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Equity Research
Global

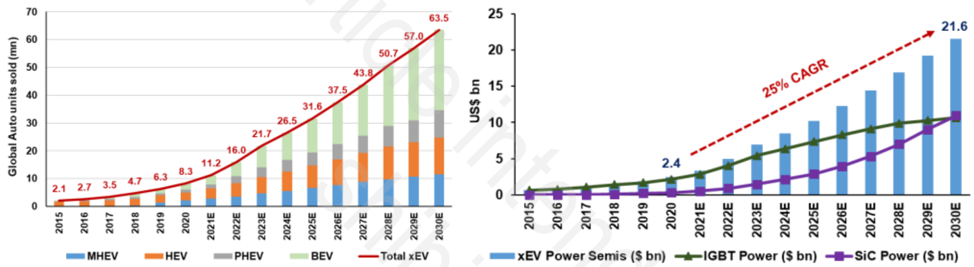
Global Semiconductors

Automotive Semis: Powering the EV megatrend

Semiconductor Devices | Global Sector Themes

Connections Series

Figure 1: Rising xEV adoption means xEV power semis market can grow 25% CAGR



Source: Credit Suisse estimates (Auto Research team for xEV; Tech team for Power semis)

In this Credit Suisse Global Sector Thematic Research report, our Technology team builds on the work of our Automotive colleagues to examine the fast-changing landscape of auto electrification around the world. We focus on the rival IGBT and SiC technologies powering the EV revolution and look across the entire supply chain to identify potential stock opportunities.

- **We forecast semiconductor content per car more than doubling by 2030, driven by xEV adoption.** Our detailed analysis suggests the adoption of battery-electric and hybrid-electric vehicles (xEV) will rise from 11% (8mn xEV units) in 2020 to 62% by 2030 (63mn xEV units, including 29mn battery-electric vehicles). Given a typical battery-electric car has twice as much semi content at $800 as a gasoline-fuelled car, with ~75% of incremental content coming from Power, we believe that average semi content can grow from ~$510 in 2020 to $1,100 by 2030, driving industry revenues from $38bn currently to $110bn over the next decade (11% CAGR).
- **Introducing our xEV Power Semis model – 25% CAGR until 2030; Powertrain and BMS key beneficiaries.** Our model looks at xEV penetration by type across regions, and by power content and technology (insulated-gate bipolar transistor (IGBT) versus the newer silicon carbide or SiC modules) within each xEV type to assess the total addressable market for xEV Power Semis. We estimate this market to grow from $2.4bn in 2020 to $22bn by 2030 (25% CAGR), with the bulk of growth driven by three product areas – Powertrain, On-Board Chargers (OBC) and Battery Management System (BMS).
- **SiC now gaining momentum as more OEMs follow Tesla.** SiC is on track to become the technology of choice in the xEV power market due to its better performance (5-10% higher efficiency, 3-5x size reduction, 50% lower weight) over IGBT, leading to Hyundai, Nio, BYD and Lucid following Tesla. We see the SiC power market growing from $0.7bn (of which $0.3bn Auto) in 2020 to $4.0bn (of which $2.9bn Auto) by 2025 (42% CAGR). Wolfspeed (Not Covered) has a c15% and c60% share of the SiC chip and wafer markets.
- **10 key Outperform-rated stocks for the EV revolution.** Within our global coverage, we highlight: i) SiC – **STM** (TP €39) and **IFX** (upgrade to O/P, new TP €42.5) in Europe and **Rohm** (TP ¥12,100) in Japan; ii) BMS in the US – **ADI** (TP $200) and **NXPI** (TP $215); and iii) Asia supply chain (assembly and packaging) – **Amkor** (TP US$23) and **ASM Pacific** (TP HK$133). Elsewhere, we view **Allegro**, **TXN** and **Microchip** as beneficiaries.

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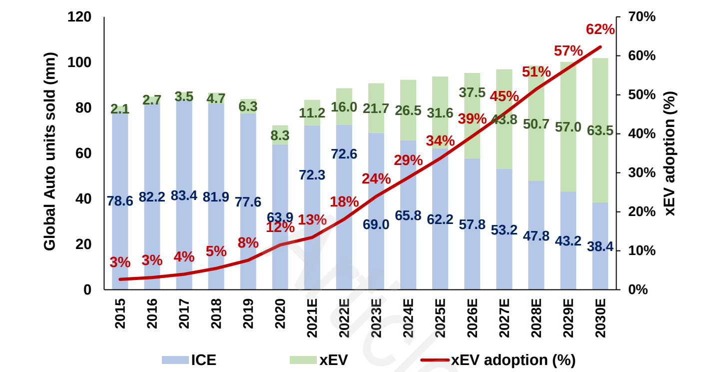
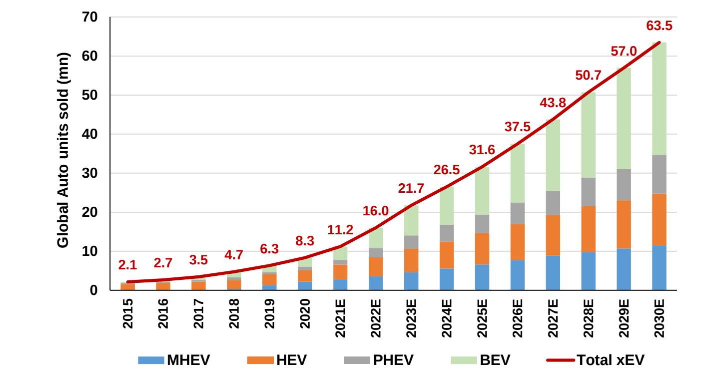
Key charts

Figure 2: Global penetration of xEV to rise from 11.5% in 2020 to 34%/62% by 2025/2030 (with scope for potential upside)



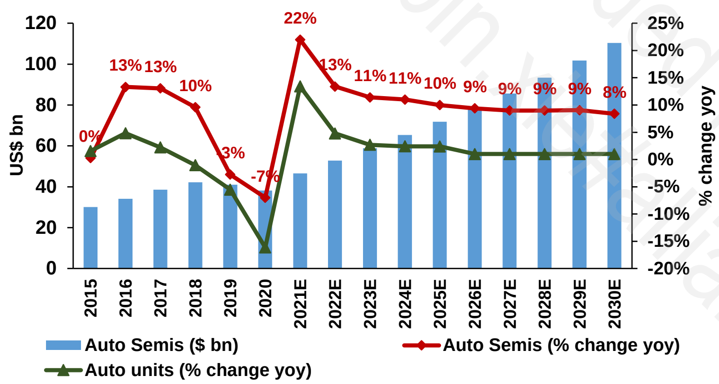
Source: Credit Suisse estimates (Global Auto Research team)

