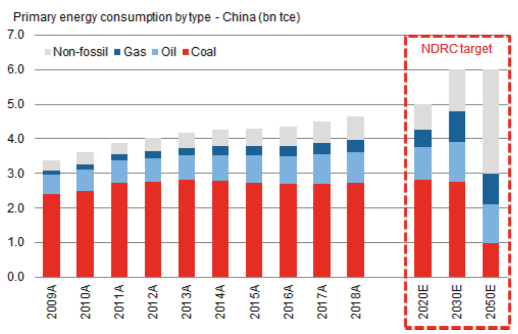
1. By 2020E, total energy consumption to control within 5bnt in standard coal and non-fossil energy to account for 15% in total. CO2 emission per unit GDP to decline by 18% versus the 2015 level.
2. During 2021E-2030E, total energy consumption to control within 6bnt in standard coal. Non-fossil energy to account for 20% in total and gas consumption to account for 15% in total. CO2 emission per unit GP to decline by 60%-65% versus the 2005 level.
3. By 2050E, total energy consumption to remain mostly stable and the contribution from non-fossil energy is targeted to increase to over 50%.

The target implies Chinese coal demand could remain plateaued in the coming decade to 2030E, when the growth in overall energy demand offsets the replacement of renewable energy. In 2030E-2050E, coal demand in China is likely to fall by two-thirds as renewable energy replacement accelerates while energy demand flattens, according to the NDRC plan. The implied pace of renewable replacement of coal is faster than the global average, should this plan get executed.

China's low carbon challenges

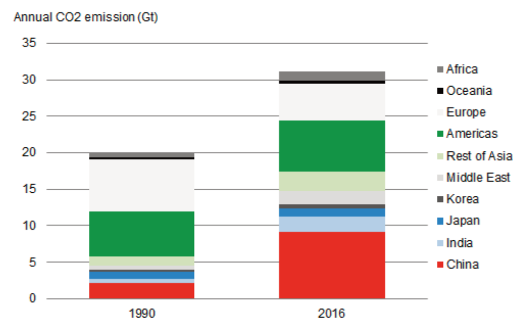
The decarbonization process in China, however, is facing challenges due to three reasons in our view 1) the higher weight of coal in overall energy, 2) the cost competitiveness of coal (and much of this also relies on how the economics improves with renewables over time, and the progress of carbon capture technology development), and 3) the fact that the overall energy demand in China would remain in growth stage in the coming decade, which would make absolute reduction of carbon more challenges in our view. While we expect China to be on the path of carbon emission reduction in the coming decades, likely more aggressive than others given its high proportion vs. peers, yet a target of complete de-carbonization as in Europe is unlikely in our view.

Exhibit 24: LT energy target set by Chinese government (2020E-2050E)



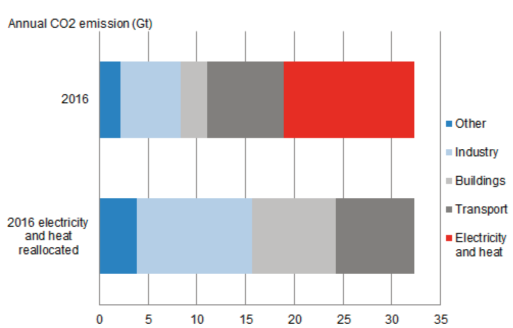
Source: National Development and Reform Commission (NDRC), National Bureau of Statistics of China, Goldman Sachs Global Investment Research

Exhibit 25: Annual CO2 emission by countries - 2016 vs 1990



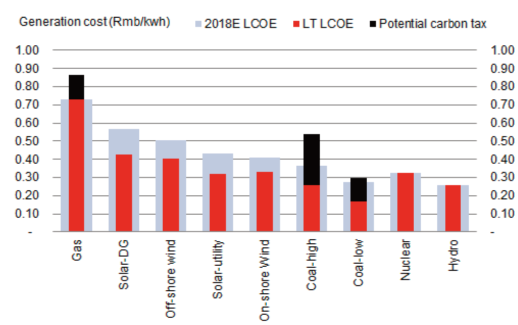
Source: IEA, Goldman Sachs Global Investment Research

Exhibit 26: Annual CO2 emission by industry - global



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 27: Power generation cost - now and potential outlook
The addition of carbon tax or cost of carbon capture will swing the economics



Source: Goldman Sachs Global Investment Research

Battery: LCA is driving changes in battery capacity per vehicle and key technological innovation

