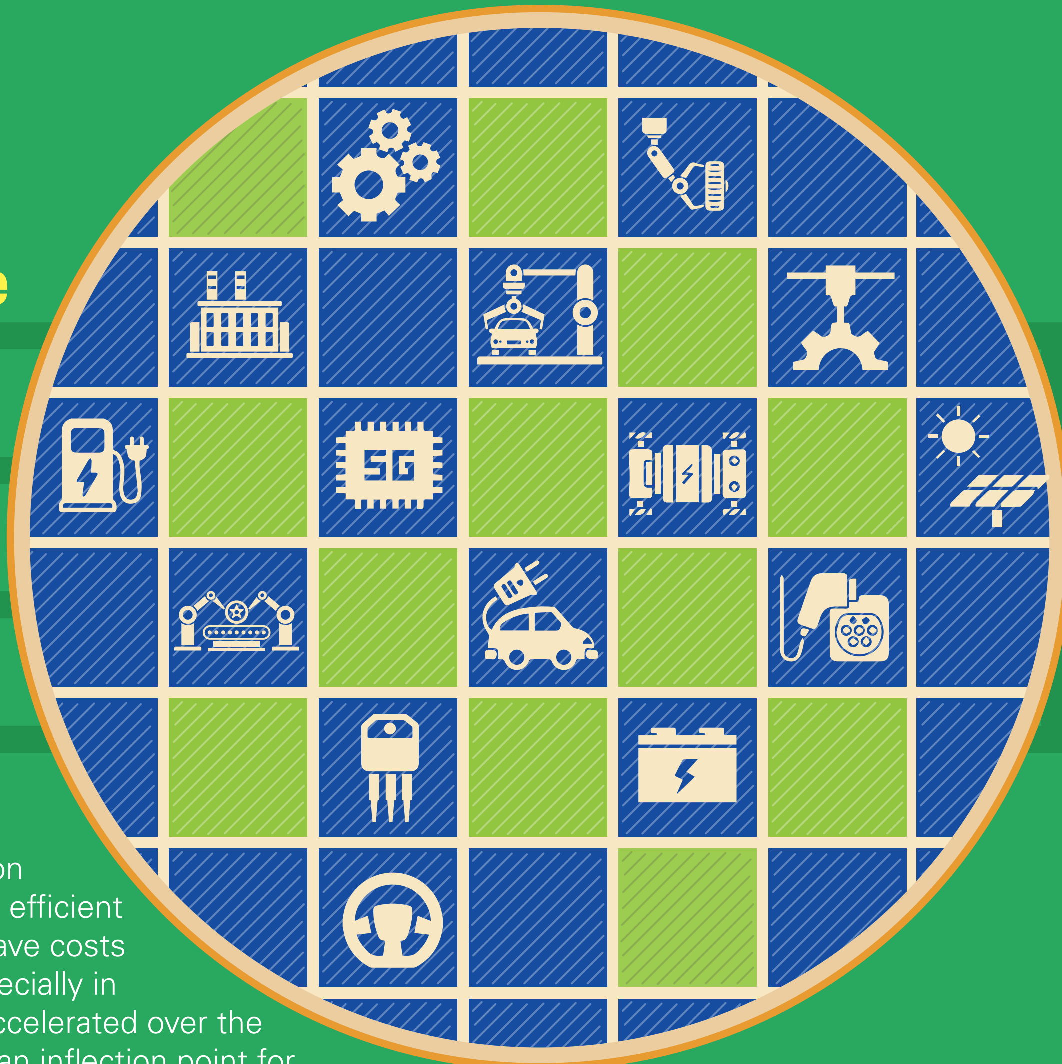
Note: The following is a redacted version of the original report published 24 June, 2022 [81 pgs].

Goldman Sachs

EQUITY RESEARCH | 24 June 2022 | 05:23AM JST



The Green Technology Cycle

SiC

Green inflation accelerates tech shift; inflection point could come sooner than expected

The outlook for increased Silicon Carbide (SiC) uptake as a more efficient alternative to silicon that can save costs and improve performance, especially in automotive applications, has accelerated over the past half year. We now expect an inflection point for rapid market growth potentially two years sooner than projected due to upgrades to capacity via large-scale investment, acceleration of tech investment by semi makers and clarification of roadmaps, and construction/upgrading of supply chains. Adding further impetus is "**green inflation**" as evidenced by recent increases in EV battery prices, accelerating the green technology cycle by fueling faster tech innovation in SiC.

Daiki Takayama
+81(3)6437-9870
daiki.takayama@gs.com
Goldman Sachs Japan Co., Ltd.

Alexander Duval
+44(20)7552-2995
alexander.duval@gs.com
Goldman Sachs International

Brian Lee
+1 917 343-3110
brian.k.lee@gs.com
Goldman Sachs & Co. LLC

Allen Chang
+852 2978-2930
allen.k.chang@gs.com
Goldman Sachs (Asia) L.L.C.

The Goldman Sachs Group, Inc.

Full list of authors inside

Contributing Authors

Daiki Takayama
+81(3)6437-9870
daiki.takayama@gs.com
Goldman Sachs Japan Co., Ltd.

Alexander Duval
+44(20)7552-2995
alexander.duval@gs.com
Goldman Sachs International

Brian Lee
+1 917 343-3110
brian.k.lee@gs.com
Goldman Sachs & Co. LLC

Allen Chang
+852 2978-2930
allen.k.chang@gs.com
Goldman Sachs (Asia) L.L.C.

Jin Guo
+86(21)2401-8943
jin.guo@gsgh.cn
Beijing Gao Hua Securities Company Limited

Toshiya Hari
+1(646)446-1759
toshiya.hari@gs.com
Goldman Sachs & Co. LLC

Brian Singer, CFA
+1(212)902-8259
brian.singer@gs.com
Goldman Sachs & Co. LLC

Sharmini Chetwode, Ph.D.
+852-2978-1123
sharmini.p.chetwode@gs.com
Goldman Sachs (Asia) L.L.C.

Shuhei Nakamura
+81(3)6437-9932
shuhei.nakamura@gs.com
Goldman Sachs Japan Co., Ltd.

Atsushi Ikeda
+81(3)6437-9940
atsushi.ikeda@gs.com
Goldman Sachs Japan Co., Ltd.

Ryo Harada
+81(3)6437-9865
ryo.harada@gs.com
Goldman Sachs Japan Co., Ltd.

Ayaka Misonou
+81 3 6437-9907
ayaka.misonou@gs.com
Goldman Sachs Japan Co., Ltd.

Bruce Lu
+852-2978-6368
bruce.lu@gs.com
Goldman Sachs (Asia) L.L.C., Taipei Branch

Lynn Luo
+886(2)2730-4244
lynn.luo@gs.com
Goldman Sachs (Asia) L.L.C., Taipei Branch

Verena Jeng
+852-2978-1681
verena.jeng@gs.com
Goldman Sachs (Asia) L.L.C.

Mitsuhiro Icho
+81 3 6437-9836
mitsuhiro.x.icho@gs.com
Goldman Sachs Japan Co., Ltd.

Enrico Chinello, Ph.D.
+1 212 357-3398
enrico.chinello@gs.com
Goldman Sachs & Co. LLC

Keebum Kim
+852-2978-6686
keebum.kim@gs.com
Goldman Sachs (Asia) L.L.C.

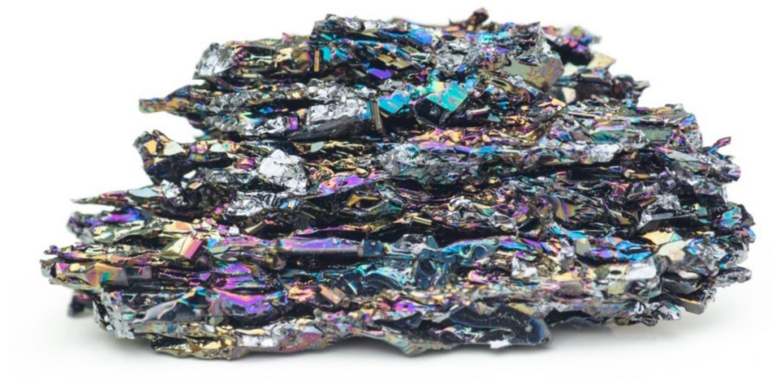
Shin Ehara
+81 3 6437-9934
shin.ehara@gs.com
Goldman Sachs Japan Co., Ltd.

Table of Contents

- The outlook for increased Silicon Carbide (SiC) uptake as a more efficient alternative to silicon (Si) that can save costs and improve performance, especially in automotive applications, has accelerated over the past half year. We now expect an inflection point for rapid market growth potentially two years sooner than projected due to upgrades to production capacity via large-scale investment, acceleration of tech investment by semi makers and clarification of roadmaps, and construction/upgrading of supply chains. Adding further impetus is **"green inflation"** as evidenced by the recent increases in EV battery prices, and which begins to accelerate the green technology cycle.
- This opportunity is being driven by two technology shifts—to SiC and to EVs. SiC devices are being positioned within the tech sector as one of the few products with upside as inflation fuels faster tech innovation. We see substantial future growth potential for SiC—we now assume 13 mn battery electric vehicles (BEVs) will use SiC as of 2030, vs. 1 mn today—and a positive impact on related companies' earnings. We believe there is a lack of consensus on potential SiC market growth and investors may be underestimating the scale trajectory and impact on the sustainable growth in SiC earnings.

Silicon Carbide

in numbers



US$11.3bn

Total (autos and industrial) SiC market (2030E)

Automotive SiC market

US$0.9 bn (2021)	→ 37% CAGR	US$3.3 bn (2025E)	→ 26% CAGR	US$7.5 bn (2030E)

42%
Incremental growth in the $19.4bn xEV Semi market (2030E) to be driven by SiC

+31%
SiC based BEVs (2021-30E CAGR)

US$720
Avg. SiC semis content per BEV (2025E) vs. US$315 for IGBT

5-10%
Increase in driving mileage on the switch to SiC from IGBT

>30%
Lower charging times on high voltage resistance

+3-6 kwH
Potential electricity consumption gains on switch from IGBT to SiC in 60kwH EV

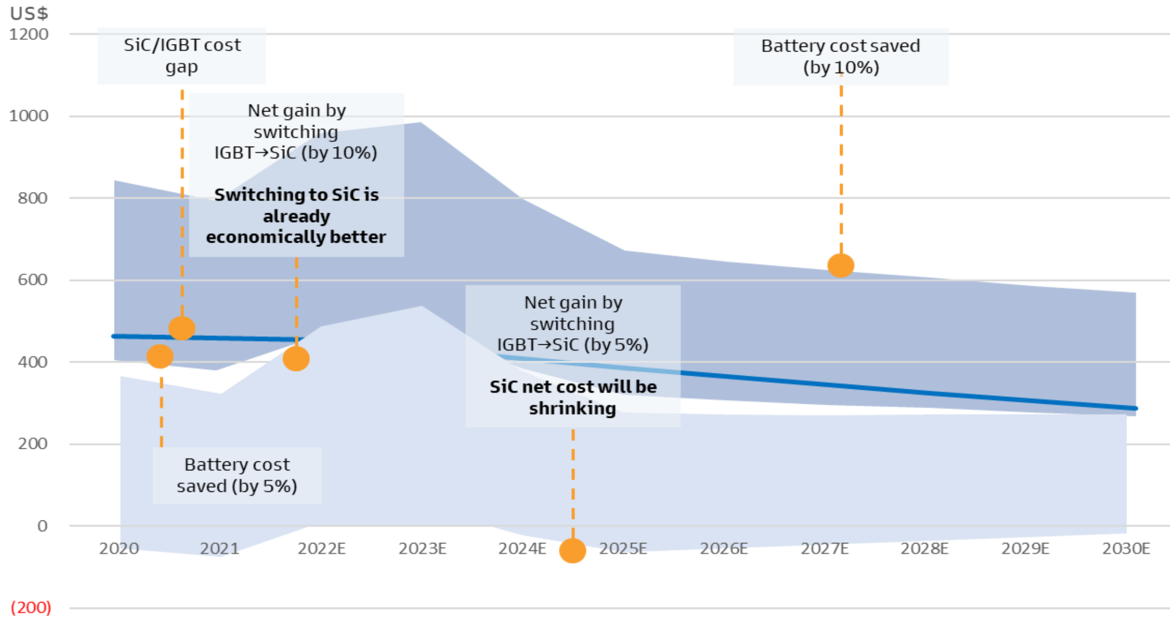
$500 Direct cost differential between SiC and IGBT
Improvement of +10% kWh would bring costs below increase in battery cost.

Key capex commitments

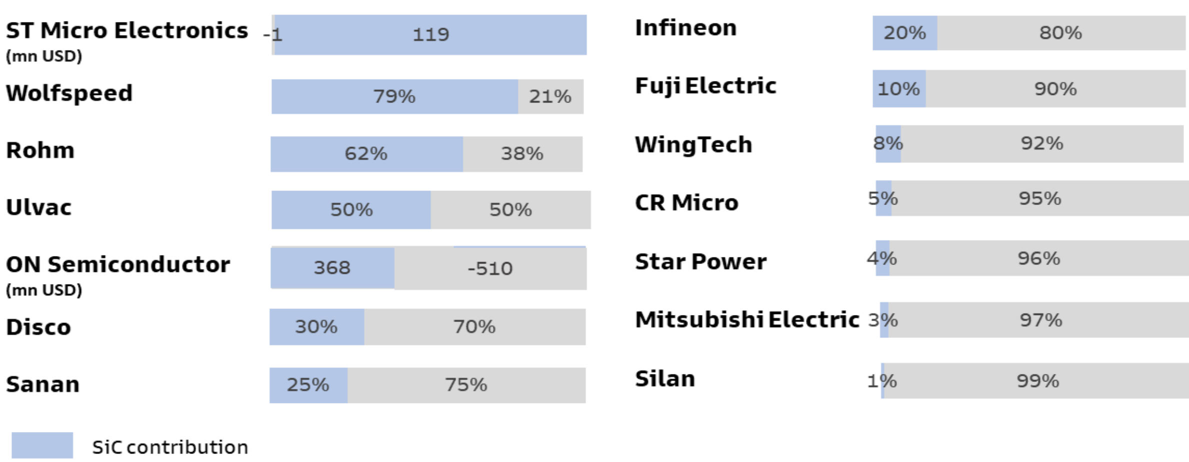
- **€2bn** investment by Infineon
- European mega-factory announced by STMicroelectronics
- Robust investment plans from Wolfspeed and onsemi
- ROHM Semiconductor aggregated 2025 capex up to **120-170bn JPY** (from 60bn JPY)

SiC/IGBT cost gap and battery cost saved by SiC

Direct cost increase on switch to SiC from IGBT less likely to be perceived as excessively high compared with rising per-kWh battery costs



SiC contribution to operating profit growth (2022-2024E)



The numbers for Mitsubishi Electric are based on FY22/FY23

Source: Goldman Sachs Global Investment Research

Why now, and why does it matter?

Why now?: Increasing evidence of an approaching inflection point for SiC

In our first round of Green Technology Cycle reports, we discussed the importance of silicon carbide (SiC) and its growth potential, given scope for this material to be used in power semis in car inverters (instead of silicon) to achieve greater efficiency and thus increase range and/or reduce battery sizes. In this report, we highlight the accelerated adoption of SiC for EVs as a new inflection point that is getting closer. We believe that **green inflation for EV batteries, alongside several other conditions now in place (discussed below), will spur the development of next-generation green technologies in the form of SiC adoption**.

Our view of this approaching inflection point is supported primarily by increased commercialization of SiC technology. First, we note the increasing number of large-scale, **triple-digit € mn design wins being awarded by car OEMs**, suggesting a more broad-based EV adoption of SiC beyond the early movers such as Tesla. For example, we note Infineon has made significant progress of late having been a late starter in the early stages of the technology's rollout, likely in part due to its focus on trench-based technology, and now has five triple-digit USD mn auto SiC design wins. Second, we highlight that multiple large semis producers have increased SiC revenue targets. For example, STMicro brought forward its US$1 bn revenue target from 2025 to 2024 and thereafter to 2023 (as compared with >US$700 mn in 2022), while Wolfspeed has also recently commented on upward pressure to its FY26 SiC revenue target since its 2021 investor day. Wolfspeed's quarterly design-ins have also recently accelerated, to US$1.6 bn in the past two quarters (vs an average of US$700 mn since 1Q21). Third, we note that based on our industry discussions, most conversations that SiC device makers have with large OEMs are now centered on the **ability to secure enough SiC production capacity, rather than evaluating and explaining the benefits** of the technology per se (suggesting that SiC has matured in recent years, with the mass production of several high-end EVs using SiC technology a key proof point, e.g. Tesla already occurring). In particular, recent Wolfspeed commentary suggests that supply chain issues for key components in ICE vehicles may contribute to a faster transition to SiC in certain instances, given SiC capacity expansions.

We see several key reasons why the conditions are now in place for the market to accelerate:

1. Major Analog Semis players are increasingly committing significant capital expenditure to the **build-out of dedicated SiC production facilities**, as they look to compete for market share in a fast-growing industry. Key examples include the €2bn investment by Infineon and the European mega-factory announced by STMicro, alongside the robust investment plans from Wolfspeed and ON Semi. Rohm has also updated its aggregated capex target through 2025 from ¥60 bn to ¥120-170 bn. In our view, this should help build **car maker confidence** in the ability to rely on SiC if used in their products.

2. We note that several semis players have also made **strategic M&A moves** to develop competitive advantages (such as STMicro's acquisition of Norstel in 2019 for wafer-supply technology, or Infineon's acquisition of Siltectra in 2018 for wafer-splitting technology), which we believe will also help to develop the roadmap for future improvement of SiC devices, giving further credibility to SiC technology.
3. We believe the **further investment in next iterations of technology from semis players** is encouraging OEMs and will bring cost and performance advantages that make adoption even more compelling. In particular, given that we are seeing increasing evidence of future roadmaps for further SiC efficiency improvements (e.g. shift to trench, 6-inch to 8-inch technology transition), we believe OEMs now have greater confidence in the ability of SiC to support long-term auto programs.
4. **Developments in the broader equipment ecosystem** are also positive for momentum. For example, we note the recent agreement (announced May 2022) between STMicro and crystal growing equipment player PVA Tepla for 200mm-ready crystal growing machines, which demonstrates efforts to alleviate SiC substrate supply shortages in our view.