Figure 3: Out of 63m xEV cars by 2030, we expect battery electric vehicles (BEVs) to account for 29m (45% of total xEV)



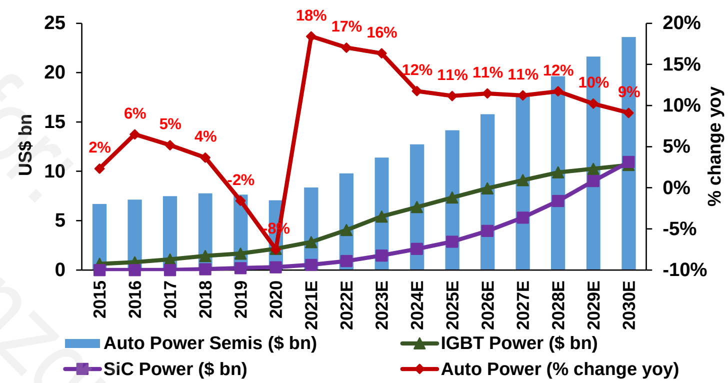
Source: Credit Suisse estimates (Global Auto Research team)

Figure 4: Semi content per car to grow >2x, reaching $1,100 by 2030 driving Auto Semis market to $110bn (11% CAGR)



Source: Gartner, Global Auto Research team, Credit Suisse estimates

Figure 5: Rising xEV adoption means Power Semis market can grow from $7bn in 2020 to $24bn by 2030 (13% CAGR)



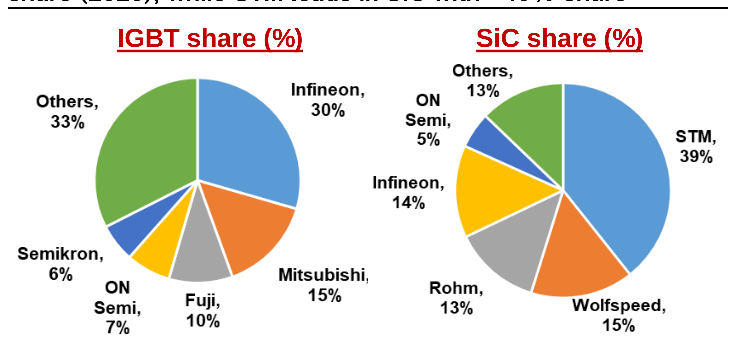
Source: Gartner, Company data, Credit Suisse estimates

Figure 6: Over $150-500 of net savings from use of SiC in a traction inverter for BEV

Areas of savings (SiC over IGBT)	$ savings
~5-10% battery cost savings from using SiC assuming 60kWh battery x $115/kWh battery cost	~$350 - $700
Space / Weight related cost savings (battery + inverter)	$ can vary
Cooling system cost savings	$ can vary
Incremental cost of using SiC	~$200
Net savings per BEV car	**> ~$150 - $500**

Source: Credit Suisse estimates

Figure 7: IFX leads in IGBT device market share with ~30% share (2020), while STM leads in SiC with ~40% share



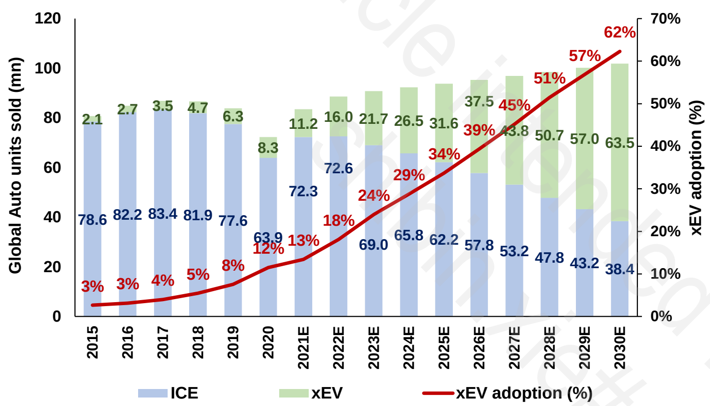
Source: Credit Suisse research

Auto Semis: Powering the EV megatrend

EV adoption now meaningfully accelerating

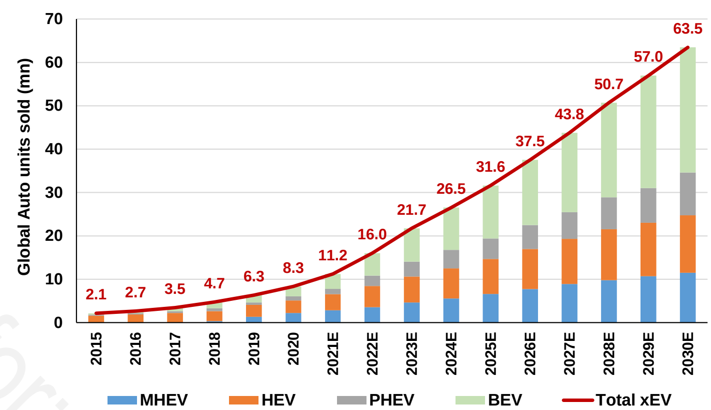
While different forms of EV cars have been around for the last decade and have gradually been rising in the mix – 1% in 2010 to 3% in 2015 and 8% in 2019 – we are now seeing a material acceleration in adoption driven by a number of factors such as stricter emission norms, proposed government bans on gasoline cars in the 2030-2035 timeframe, various car OEMs' ambitions to go full electric in the future, improving driving range and shorter charging times. This resulted in total xEV penetration of 11.5% in 2020, which we expect to rise to 34% by 2025 (with scope for potential upside) and 62% by 2030. This will result in xEV car units growing from 8mn in 2020 to 63mn by 2030 (29mn or 45% of which will be BEV units).

Figure 8: Global penetration of xEV to rise from 11.5% in 2020 to 34%/62% by 2025/2030 (with scope for potential upside)



Source: Credit Suisse estimates (Global Auto Research team)

Figure 9: Out of 63mn xEV cars by 2030, we expect BEV to account for 29mn or 45% of total xEV



Source: Credit Suisse estimates (Global Auto Research team)

Trend to drive >2x growth in semis content per car

The auto semis market was $38bn in size in 2020 (75mn auto production units X $512 semis content per car), but included only 8mn xEV unit sales. With xEV adoption rising from 11.5% in 2020 to 62% by 2030, we believe that the auto semis market can grow to $110bn (96mn units x $1,100) or 11% CAGR over the next decade.