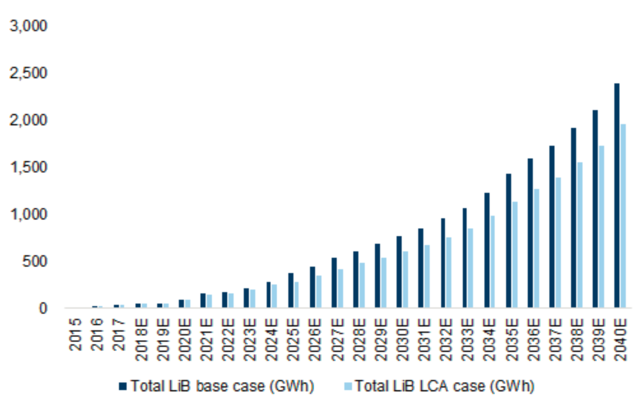
EV battery capacity looks set to grow

While the pace of EV adoption remains debatable, the spread of EVs is not. We estimate that the EV battery market will grow considerably, from 55 GWh in 2019 to 761 GWh in 2030 and then 2,383 GWh in 2040. This is because battery capacity of 50-60 kWh per EV is much higher than the roughly 2 kWh per HEV. We expect battery demand to accelerate significantly from 2030, when EV market penetration gets fully underway.

LCA could have negative impact on battery capacity per vehicle

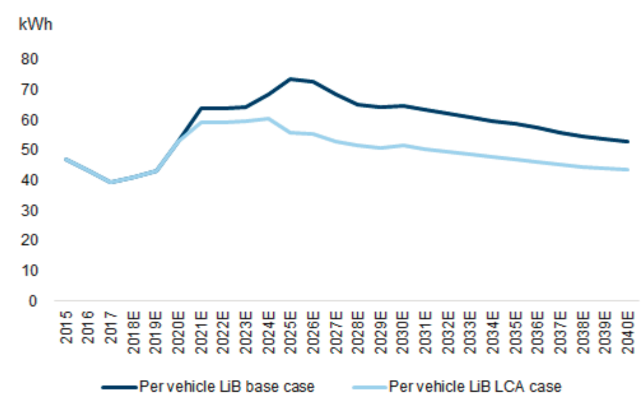
We think that applying LCA criteria could put downward pressure on battery capacity per EV because CO2 emissions get worse as battery capacity increases under this method. We expect greater investment in expanding production capacity in the EU and Canada to meet power generation mix targets in order to reduce CO2 emissions in battery production. We think that Sweden's Northvolt project (participants include VW and other European automakers) is consistent with the shift to LCA.

Exhibit 28: LiB demand could decline with lower battery capacity per vehicle
LiB demand forecast



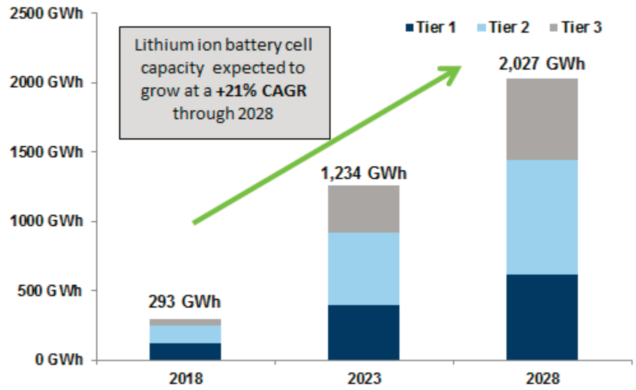
Source: Goldman Sachs Global Investment Research

Exhibit 29: Downward pressure on battery capacity per vehicle
EV battery capacity per vehicle forecast



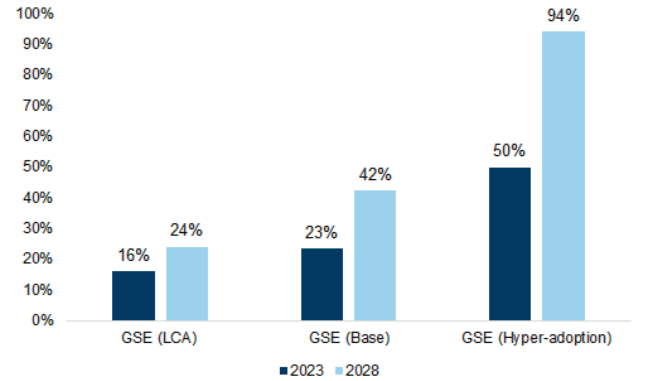
Source: Goldman Sachs Global Investment Research