As such, we now estimate an automotive SiC market of US$3.3bn in 2025, suggesting a CAGR of 37% over 2021-2025E.

Challenges typically drive technological innovation

SiC is a superior material to silicon (Si) in terms of performance, but observers have pointed out that its uptake will take time due to the difficulty of manufacturing/processing, supply chain capacity restrictions, and relatively high cost, among other factors. However, our analysis suggests that **the rising kWh cost of batteries, in addition to advances in technology and manufacturing capacity, are increasing the economic viability of adopting SiC and this could help drive market expansion**.

While not the only reasons, past experience suggests that major economic change accelerates the development of new technologies. We think this could be priced into the earnings and valuations of companies with exposure in this area sooner than expected.

Competition for EV performance and optimal solutions

Driving mileage relative to cost is a key area of technological competition for EV makers. Optimal solutions for batteries, motors, and inverters are crucial in this regard. The further development of technologies that lower battery cost per kWh has been the most effective means employed to date, and the importance of this for promoting the uptake of EVs going forward will not change, in our view. However, as shown in Exhibit 1, **we expect the kWh cost for batteries in 2022-2023 to be much higher than we previously forecast**. As such, we believe the adoption of SiC is increasing in relative importance as a means of raising EV performance.

We note several merits for employing SiC (MOSFET using SiC): (1) This raises driving mileage per kWh by 5-10% as SiC is superior to general Si (IGBT using Si) in terms of heat/voltage resistance, low on-resistance, and faster performance. (2) The high voltage resistance enables shorter charging times (reduces charging times by around over 30%). Consequently, the adoption of SiC will offer distinct benefits for the shift to 800-volt (high-voltage) batteries for EVs. Some high-end 400-volt EVs (e.g., Tesla) already use SiC.

The barrier to adopting SiC, which has been regarded as relatively costly to date (several times higher than IGBTs), has declined with the rise in battery costs. Given scope for technological advances in SiC in the future as compared with Si and the fast-charging advantage, we think the economic viability of employing SiC at an early stage has increased (alongside aforementioned factors such as automakers' recently increased confidence in the ability to rely on long term production capacity of SiC).

Verifying economic viability of SiC adoption

We use a simple model to verify the economic viability of employing SiC.

Based on the assumption that typical middle to high end EV battery capacity is 60-80kWh, we estimate that driving distance could increase by +5-10% on the switch to SiC from IGBT. In other words, we see potential electricity consumption gains of +3-6 kWh (in the case of a 60kWh EV battery). Converting this into battery costs based on our current per-kWh cost assumptions of US$160/US$164 in 2022/2023, we calculate that the additional +3-6 kWh would push costs up to **US$480-960 in 2022 and US$492-984 in 2023**. Of note, our previous per-kWh battery cost assumptions were US$136 in 2022 and US$130 in 2023, suggesting the impact of these electricity consumption gains would be considerable.

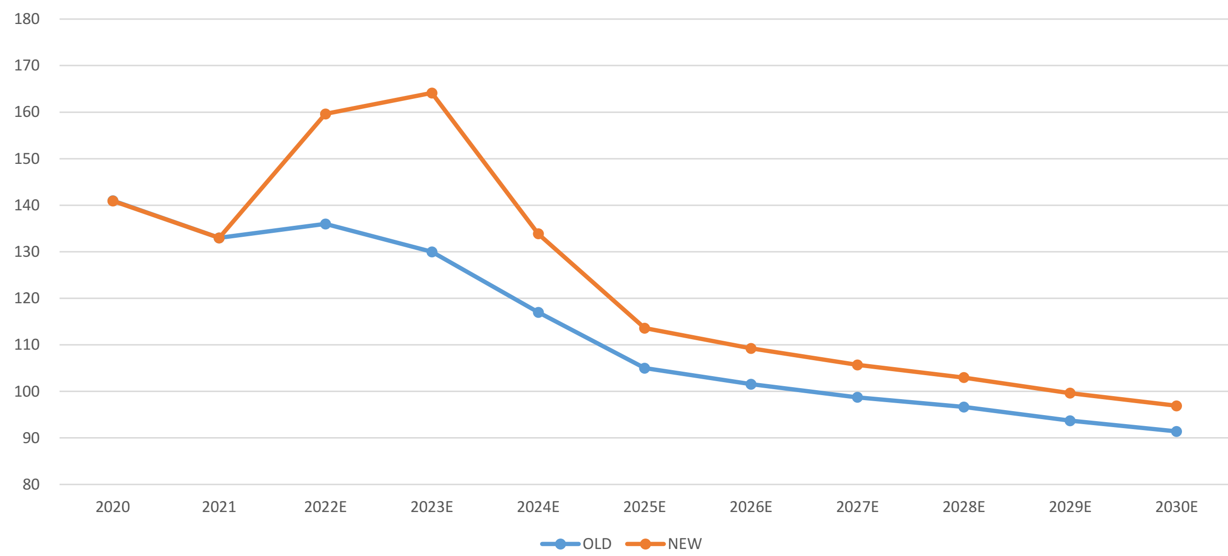
Meanwhile, IGBT semiconductor costs are around US$300, putting the difference between these and SiC semiconductor costs at around several times. If we assume SiC costs are currently around US$800 (based on our estimates), **the direct cost differential is US$500**. While the cost increase remains slightly high (or almost even) with improvement of 5% (+3 kWh), improvement of 10% (+6 kWh) would already bring costs down to a level below the increase in battery costs. SiC is also expected to provide other cost benefits given lower cooling costs due to its superior heat-resistance properties, and limited overcurrent/backflow, which removes the need to install semiconductor diodes (required with IGBT).

In short, we believe that moving ahead with **the employment of SiC is a more economically viable solution than increasing battery capacity in terms of the additional costs required to extend driving distances** (and can also reduce battery costs per driving distance). Through our channel checks, we note that some SiC suppliers are already negotiating supply increases several years in advance, based on the assumption that the direct semiconductor cost difference between IGBT and SiC is reduced to around 2-3X. The prevailing view in the EV inverter industry is that full-fledged uptake of SiC is likely to occur when the cost difference between IGBT and SiC narrows, but we believe this inflection point has already arrived. We also assume the market would expand at a faster-than-expected rate if this cost differential were to narrow even further.

Exhibit 1: Long-term EV battery cost outlook (per-kWh): Our new/old assumptions

$/kWh

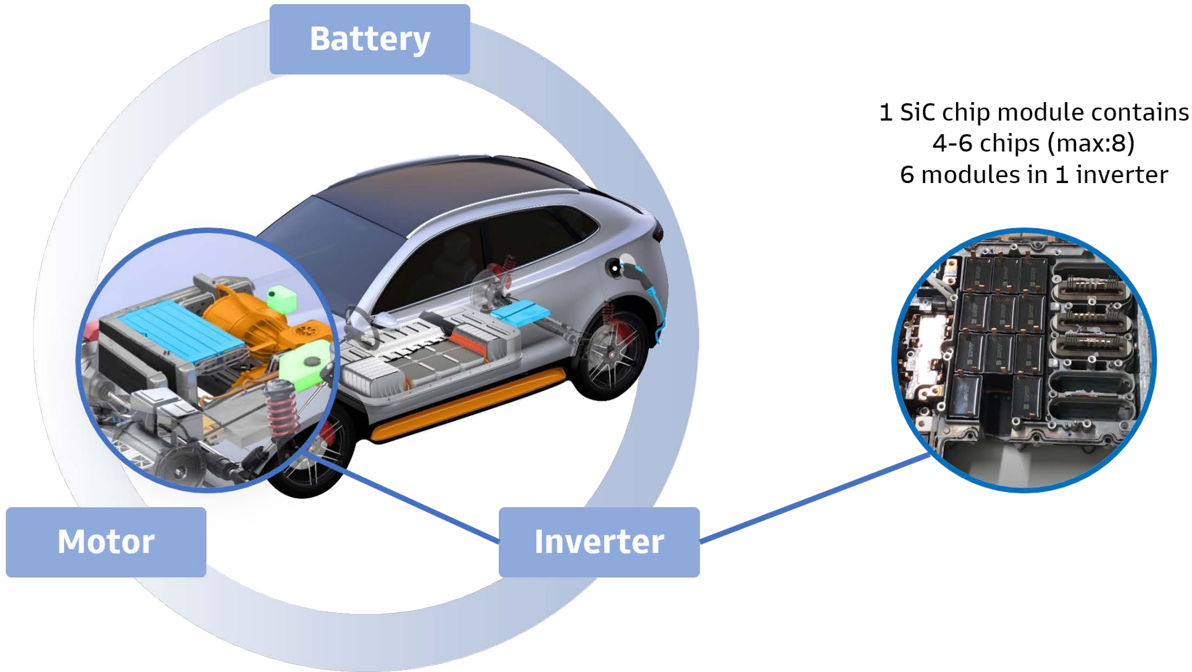
	2020	2021	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
OLD	141	133	136	130	117	105	102	99	97	94	91
NEW	141	133	160	164	134	114	109	106	103	100	97



X Axis: Year Y Axis: $/kWh

Source: Goldman Sachs Global Investment Research

Exhibit 2: Improving economic viability (and increasing industry capacity ramp) key to triggering acceleration in EV-related SiC industry growth



Battery Cost Saved by IGBT→SiC

\$/kwh × SiC electricity efficiency gain (+5-10%) vs. IGBT

>

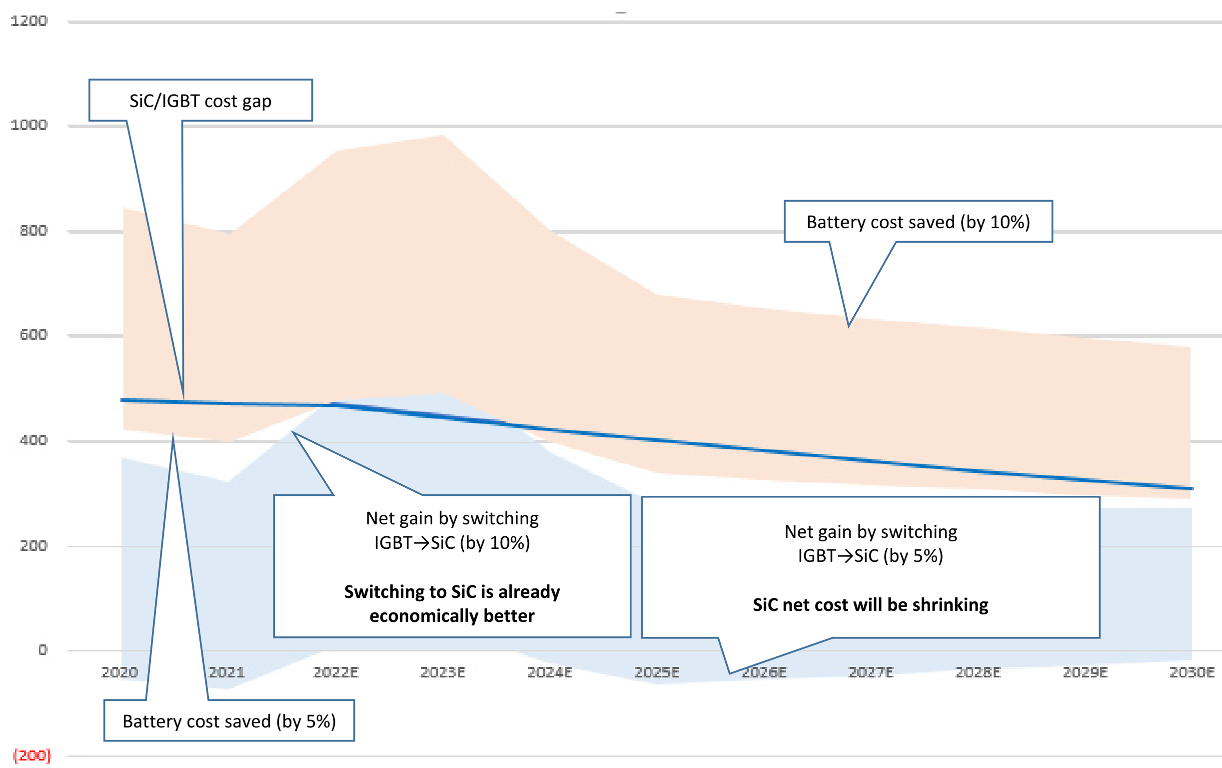
IGBT→SiC Switching Cost

Content per vehicle × Price per Chip (\$)

Source: Goldman Sachs Global Investment Research

Exhibit 3: Comparison of costs per-kWh

Direct cost increase on switch to SiC from IGBT less likely to be perceived as excessively high compared with rising per-kWh battery costs



X Axis: Year Y Axis: USD

Source: Goldman Sachs Global Investment Research

Why does it matter?

We think investors would view faster-than-expected acceleration in SiC employment as an important development for two reasons.

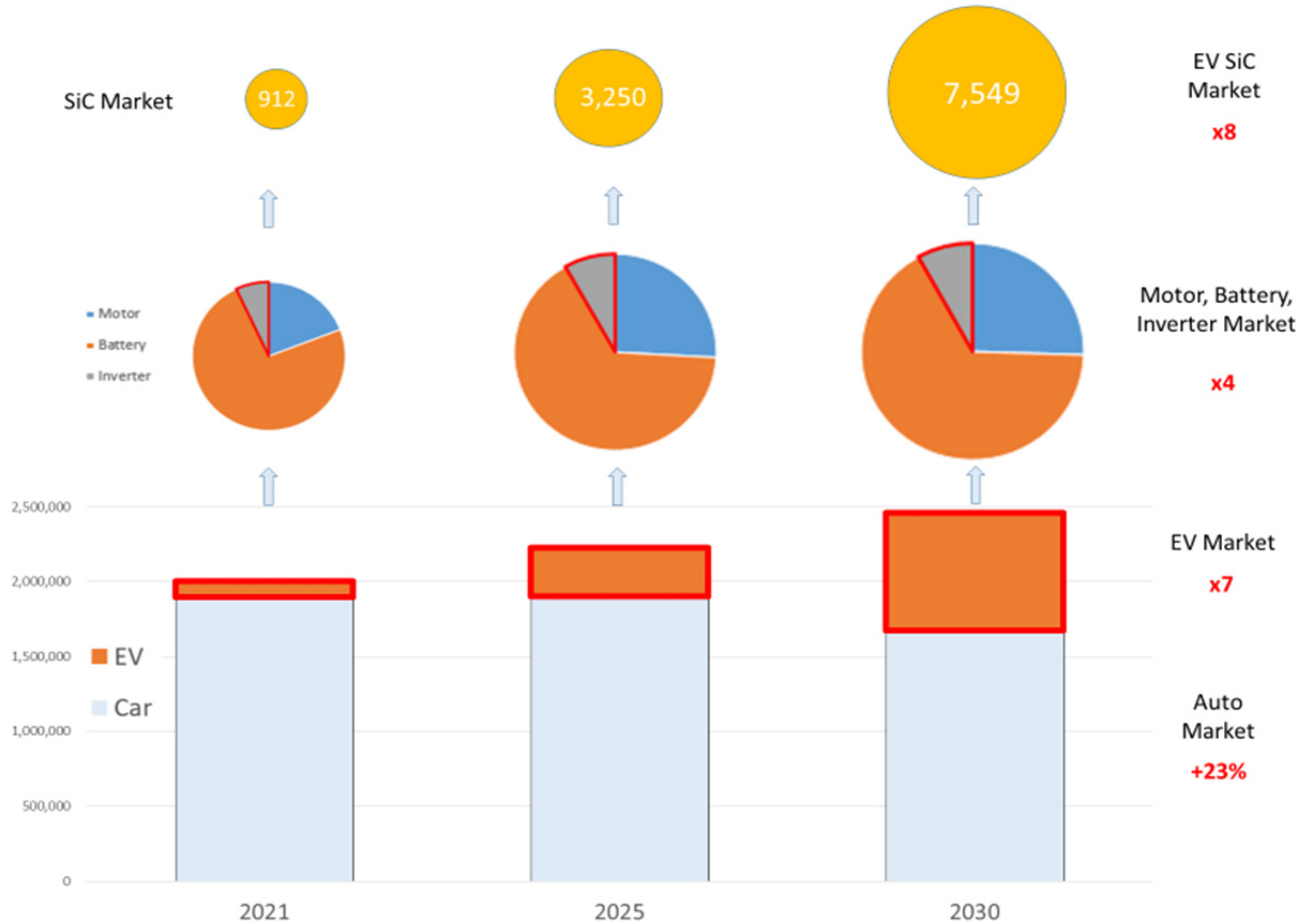
First, we assume this equity theme is less exposed to macro impacts (although inflation is clearly a tailwind fueling faster technological innovation). On June 1, our global autos team revised down its assumptions for global auto sales and production volume to reflect the uncertain macroeconomic outlook and the impact of supply chain disruptions. However, our SiC outlook is premised on two technological shifts (1) the broader market shift to electric vehicles, and (2) the industry shift to SiC. We view this product segment as one of the few among a number of global semiconductor/ electronic device segments where trends are both stronger-than-expected and accelerating.

Second, our estimates suggest that the SiC market will scale up to the point where it has a significant impact on earnings at related companies, especially in terms of share of incremental growth on a multi-year period. We also expect the pace of growth in reaching this level will stand out among factors driving changes in the auto-related profit pool.

Third, for incumbents who have a robust presence in Si-based IGBT inverters, if they were not to execute well on the transition to SiC in future this could potentially suggest negative impacts (i.e cannibalization of revenues or extra costs) and/or multiple de-rating, in the long term.