Figure 10: Since 2015, growth in Auto semis sales has outperformed auto unit growth by an average of 7pp per year, and we expect an average of 8pp over 2021-2030 as semis content per car more than doubles from $510 in 2020 to $1,100 by 2030

																	CAGR		
Auto (Light Vehicles)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**2028E**	**2029E**	**2030E**	**2010-15**	**2015-20**	**2010-20**
Production units (mn)	**88.8**	**93.1**	**95.2**	**94.2**	**89.0**	**74.6**	**84.6**	**88.7**	**91.1**	**93.3**	**95.5**	**96.5**	**97.4**	**98.4**	**99.4**	**100.4**	3.6%	-3.4%	0.0%
% change yoy	2%	5%	2%	-1%	-6%	-16%	13%	5%	3%	2%	2%	1%	1%	1%	1%	1%			
Auto Semis revenue ($ bn)	**30.1**	**34.1**	**38.5**	**42.2**	**41.0**	**38.2**	**46.6**	**52.8**	**58.8**	**65.3**	**71.8**	**78.6**	**85.7**	**93.4**	**101.8**	**110.4**	6.4%	4.9%	5.7%
% change yoy	0%	13%	13%	10%	-3%	-7%	22%	13%	11%	11%	10%	9%	9%	9%	9%	8%			
Semi content per car ($)	**339**	**366**	**405**	**448**	**461**	**512**	**550**	**596**	**646**	**700**	**752**	**815**	**879**	**949**	**1,025**	**1,100**	2.7%	8.6%	5.6%
% change yoy	-1%	8%	11%	11%	3%	11%	8%	8%	8%	8%	7%	8%	8%	8%	8%	7%			
Auto Semis growth O/P vs. LV units	**-1%**	**8%**	**11%**	**11%**	**3%**	**9%**	**9%**	**9%**	**9%**	**9%**	**8%**	**8%**	**8%**	**8%**	**8%**	**7%**	**5%**	**7%**	**6%**

Source: Gartner (Auto Semis sales till 2019), IHS (LVP units till 2020), Credit Suisse estimates

SiC emerging as the technology of choice vs. IGBT

Historically, the xEV market was dominated by IGBT technology, which had limitations around driving range, charging time, the need for more powerful (and hence expensive) batteries and device compactness. Now with SiC offering significant improvement over IGBT on these metrics, along with the ability to lower the battery cost by $350-700, this means that the higher cost of SiC chips may not be a barrier as supply constraints ease, scale ramps up and yields improve. In addition to Tesla, recent BEV model launches from BYD, Hyundai, Lucid and Nio, which use SiC as the main powertrain technology, support our view of momentum increasing.

Figure 11: Over $150-500 of net savings from use of SiC in a traction inverter for battery electric vehicles (BEVs)

Areas of savings (SiC over IGBT)	$ savings
~5-10% battery cost savings from using SiC assuming 60kWh battery x $115/kWh battery cost	~$350 - $700
Space / Weight related cost savings (battery + inverter)	$ can vary
Cooling system cost savings	$ can vary
Incremental cost of using SiC	~$200
Net savings per BEV car	**> ~$150 - $500**

Source: Credit Suisse estimates

Figure 12: Car OEMs now starting to join Tesla in launching BEVs with SiC inverter

Auto OEM	Model	Launch year	Range (miles)
Tesla	Tesla Roadster	2022E	620
Tesla	Tesla Cybertruck	2021E	500
Nio	ET7	2022E	435
Lucid	Lucid Air	2021E	406
Tesla	Model S (Long Range)	2020	402
BYD	Han	2020	376
Tesla	Model 3 (Long Range)	2019	353
Tesla	Model X (Long Range)	2019	370
Tesla	Model Y (Long Range)	2020	326
Hyundai	Ioniq 5	2021E	310

Source: Credit Suisse research

Significant SiC runway; supply ramping to meet demand

Based on our assumptions for xEV adoption by type and average power semis content for each type of xEV vehicle, we believe the xEV Power semis market has grown from $0.6bn in 2015 to $2.4bn in 2020 (CAGR of 31%). Further, we expect this to grow to $10bn by 2025E (CAGR of 33% over 2020-2025E) and $22bn by 2030E (CAGR of 16% over 2025-2030E).

For BEV (where the SiC use case appears most justified given benefits of higher mileage), we assume SiC adoption will rise from 28% in 2020 (driven by Tesla) to 50% by 2025E and 75% by 2030E. For PHEV, we model SiC penetration to rise from 3% in 2024E to 35% by 2030E. This will result in the total size of the SiC power market for xEV growing from around $300mn in 2020E to $2.9bn by 2025E, and $11.0bn by 2030E. Over the same period, we expect IGBT for the xEV market to grow from $2.1bn in 2020E to $7.3bn/$10.6bn by 2025/2030E.

Figure 13: Power semis accounts for ~20% of the overall Auto semis market; Power Semis used in xEV cars to grow from $2.4bn in 2020 to nearly $22bn by 2030 (around 25% CAGR over the next 10 years)

																	Incremental growth ($ bn)		
Market size ($ bn)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**2028E**	**2029E**	**2030E**	**2015-2020**	**2020-2025**	**2025-2030**
Auto Semis market	**30.1**	**34.1**	**38.5**	**42.2**	**41.0**	**38.2**	**46.6**	**52.8**	**58.8**	**65.3**	**71.8**	**78.6**	**85.7**	**93.4**	**101.8**	**110.4**	**8.1**	**33.7**	**38.5**
% change yoy	0%	13%	13%	10%	-3%	-7%	22%	13%	11%	11%	10%	9%	9%	9%	9%	8%			
Auto Power Semis	**6.7**	**7.1**	**7.5**	**7.8**	**7.6**	**7.1**	**8.4**	**9.8**	**11.4**	**12.7**	**14.2**	**15.8**	**17.6**	**19.6**	**21.6**	**23.6**	**0.4**	**7.1**	**9.4**
% change yoy	2%	6%	5%	4%	-2%	-8%	18%	17%	16%	12%	11%	11%	11%	12%	10%	9%			
Power as % of Auto semis	22%	21%	19%	18%	19%	19%	18%	19%	19%	20%	20%	20%	21%	21%	21%	21%	5%	21%	24%
ICE Power Semis	**6.1**	**6.3**	**6.4**	**6.3**	**5.8**	**4.6**	**5.0**	**4.8**	**4.5**	**4.2**	**3.9**	**3.5**	**3.1**	**2.7**	**2.4**	**2.0**	**(1.4)**	**(0.7)**	**(1.9)**
xEV Power Semis	**0.6**	**0.8**	**1.1**	**1.5**	**1.9**	**2.4**	**3.4**	**5.0**	**6.9**	**8.5**	**10.2**	**12.2**	**14.4**	**16.9**	**19.3**	**21.6**	**1.8**	**7.8**	**11.4**
% change yoy	12%	27%	35%	40%	24%	31%	38%	48%	39%	23%	20%	20%	18%	17%	14%	12%			
IGBT Power	0.6	0.8	1.1	1.4	1.7	2.1	2.8	4.1	5.4	6.4	7.3	8.3	9.1	9.9	10.3	10.6	1.5	5.2	3.3
SiC Power	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.9	1.5	2.1	2.9	4.0	5.3	7.0	9.0	11.0	0.3	2.6	8.1