Exhibit 30: LiB production capacity is rising
LiB production capacity forecast



Source: Benchmark Mineral Intelligence

Exhibit 31: LiB factory utilization could decline due to LCA adoption
LiB factory utilization forecasts (Tier 1-2 only)

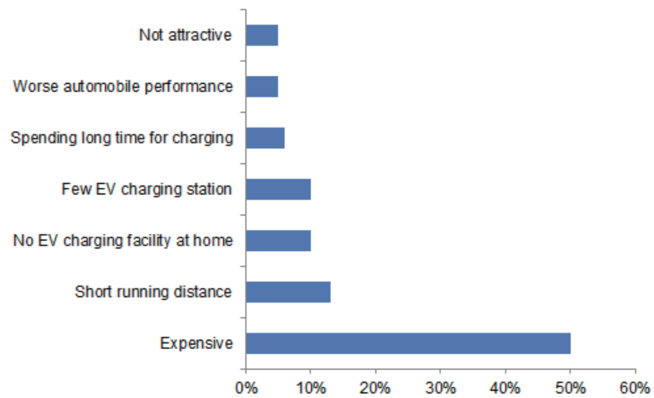


Source: Goldman Sachs Global Investment Research

Consumers concerned about EV range

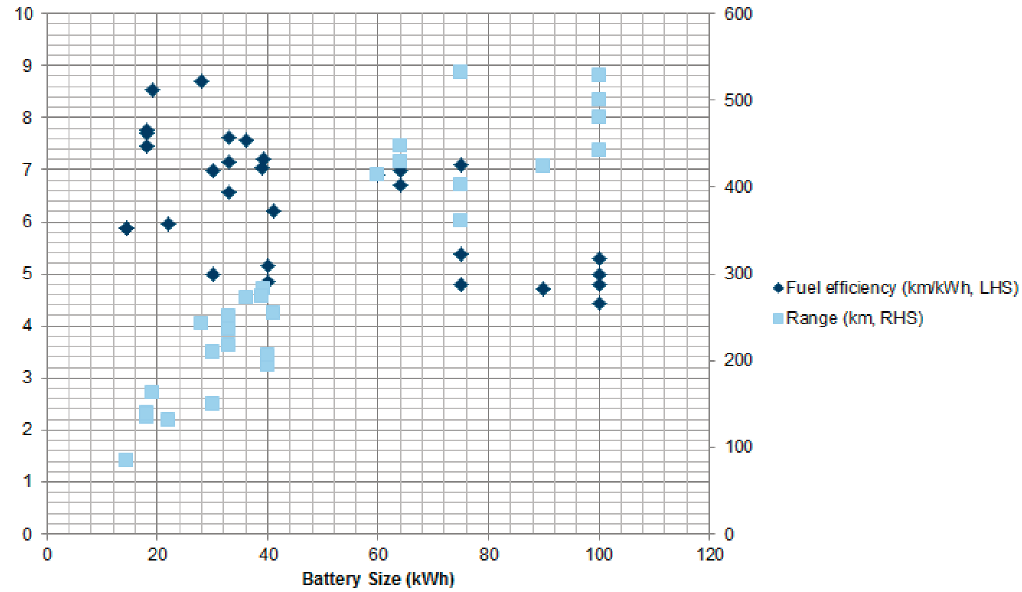
Limiting battery capacity is advantageous from an LCA perspective because the smaller the battery the smaller the CO2 emissions during production and the greater the energy efficiency of the vehicle (mainly due to lighter weight). However, concerns about range is the second most common reason why consumers say they refrain from purchasing an EV, after high prices. We therefore think that automakers will strive for balance between LCA-based efficiency and consumer satisfaction. A fundamental resolution to this issue would involve higher energy density batteries and a better power generation mix in regions where batteries are made. At the same time, expectations are rising for breakthroughs, such as all solid-state batteries.