Exhibit 4: Changes in auto industry profit pool (2021/2025/2030)

We expect auto-related (EV) SiC market growth to stand out, rising to US$3.3bn in 2025 and from US$7.5bn in 2030



Y Axis: USD. The numbers on the right shows the growth of each market compared with 2021

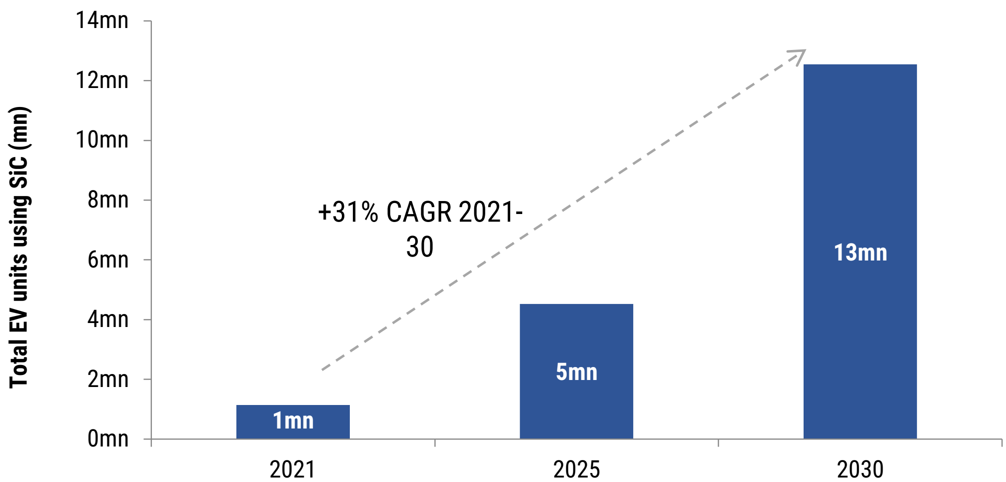
Source: Goldman Sachs Global Investment Research

Raising TAM outlook for SiC for EVs

Raising market outlook for SiC for EVs

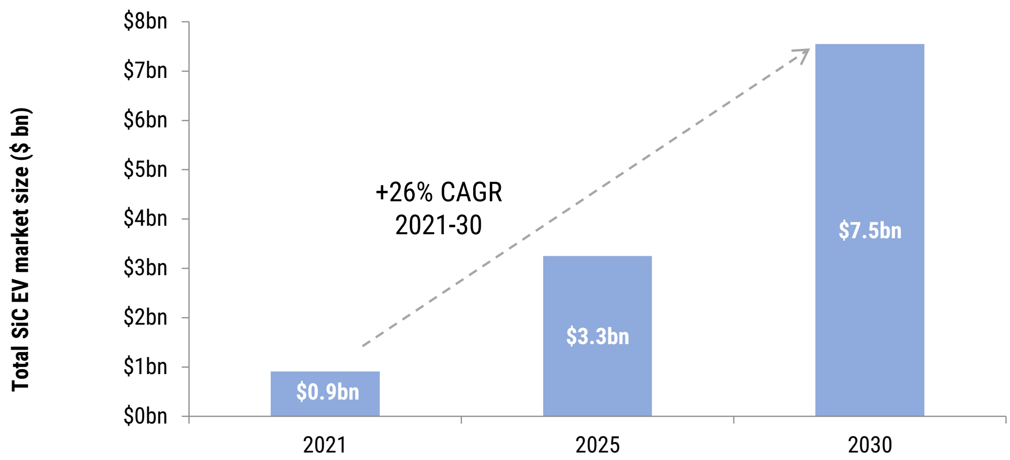
We now expect the **automotive SiC market (ie. for xEVs) to grow to US$3.3bn/US$7.5bn by 2025/30** (60%/35% higher than prior forecasts), representing a **37%/26% CAGR from a market size of US$0.9bn today**. Note that our **xEV SiC market forecast is purely focused on automotive SiC devices** and does not include non-auto applications e.g. industrials, renewables etc. On the assumption that the automotive SiC market comprises c.2/3 of the total SiC market, we estimate this would imply a **total (autos and industrial) SiC market scenario of US$4.9bn/US$11.3bn in 2025/30.**

Exhibit 7: We expect the number of BEVs that are SiC-based to grow at a 31% 2021-30 CAGR...



Source: Goldman Sachs Global Investment Research

Exhibit 8: ...driving our forecast for a total SiC EV TAM of $3.3bn/$7.5bn in 2025/30



Source: Goldman Sachs Global Investment Research

As such, we also **raise our forecasts for the xEV semis market to US$11.0bn/US$19.4bn in 2025/30** (12%/19% higher than prior forecasts), of which we expect the **autos SiC market to drive 42% of incremental growth.**

- On our latest upwardly revised SiC TAM forecasts, we now expect the **Silicon Carbide market to drive 43% of the incremental growth in the broader xEV semis market across 2021-30** (vs 43% stemming from IGBTs).
- Within the total EV TAM, we also include **IGBTs, noting that these will be more applicable over time in certain cars other than high-end cars,** e.g. plug-in hybrids, where the benefits of extra range are less important given smaller distances driven around cities.
- We have **updated our IGBT TAM assumptions to include a less aggressive price deflation gradient** given current semiconductor shortages (and recent management commentary at our GS Semis conference that semiconductors can help differentiate OEMs' offerings). As such, while our **IGBT EV penetration estimates for 2025/30 fall** (given we are more bullish on SiC penetration), the **overall IGBT xEV TAM revenues increase** (albeit by not as large a percentage as our SiC TAM forecast).

We summarize our key assumptions behind our automotive SiC TAM estimate in Exhibit 9 below.

- We assume that **only BEVs use SiC,** as hybrid vehicles do not use a significant enough amount of electrical energy to warrant SiC use (given supplemental power from an internal combustion engine).
- We estimate **average SiC semis content per BEV of c.US$720 in 2025**, as compared to average **IGBT semis content of US$315** (both incremental to the semis content found in a regular ICE car). Note that this is an **average** and **may vary between different producers and types of SiC**. For example, we believe **trench-based SiC chips may be more expensive.** Furthermore, some types of

chips provided to OEMs may have a **higher or lesser degree of customization provided by the chipmaker.**

- We assume that **SiC adoption in BEVs grows to 35%/40% in 2025/30** (vs prior forecasts of 30%/40%), reflecting an accelerated trajectory of penetration gains.

Exhibit 9: Key SiC EV TAM Model Assumptions

Key SiC EV TAM Model Assumptions

Proportion of SiC-based BEVs	• **2025E:** Assume **35%** (vs 30% prior) • **2030E:** Assume **40%** (unchanged) • *Note, prior 2018 SiC deepdive assumed **20%/35% in 2025/30***
Average SiC content per BEV	• **2025E: c$720** (vs c$500 prior) • *Assuming **IGBT** semis content of **$315** (vs c$300 prior)* • *All semis content is **incremental to regular ICE** car.*
xEV Units	• Our **xEV units estimates** are based on **GS Global Auto Team forecasts** • **6.2mn/12.9mn/31.4mn BEV units** in 2022/25/30

Regular ICE car semis content is typically US$300-400

Source: Goldman Sachs Global Investment Research

We raise China TAM estimates to factor in a faster adoption curve and higher SiC content per car

We raise our China EV SiC TAM estimates by 149%/71%/96%/112% for 2022-25E vs our previous estimates, to US$618mn/774mn/1,081mn/1,269mn, implying a 27% CAGR in 2022-25E. Our upgraded outlook mainly reflects: 1) faster SiC adoption as local OEMs have launched new EV models for 2H22 delivery (Xiaopeng, BYD, and NIO, etc.); 2) higher SiC content per car driven by migration to 800V (higher spec SiC MOSFET needed) and dual-motor configuration (more SiC MOSFET units per car needed vs. single-motor EVs). Also, we think cost deflation for SiC MOSFET will be slower than previously expected given capacity constraints. In our updated model, we have extended our estimates to 2030E with breakdowns for 800V vs. 400V and single-motor vs. dual-motor. We expect the EV SiC T AM in China to reach US$2.1 bn by 2030E, implying a 17% CAGR in 2022-30E. We summarize our key assumptions below.

Exhibit 10: We factor in a faster SiC adoption curve and higher SiC content per car; our TAM size is revised up accordingly

China EV SiC TAM		2022E	2023E	2024E	2025E
China TAM - old	US$ mn	248	454	551	598
China TAM - new	**US$ mn**	**618**	**774**	**1,081**	**1,269**
Change%	%	149%	71%	96%	112%
Volume estimate changes					
#EVs with SiC inverters - old	mn units	0.43	0.69	1.05	1.43
#EVs with SiC inverters - new	mn units	0.78	1.01	1.45	1.81
Change%	%	82%	47%	38%	26%
Implied SiC penetration					
SiC penetration in EV - old	%	11%	15%	20%	25%
SiC penetration in EV - new	%	21%	23%	29%	33%
Change (ppts)	%	10ppts	8ppts	9ppts	8ppts
SiC content per car					
Old estimate	US$	579	654	524	419
New estimate	US$	791	766	744	703
Change%	%	37%	17%	42%	68%

Source: Goldman Sachs Global Investment Research

800V EVs to enter market in China in 2022 and reach 10% penetration by 2025E: Xiaopeng and BYD have launched 800V EV models in 2022. The migration to 800V platforms will first start with high-end EV models (price range Rmb300k+), based on our observations. Other local OEMs have also released plans for 800V EVs in the coming 2-3 years to catch up or differentiate with their competitors. In our base case, we have modeled high-end EVs (priced at Rmb300k+) will mostly migrate to the 800V platform by 2025. Going into 2030, we factor in 21% of EVs will migrate to the 800V platform (i.e. EVs priced at Rmb250k+). As mentioned earlier, 800V EVs will use 1200V SiC MOSFETs considering the IGBT's limitations in a high voltage environment. Therefore, the rise of 800V EVs will be a key driver of SiC adoption.

Dual-motor configuration drives higher power semi content. From a power semi perspective, a dual-motor setup will typically require higher inverter content (hence higher power semis content). High-end EVs are typically equipped with two motors (one in the front wheels, the other in the rear). Since the front motor typically has lower power, the power semis content in the front motor is normally lower than the rear one. We have factored in 40% higher SiC content per car in dual-motor EVs vs. single-motor EVs.

OBC and DC-DC converter: OBC (on-board charger) is an essential component for EVs and its main function is to charge the EV battery when it connects to an external AC (alternative current) charging pile. For a typical EV's OBC unit, common power semis used are silicon-based devices such as super junction MOSFET, IGBT, and diodes. However, as OBC migrates to higher power (from 6.6kw to 11kW and 20kw+) and to improve power efficiency and charging speed, OBCs are also adopting SiC devices. For 800V EVs, we model that OBC will use SiC devices instead of silicon-based devices. For 400V EVs, we currently assume silicon-based power devices will remain as the main choice for OBC units. In terms of DC-DC converter, it can convert low voltage to high voltage, and vice versa. 800V EVs will require a DCDC converter to convert from 400V to 800V to charge the battery given they will still need to use 400V-based charging stations. Therefore, the DCDC converter will be another unit to adopt SiC devices, in our view.

SiC adoption in PHEV could present additional upside to our TAM estimates: In our TAM analysis, we currently assume that PHEVs will not adopt SiC devices in the coming years as we have not seen meaningful volume of PHEVs that are SiC-based. However, we do not rule out the possibility of PHEVs adopting SiC, and we have conducted a scenario analysis on PHEV's SiC adoption. Assuming PHEVs start to adopt SiC in 2025, and by 2030E, PHEVs at a Rmb400k+ price range will be 800V and SiC-based (i.e. 12% of PHEVs), our analysis suggests 2%-12% upside to our base case TAM estimates in 2025-30E.

Exhibit 11: China EV SiC TAM breakdown

		2020	2021	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
TAM breakdown:												
EV	US$ mn	111	397	618	774	1,081	1,269	1,488	1,667	1,826	1,973	2,100
800V platform	**US$ mn**	**-**	**-**	**89**	**137**	**406**	**652**	**816**	**979**	**1,134**	**1,288**	**1,430**
SiC MOSFET 1200V - inverter for single motor	US$ mn	-	-	10	16	26	41	51	62	72	82	91
SiC MOSFET 1200V - inverter for dual motor	US$ mn	-	-	66	102	323	515	644	779	909	1,031	1,143
SiC MOSFET/diode - OBC	US$ mn	-	-	8	11	35	58	73	84	93	106	119
SiC MOSFET - DCDC converter	US$ mn	-	-	5	7	23	38	48	54	60	69	77
400V platform	**US$ mn**	**111**	**397**	**530**	**638**	**676**	**617**	**672**	**688**	**692**	**685**	**670**
SiC MOSFET 650V- inverter for single motor	US$ mn	44	159	212	255	270	247	269	275	277	274	268
SiC MOSFET 650V - inverter for dual motor	US$ mn	67	238	318	383	406	370	403	413	415	411	402
SiC diode - OBC	US$ mn	-	-	-	-	-	-	-	-	-	-	-

Source: Goldman Sachs Global Investment Research, Gao Hua Securities Research

IGBT: we update EV TAM to factor in the latest EV volume estimates

We reflect the latest NEV (new energy vehicles) volume estimates from our China auto team and SiC penetration rates. We also factor in a higher IGBT content per car vs. before as we think pricing decline will be slower than previously expected, in line with our global team's view. Our updated IGBT content per car estimate in our China TAM model is c.10%-20% lower than that of our global model as we consider China local players' product pricing typically has a 10%-20% discount vs. global major IGBT suppliers. With this, we expect China's EV IGBT market size to reach US$1.5bn/2bn in 2022/25E, 56%/35% higher than our previous estimates.

Exhibit 12: We update IGBT TAM to reflect our China auto team's latest EV volume estimates

mn units	2020	2021	2022E	2023E	2024E	2025E
China EV units (old)						
HEV	0.20	0.99	2.94	4.84	6.10	7.56
PHEV	0.25	0.55	0.74	0.99	1.24	1.50
BEV	1.11	1.94	2.62	3.49	4.38	5.30
China EV units						
HEV	0.20	0.96	2.50	4.17	5.10	6.20
PHEV	0.20	0.55	1.40	1.75	2.08	2.36
FEV	0.91	2.44	3.79	4.49	5.09	5.51
Change: new vs. old (%)						
HEV	0%	-3%	-15%	-14%	-16%	-18%
PHEV	-18%	-1%	90%	77%	68%	58%
FEV	-18%	26%	45%	29%	16%	4%

Source: Goldman Sachs Global Investment Research, IHS Global Insight

Exhibit 13: We revise up IGBT content per car as we expect slower pricing deflation

US$	2020	2021	2022E	2023E	2024E	2025E
China EV $ content (old)						
HEV	79	77	73	70	66	63
PHEV	269	262	249	236	225	213
FEV	308	301	286	271	258	245
China EV IGBT $ content per car						
HEV	79	77	75	72	70	68
PHEV	269	269	269	262	255	249
FEV	308	308	301	293	286	279
Change (%)						
HEV	0%	0%	3%	3%	5%	8%
PHEV	0%	3%	8%	11%	14%	17%
FEV	0%	3%	5%	8%	11%	14%

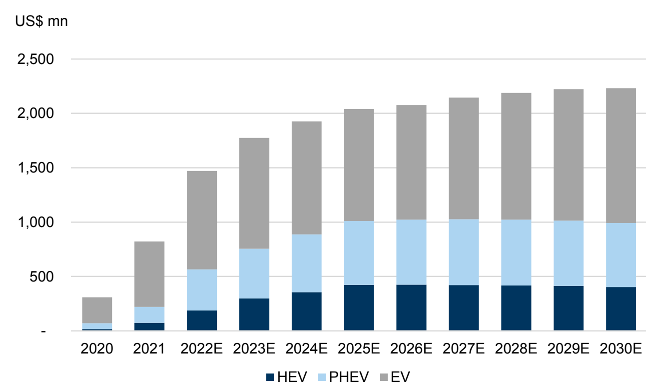
Source: Goldman Sachs Global Investment Research

Exhibit 14: Our IGBT TAM is revised up by 56%/35% in 2022/25E, mainly driven by increase in EV and PHEV volume

US$ mn	2020	2021	2022E	2023E	2024E	2025E
EV-IGBT TAM (old)						
Total	**366**	**674**	**940**	**1,199**	**1,367**	**1,509**
HEV	16	76	216	338	404	476
PHEV	66	144	184	233	278	319
FEV	285	454	540	629	685	713
EV-IGBT TAM						
Total	**308**	**823**	**1,471**	**1,775**	**1,927**	**2,041**
HEV	16	74	189	298	356	422
PHEV	54	146	377	457	531	588
FEV	238	602	905	1,019	1,039	1,032
Change: new vs. old						
Total	**-16%**	**22%**	**56%**	**48%**	**41%**	**35%**
HEV	0%	-3%	-13%	-12%	-12%	-11%
PHEV	-18%	2%	105%	96%	91%	84%
FEV	-16%	33%	68%	62%	52%	45%
Mix (%)	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
HEV	5%	9%	13%	17%	18%	21%
PHEV	18%	18%	26%	26%	28%	29%
FEV	77%	73%	62%	57%	54%	51%

Source: Goldman Sachs Global Investment Research

Exhibit 15: We expect China's NEV IGBT TAM to reach US$1.5bn/2.0bn/2.2bn in 2022/25/30E



Source: Goldman Sachs Global Investment Research

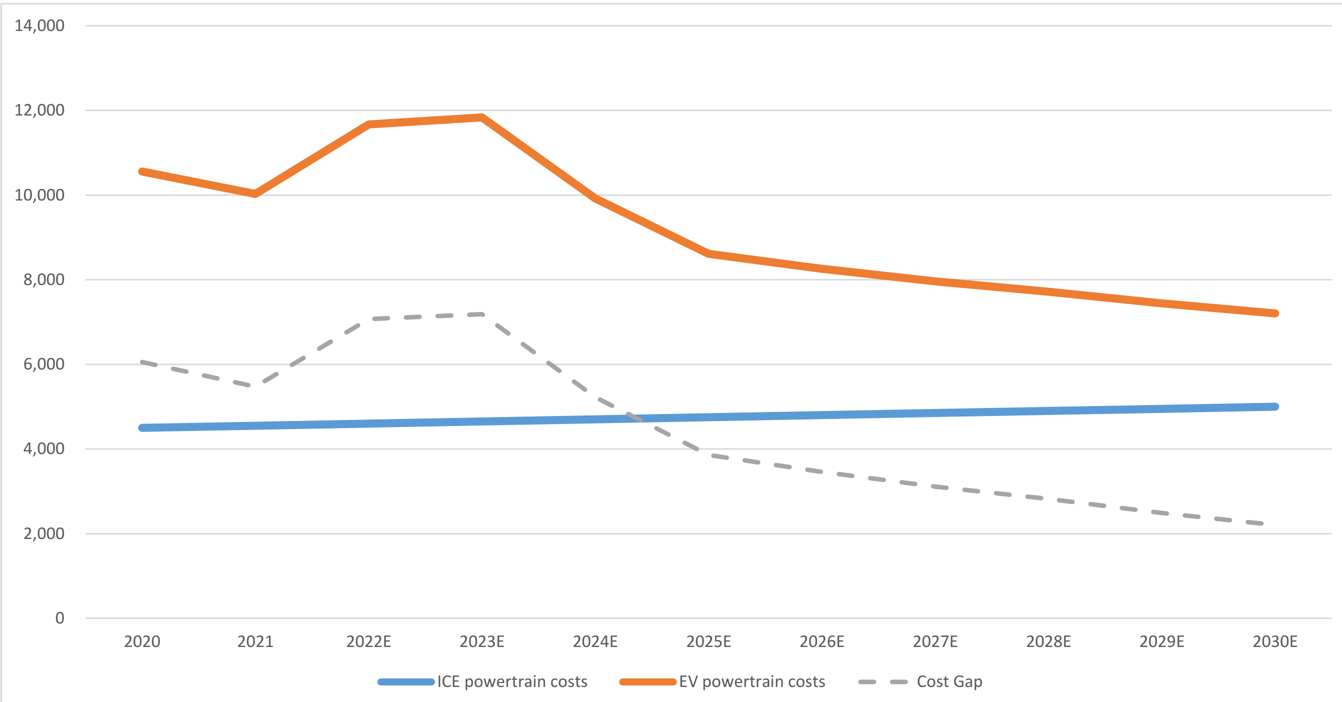
Approach based on vehicle cost structure

Here we verify the appropriateness of our global TAM estimates using an approach based on vehicle cost structure. Assuming an ASP for an ordinary passenger car of around US$25,000, we calculate the difference in powertrain cost between EVs and ICE vehicles in the case of a 60 kWh EV. In our view, reducing the powertrain cost gap is key for the uptake of EVs. Technological innovation in batteries is unquestionably the area with the biggest scope for reducing the cost of EVs, in our view. That said, reducing the cost weightings of motors and inverters is also important.