Source: Gartner, Company data, Credit Suisse estimates

Company exposure to the EV theme

SiC is on track to become the technology of choice in the xEV power market due to its better performance (5-10% higher efficiency, 3-5x size reduction, 50% lower weight) over IGBT, leading to Hyundai, Nio, BYD and Lucid following Tesla. We see the SiC power market growing from $0.7bn (of which $0.3bn Auto) in 2020 to $4.0bn (of which $2.9bn Auto) by 2025. Wolfspeed (Not Covered) has c15% and c60% shares of the SiC chip and wafer markets.

Within our coverage, we highlight companies that are strongly positioned in specific product areas and can deliver outsized growth. Given our forecasts for SiC in Autos, and high barriers to entry, we view **STM (O/P, TP €39)** and **IFX (upgrade to O/P, new TP €42.5)** as key beneficiaries in the EU, along with **Rohm (O/P, TP ¥12,100)** in Japan.

For BMS in the US, we see **ADI (O/P, TP $200)** and **NXPI (O/P, TP $215)** as major beneficiaries from increasing focus on wireless BMS and scope for TAM to grow to $4-5bn by 2025. In the Asian supply chain, we view **Amkor (O/P, TP US$23)** and **ASM Pacific (O/P, HK$133)** as key beneficiaries from the rising need for assembly/testing and back-end equipment respectively. We also see **Allegro**, **Texas Instruments** and **Microchip** as beneficiaries.

List of key Auto semis suppliers

Figure 14: Top Auto semis suppliers across all products – IFX (incl. CY) and NXP have significant lead over others in terms of size

Rank		Company Name	Auto semis sales ($ mn)		Total semis sales ($ mn)		Auto as % of group sales		Auto semis market share (%)	
2018	2019		2018	2019	2018	2019	2018	2019	2018	2019
1	1	Infineon (incl. Cypress)	4,843	4,771	11,187	10,616	43%	45%	11%	12%
2	2	NXP	4,507	4,212	9,022	8,758	50%	48%	11%	10%
3	3	Renesas	3,315	3,140	6,710	6,716	49%	47%	8%	8%
4	4	Texas Instruments	3,056	2,790	14,592	13,364	21%	21%	7%	7%
5	5	STMicro	2,637	2,752	9,579	9,451	28%	29%	6%	7%
6	6	Robert Bosch	1,872	1,783	2,494	2,430	75%	73%	4%	4%
7	7	ON Semi	1,797	1,755	5,642	5,327	32%	33%	4%	4%
8	8	Denso	1,123	1,193	1,123	1,193	100%	100%	3%	3%
10	9	Micron	1,033	1,053	29,742	20,254	3%	5%	2%	3%
9	10	Rohm	1,068	1,028	3,025	2,768	35%	37%	3%	3%
15	11	Intel	813	924	66,290	67,754	1%	1%	2%	2%
11	12	Analog Devices	993	908	6,207	5,831	16%	16%	2%	2%
13	13	Microchip	907	835	5,154	5,161	18%	16%	2%	2%
12	14	Osram	950	787	1,970	1,635	48%	48%	2%	2%
14	15	Toshiba	820	785	5,614	2,435	15%	32%	2%	2%
16	16	Sanken	737	689	1,333	1,265	55%	54%	2%	2%
20	17	Qualcomm	584	668	15,375	13,613	4%	5%	1%	2%
19	18	Nvidia	592	626	8,073	7,331	7%	9%	1%	2%
18	19	Nexperia	600	589	1,496	1,466	40%	40%	1%	1%
21	20	Maxim	542	564	2,497	2,183	22%	26%	1%	1%
17	21	Melexis	611	497	672	543	91%	92%	1%	1%
22	22	Mitsubishi	430	458	1,310	1,352	33%	34%	1%	1%
23	23	Sony	386	421	6,465	8,536	6%	5%	1%	1%
24	24	Nichia	369	384	1,842	1,794	20%	21%	1%	1%
		Others	7,602	7,401	258,737	217,372	3%	3%	18%	18%
		Total Market	**42,187**	**41,013**	**476,151**	**419,148**	**9%**	**10%**	**100%**	**100%**

Source: Gartner, Credit Suisse research

Figure 15: List of leading Auto semis suppliers with their Auto sales breakdown by products – companies with high Discrete and Analog exposure, along with MCU, likely to be key beneficiaries of electrification theme