Exhibit 32: Reasons why consumers think twice about buying an EV
2016 survey asking why consumers have not bought an EV



Source: Ministry of Economy, Trade and Industry

Exhibit 33: Range increases with greater battery capacity, but energy efficiency decreases
Relationship between battery capacity and energy efficiency/range

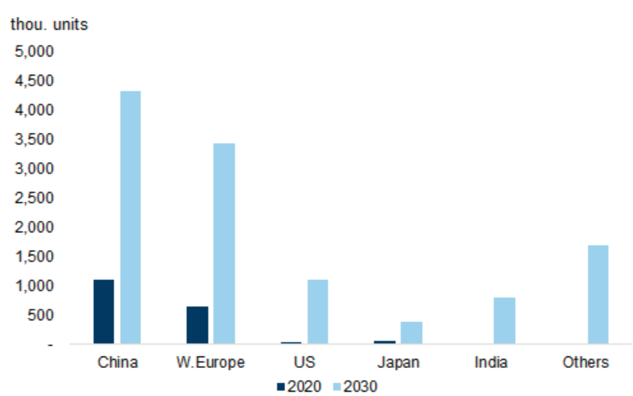


Source: Auto Catalog, Goldman Sachs Global Investment Research

World's largest EV market undergoing a correction

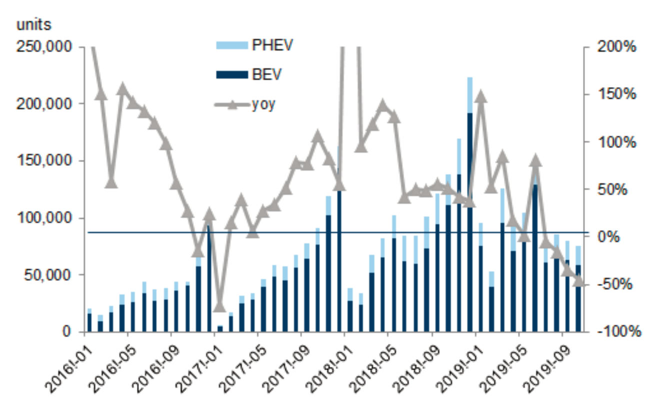
In addition, consumer views on EVs remain harsh due to price and range concerns. China has grown into the world's largest EV market, accounting for roughly 60% of global sales, thanks to the government's New Energy Vehicle policy (NEVs are EVs, PHEVs, and FCVs; HEVs are not included). However, NEV sales have declined rapidly with the government's shift from a carrot to a stick policy. Since late June of this year, the government has reduced NEV purchase subsidies by 50%-60%, and in principle is not allowing any additional subsidies by regional governments. Following the subsidy cuts, China's NEV sales declined by increasingly wide margins, falling 5%/16%/34%/46% yoy in July-October. With subsidies expected to completely disappear before 2021, NEV sales will likely continue to struggle.

Exhibit 34: China is the world's largest EV market
EV sales volume forecasts by region



Source: Global Insight, Goldman Sachs Global Investment Research

Exhibit 35: NEV sales continue declining yoy following subsidy cuts
Monthly NEV sales in China



Source: CAAM

FCV: Image vs. reality

Is the fuel cell vehicle the ultimate eco-car?

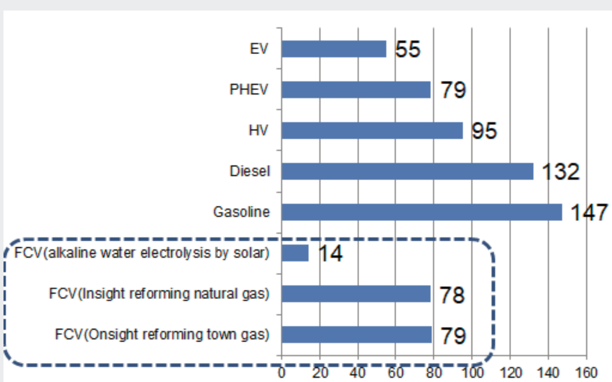
The amount of CO2 generated in the production of hydrogen, the fuel source for FCVs, varies depending on the method, but is generally around 80-130g/km (source: Japan Automobile Research Institute). Even secondary hydrogen (hydrogen generated during steel and petrochemical manufacturing processes) has a CO2 emission level of 60-110g/km. Also, from a well-to-wheel perspective (taking into consideration the electricity consumed in the compression and high-pressure storage of hydrogen), maybe FCVs are inferior not only to EVs and HEVs but to ICEs also. Moreover, the construction of hydrogen filling stations and technology advances to reduce the cost of hydrogen production and storage is essential for FCV market penetration.