Based on this thinking, we think it is important to look at how much the semiconductor component of an inverter costs. Assuming that the cost weighting of inverters in EVs declines gradually, the relative advantage of SiC would rise further and EVs incorporating SiC could exceed vehicles incorporating IGBTs by sometime in the near future.

We think even this approach based on vehicle cost structure verifies the reasonableness of our aforementioned TAM estimates, and we expect the SiC market to grow sharply and sooner than expected.

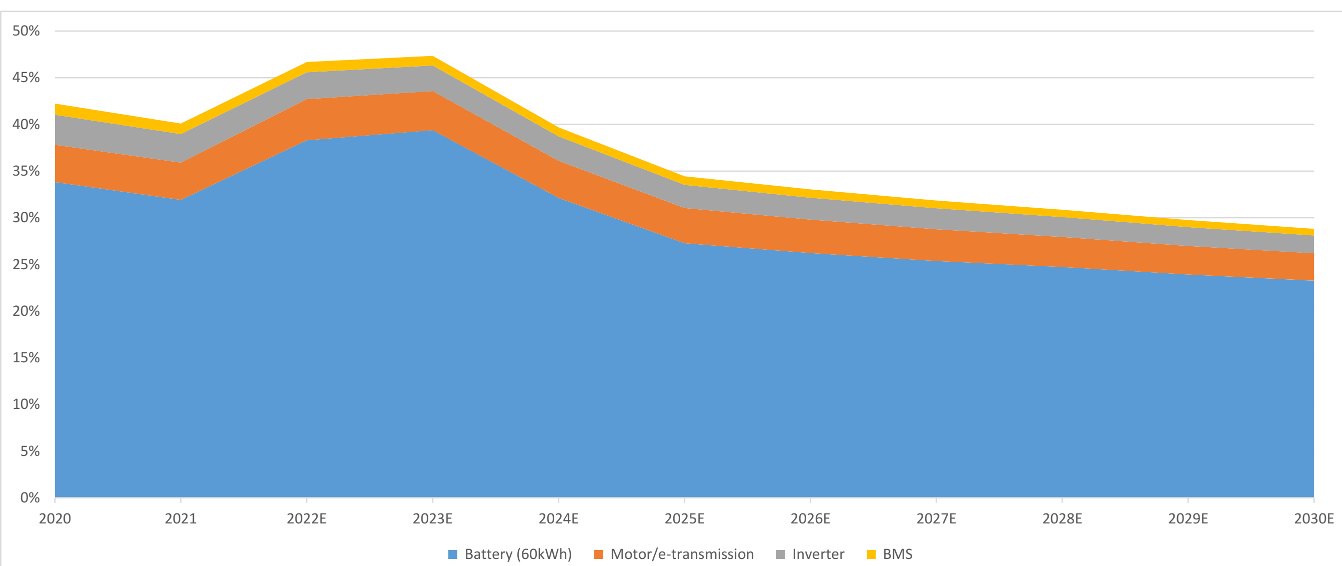
Exhibit 16: Powertrain cost structure for ICE and EV
We estimate the ICE power train cost to be stable and EV powertrain cost to be smaller from 2023, narrowing the cost gap



X Axis: Year; Y Axis: USD

Source: Goldman Sachs Global Investment Research

Exhibit 17: Powertrain cost weighting in EVs
Inverter cost is around 2-3% of the EV cost



X Axis: Year; Y Axis: % of cost of each element out of the entire EV cost

Source: Goldman Sachs Global Investment Research

Success factors for key semiconductor players to maximize profit pool

How will companies lean into the aforementioned sharp market expansion and monetize it? We see eight points for evaluating companies.

1. **Access to sufficient SiC wafer supply**
2. **Capacity upgrades**
3. **Technological progress**
4. **Supply chain / Vertical integration**
5. **Robust system level knowledge**
6. **Reliability and durability**
7. **Access to customers that are growing**
8. **Government support**

In short, at this time when the market is on the cusp of entering a full-scale growth period, this is also a time when earnings expectations for related companies are likely to rise. We think positive evaluations of supply chains could be given greater emphasis than inter-company differences. That said, we will be focusing on the following points for each company given there are clear differences.

- **STMicroelectronics**: (1) Speed of capacity expansion, (2) shift to trench from planar, (3) diversification of concentrated customer base, (4) benefits of vertical integration.
- **Infineon**: (1) Further evidence of large triple digit mn euro wins, (2) continued progress on wafer-splitting technology (mitigating lack of vertical integration), (3) evidence of benefits of trench leadership.
- **Wolfspeed**: (1) Mohawk Valley will increase WOLF's capacity and will shift WOLF to 200mm production, (2) the company is the largest SiC wafer supplier in the world and its vertically integrated scale provides a volume/cost advantage, (3) the majority of WOLF's design-ins are for the auto industry, especially for EV, (4) WOLF receives New York state reimbursements for capacity expansions
- **ON Semiconductor**: (1) Speed of capacity expansion, (2) progress on additional customer wins and committed revenue pipeline, (3) benefits of vertical integration.
- **Rohm**: (1) speed of capacity ramp-up (whether it is slower than European and US companies), (2) benefits of vertical integration, (3) benefits of being a leader of technological development (including the trench-based architectures), (4) timing of swing to profitability
- **Fuji Electric**: Timing of SiC shift by major customer (Toyota), i.e., customer roadmap

Exhibit 19: Checklist for the competitiveness of major companies

	Sufficient SiC wafer supply	Capacity expansion	Technology		Secure supply chain /Vertical integration	Robust system level knowledge	Reliability and durability	Access to growing client	Government support
			Cost reduction	Performance					
Infineon	★★ ~ ★★★	★★★	★★ ~ ★★★	★★★	★★ ~ ★★★	★★★	★★★	★★★	★★
Wolfspeed	★★★	★★★	★	★★	★★★	★★★	★★ ~ ★★★	★★★	★★★
Rohm	★★★	★★	★★	★★ ~ ★★★	★★★	★★	★★★	★★★	★★
STMicroelectronics	★★★	★★★	★★★	★★ ~ ★★★	★★★	★★ ~ ★★★	★★★	★★★	★★
Fuji Electric	★ ~ ★★	★ ~ ★★	★	★★ ~ ★★★	★★	★★~ ★★★	★★★	★★★	-
ONSemiconductor	★★★	★★ ~ ★★★	★★	★★	★★★	★★~ ★★★	★★~ ★★★	★★★	-
Mitsubishi Electrc	★ ~ ★★	★	★	★★ ~ ★★★	★	★★★	★★★	★	-
StarPower	★ ~ ★★	★★	★ ~ ★★	★~★★	★★	★★	★~★★	★★★	★★
CR Micro	★ ~ ★★	★ ~ ★★	★ ~ ★★	★~★★	★★	★	★~★★	★★★	★★
Silan	★ ~ ★★	★	★	★~★★	★★	★	★~★★	★★★	★★
Wingtech	★ ~ ★★	★ ~ ★★	★ ~ ★★	★~★★	★★	★★	★~★★	★★★	★★
Sanan	★★	★★	★ ~ ★★	★~★★	★★~ ★★★	★★	★~★★	★★★	★★

retaltively advanced	★★★
industry average	★★
relatively lagging	★

Source: Goldman Sachs Global Investment Research

1. Access to sufficient SiC wafer supply

We believe that access to a sufficient and **resilient supply of high-quality SiC wafers** will be critical in enabling players to scale production capacity in order to meet potential future customer demand. Given the increasing focus from OEMs in broadening EV offerings, we believe it will be important for leading semis players to demonstrate a viable long-term supply strategy in order to win long-term automotive customer contracts, such as Wolfspeed's agreement to supply STMicro with 150mm silicon carbide bare and epitaxial wafers over the next several years, worth over $800mn. That being said, we believe innovations around **wafer-splitting** could help secure sufficient volume.

2. Capacity upgrades

The past few years have seen announcements of major capex spanning several years and capacity upgrades related to SiC. Amid the rapid rise in the demand outlook, we think how quickly a company can ramp up capacity is a key criterion for evaluating competitiveness. We highlight three points in this regard: (1) **Balance sheet strength** to withstand upfront investments (we assume the production value relative to the investment amount for SiC semiconductors is around 1:1); (2) **decision-making speed** for ramping up capacity so as not to lose in the power game; and (3) conditions for ensuring **smooth recoupment of investment** (technology, supply chain, and customer acquisition). Overall, we think European and US companies have the lead in terms of scale and speed on this point.

While a number of Analog semis players have announced significant capacity expansion plans (in Silicon Carbide, but also more broadly) in the next 1-2 years, we believe that in the current environment of semis tightness, having **sufficient scale and capital available to invest into dedicated SiC capacity** could provide competitive advantages. With prolonged lead-times for several key semicap equipment tools (e.g. >12 months lead time for certain lithography equipment), we expect that players with sufficient clean room spaces and processing equipment will be better-positioned to secure LT customer orders. We expect that large customers will want to see a **credible roadmap for production at scale**, and may have less appetite for SiC autos programs if there is a lingering risk of undersupply of silicon carbide in the future.

Exhibit 20: Capex and capacity ramp-up status at SiC-related companies

	Capex	Capacity expansion
Infineon	• €2bn to add manufacturing capacity for SiC and GaN at its site in Kulim, Malaysia	• The new capacity in Kulim is expected to generate annual revenues of approximately €2bn once fully equipped.
Wolfspeed	• $2.9bn USD gross capex during FY2020-FY2024 (Roughly $2bn of gross capex for new 8" SiC fab in Mohawk Valley(MVF))	• Ramping 8" capacity in its new Mohawk Valley fab, which began operation in 2022. • Also considering building a new fab in addition to Mohawk Valley in the coming years (have not provided more specificity on the timeline)
Rohm	• 120bn-170bn JPY (total) SiC related capex during FY21-25	• launched a new SiC factory in Chikugo, Fukuoka (21/1) • Aims to increase the SiC capacity by 500+% by FY25 from FY21 (22/5)
STMicroelectronics	• Total of $900 mn of capex in 2022 on 1) SiC raw material initiatives 2) industrialisation of new 300mm wafer fab in Agrate 3) GaN technology	• Development of 6" SiC wafer fabs in Catania and Singapore • Plans to grow SiC capacity by >2.5x in 2022 (vs 2020), and then double 2022 capacity by 2025.
Fuji Electric	• 30bn JPY SiC capex by FY23.	• 6 inch wafer SiC line for Auto application in Tsugaru, start production from FY24
ONSemiconductor	• Plans to spend ~12% of total revenue on capex in 2022 and 2023, and revert lower to ~9% by 2025. • Most capex dollars focused on expanding its internal 300mm company-wide capacity and its SiC-specific capacity	・Plans to expand 200mm SiC capacity of GTAT (An SiC wafer manufacturer it acquired in 2021) ・Plans to 4x the capacity of GTAT in 2022 and to source most of its SiC substrate capacity internally by 2024/25
Mitsubishi Electric	• Existing 6inch fab is enough for a few years	・No SiC expansion plan announced.
StarPower	• The company has not disclosed SiC capex alone, around Rmb1bn SiC/IGBT fab capex for the construction stage	・targets to produce SiC chips in its own 6'' fab in 1H23 ・6" fab total planned capacity at 30k wpm, with 25k wpm allocating to IGBT chips and 5k wpm to SiC chips
CR Micro	• The company has not disclosed SiC capex alone, around Rmb1.5bn power semi capex in 2022	・currently has 6" SiC wafer fab capacity of 1k wafer/month, and the future capacity expansion will depend on customers' demand
Silan	• The company has not disclosed SiC capex alone, around Rmb1bn power semi capex in 2023	・Capacity of 6" trial production line for R&D of SiC device at hunderds wafers per month, 1-2k wafers per month for mass production
Wingtech	• The company has not disclosed SiC capex alone, around Rmb2.3bn power semi capex in 2024	・No disclosure on SiC capacity expansion, but around 15% capacity expansion every year in factories in Europe, via 6" to 8" and production lines upgrade; new 12-inch factory in SH has 33k wpm planned capacity
Sanan	• The company has not disclosed SiC capex alone, around Rmb2bn power semi capex in 2022	・The company plans to expand its SiC capacity from 3k wafers/month currently to 30k in coming years

Based on company disclosures and comments

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

3. Technological progress

In our view, two factors are essential for technological advances in SiC semiconductors: (A) product performance (improvement in attributes such as low-on resistance and speed, smaller chips, development of single chips, etc.), including potentially the transition to trench-based architectures (from planar), and (B) production process efficiency for reducing costs. We think these two factors will translate directly into competitiveness and smooth investment recoupment. In regards to (B), many US and European makers plan to shift to 8-inch wafers, from 6-inch wafers, over the next one to two years (should reduce cost by increasing the number of chips from each process), and thus differences in competitiveness are likely to arise through this process. In SiC, technological advances in terms of yield and cost, such as enhancement of film quality (low particle), uniformity, stress control (wafer warpage countermeasures) will be key points.

As far as product performance is concerned, we believe that key customers will look for proof points of a **robust future technological roadmap** that can support continued improvements in areas such as resistance, durability, device architecture, cost efficiency, among others. Our research suggests that **trench-based devices** could have **advantages relating to durability, reliability, and low-resistance** (therefore allowing for greater efficiency in energy conversion alongside a lower risk of product recalls on a multi-year basis). We also note that trench may have benefits including a smaller form factor, albeit we see this as potentially less important for cars than other devices like smartphones. While some players (e.g. Infineon) are already manufacturing using trench-based designs, several players (e.g. STM) have incorporated trench onto future technology roadmaps, suggesting that the capability to do trench could be a success factor in the long run, with several SiC customers (e.g. Asian OEMs) particularly focused on quality. That being said, our industry discussions suggest that further iterations of planar-based SiC devices can also offer benefits in terms of resistance (with potential time-to-market advantages due to yield), with ST having had meaningful success in recent years through evolving its planar-based approach.

Further, as far as production process efficiency is concerned, we believe that given that the cost of SiC wafers is significantly higher than that of Si wafers, leading semis players will eventually likely need to **shift to 8 inch manufacturing** to reduce cost per unit (vs Si chips largely being produced on 8/12 inch wafers) and improve yield. As such, we believe the transition to 8-inch could generate significant gross margin benefits. We note that companies such as Infineon, STMicro, Rohm, ON Semi and Wolfspeed are testing 8-inch wafer production for SiC.

Exhibit 21: Technological advances (product performance improvement, production processes) at SiC-related companies

	Technology	Wafer Size (inch)
Infineon	**(related with cost)** • Infineon plans to transfer from 6 inch to 8 inch SiC wafers, and Infineon's new tools for its Kulim capacity expansion plans will have the ability to switch to 8-inch. Infineon has also qualified its first product using its proprietary boule-splitting technology (Siltectra) faster than its initial expectations (May 2022) **(related with performance)** • Infineon has developed SiC devices using trench technology (vs most competition on planar), which could have advantages related to durability, reliability, and resistance (therefore allowing greater efficiency in energy conversion). • Infineon expects its upcoming Gen 2 SiC trench product to improve power handling capabilities by 25-30% vs its Gen 1 product. • We believe Infineon has a strong reputation for reliability and durability, which is critical to reach automotive-grade safety levels, alongside robust system-level knowledge given a long-standing history with automotive IGBTs. • Infineon's ability to offer interchangeability between SiC and IGBT devices in autos offers attractive flexibility for OEMs in our view.	6" → 8"
Wolfspeed	•WOLF's new 200mm SiC fab, Mohawk Valley, is outfitted with better automation and manufacturing efficiencies. These manufacturing advantages, over WOLF's current 150mm processes, are expected to drive lower processing costs.	6"→8" (2022~ in MVF)
Rohm	• Device Generation FY21: Gen3 FY22:Gen4 (close to half) + Gen3 FY25: Gen4+Gen5(start) • On-resitance reduction: Gen2: -50% Gen3: -40% Gen4: -30% Gen5: -30%	FY22:6"only FY23:6"+8" (start) FY25:6"+ 8" (less than half)
STMicroelectronics	**(related with cost)** • STM is using planar technology for its current 3rd generation of SiC devices. It is planning to shift to trench-based architectures at its 5th generation. • STM is testing 8-inch manufacturing, and expects to complete a fully integrated 8-inch SiC wafer fab by 2023, which could reduce cost per unit. **(related with performance)** • STM has improved (ie. lowered) resistance with each successive generation of planar-based SiC devices (currently on 3rd generation). ST expects upcoming 4th generation to also improve resistance. • As such, STM has successfully evolved its planar technology and has not felt pressured to move to trench. Given trench is a more complex technology, we see scope for planar-based devices to have a time-to-market benefit • While we see history in IGBTs as a potential success factor, we note STM's success (ie. #1 market share in auto SiC) in multiple generations of vehicles with large OEMs without having been as strong in IGBTs vs some others.	6 " → 8"(2024~)
Fuji Electric	• Gen1,2 are used for industry application. • Gen 3 is under development with 15% lower loss, maintaining high Vth level	6 " → 8" (2024~ in Tsugaru Fab)
ONSemiconductor	• ON plans to transfer from 6-inch to 8-inch SiC wafers in the future as it scales production but currently uses 6-inch wafers • ON has a wide portfolio of SiC products including SiC Diodes, MOSFETs and Modules for Automotive and Industrial applications (650V to 1700V)	6" → 8"
Mitsubishi Electric	-	6"
StarPower	StarPower's SiC modules will be used on 800V platforms for EV main inverters	6"
CR Micro	SiC MOSFET for EV OBC in sampling	6"
Silan	-	6"
Wingtech	Currently in SiC Diodes, target to have SiC MOSFET product launch in 2022	6"
Sanan	SiC MOSFET for charging piles ready for product launch; SiC MOSFET for EV under R&D and testing; better cost structure given the vertical integration of the processes	6"

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

4. Supply chain / Vertical integration

The SiC supply chain is made up of equipment, materials (wafers), semiconductor device formation (chip), and modules. Similar to the semiconductor supply chain for Si (silicon), many equipment makers are independent, but the main differences are that for SiCs, (1) the value chain for materials such as wafers has been brought in-house at semiconductor device manufacturers (or partnerships have been formed), and (2) modules after chip formation play an important role in customization.