Split of 2019 sales in Auto	IFX (incl. CY)		NXP		Renesas		Texas		STMicro		ON Semi		Denso		Rohm		ADI		Maxim	
Auto sales breakdown by product	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**	**$ mn**	**%**
Memory	267	6%	0	0%	0	0%	0	0%	47	2%	5	0%	0	0%	28	3%	0	0%	0	0%
MCUs	1,237	26%	1,894	45%	2,116	67%	685	25%	392	14%	3	0%	176	15%	0	0%	45	5%	0	0%
General Purpose Logic	0	0%	0	0%	0	0%	113	4%	0	0%	58	3%	0	0%	42	4%	0	0%	0	0%
Analog	102	2%	68	2%	85	3%	845	30%	79	3%	268	15%	0	0%	34	3%	681	75%	257	46%
Discrete	1,068	22%	0	0%	461	15%	0	0%	426	15%	695	40%	367	31%	528	51%	0	0%	0	0%
Optical sensors	0	0%	0	0%	3	0%	0	0%	7	0%	400	23%	22	2%	48	5%	0	0%	0	0%
Non-Optical sensors	768	16%	394	9%	12	0%	23	1%	84	3%	11	1%	354	30%	16	2%	176	19%	10	2%
Application / Multimedia Processor	0	0%	437	10%	258	8%	173	6%	344	13%	0	0%	0	0%	22	2%	0	0%	0	0%
Wireless Connectivity	85	2%	8	0%	8	0%	32	1%	356	13%	13	1%	0	0%	0	0%	0	0%	13	2%
Wired Connectivity	208	4%	454	11%	41	1%	53	2%	72	3%	36	2%	0	0%	0	0%	5	1%	10	2%
RF FE + Transceivers	360	8%	427	10%	0	0%	61	2%	36	1%	0	0%	41	3%	0	0%	0	0%	15	3%
Power Management	461	10%	319	8%	76	2%	594	21%	319	12%	117	7%	146	12%	201	20%	0	0%	216	38%
Other Application Specific	215	5%	211	5%	80	3%	211	8%	590	21%	149	8%	87	7%	109	11%	1	0%	43	8%
Total Automotive semis sales	**4,771**	**100%**	**4,212**	**100%**	**3,140**	**100%**	**2,790**	**100%**	**2,752**	**100%**	**1,755**	**100%**	**1,193**	**100%**	**1,028**	**100%**	**908**	**100%**	**564**	**100%**

Source: Gartner, Credit Suisse research

Figure 16: Leading Discrete chip suppliers in the Auto market – IFX is around 1.5x the size of ON Semi (#2 operator)

Rank		Company Name	Auto Discrete Sales ($ mn)		Auto Sales ($ mn)		Total Sales ($ mn)		Discrete exposure in Auto %		Auto exposure %	
2018	2019		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
1	1	Infineon (incl. Cypress)	1,068	1,068	4,843	4,771	11,187	10,616	22%	22%	43%	45%
2	2	ON Semi	665	695	1,797	1,755	5,642	5,327	37%	40%	32%	33%
3	3	Rohm	549	528	1,068	1,028	3,025	2,768	51%	51%	35%	37%
4	4	Nexperia	495	488	600	589	1,496	1,466	83%	83%	40%	40%
5	5	Renesas	534	461	3,315	3,140	6,710	6,716	16%	15%	49%	47%
6	6	STMicro	326	426	2,637	2,752	9,579	9,451	12%	15%	28%	29%
7	7	Denso	323	367	1,123	1,193	1,123	1,193	29%	31%	100%	100%
8	8	Toshiba	305	299	820	785	5,614	2,435	37%	38%	15%	32%
10	9	Toyota	294	296	317	318	317	318	93%	93%	100%	100%
9	10	Vishay	283	256	368	318	1,551	1,289	77%	81%	24%	25%
16	11	Mitsubishi	223	255	430	458	1,310	1,352	52%	56%	33%	34%
11	12	Fuji Electric	161	217	266	330	810	840	61%	66%	33%	39%
		Others	929	892	24,603	23,576	427,787	375,377	4%	4%	6%	6%
		Total Market	**6,155**	**6,248**	**42,187**	**41,013**	**476,151**	**419,148**	**15%**	**15%**	**9%**	**10%**

Source: Gartner, Credit Suisse research

Global valuation table: Auto power semis companies

Figure 17: Valuation table for Auto power semis companies – list of names with exposure to Discrete (IGBT, SiC), MCU/Sensor and Analog chips along with xEV chip supply chain in Asia