Next-generation Mirai has potential

There were fewer than 3,000 FCVs in Japan as of 2018. This equates to a tiny, 0.005% of the total number of vehicles (60 mn). Toyota was the first automaker to release an FCV, the Mirai, and it is currently developing a next-generation model. Toyota aims to increase Mirai sales volume to at least 10X the current level (to around 30,000 units) in 2020. FCVs have a greater driving range and are more durable than EVs, but the target market is still small. Various projects are underway from an LCA perspective to reduce the amount of CO2 emitted during hydrogen production. However, as the FCV market is still in its infancy, we believe the likelihood of automakers allocating considerable resources to it in the short term are low. FCVs will probably have to be nurtured as a long-term market prospect.

Exhibit 36: FCVs are not the best option in terms of CO2 emissions

Comparison of well to wheel CO2/KM emissions



Source: METI, Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Kota Yuzawa, George Galliers, Fei Fang, Trina Chen, Sharmini Chetwode, Ph.D., Pramod Kumar, Jaewon Choi, Gungun Verma, Haifeng Mo, Yusuke Akiyama, SoYoung Lee and Sahana Subbaraman, 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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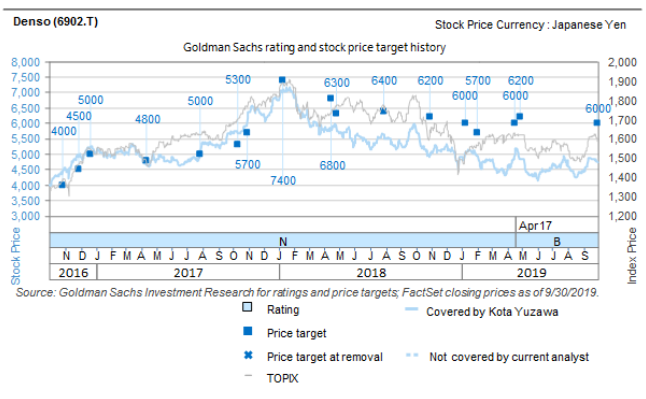

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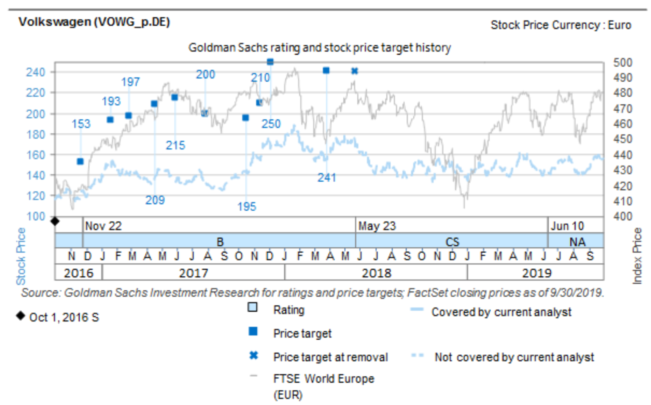

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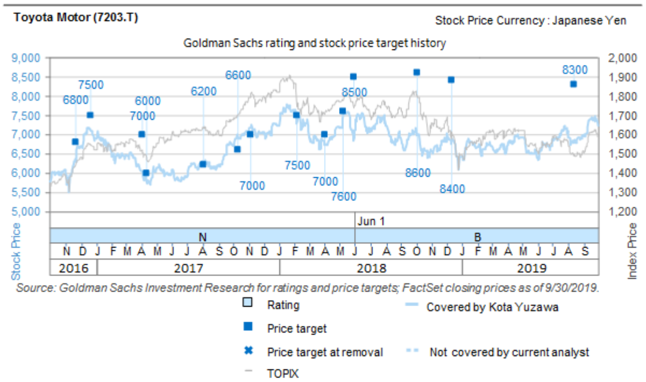

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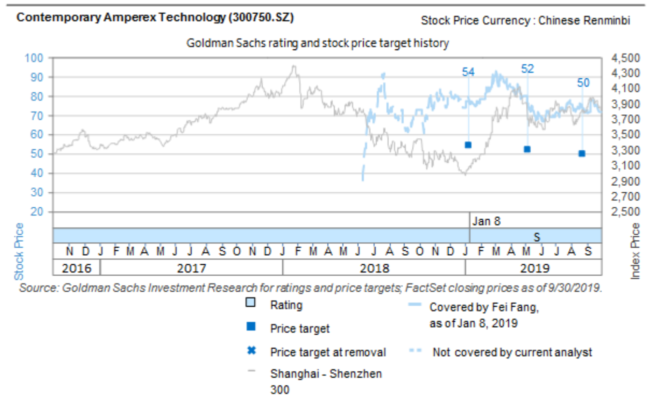

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