As regards (1), scope exists to improve the stability and technology for SiC itself as opposed to Si. With respect to (2), the structure of inverters that drive EV motors have 6 modules (6 chip modules containing multiple SiC semiconductors are needed for 1 EV motor). These factors can shape the supply chain. As such, whereas the supply chain for Si is already close to being completely formed, we think each company's view on what is strategically important for securing the value chain is different with SiC (and will change going forward).

We see scope for vertical integration of both SiC wafer supply and SiC chip production to help develop a **greater degree of base material know-how**, which could help mitigate the significant technical challenges of using SiC, such as the higher defect density of the substrates (i.e. the wafers) vs Si. As such, exposure to wafer supply could help to accelerate learning curves and drive improvements in materials quality and manufacturing yields, lowering costs, which could help margins in our view. Further, having a degree of internal SiC substrate supply could mitigate any potential **risk of supply chain disruption** from unforeseeable interferences or geopolitical tensions (which could impact non-vertically integrated players disproportionately) and/or help mitigate risk of cost input inflation for device makers (by having internal supply, but also having an understanding of the cost structure of SiC wafer manufacturing when entering supply negotiations).

That said, we do **not** believe vertical supply chain integration is a necessary or sufficient condition to success in the long-run, and note that supply of *Si* wafers has become relatively commoditized and does not offer significant synergy benefits to Analog semis players today. Further, we note that **wafer-splitting technologies** (e.g. from Infineon, Soitec etc) could help hedge against a lack of vertical integration from a cost perspective. We note that Infineon recently highlighted it has qualified its wafer-splitting ahead of schedule, which could help it hedge against some of the aforementioned risks given greater scope to avoid wastage of silicon carbide wafer material.

Broadly-speaking, we note that players such as STMicro, Rohm and ON Semis have made efforts to vertically integrate some elements of the SiC supply chain, while others such as Infineon have not followed this approach (although it sought to acquire assets in this area, ultimately it did not happen). Given our view that the auto SiC market will grow to be a large and attractive opportunity, we see room for several players and a variety of business models within the market.

Exhibit 22: SiC supply chain and approach to vertical integration

	Supply Chain
Infineon	**Supplier**: SiC wafer Supply agreements with GT Advanced technologies for SiC boules, Showa Denko for extensive range of SiC materials, including epitaxy. Cree/Wolfspeed for Silicon Carbide wafers **Client**: Hyundai, XPENG, US OEM and Asian OEM,Recent Wins include two Chinese autos makers for traction inverters and on-board chargers. (We believe Infineon has several hundred industrial and around a dozen automotive SiC customers) **Partnership:** 5 triple digit million EUR automotive SiC customer wins. Hyundai, XPENG, undisclosed US OEM, undisclosed Asian OEM, two Chinese autos makers
Wolfspeed	**Client**: WOLF's materials and device customers are geographically diverse and also cover a wide range of end markets. The majority of its design-ins have been for the auto industry.
Rohm	**Supplier**:SiCrystal (acquired in 2009), Showa Denko:(Agreed on LTA for SiC epitaxial wafer in 2021) **Client**: Majority of client of Rohm are European and Chinese We estimate among the Japanese clients Honda has a relatively high share **Partnership:** Haimosic (Power module joint ventur) Geely (Strategic partnership on SiC for EV) LEADRIVE (Joint R&D center since 2020) UAES (Joint R&D center since 2020)
STMicroelectronics	**Supplier**: Agreement with Cree/Wolfspeed worth over $800mn to supply 150mm SiC bare and epitaxial wafers over next several years. **Client**: We believe Tesla is STM's main automotive SiC customer. STM serves close to 80 customers, approximately 20 carmakers, with approx. 100 programs awarded (per 2022 CMD) Important customers also include BMW, Hyundai, XPENG and Huawei
Fuji Electric	**Supplier**:Based on long term supply contracts **Client**: Toyota and Denso are their main clients
ONSemiconductor	**Supplier**:Bought SiC wafer supplier GTAT in 2021. ON is the only SiC player in the industry with end-to-end capabilities encompassing modules, devices and substrates. **Client**:NIO: Recently announced NIO chose ON's latest VE-Trac™ Direct SiC power modules for its next-generation EVs (2022) Mercedes: Announced ON's SiC modules are powering the Mercedes EQXX research prototype EV platform (2021)
Mitsubishi Electric	**Supplier**:Based on long term supply contracts **Client**: Most of domestic OEMs are their customers. Toyota/Denso portion is relatively low.
StarPower	**Supplier**:SiC module products of StarPower are equipped with SiC chips of overseas suppliers to fulfill the module delivery **Client**: Majority of clients are Chinese EV players, as StarPower's SiC modules will be used on 800V platforms for EV main inverters **Partnership:** Yutong Bus(SiC module)
CR Micro	**Supplier**: CR Micro uses SiC substrates of overseas suppliers **Client**: Its SiCs are currently used in industrial and EV charging piles, and are under testing/qualification with EV customers **Partnership:** The compnay has been investigating/collaborating with local SiC substrate and epiwafer suppliers
SG Micro	**Supplier**: SG Micro uses SiC substrates of overseas suppliers **Client**: The company completed R&D on SiC MOSFET for automotive application and the sample is under its internal testing/evaluation
Silan	**Supplier**: Silan uses SiC substrates of overseas suppliers **Client**:The company completed R&D on SiC MOSFET for automotive application and the sample is under its internal testing/evaluation **Partnership:** BASiC semiconductor (SiC MOSFET and SiC diodes)
Wingtech	**Supplier**: Wingtech uses SiC substrates of overseas suppliers **Client**: Could leverage existing clients in mid / low-voltage Si MOSFET; Bosch, Continental, Delphi are existing clients for mid / low-voltage Si MOSFET **Partnership:** King Long (SiC power devices)
Sanan	**Supplier**: Sanan's SiC production line in Hunan covers a comprehensive SiC production line from substrate growth, epiwafer, device fabrication, to IC packaging **Client**: Sanan's SiC diodes are currently in mass production for customers in power supply, solar inverter, on-board chargers, charging piles, home appliances, etc. SiC MOSFET is under qualification with industrial customers, and under R&D and testing with automotive customers **Partnership:** King Long: SiC power devices

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

5. Robust system level knowledge

While multiple players are capable of producing viable SiC devices, we see scope for differentiation among players that have robust system-level knowledge in order to meet the **very high standards required for automotive-grade safety.** We see companies such as Infineon, STMicro, Fuji Electric, Mitsubishi Electric and ON Semi as examples of companies that have good system level knowledge in our view. Furthermore, we believe that the interchangeability between IGBT and SiC devices in autos (i.e. ability to offer both) is a feature that large OEMs find attractive, due to the greater flexibility that this supports. Similarly, we see scope for large OEMs to prefer SiC device suppliers that are able to demonstrate modular and packaging competency.

6. Reliability and durability

In our view, reputation for durability and reliability may bring competitive advantages to auto semis incumbents. Reliability is a key success factor given that power semis in EV applications are exposed to **harsh environments** (e.g. extreme temperature / force etc) and need to perform without defects through the car's long lifecycle, or otherwise may lead to product recalls. We see semis players with a longstanding history in **IGBT power semis** (e.g. Infineon, ON Semi, Fuji Electric, Mitsubishi Electric) as potentially more likely to have garnered such a reputation, and also note that well-established auto semis players could benefit from existing customer relationships (although several companies are investing to challenge the incumbency). That being said, we note STMicro's success with multiple generations of vehicles with some large players without having been such a strong IGBT player within auto semis compared with some peers.

7. Access to customers that are growing

Access to customers that are growing has a direct impact on sales and is thus important for sustainable business growth (unlike consumer electronics, suppliers to automobile customers are not changed frequently). Furthermore, in our view, some of the early movers in the space who have been able to ramp up their device production volumes may be at an advantage in terms of mastering the technical aspects of Silicon Carbide, and also in **establishing their reputation** and credibility with this new more complex technology (as compared with silicon-based devices). Moreover, we also see scope to **drive scale economies.**

That being said, we also highlight evidence of **some players being able to catch-up / accelerate** their progress after a slower start. For example, we think Infineon has made significant progress of late having been slower than peers in the early stages of the technology's rollout, likely in part due to its focus on trench-based technology, which is more complicated to work with compared with planar-based technology. Further, in the longer-term, we see some risks that large customers may look to **dual-source** SiC devices in order to diversify supply chains and improve security of supply, meaning that the benefits of having access to a fast-growing customer may diminish over time.

We believe STMicroelectronics is supplying Tesla, thereby giving it credibility in the market, but also affording it scale-benefits. Amid ongoing trade tensions, it seems that Chinese EV makers are now relying on Japanese company Rohm, which has said that Europe and China will account for a large proportion of its SiC sales growth going forward. We expect Toyota Motor to take longer than European, US, and Chinese automakers to use SiC more widely, given the scope for technological advances in IGBT. Japanese power semiconductor makers such as Fuji Electric, which focuses on Japanese automakers, are working toward being able to supply both IGBT and SiC, depending on their customers' schedules.

Securing a reliable supply of SiC semiconductors is set to become a key issue for global EV makers. As SiC semiconductor makers increase their production capacity, we could start to see further news flow about customers signing long-term supply agreements, in order to secure a portion of that capacity. Note that we have already seen some announcements about long term supply at an earlier stage of the market's evolution, as described above.

8. Government support

SiC and more broadly power semiconductors are playing an increasingly important role when it comes to upgrading social infrastructure. We note moves by the Chinese government to support SiC (as detailed in the exhibit below), and believe that there could be potential for initiatives to benefit SiC in other countries, in line with recent announcements by the Chinese government to support **re-shoring of chip manufacturing,** given its critical role in a variety of supply chains. While there already exist multiple government subsidies to support R&D efforts in semis more broadly, we believe new announcements (e.g. US / European Chips Acts) may place a greater emphasis on supporting the construction of manufacturing facilities, which could support further Silicon Carbide capacity expansion. That said, we note that often it can take many years for companies to actually receive government subsidies, with our industry discussions suggesting that multiple companies already pursuing SiC capacity expansion plans ahead of subsidies being finalized (e.g. STMicro's European megafactory). Elsewhere, in the US, Wolfspeed is drawing on government subsidies to fund its capex, while in China, power device-related public projects are underway in several provinces.

More broadly, we also note the possibility for governmental regulation to accelerate the transition towards EVs in the global push for decarbonization, which could indirectly catalyze further adoption of SiC EVs in certain regions.

Exhibit 23: Power device projects supported by the Chinese government

Name	Details
深圳市国民経済・社会発展第14次5ヶ年規画 (Shenzhen 14th Five-Year Plan for Economic and Social Development)	Promotes expanding IC production and developing IGBT and SiC power devices Aim is to become self-sufficient in power devices, expanding total output in the region to roughly RMB 4 tn by 2025
江蘇省(Jiangsu Province) 市政府関于加快集成電路産業発展的意見	Build an R&D platform by 2025, including corporate technology centers, focused testing offices, technological research centers, and process testing offices, in order to boost development technologies
上海市(Shanghai) 上海臨港新片区発布集成電路産業専項規劃	Construct production lines for next-gen 6-inch and 8-inch wafers for SiC and GaN power devices, to faciliate sales for applications in 5G products, renewable energy, and electric vehicles
重慶市(Chongqing) 重慶市半導体産業発展五年工作方案	Focus on four areas of power devices, memory chips, hybrid analog/digital chips, and AI/IoT chips, and provide support for boosting wafer production capacity, and enhancing reliability of package test levels and production line technologies
山東省(Shandong Province) 関于支持八大発展戦略的財政政策的通知	Promote EV development, provide subsidies for power device production and support payments to package testing contractors
発改委(NDRC) 産業結構調整指導目録(2019年) (National Development and Reform Commission Catalogue for Guiding Industry Restructuring (2019))	Promote technological innovation in conduction drive systems, braking systems, and IGBT.XIC power devices for electric rail cars, and provide support for increased production of 750V/300A IGBT for EVs
発改委(NDRC) 中華人民共和国国民経済和車載発展第十四箇五年規劃2035年遠景目標綱要	Establish production process technology plants for power transistors such as IGBT and MOSFET, and support initiatives for developing next-generation component technologies such as GaN power devices
国務院(State Council) 中華人民共和国国民経済和車載発展第十四箇五年規劃2035年遠景目標綱要	Government to exempt taxes (for the first two years, starting from the first year profits generated) on companies focused on semiconductor design, equipment, materials, packaging, and testing software. For years 3-5, tax rate to be half the statutory 25% corporate income tax rate.

Source: Fuji Chimera Research Institute, Data compiled by Goldman Sachs Global Investment Research

We see no insurmountable show-stoppers to scaling of the auto SiC industry

Supply chain bottlenecks and need to continue scaling wafer capacity: As we described above, while the market looks set to grow rapidly, when it comes to the overall supply chain covering equipment, materials, semiconductors, and modules, in comparison to the Si based semiconductors, vertical supply chain integration and the horizontal division of labor for SiC is in its process of being established. That said, while in prior years some concerns had emerged about the capacity for SiC wafer supply—and we are monitoring whether companies can achieve output as expected at each stage of the supply chain—we note that the situation has significantly improved in the past year or two. This stems partly from public supply agreements between chip makers and wafer suppliers, and is further reinforced by recently stated intentions to ramp wafer capacity e.g. by STM and Wolfspeed. Further, as discussed above, we think wafer splitting is another potential mitigant.

At the same time, we need to keep an eye over the long term on the underlying capacity of local Chinese companies. While a relatively small amount of supply is currently destined for EVs and there does not appear to be any risk of over-supply, we will monitor potential changes over the next 10 years in their competitiveness and supply capacity. That being said, so far the most advanced technology has been demonstrated in mass production by European/US players.

Risk of slowdown in cost reductions, albeit mitigated by ongoing transition to 8-inch/trench technology: One of the key differences between Si and SiC is that the latter's manufacturing and processing stages are more complicated. For example, the very fact of having to grow crystals will tend to involve cost over and above that needed for Si wafer production. While the switch from 6-inch to 8-inch is expected to result in major cost savings, it is also likely to bring new challenges regarding the yield between wafer and semiconductor device production. In order to further narrow the cost gap between SiC and IGBT, we think SiC technological advances and cost savings will need to outpace those of IGBT. That being said, we note that further technological advances such as the move towards trench based technologies (alongside other innovations, even on planar based SiC) could potentially help with efficiency and space within the car, and thereby yield countervailing benefits to the OEM.

Upfront investment burden could be a risk to margins, albeit scale should help cost levels: We estimate that the investment/output ratio for SiC semiconductors is fairly similar to regular semiconductors, at around 1:1. However, companies are being compelled to make substantial capex in order to respond to the rapid rise in demand, and the scale of investment required means that profitability is currently relatively low for some players. When establishing vertical production lines, there could be a risk that unexpected problems could quickly impact the envisaged profit growth scenario for some market participants if extra unforeseen investment is needed. That being said, we note that Infineon has disclosed that its **automotive and industrial SiC margins are accretive to their respective segments,** and moreover that over time it could get benefits from scale effects as its further expands this revenue line. We believe this player has likely been selective on the contracts it accepts, given current shortages. On the other hand, we note that STM's margins have been improving even if we estimate they are currently below those of the group average. More broadly, within SiC, we do expect SiC device makers to benefit from higher margins when selling to industrial customers, given that the customer base is more fragmented and operates lower volumes than the autos market.

Significant technical challenges of working with SiC: Further, our industry discussions suggest that there are significant technical challenges when using SIC, such as the higher defect density of the substrates (i.e. the wafers) vs Si. Therefore, the future improvement of manufacturing processes (e.g. the transition to 8-inch to lower cost per unit) will be a further area to monitor.

SiC potentially not appropriate for all vehicle types, such as hybrids: Finally, we believe that Silicon Carbide may be more appropriate for some types of vehicle than others, which potentially could limit the applicability of the technology. We note that given SIC wafers are much more expensive than those used for IGBT, SiC may be best suited to high end cars, while IGBT better suited in others e.g. smaller city cars where cost is more important and the benefits from a range perspective (and from space saving angle) are more limited.

Implications for material makers

SiC wafers

Silicon wafers are currently the mainstream substrate material for semiconductors, and we estimate that the silicon carbide (SiC) wafer market is less than 0.1% the size of the silicon wafer market on a surface area basis (as of 2021). SiC, though, is widely viewed as a promising material, especially in high-voltage fields, including for power semiconductors used in high-voltage power sources with close to 1m VA capacity. We also see potential advantages for SiC wafers as high-voltage applications become increasingly important along with rising demand for rapid and fast charging devices. However, the extremely high cost of SiC wafers is an issue; we estimate SiC wafer ASP is more than ~15x higher than for silicon wafers. Wafer diameter also plays a key role in reducing costs, and we surmise that there are only around four companies at present capable of mass-producing 6-inch SiC wafers, and therefore that production capacity is likely to limit output in the near term.