RIC	Company Name	Currency	Share Price	Target Price	Upside/Downside	CS Rating	Mkt Cap ($)	PE (x)		EV/EBIT		EV/EBITDA		Sales Growth		EPS Growth		P/B	
			Price LCY	Price LCY	(%)		USD mn	2021E	2022E	2021E	2022E	2021E	2022E	2021E	2022E	2021E	2022E	2021E	2022E
IGBT device makers																			
IFXGn.DE	Infineon Technologies AG	EUR	33.9	42.5	25%	OUTPERFORM	52,785	29.2	23.9	35.8	26.9	13.6	12.2	28%	11%	81%	22%	4.1	3.8
6502.T	Toshiba	JPY	3,885.0	3,930.0	1%	NEUTRAL	16,191	23.4	15.7	16.3	9.3	9.6	6.5	-10%	7%	170%	49%	1.8	1.6
6503.T	Mitsubishi Electric	JPY	1,775.5	2,310.0	30%	OUTPERFORM	34,977	16.2	14.5	10.5	9.4	6.6	6.1	6%	3%	6%	11%	1.4	1.3
6504.T	Fuji Electric	JPY	4,815.0	NA		NOT COVERED	6,601	21.3	18.0	NA	NA	11.2	9.1	-4%	4%	12%	18%	NM	NM
ON.OQ	ON Semiconductor Corp.	USD	39.1	17.0	-57%	UNDERPERFORM	16,121	24.4	20.6	26.7	19.7	11.7	12.8	14%	3%	89%	19%	5.2	5.0
STM.PA	STMicroelectronics NV	EUR	30.4	39.0	28%	OUTPERFORM	32,994	23.3	19.6	18.6	15.7	11.5	10.1	15%	8%	28%	19%	3.7	3.2
603290.SS	StarPower	CNY	177.0	242.0	37%	NEUTRAL	4,347	105.7	68.6	94.0	60.6	81.0	53.8	41%	41%	42%	54%	21.9	17.4
688396.SS	CR Micro	CNY	55.5	83.0	50%	OUTPERFORM	10,363	37.9	31.9	38.9	32.8	26.4	22.9	30%	16%	74%	19%	5.6	4.8
SiC device makers																			
STM.PA	STMicroelectronics NV	EUR	30.4	39.0	28%	OUTPERFORM	32,994	23.3	19.6	18.6	15.7	11.5	10.1	15%	8%	28%	19%	3.7	3.2
IFXGn.DE	Infineon Technologies AG	EUR	33.9	42.5	25%	OUTPERFORM	52,785	29.2	23.9	35.8	26.9	13.6	12.2	28%	11%	81%	22%	4.1	3.8
6963.T	ROHM	JPY	10,660.0	12,100.0	14%	OUTPERFORM	9,606	49.1	33.3	30.5	18.7	11.6	8.8	-5%	9%	-13%	48%	1.5	1.5
6503.T	Mitsubishi Electric	JPY	1,775.5	2,310.0	30%	OUTPERFORM	34,977	16.2	14.5	10.5	9.4	6.6	6.1	6%	3%	6%	11%	1.4	1.3
CREE.OQ	Wolfspeed (CREE)	USD	105.4	NA		NOT COVERED	11,703	-119.5	-268.9	-69.9	-171.8	-1118.5	152.0	-32%	14%	96%	-56%	19.0	18.7
Discrete																			
IFXGn.DE	Infineon Technologies AG	EUR	33.9	42.5	25%	OUTPERFORM	52,785	29.2	23.9	35.8	26.9	13.6	12.2	28%	11%	81%	22%	4.1	3.8
ON.OQ	ON Semiconductor Corp.	USD	39.1	17.0	-57%	UNDERPERFORM	16,121	24.4	20.6	26.7	19.7	11.7	12.8	14%	3%	89%	19%	5.2	5.0
6963.T	ROHM	JPY	10,660.0	12,100.0	14%	OUTPERFORM	9,606	49.1	33.3	30.5	18.7	11.6	8.8	-5%	9%	-13%	48%	1.5	1.5
6723.T	Renesas Electronics	JPY	1,228.0	1,530.0	25%	OUTPERFORM	19,533	22.3	16.9	24.8	18.7	12.6	11.0	13%	10%	-14%	32%	2.9	2.4
STM.PA	STMicroelectronics NV	EUR	30.4	39.0	28%	OUTPERFORM	32,994	23.3	19.6	18.6	15.7	11.5	10.1	15%	8%	28%	19%	3.7	3.2
6902.T	Denso	JPY	7,732.0	6,700.0	-13%	OUTPERFORM	55,016	63.7	21.6	44.4	16.9	12.5	8.4	-7%	12%	38%	196%	1.7	1.6
6502.T	Toshiba	JPY	3,885.0	3,930.0	1%	NEUTRAL	16,191	23.4	15.7	16.3	9.3	9.6	6.5	-10%	7%	170%	49%	1.8	1.6
6503.T	Mitsubishi Electric	JPY	1,775.5	2,310.0	30%	OUTPERFORM	34,977	16.2	14.5	10.5	9.4	6.6	6.1	6%	3%	6%	11%	1.4	1.3
6504.T	Fuji Electric	JPY	4,815.0	NA		NOT COVERED	6,601	21.3	18.0	NA	NA	11.2	9.1	-4%	4%	12%	18%	NM	NM
Analog																			
TXN	Texas Instruments Inc.	USD	174.4	200.0	15%	OUTPERFORM	160,936	25.8	23.9	21.7	20.2	21.7	20.2	15%	5%	17%	8%	13.5	27.3
ADI	Analog Devices Inc.	USD	149.5	200.0	34%	OUTPERFORM	55,131	24.5	22.5	27.7	NM	20.2	18.6	16%	6%	24%	9%	4.5	4.2
ON.OQ	ON Semiconductor Corp.	USD	39.1	17.0	-57%	UNDERPERFORM	16,121	24.4	20.6	26.7	19.7	11.7	12.8	14%	3%	89%	19%	5.2	5.0
6707.T	Sanken Electric	JPY	5,230.0	NA		NOT COVERED	1,205	-23.8	60.1	NA	NA	15.1	6.2	-4%	-1%	-4%	-140%	NM	NM
MCUs & Sensors																			
6723.T	Renesas Electronics	JPY	1,228.0	1,530.0	25%	OUTPERFORM	19,533	22.3	16.9	24.8	18.7	12.6	11.0	13%	10%	-14%	32%	2.9	2.4
NXPI.OQ	NXP Semiconductors N.V.	USD	198.6	215.0	8%	OUTPERFORM	55,011	21.0	19.0	18.3	16.6	15.8	14.4	23%	5%	57%	11%	4.3	3.7
IFXGn.DE	Infineon Technologies AG	EUR	33.9	42.5	25%	OUTPERFORM	52,785	29.2	23.9	35.8	26.9	13.6	12.2	28%	11%	81%	22%	4.1	3.8
TXN.OQ	Texas Instruments Inc.	USD	174.4	200.0	15%	OUTPERFORM	160,936	25.8	23.9	21.7	20.2	21.7	20.2	15%	5%	17%	8%	13.5	27.3
STM.PA	STMicroelectronics NV	EUR	30.4	39.0	28%	OUTPERFORM	32,994	23.3	19.6	18.6	15.7	11.5	10.1	15%	8%	28%	19%	3.7	3.2
MCHP.OQ	Microchip Technology Inc.	USD	145.5	180.0	24%	OUTPERFORM	39,175	25.3	21.5	69.6	55.5	19.4	16.7	3%	14%	16%	18%	6.9	6.7
ALGM.OQ	Allegro Microsystems, Inc.	USD	26.1	36.0	38%	OUTPERFORM	4,939	57.6	40.9	49.6	34.2	33.0	25.4	8%	17%	-16%	41%	3.2	3.6
MLXS.BR	Melexis	EUR	85.4	NA		NOT COVERED	4,107	33.4	28.5	28.6	23.8	20.2	17.5	21%	10%	48%	17%	8.3	9.2
Supply Chain																			
2330.TW	Taiwan Semiconductor Manufacturing	TWD	591.0	650.0	10%	OUTPERFORM	538,394	28.1	24.1	25.1	21.6	14.8	12.7	10%	13%	5%	17%	7.2	6.2
2303.TW	United Microelectronics	TWD	46.1	63.0	37%	OUTPERFORM	20,097	18.0	13.9	16.0	11.8	6.6	6.2	10%	4%	5%	29%	2.3	2.2
1347.HK	Hua Hong Semiconductor Limited	HKD	42.6	49.0	15%	NEUTRAL	7,123	50.6	43.6	209.8	74.0	13.2	9.2	38%	21%	43%	16%	2.8	2.6
0981.HK	Semiconductor Manufacturing International	HKD	25.9	19.6	-24%	NEUTRAL	19,868	69.0	54.3	111.2	66.8	10.1	8.5	7%	13%	-32%	27%	1.8	1.7
AMKR.OQ	Amkor Technology Inc.	USD	23.1	23.0	0%	OUTPERFORM	5,624	11.5	11.0	9.5	9.1	5.2	4.9	13%	4%	44%	5%	2.0	1.7
3711.TW	ASE Industrial Holdings	TWD	108.0	124.0	15%	OUTPERFORM	16,508	12.2	11.3	12.2	11.4	6.3	5.9	15%	7%	17%	8%	1.9	1.8
0522.HK	ASM Pacific Technology Ltd	HKD	98.5	133.0	35%	OUTPERFORM	5,207	18.6	16.0	13.1	11.0	12.0	10.2	9%	6%	34%	16%	3.0	2.7
2355.TW	Chin-Poon Industrial Co., Ltd.	TWD	34.0	41.0	21%	OUTPERFORM	474	34.8	31.6	31.0	20.3	6.4	5.5	26%	6%	1375%	10%	0.9	0.9
4958.TW	ZDT	TWD	127.5	152.0	19%	OUTPERFORM	4,242	11.0	9.4	5.3	4.4	3.5	3.0	14%	14%	28%	17%	1.5	1.3
6146.T	DISCO	JPY	34,300.0	17,250.0	-50%	UNDERPERFORM	11,350	43.6	43.3	29.6	29.4	25.4	25.2	3%	1%	2%	1%	5.2	5.0
XFAB.PA	X-FAB	EUR	6.8	3.4	-50%	UNDERPERFORM	1,053	41.8	28.8	35.5	24.6	8.9	7.7	21%	6%	86%	45%	1.5	1.5
IIVI.OQ	II-VI	USD	68.4	NA		NOT COVERED	7,169	18.4	16.0	12.7	10.3	9.0	7.7	30%	11%	30%	15%	27.2	30.1