Shin-Etsu Chemical, the world leader in silicon wafers, commented on its initiatives in respect of SiC wafers for the first time at its 3Q3/22 conference call. Company management said that while SiC could grow in high-voltage applications going forward, issues remain in terms of supply capacity and quality. Shin-Etsu said that as a result market growth could be moderate. It said it has been researching this area for some time now and crystallization was still an issue, but SiC wafers had won acceptance from processing customers and it is actively considering volume production.

SiC epitaxial wafer sales at **Showa Denko** were ¥8.5 bn in 2021, while it swung to an operating profit in this area in 3Q12/21 and generated more than ¥0.5 bn in profits in 4Q. It has a global share of around 30% in SiC epitaxial wafers in terms of sales and production capacity of 9,000 wafers/month. It has multi-year, long-term supply agreements with Toshiba subsidiary Toshiba Electronic Devices & Storage Corporation, Rohm, and Infineon. Showa Denko's technological strength lies in its ability to uniformly add nitrogen and lower surface defects.

Photoresists, CMP slurry, and SiC focus rings

We think other materials that could attract attention as having the potential to impact SiC expansion are photoresists and CMP slurry. KrF and i-line photoresists are mainly used in power semiconductors, but SiC in particular will require thick-film resists for high resistance because processing with higher energy is necessary. **Tokyo Ohka Kogyo** has the leading global share in i-line and KrF photoresists and a broad product lineup, and will therefore play an important role in SiC power semiconductor market expansion, in our view.

We think the CMP slurry field, in which **Fujimi** is active, will also attract attention. SiC is difficult to process because it has very strong crystal bonds and is chemically and physically stable. The time it takes for polishing is an issue. Currently, high-purity colloidal silica and high-purity alumina are used as polishing materials, but the development of other materials is progressing, and we see trends in this space as a focal point.

Tokai Carbon has an approximate 80% global share (sales of around ¥26 bn) in SiC focus rings that are used for fixing silicon wafers in the etching process. SiC focus rings are not used in all etching processes for silicon wafers, but in the past two years sales have grown by close to 30% annually due to multilayering and process node shrink in semiconductors as a whole. We think growth will outstrip the overall semiconductor market going forward.

Implications for equipment makers

Since the start of 2022, growth expectations for the SiC market have gained momentum, with major SiC-related makers Infineon, STMicroelectronics, and Rohm announcing or raising capex plans, and capex is currently accelerating. The SiC market is in a phase of rapid expansion, prompting companies to increase production capacity in order to maintain or increase market share, which is likely to have knock-on benefits for makers of related equipment.

We estimate that the EV SiC market will grow to US$3.3bn in 2025 (around US$4.9bn including industrial applications) from US$0.9bn in 2021 (around US$1.15 bn including industrial applications) and that in step with this growth, aggregate capex by related makers could reach ¥600-800 bn.

Exhibit 24: Disco and Ulvac have relatively high exposure
Weighting of SiC-related sales across our SPE coverage

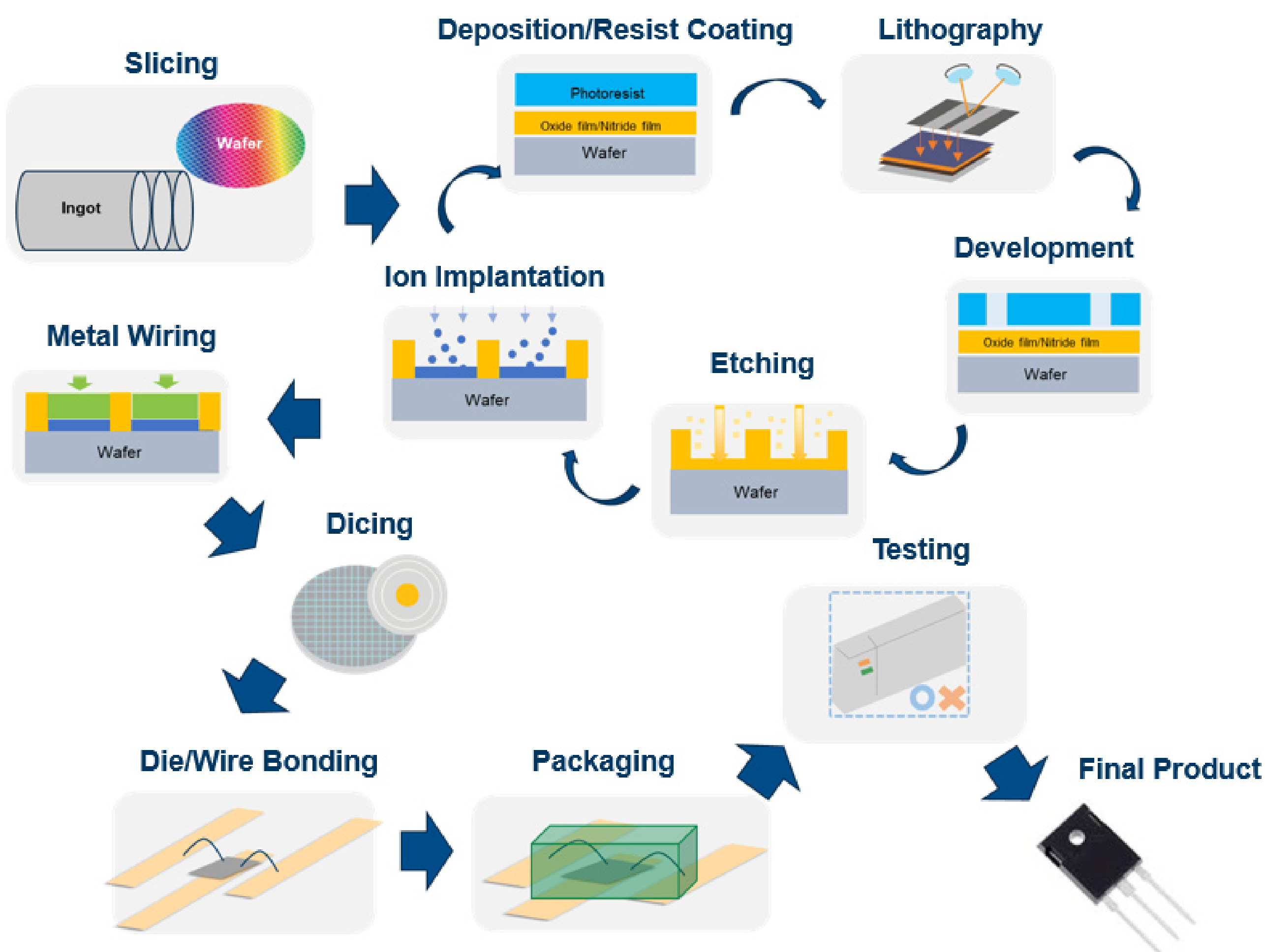
	SiC-related revenue exposure (FY21 basis)	Related products
DISCO	5-6%	Dicer, grinder and consumables
Ulvac	3-4%	Ion implantation, deposition (sputtering) equipment
Lasertec	2-3%	SiC wafer inspection tools
Tokyo Seimitsu	2-3%	High-rigid grinders
SCREEN HD	1-2%	Cleaning tools
Tokyo Electron	<1%	SiC epitaxial deposition systems
Advantest	0%	**Aims to enter the power device test market (including SiC) thru recently-announced acquisition of CREA
HOYA	0%	
JEOL	0%	

GS estimate for SiC-related revenue exposure.

Source: Company data, Goldman Sachs Global Investment Research

The semiconductor chip production process involves taking an ingot made from Si or SiC crystals and slicing it into thin circular wafers. Circuits are created on the surface of the wafers, which are sliced and diced into chips and incorporated into end devices. This process is the same regardless of whether the wafers are made of Si or SiC. Given the different nature of these materials, however, differences do emerge with each piece of equipment used in the production process. Below we look at exposure to the SiC market across our coverage (excluding HOYA and JEOL, where we estimate exposure is minimal).

Exhibit 25: Overall manufacturing process is essentially the same for both Si and SiC, but differences can emerge with certain production equipment due to the different nature of the materials
Manufacturing process for standard semiconductor chips



Source: Company data, Goldman Sachs Global Investment Research

Disco

In Disco's new equipment sales, power semiconductors account for around 15% of dicer sales (FY3/22) and 20% of grinder sales. This includes both Si- and SiC-based power semiconductors. We estimate that SiC-related products account for 5% of Disco's total sales (SiC-related sales are included in consumables and other equipment). SiC is a much harder material than Si, and this creates more opportunities for value-adding using dicers, which cut chips into smaller pieces, and grinders, which reduce wafer thickness. SiC increases the need for dicing blades, grinding wheels, and other consumables by up to 10X, which we expect to translate into higher consumable sales per system. Disco supplies equipment that can substantially improve the productivity of the SiC wafer production process by using lasers to cut the wafers. This has translated into a high share of sales to SiC wafer makers and device makers.

Ulvac

Based on our FY6/22 estimates, orders related to equipment for power semiconductors account for just under 7% of companywide orders and around 6% of companywide sales, divided roughly evenly between sputtering systems for Si power semiconductors, mainly for domestic customers, and ion implanters for SiC power semiconductors, mainly for Chinese customers (we think amounting to several hundred million yen per system in each case). Unlike with logic semiconductors, the process for making Si power semiconductors involves the formation of electrodes on the underside of the semiconductor as well, and Ulvac has a large share of the market for the sputtering systems used in this process. In ion implanters for SiC applications, dedicated equipment is needed because high-temperature implantation is required with SiC to prevent wafer crystal defects, unlike with Si. In China, Ulvac has a market share of roughly 70% for this kind of equipment, and the company remains well positioned thanks to its first-mover advantage and its reputation for reliability given its track record of supplying to Japanese and South Korean companies. Ulvac's main competitors in both sputtering systems and ion implanters are Applied Materials and Nissin Electric, although it largely serves a different customer base to these two companies.

Tokyo Electron

Tokyo Electron has a broad product lineup among global SPE makers, and in the dedicated SiC product field it makes deposition equipment that is used to form epitaxial films on the surface of SiC wafers (high-quality single crystal films with few defects). Higher temperatures are required compared with in the formation of epitaxial films on Si wafers, which means dedicated equipment is needed. Tokyo Electron began selling these products in 2010, and its systems are priced at around the ¥0.5-¥1.0 bn range, and we estimate that sales account for less than 1% of the company's overall sales of new equipment. However, its global market share in deposition equipment for SiC semiconductors is above 50%, and most of its customers are located in Europe. Competitors include Nuflare Technology and Aixtron. Nuflare has supplied a relatively large number of systems to customers in Japan, while Aixtron also handles MOCVD systems for GaN devices, as well as products for SiC.

Lasertec

Lasertec's SiC-related offerings comprise inspection equipment for SiC wafers, in which it dominates with a market share of approximately 90% (US-based KLA is a competitor). Systems sell for around ¥150 mn-¥200 mn, and the market to date had been worth around ¥2 bn per year. However, rising capex at SiC wafer makers is now driving market expansion, and Lasertec's orders have grown to around ¥6-8 bn per year. According to the company, throughput on its systems is around 10 wafers per hour. We think SiC wafer inspection systems are unlikely to become a major driver of overall earnings for Lasertec, given the scale of its EUV mask inspection equipment sales. However, as SiC semiconductors are compound semiconductors, completely eliminating crystal defects will be difficult, and we therefore expect demand for SiC wafer inspection equipment to increase in proportion with wafer production volume.

Tokyo Seimitsu

Tokyo Seimitsu's SiC-related product lineup includes high-rigidity grinders for SiC wafer and device makers. The company said at its recent earnings briefing that it is seeing a constant stream of orders for around three systems per month, and we estimate that its SiC-related sales come to ¥2 bn-¥3 bn annually, including consumables (consumables tend to be used up more rapidly with SiC than Si because SiC is a harder material, so sales of consumables for installed systems tend to rise readily). The company does not disclose who it sells its SiC high-rigidity grinders to, but we believe that it sells them mainly to Chinese makers. If the migration to larger diameter SiC wafers (from 6-inch to 8-inch wafers) progresses, new investment will be required, which we think could give rise to new equipment demand.

SCREEN Holdings

At SCREEN Holdings, a leading cleaning equipment maker, we estimate that sales of products for power semiconductors (both Si and SiC) came to nearly ¥20 bn in FY3/22, accounting for around 5% of companywide sales. The company supplies SiC power semiconductor cleaning equipment mainly to customers in Europe. Wafers up to 6 inches in diameter are the mainstream in SiC wafers currently, and because these are smaller than 8-12-inch Si wafers, the cost of cleaning systems tend to be slightly lower than those for Si wafers. We see the increased spread of SiC having limited direct benefits for SCREEN Holdings because we believe that the switchover to SiC will not significantly change cleaning needs.

Advantest

Currently, the main arena of competition for Advantest, a leader in the tester field, is leading-edge SoC and memory testers. Up to this time, the company has not made testers for high-voltage power semiconductors (which require dedicated testers compatible with high-temperature processes). However, Advantest plans to expand its lineup of testers for power semiconductors, including SiC and other compound semiconductors, with the acquisition of Collaudi Elettronici Automatizzati, announced on June 1 as a foothold. The TAM for high-voltage power semiconductor testers is currently less than 1% of the US$4.3 bn SoC tester market (CY2021), but Advantest expects this market to roughly triple by 2030 and anticipates synergies achieved by leveraging its existing broad customer base and sales network.

GS SUSTAIN: SiC can drive Green Capex goals, increase ESG fund ownership

This section is authored by the GS SUSTAIN team, as attributed in the author list.

Green Capex a secular theme driving semiconductors and SiC revenue growth

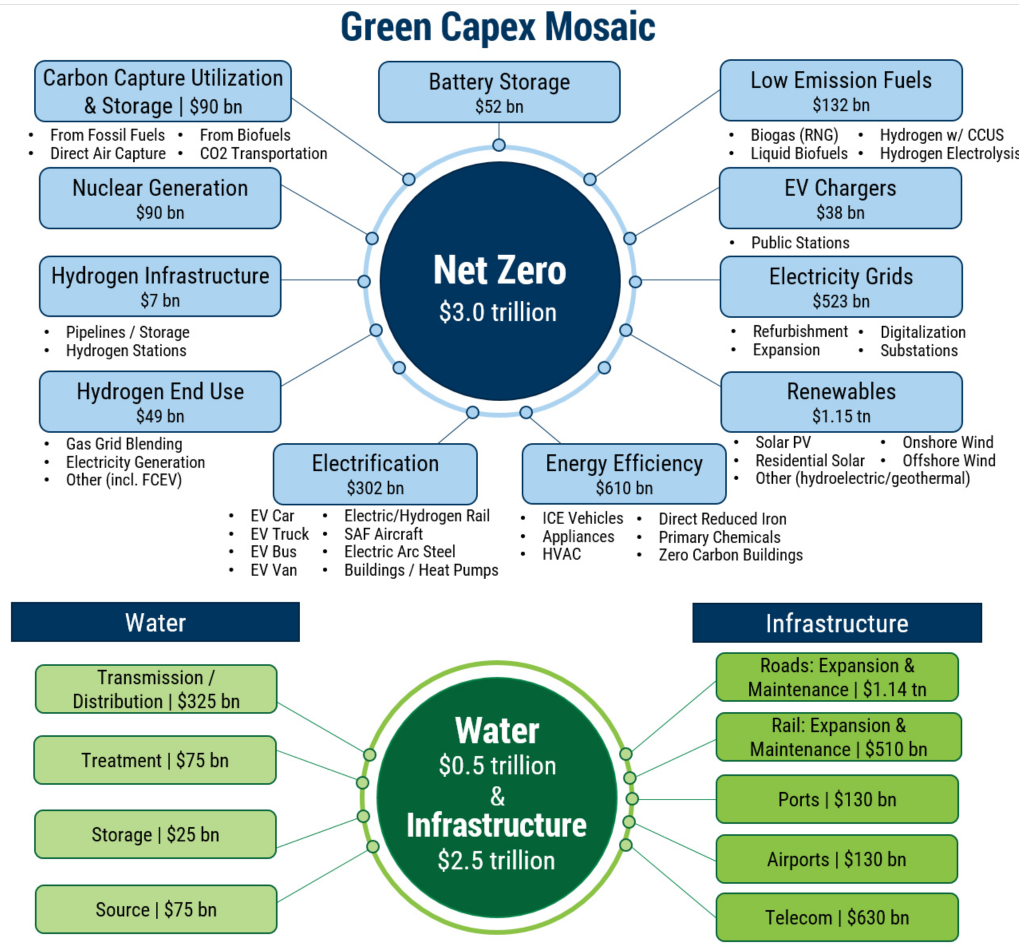
We continue to believe Green Capex will be the multi-year secular theme driving the next wave of infrastructure as focus rises to decarbonize the world and meet Clean Water and infrastructure goals. As detailed in our Green Capex: Making Infrastructure Happen report, we see the need for $6.0 trillion in annual investments on average in the 2020s on the path to Decarbonization, Clean Water and Infrastructure goals — this represents a $2.8 tn increase vs. the 2016-2020 historical average of $3.2 tn. In our view, this will require an all-in approach embracing multiple technology verticals (see Exhibit 26). As discussed earlier, SiC can enable higher efficiency and greater power throughput in Semiconductor devices, and thus could potentially benefit multiple verticals within the Green Capex mosaic — **Electrification**, **Energy Efficiency** and **Electricity Grids** (in particular, **Digitalization**) as examples. Given its role in power conversion and power management devices, SiC could be instrumental in unlocking Green Capex spending in **Renewables** as well.

Semiconductors are key Greenablers, where we see rising need for investment and expect greater Sustainability investor focus. We expect rising investor focus on the Greenablers (Green enablers) — i.e., sectors in which investments are needed more urgently to avoid supply chain bottlenecks given long project lead-times. See Exhibit 27 for more details. While not exclusive, in our Green Capex report we identify four sectors that are needed/critical in the Green Capex mosaic:

- **Semiconductors** — due to their role in enabling electrification, digitalization and factory automation;
- **Electricity Transmission** — critical in ensuring that greater renewable build-outs do not impact reliability of power networks, as well as in enabling access to power and electrification to underserved regions and communities;
- **Copper/Aluminum** — play a critical role in enabling electrification and energy efficiency across the Green Capex mosaic;
- **Cybersecurity** — critical in insulating from cyber-threats as electrification/digitalization trends increase the number of vulnerability points in a network.

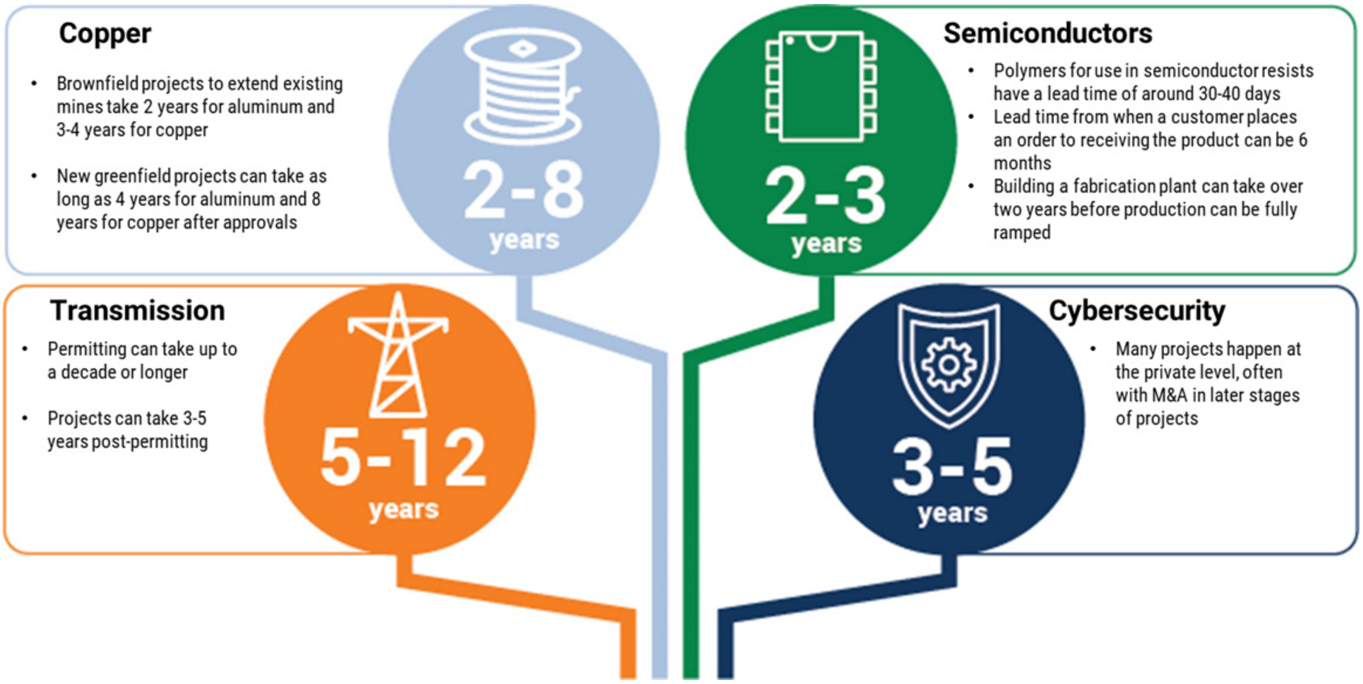
Exhibit 26: The Net Zero, Infrastructure and Clean Water mosaic

Critical technologies/focus areas and annual investment in the 2020s to achieve Net Zero, Infrastructure and Clean Water needs



Source: IEA, McKinsey, OECD, Company data, Goldman Sachs Global Investment Research

Exhibit 27: We estimate the lead time for Greenablers projects is 2-12 years, which will likely add an urgency/greater focus on investment levels for Semiconductors, Copper/Aluminum, Electricity Transmission and Cybersecurity in particular



Source: Goldman Sachs Global Investment Research

Role of semiconductors in emissions reduction is underappreciated

Semiconductors have helped improve energy efficiency and avoid emissions. In the report, we estimated that for every unit of emissions that the broader Semiconductor industry generates on a Scope 1-2 basis, it has helped avoid 5x more emissions for end-customers.

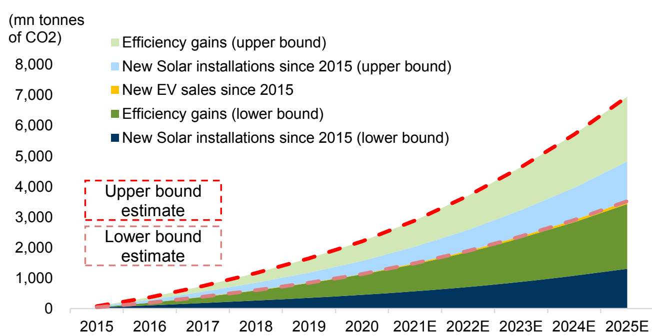
Power Semis and SiC could help drive next leg of innovation. We noted early signs of a potential deceleration in energy efficiency gains in semiconductors (especially in logic devices). This has added some urgency to broader industry discussions to find the next leg of innovation to drive efficiencies. Strategies include efficiency gains via material innovations (e.g. advancements in SiC based power semiconductors) and innovations in design and packaging (e.g. FinFET/stacked 3D transistors in logic and memory devices). Our Semiconductor analysts believe that SiC will drive the next leg of efficiency growth in power semiconductors, which will play a critical role in reducing global energy consumption over time, leading to greater avoided emissions for consumers.

While we have not performed a similar analysis focused on the subset of power semiconductors, we note that according to the CDP (formerly known as the Carbon Disclosure Project), power semiconductor majors such as Infineon reported greater net environmental benefits (~40x) than their semiconductor peers. While this may be driven by power semiconductors' greater exposure to clean technology products compared to other semiconductor segments, we caveat that methodologies to estimate avoided emissions are not always consistent in corporate disclosures so there may be limitations in drawing direct apples-to-apples comparisons between companies.

Investors will continue to care about operational emissions, even as we see room for greater credit for emissions avoidance. We see continued focus by investors and governments on operational emissions, both in absolute terms and in terms of emissions intensity, driven by Net Zero initiatives. This is in spite of relatively few emissions-limiting regulations for the sector, given rising adoption of Net Zero initiatives (e.g., UN PRI-convened Net Zero Asset Owner Alliance). As highlighted in our EMEA Energy team's Carbonomics report, semiconductor companies need to reduce carbon intensity by 35% by 2030 as part of our scenario for global Net Zero by 2060 at a <2.0°C temperature rise. Operational emissions of perfluorocarbons (PFCs) will also remain in focus given their global warming potential is >5,000 times that of CO2 according to IPCC's Sixth Assessment Report. Overall, we believe the benefits from emissions avoided will outweigh environmental concerns over the operational footprint. Currently, investors do not appear to be differentiating on the basis of our operational Environmental and Social score and appear to be prioritizing product impact based on fund weighting positions discussed below.

Exhibit 28: Semiconductors are significant enablers of climate change mitigation, as they enable energy efficiency of end products and the proliferation of clean technologies

CO2 avoided through new clean technology installations and efficiency gains, including LEDs and solar panels (base year of 2015)



Note: 1) Upper/lower bound avoidance estimates assume efficiency gains and solar installations displace 100% coal/100% gas. 2) Efficiency gains only include those from lamps, data centers, PCs and smartphones.

Source: IEA, BNEF, World Bank, Goldman Sachs Global Investment Research

Corporate returns, not just Green Capex, important for Sustainability investors; Semis stand out favorably

With price inflation a necessity for some sectors and cost inflation a risk for other sectors within the Green Capex mosaic, we believe investors' focus on corporate returns and their forward momentum will be elevated — particularly as the market focuses more closely on profitability across sectors as a result of rising input costs. We continue to see opportunities in the Green Capex supply chain, particularly among those sectors for which returns are forecast to be resilient. We detail in our Green Capex: Greenflation, Returns and Opportunity report that **Semiconductors** is one of the two sectors for which corporate returns expectations: (1) have not degraded vs. prior reports, (2) are still above the all-sectors average, ex. Financials and Real Estate, and (3) are forecast to rise in 2023E or 2024E vs. 2022E.

Why Sustainability investors could raise weightings and 'CARE' about Power Semis

Much of our client discussion around companies investing in new sustainable use case revenue streams centers around what will it take for Sustainability investors to afford credit and raise their weighting. In our view, investor will begin to "CARE" about Green Capex initiatives based on whether the company can demonstrate:

- **C**ore competencies in that area
- **A**vailable capital to deploy
- **R**eturns at the corporate level that are/remain favorable
- **E**xecution to meet goals and raise revenue contribution from Green initiatives that are material.

Timing is key, with a revenue inflection for Power Semis as highlighted by our analysts. Based on our analyst team's analysis, we believe Sustainability investors could begin to afford greater credit to power semiconductors based on our CARE criteria, with the catalyst being SiC's greater materiality to revenue/earnings driven by electrification demand that leads to greater confidence in Execution. We note companies levered to Green Capex that have seen the greatest rise in consensus capex increases have lagged, which could represent a risk. However, we believe this is offset by the rising revenue CAGR visibility highlighted by our analysts.

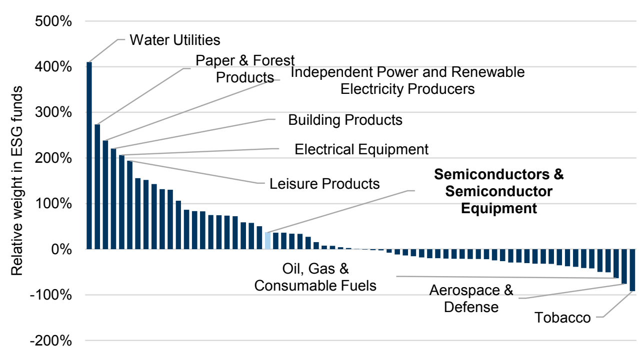
Power Semis have seen rising ownership over the last year while Semis have been flattish. We note the relative ownership in ESG funds has shifted towards greater overweight positions — on a median basis — for Power Semiconductors since 2021 and continuing into 2022 vs. data points from 2020, with the broader Semiconductor universe stable around more modest overweight positions (on a median basis) since early 2021. See Exhibit 31 for more details.

What can drive greater Power Semis ESG fund ownership?

1. Potential for power semis to have growing revenue alignment with UN SDGs and ESG regulatory frameworks defining sustainable business activities, such as the EU Taxonomy.
2. Greater investor appreciation of SiC's growing role in driving Green Capex goals as further energy efficiency gains are delivered.
3. Secular demand tailwinds for power semiconductors as the urgency to electrify diffuses up the value chain and the need to deploy green solutions continues to expand.

Exhibit 29: Semiconductors are modestly overweight in ESG funds; we see room for greater weightings with greater appreciation for Greenablers with attractive corporate returns

Relative weight ESG fund holdings vs MSCI ACWI by GICS 3 sub-sector (as of Mar 2022)

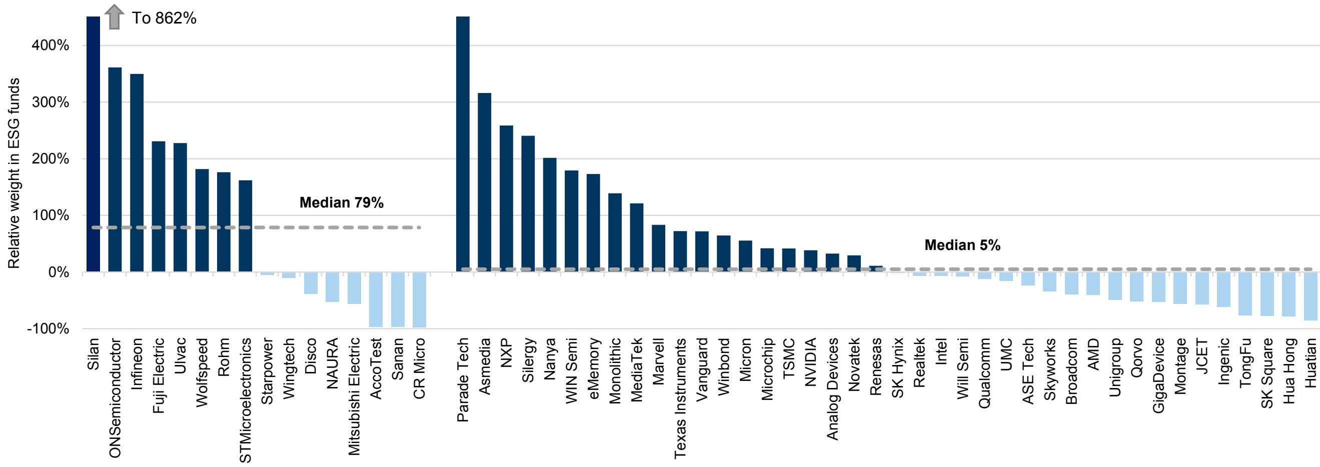


Note: The chart excludes Diversified Consumer Services, which is >1,000% relatively overweight.

Source: Morningstar, Thomson Reuters Eikon, Goldman Sachs Global Investment Research

Exhibit 30: By segment, power semiconductors that we highlight in the report tend to be more overweight in ESG funds compared to the broader semiconductor universe

Weight in ESG funds relative to weightings in the MSCI ACWI by company

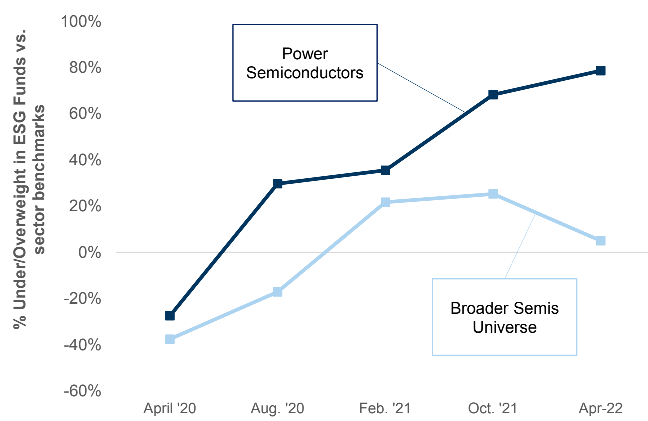


Note: We include the power semiconductor companies featured in this report and GICS 4 Semiconductor companies in the MSCI ACWI. We excluded selected Semiconductor Equipment and solar pure-play companies.

Source: Morningstar, Thomson Reuters Eikon, Goldman Sachs Global Investment Research

Exhibit 31: Since 2020, Power Semis have gained a greater overweight percentage vs. sector benchmarks than the broader Semis universe — on a median basis

Profile of % under/overweight for Power Semis and the broader Semis universe over time, based on 5 data points: April 2020, August 2020, February 2021, October 2021 and March 2022



Data points refer to GS SUSTAIN's ESG Fund Holdings data pulls and related analyses

Source: Morningstar, Thomson Reuters Eikon, Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Daiki Takayama, Alexander Duval, Allen Chang, Jin Guo, Brian Lee, CFA, Toshiya Hari, Brian Singer, CFA, Sharmini Chetwode, Ph.D., Shuhei Nakamura, Atsushi Ikeda, Ryo Harada, Ayaka Misonou, Bruce Lu, Lynn Luo, Verena Jeng, Mitsuhiro Icho, Enrico Chinello, Ph.D., Keebum Kim and Shin Ehara, 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.

Unless otherwise stated, the individuals listed on the cover page of this report are analysts in Goldman Sachs' Global Investment Research division.

GS Factor Profile

The Goldman Sachs Factor Profile provides investment context for a stock by comparing key attributes to the market (i.e. our coverage universe) and its sector peers. The four key attributes depicted are: Growth, Financial Returns, Multiple (e.g. valuation) and Integrated (a composite of Growth, Financial Returns and Multiple). Growth, Financial Returns and Multiple are calculated by using normalized ranks for specific metrics for each stock. The normalized ranks for the metrics are then averaged and converted into percentiles for the relevant attribute. The precise calculation of each metric may vary depending on the fiscal year, industry and region, but the standard approach is as follows:

Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

Financial Returns and Multiple use the Goldman Sachs analyst forecasts at the fiscal year-end at least three quarters in the future. Growth uses inputs for the fiscal year at least seven quarters in the future compared with the year at least three quarters in the future (on a per-share basis for all metrics).

For a more detailed description of how we calculate the GS Factor Profile, please contact your GS representative.

M&A Rank

Across our global coverage, we examine stocks using an M&A framework, considering both qualitative factors and quantitative factors (which may vary across sectors and regions) to incorporate the potential that certain companies could be acquired. We then assign a M&A rank as a means of scoring companies under our rated coverage from 1 to 3, with 1 representing high (30%-50%) probability of the company becoming an acquisition target, 2 representing medium (15%-30%) probability and 3 representing low (0%-15%) probability. For companies ranked 1 or 2, in line with our standard departmental guidelines we incorporate an M&A component into our target price. M&A rank of 3 is considered immaterial and therefore does not factor into our price target, and may or may not be discussed in research.

Quantum

Quantum is Goldman Sachs' proprietary database providing access to detailed financial statement histories, forecasts and ratios. It can be used for in-depth analysis of a single company, or to make comparisons between companies in different sectors and markets.

Disclosures

Logo disclosure

Third party brands used in this report are the property of their respective owners, and are used here for informational purposes only. The use of such brands should not be viewed as an endorsement, affiliation or sponsorship by or for Goldman Sachs or any of its products/services.

Company-specific regulatory disclosures

Compendium report: please see disclosures at https://www.gs.com/research/hedge.html. Disclosures applicable to the companies included in this compendium can be found in the latest relevant published research

Distribution of ratings/investment banking relationships

Goldman Sachs Investment Research global Equity coverage universe

	Rating Distribution			Investment Banking Relationships		
	Buy	Hold	Sell	Buy	Hold	Sell
Global	50%	35%	15%	65%	57%	45%

As of April 1, 2022, Goldman Sachs Global Investment Research had investment ratings on 3,143 equity securities. Goldman Sachs assigns stocks as Buys and Sells on various regional Investment Lists; stocks not so assigned are deemed Neutral. Such assignments equate to Buy, Hold and Sell for the purposes of the above disclosure required by the FINRA Rules. See 'Ratings, Coverage universe and related definitions' below. The Investment Banking Relationships chart reflects the percentage of subject companies within each rating category for whom Goldman Sachs has provided investment banking services within the previous twelve months.