Source: Credit Suisse estimates for covered companies, Refinitiv estimates for Not Covered companies. Table is priced as of close on 18 March 2021.

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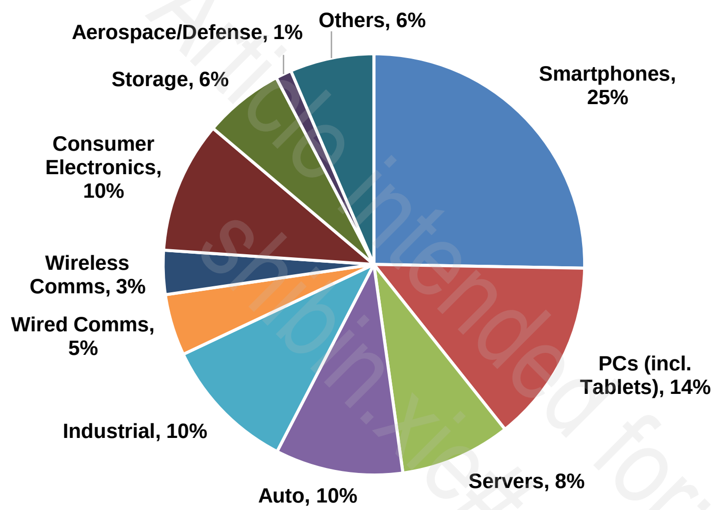
Accelerating xEV adoption to drive rising semis content per car

The auto semiconductors market was around $41bn in size in 2019 accounting for ~10% of total semis chip revenues. Given a significant decline in auto units during 2020, we estimate that the auto semis market was around $38bn in 2020. But with signs of unit recovery, inventory replenishment in the channel and accelerating content growth (driven by xEV, ADAS, Connectivity), we expect the auto semis market to grow by 22%/13% in 2021E/22E to around $47bn/$53bn respectively.

Figure 18: Automotive accounts for ~10% of total semiconductor chip market (2019)

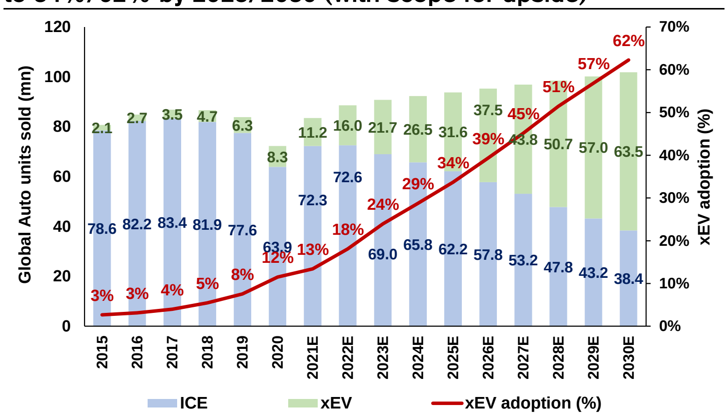


Source: Credit Suisse research

EV adoption – significant potential ahead

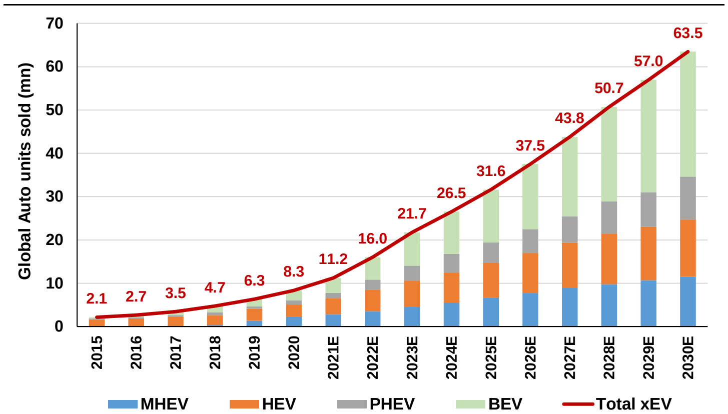
While different forms of EV cars have been around for the last decade and have gradually been rising in the mix – 1% in 2010 to 3% in 2015 and 8% in 2019 – we are now seeing a material acceleration in adoption in the last 18 months especially post the COVID-19 pandemic. This resulted in total xEV penetration of 11.5% in 2020, which we expect to rise to 34% by 2025E (with scope for potential upside), and 62% by 2030E (Figure 19). This should result in xEV car units growing from 8mn in 2020 to 63mn by 2030E.

Figure 19: Global xEV penetration to rise from 11.5% in 2020 to 34%/62% by 2025/2030 (with scope for upside)



Source: Credit Suisse estimates (Global Auto Research team)

Figure 20: Out of 63mn xEV cars by 2030, we expect BEV to account for 29mn or 45% of total xEV



Source: Credit Suisse estimates (Global Auto Research team)

MHEV + HEV drove the early part of xEV adoption… Over the last few years, both HEV and MHEV cars have seen a rise in penetration – MHEV + HEV adoption growing from 2% in 2015 to 7% in 2020 – driven by the launch of a number of new models, the specific use case of short distance driving and flexibility of shifting between electric and fuel depending on driving conditions and range.