Price target and rating history chart(s)

Compendium report: please see disclosures at https://www.gs.com/research/hedge.html. Disclosures applicable to the companies included in this compendium can be found in the latest relevant published research

Regulatory disclosures

Disclosures required by United States laws and regulations

See company-specific regulatory disclosures above for any of the following disclosures required as to companies referred to in this report: manager or co-manager in a pending transaction; 1% or other ownership; compensation for certain services; types of client relationships; managed/co-managed public offerings in prior periods; directorships; for equity securities, market making and/or specialist role. Goldman Sachs trades or may trade as a principal in debt securities (or in related derivatives) of issuers discussed in this report.

The following are additional required disclosures: **Ownership and material conflicts of interest:** Goldman Sachs policy prohibits its analysts, professionals reporting to analysts and members of their households from owning securities of any company in the analyst's area of coverage. **Analyst compensation:** Analysts are paid in part based on the profitability of Goldman Sachs, which includes investment banking revenues. **Analyst as officer or director:** Goldman Sachs policy generally prohibits its analysts, persons reporting to analysts or members of their households from serving as an officer, director or advisor of any company in the analyst's area of coverage. **Non-U.S. Analysts:** Non-U.S. analysts may not be associated persons of Goldman Sachs & Co. LLC and therefore may not be subject to FINRA Rule 2241 or FINRA Rule 2242 restrictions on communications with subject company, public appearances and trading securities held by the analysts.

Distribution of ratings: See the distribution of ratings disclosure above. **Price chart:** See the price chart, with changes of ratings and price targets in prior periods, above, or, if electronic format or if with respect to multiple companies which are the subject of this report, on the Goldman Sachs website at https://www.gs.com/research/hedge.html.

Additional disclosures required under the laws and regulations of jurisdictions other than the United States

The following disclosures are those required by the jurisdiction indicated, except to the extent already made above pursuant to United States laws and regulations. **Australia:** Goldman Sachs Australia Pty Ltd and its affiliates are not authorised deposit-taking institutions (as that term is defined in the Banking Act 1959 (Cth)) in Australia and do not provide banking services, nor carry on a banking business, in Australia. This research, and any access to it, is intended only for "wholesale clients" within the meaning of the Australian Corporations Act, unless otherwise agreed by Goldman Sachs. In producing research reports, members of the Global Investment Research Division of Goldman Sachs Australia may attend site visits and other meetings hosted by the companies and other entities which are the subject of its research reports. In some instances the costs of such site visits or meetings may be met in part or in whole by the issuers concerned if Goldman Sachs Australia considers it is appropriate and reasonable in the specific circumstances relating to the site visit or meeting. To the extent that the contents of this document contains any financial product advice, it is general advice only and has been prepared by Goldman Sachs without taking into account a client's objectives, financial situation or needs. A client should, before acting on any such advice, consider the appropriateness of the advice having regard to the client's own objectives, financial situation and needs. A copy of certain Goldman Sachs Australia and New Zealand disclosure of interests and a copy of Goldman Sachs' Australian Sell-Side Research Independence Policy Statement are available at: https://www.goldmansachs.com/disclosures/australia-new-zealand/index.html. **Brazil:** Disclosure information in relation to CVM Resolution n. 20 is available at https://www.gs.com/worldwide/brazil/area/gir/index.html. Where applicable, the Brazil-registered analyst primarily responsible for the content of this research report, as defined in Article 20 of CVM Resolution n. 20, is the first author named at the beginning of this report, unless indicated otherwise at the end of the text. **Canada:** This information is being provided to you for information purposes only and is not, and under no circumstances should be construed as, an advertisement, offering or solicitation by Goldman Sachs & Co. LLC for purchasers of securities in Canada to trade in any Canadian security. Goldman Sachs & Co. LLC is not registered as a dealer in any jurisdiction in Canada under applicable Canadian securities laws and generally is not permitted to trade in Canadian securities and may be prohibited from selling certain securities and products in certain jurisdictions in Canada. If you wish to trade in any Canadian securities or other products in Canada please contact Goldman Sachs Canada Inc., an affiliate of The Goldman Sachs Group Inc., or another registered Canadian dealer. **Hong Kong:** Further information on the securities of covered companies referred to in this research may be obtained on request from Goldman Sachs (Asia) L.L.C. **India:** Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (India) Securities Private Limited, Research Analyst - SEBI Registration Number INH000001493, 951-A, Rational House, Appasaheb Marathe Marg, Prabhadevi, Mumbai 400 025, India, Corporate Identity Number U74140MH2006FTC160634, Phone +91 22 6616 9000, Fax +91 22 6616 9001. Goldman Sachs may beneficially own 1% or more of the securities (as such term is defined in clause 2 (h) the Indian Securities Contracts (Regulation) Act, 1956) of the subject company or companies referred to in this research report. **Japan:** See below. **Korea:** This research, and any access to it, is intended only for "professional investors" within the meaning of the Financial Services and Capital Markets Act, unless otherwise agreed by Goldman Sachs. Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (Asia) L.L.C., Seoul Branch. **New Zealand:** Goldman Sachs New Zealand Limited and its affiliates are neither "registered banks" nor "deposit takers" (as defined in the Reserve Bank of New Zealand Act 1989) in New Zealand. This research, and any access to it, is intended for "wholesale clients" (as defined in the Financial Advisers Act 2008) unless otherwise agreed by Goldman Sachs. A copy of certain Goldman Sachs Australia and New Zealand disclosure of interests is available at: https://www.goldmansachs.com/disclosures/australia-new-zealand/index.html. **Russia:** Research reports distributed in the Russian Federation are not advertising as defined in the Russian legislation, but are information and analysis not having product promotion as their main purpose and do not provide appraisal within the meaning of the Russian legislation on appraisal activity. Research reports do not constitute a personalized investment recommendation as defined in Russian laws and regulations, are not addressed to a specific client, and are prepared without analyzing the financial circumstances, investment profiles or risk profiles of clients. Goldman Sachs assumes no responsibility for any investment decisions that may be taken by a client or any other person based on this research report. **Singapore:** Goldman Sachs (Singapore) Pte. (Company Number: 198602165W), which is regulated by the Monetary Authority of Singapore, accepts legal responsibility for this research, and should be contacted with respect to any matters arising from, or in connection with, this research. **Taiwan:** This material is for reference only and must not be reprinted without permission. Investors should carefully consider their own investment risk. Investment results are the responsibility of the individual investor. **United Kingdom:** Persons who would be categorized as retail clients in the United Kingdom, as such term is defined in the rules of the Financial Conduct Authority, should read this research in conjunction with prior Goldman Sachs research on the covered companies referred to herein and should refer to the risk warnings that have been sent to them by Goldman Sachs International. A copy of these risks warnings, and a glossary of certain financial terms used in this report, are available from Goldman Sachs International on request.

European Union and United Kingdom: Disclosure information in relation to Article 6 (2) of the European Commission Delegated Regulation (EU) (2016/958) supplementing Regulation (EU) No 596/2014 of the European Parliament and of the Council (including as that Delegated Regulation is implemented into United Kingdom domestic law and regulation following the United Kingdom's departure from the European Union and the European Economic Area) with regard to regulatory technical standards for the technical arrangements for objective presentation of investment recommendations or other information recommending or suggesting an investment strategy and for disclosure of particular interests or indications of conflicts of interest is available at https://www.gs.com/disclosures/europeanpolicy.html which states the European Policy for Managing Conflicts of Interest in Connection with Investment Research.

Japan: Goldman Sachs Japan Co., Ltd. is a Financial Instrument Dealer registered with the Kanto Financial Bureau under registration number Kinsho 69, and a member of Japan Securities Dealers Association, Financial Futures Association of Japan and Type II Financial Instruments Firms Association. Sales and purchase of equities are subject to commission pre-determined with clients plus consumption tax. See company-specific disclosures as to any applicable disclosures required by Japanese stock exchanges, the Japanese Securities Dealers Association or the Japanese Securities Finance Company.

Ratings, coverage universe and related definitions

Buy (B), Neutral (N), Sell (S) Analysts recommend stocks as Buys or Sells for inclusion on various regional Investment Lists. Being assigned a Buy or Sell on an Investment List is determined by a stock's total return potential relative to its coverage universe. Any stock not assigned as a Buy or a Sell on an Investment List with an active rating (i.e., a stock that is not Rating Suspended, Not Rated, Coverage Suspended or Not Covered), is deemed Neutral. Each region's Investment Review Committee manages Regional Conviction lists, which represent investment recommendations focused on the size of the total return potential and/or the likelihood of the realization of the return across their respective areas of coverage. The addition or removal of stocks from such Conviction lists do not represent a change in the analysts' investment rating for such stocks.

Total return potential represents the upside or downside differential between the current share price and the price target, including all paid or anticipated dividends, expected during the time horizon associated with the price target. Price targets are required for all covered stocks. The total return potential, price target and associated time horizon are stated in each report adding or reiterating an Investment List membership.

Coverage Universe: A list of all stocks in each coverage universe is available by primary analyst, stock and coverage universe at https://www.gs.com/research/hedge.html.

Not Rated (NR). The investment rating, target price and earnings estimates (where relevant) have been suspended pursuant to Goldman Sachs policy when Goldman Sachs is acting in an advisory capacity in a merger or in a strategic transaction involving this company, when there are legal, regulatory or policy constraints due to Goldman Sachs' involvement in a transaction, and in certain other circumstances. **Rating Suspended (RS).** Goldman Sachs Research has suspended the investment rating and price target for this stock, because there is not a sufficient fundamental basis for determining an investment rating or target price. The previous investment rating and target price, if any, are no longer in effect for this stock and should not be relied upon. **Coverage Suspended (CS).** Goldman Sachs has suspended coverage of this company. **Not Covered (NC).** Goldman Sachs does not cover this company. **Not Available or Not Applicable (NA).** The information is not available for display or is not applicable. **Not Meaningful (NM).** The information is not meaningful and is therefore excluded.

Global product; distributing entities

The Global Investment Research Division of Goldman Sachs produces and distributes research products for clients of Goldman Sachs on a global basis. Analysts based in Goldman Sachs offices around the world produce research on industries and companies, and research on macroeconomics, currencies, commodities and portfolio strategy. This research is disseminated in Australia by Goldman Sachs Australia Pty Ltd (ABN 21 006 797 897); in Brazil by Goldman Sachs do Brasil Corretora de Títulos e Valores Mobiliários S.A.; Public Communication Channel Goldman Sachs Brazil: 0800 727 5764 and / or contatogoldmanbrasil@gs.com. Available Weekdays (except holidays), from 9am to 6pm. Canal de Comunicação com o Público Goldman Sachs Brasil: 0800 727 5764 e/ou contatogoldmanbrasil@gs.com. Horário de funcionamento: segunda-feira à sexta-feira (exceto feriados), das 9h às 18h; in Canada by Goldman Sachs & Co. LLC; in Hong Kong by Goldman Sachs (Asia) L.L.C.; in India by Goldman Sachs (India) Securities Private Ltd.; in Japan by Goldman Sachs Japan Co., Ltd.; in the Republic of Korea by Goldman Sachs (Asia) L.L.C., Seoul Branch; in New Zealand by Goldman Sachs New Zealand Limited; in Russia by OOO Goldman Sachs; in Singapore by Goldman Sachs (Singapore) Pte. (Company Number: 198602165W); and in the United States of America by Goldman Sachs & Co. LLC. Goldman Sachs International has approved this research in connection with its distribution in the United Kingdom.

Effective from the date of the United Kingdom's departure from the European Union and the European Economic Area ("Brexit Day") the following information with respect to distributing entities will apply:

Goldman Sachs International ("GSI"), authorised by the Prudential Regulation Authority ("PRA") and regulated by the Financial Conduct Authority ("FCA") and the PRA, has approved this research in connection with its distribution in the United Kingdom.

European Economic Area: GSI, authorised by the PRA and regulated by the FCA and the PRA, disseminates research in the following jurisdictions within the European Economic Area: the Grand Duchy of Luxembourg, Italy, the Kingdom of Belgium, the Kingdom of Denmark, the Kingdom of Norway, the Republic of Finland, the Republic of Cyprus and the Republic of Ireland; GS -Succursale de Paris (Paris branch) which, from Brexit Day, will be authorised by the French Autorité de contrôle prudentiel et de resolution ("ACPR") and regulated by the Autorité de contrôle prudentiel et de resolution and the Autorité des marches financiers ("AMF") disseminates research in France; GSI - Sucursal en España (Madrid branch) authorized in

Spain by the Comisión Nacional del Mercado de Valores disseminates research in the Kingdom of Spain; GSI - Sweden Bankfilial (Stockholm branch) is authorized by the SFSA as a "third country branch" in accordance with Chapter 4, Section 4 of the Swedish Securities and Market Act (Sw. lag (2007:528) om värdepappersmarknaden) disseminates research in the Kingdom of Sweden; Goldman Sachs Bank Europe SE ("GSBE") is a credit institution incorporated in Germany and, within the Single Supervisory Mechanism, subject to direct prudential supervision by the European Central Bank and in other respects supervised by German Federal Financial Supervisory Authority (Bundesanstalt für Finanzdienstleistungsaufsicht, BaFin) and Deutsche Bundesbank and disseminates research in the Federal Republic of Germany and those jurisdictions within the European Economic Area where GSI is not authorised to disseminate research and additionally, GSBE, Copenhagen Branch filial af GSBE, Tyskland, supervised by the Danish Financial Authority disseminates research in the Kingdom of Denmark; GSBE - Sucursal en España (Madrid branch) subject (to a limited extent) to local supervision by the Bank of Spain disseminates research in the Kingdom of Spain; GSBE - Succursale Italia (Milan branch) to the relevant applicable extent, subject to local supervision by the Bank of Italy (Banca d'Italia) and the Italian Companies and Exchange Commission (Commissione Nazionale per le Società e la Borsa "Consob") disseminates research in Italy; GSBE - Succursale de Paris (Paris branch), supervised by the AMF and by the ACPR disseminates research in France; and GSBE - Sweden Bankfilial (Stockholm branch), to a limited extent, subject to local supervision by the Swedish Financial Supervisory Authority (Finansinpektionen) disseminates research in the Kingdom of Sweden.

General disclosures

This research is for our clients only. Other than disclosures relating to Goldman Sachs, this research is based on current public information that we consider reliable, but we do not represent it is accurate or complete, and it should not be relied on as such. The information, opinions, estimates and forecasts contained herein are as of the date hereof and are subject to change without prior notification. We seek to update our research as appropriate, but various regulations may prevent us from doing so. Other than certain industry reports published on a periodic basis, the large majority of reports are published at irregular intervals as appropriate in the analyst's judgment.

Goldman Sachs conducts a global full-service, integrated investment banking, investment management, and brokerage business. We have investment banking and other business relationships with a substantial percentage of the companies covered by our Global Investment Research Division. Goldman Sachs & Co. LLC, the United States broker dealer, is a member of SIPC (https://www.sipc.org).

Our salespeople, traders, and other professionals may provide oral or written market commentary or trading strategies to our clients and principal trading desks that reflect opinions that are contrary to the opinions expressed in this research. Our asset management area, principal trading desks and investing businesses may make investment decisions that are inconsistent with the recommendations or views expressed in this research.

The analysts named in this report may have from time to time discussed with our clients, including Goldman Sachs salespersons and traders, or may discuss in this report, trading strategies that reference catalysts or events that may have a near-term impact on the market price of the equity securities discussed in this report, which impact may be directionally counter to the analyst's published price target expectations for such stocks. Any such trading strategies are distinct from and do not affect the analyst's fundamental equity rating for such stocks, which rating reflects a stock's return potential relative to its coverage universe as described herein.

We and our affiliates, officers, directors, and employees, excluding equity and credit analysts, will from time to time have long or short positions in, act as principal in, and buy or sell, the securities or derivatives, if any, referred to in this research.

The views attributed to third party presenters at Goldman Sachs arranged conferences, including individuals from other parts of Goldman Sachs, do not necessarily reflect those of Global Investment Research and are not an official view of Goldman Sachs.

Any third party referenced herein, including any salespeople, traders and other professionals or members of their household, may have positions in the products mentioned that are inconsistent with the views expressed by analysts named in this report.

This research is not an offer to sell or the solicitation of an offer to buy any security in any jurisdiction where such an offer or solicitation would be illegal. It does not constitute a personal recommendation or take into account the particular investment objectives, financial situations, or needs of individual clients. Clients should consider whether any advice or recommendation in this research is suitable for their particular circumstances and, if appropriate, seek professional advice, including tax advice. The price and value of investments referred to in this research and the income from them may fluctuate. Past performance is not a guide to future performance, future returns are not guaranteed, and a loss of original capital may occur. Fluctuations in exchange rates could have adverse effects on the value or price of, or income derived from, certain investments.

Certain transactions, including those involving futures, options, and other derivatives, give rise to substantial risk and are not suitable for all investors. Investors should review current options and futures disclosure documents which are available from Goldman Sachs sales representatives or at https://www.theocc.com/about/publications/character-risks.jsp and https://www.fiadocumentation.org/fia/regulatory-disclosures_1/fia-uniform-futures-and-options-on-futures-risk-disclosures-booklet-pdf-version-2018. Transaction costs may be significant in option strategies calling for multiple purchase and sales of options such as spreads. Supporting documentation will be supplied upon request.

Differing Levels of Service provided by Global Investment Research: The level and types of services provided to you by the Global Investment Research division of GS may vary as compared to that provided to internal and other external clients of GS, depending on various factors including your individual preferences as to the frequency and manner of receiving communication, your risk profile and investment focus and perspective (e.g., marketwide, sector specific, long term, short term), the size and scope of your overall client relationship with GS, and legal and regulatory constraints. As an example, certain clients may request to receive notifications when research on specific securities is published, and certain clients may request that specific data underlying analysts' fundamental analysis available on our internal client websites be delivered to them electronically through data feeds or otherwise. No change to an analyst's fundamental research views (e.g., ratings, price targets, or material changes to earnings estimates for equity securities), will be communicated to any client prior to inclusion of such information in a research report broadly disseminated through electronic publication to our internal client websites or through other means, as necessary, to all clients who are entitled to receive such reports.

All research reports are disseminated and available to all clients simultaneously through electronic publication to our internal client websites. Not all research content is redistributed to our clients or available to third-party aggregators, nor is Goldman Sachs responsible for the redistribution of our research by third party aggregators. For research, models or other data related to one or more securities, markets or asset classes (including related services) that may be available to you, please contact your GS representative or go to https://research.gs.com.

Disclosure information is also available at https://www.gs.com/research/hedge.html or from Research Compliance, 200 West Street, New York, NY 10282.