…but now BEV leading the charge. Since 2018, we have seen that both PHEV and BEV (specifically BEV) adoption has seen a surge post the launch of Tesla Model 3. This has been driven by the increased push by regulators towards reducing emissions, rising government subsidies, lowering production cost, aggressive pricing strategy from carmakers, improved technology allowing much higher mileage per charge, and better availability of charging infrastructure. This has resulted in PHEV + BEV adoption rising from 0.7% in 2015 to 1.5% in 2017, increasing to 4.5% in 2020. Within this, BEV is well on track to becoming the dominant technology of choice, as we predict its adoption should rise to 13% of all cars by 2025E, and 28% by 2030E (although we continue to see potential upside risk to these estimates). We expect combined PHEV + BEV adoption to rise from 4.5% in 2020 to 38% by 2030E.

Figure 21: Split of xEV by MHEV, HEV, PHEV and BEV: BEV + PHEV adoption to rise from 4% in 2020 to 18%/38% by 2025/2030E

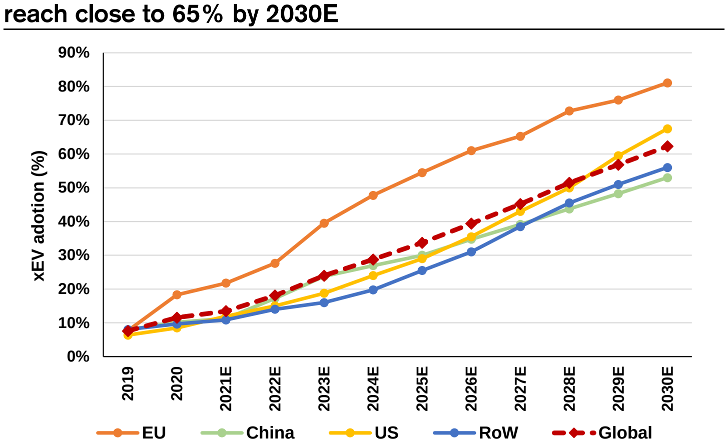
	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Global LV sales (mn)	**80.7**	**84.9**	**86.8**	**86.6**	**83.9**	**72.3**	**83.5**	**88.6**	**90.8**	**92.3**	**93.8**	**95.3**	**96.9**	**98.5**	**100.2**	**101.9**
% change yoy	2%	5%	2%	0%	-3%	-14%	16%	6%	2%	2%	2%	2%	2%	2%	2%	2%
MHEV	0.00	0.03	0.05	0.32	1.34	2.23	2.83	3.55	4.63	5.56	6.62	7.75	8.89	9.78	10.71	11.48
MHEV adoption (%)	0.0%	0.0%	0.1%	0.4%	1.6%	3.1%	3.4%	4.0%	5.1%	6.0%	7.1%	8.1%	9.2%	9.9%	10.7%	11.3%
HEV	1.60	1.84	2.16	2.33	2.74	2.87	3.71	4.89	5.99	6.93	8.07	9.21	10.42	11.76	12.33	13.28
HEV adoption (%)	2.0%	2.2%	2.5%	2.7%	3.3%	4.0%	4.4%	5.5%	6.6%	7.5%	8.6%	9.7%	10.7%	11.9%	12.3%	13.0%
MHEV + HEV adoption (%)	2.0%	2.2%	2.5%	3.1%	4.9%	7.1%	7.8%	9.5%	11.7%	13.5%	15.7%	17.8%	19.9%	21.9%	23.0%	24.3%
PHEV	0.22	0.28	0.42	0.64	0.58	0.98	1.24	2.38	3.41	4.26	4.70	5.52	6.17	7.36	7.96	9.83
PHEV adoption (%)	0.3%	0.3%	0.5%	0.7%	0.7%	1.4%	1.5%	2.7%	3.8%	4.6%	5.0%	5.8%	6.4%	7.5%	7.9%	9.6%
BEV	0.32	0.51	0.84	1.44	1.68	2.25	3.44	5.20	7.71	9.79	12.23	15.04	18.29	21.81	25.96	28.88
BEV adoption (%)	0.4%	0.6%	1.0%	1.7%	2.0%	3.1%	4.1%	5.9%	8.5%	10.6%	13.0%	15.8%	18.9%	22.1%	25.9%	28.3%
PHEV + BEV adoption (%)	0.7%	0.9%	1.5%	2.4%	2.7%	4.5%	5.6%	8.6%	12.3%	15.2%	18.0%	21.6%	25.2%	29.6%	33.9%	38.0%
Total xEV	**2.14**	**2.66**	**3.47**	**4.73**	**6.34**	**8.33**	**11.23**	**16.02**	**21.74**	**26.54**	**31.61**	**37.53**	**43.77**	**50.71**	**56.96**	**63.47**
xEV adoption (%)	2.7%	3.1%	4.0%	5.5%	7.6%	11.5%	13.4%	18.1%	24.0%	28.8%	33.7%	39.4%	45.2%	51.5%	56.8%	62.3%
Total ICE	78.57	82.25	83.38	81.92	77.55	63.93	72.29	72.57	69.03	65.75	62.19	57.82	53.16	47.83	43.24	38.43

Source: Credit Suisse estimates (Global Auto Research team)

EV adoption curve by region – EU and China in the lead

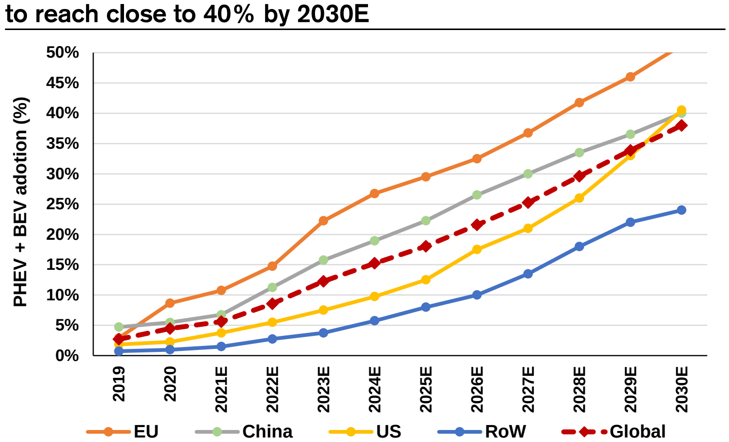
In the early part of EV adoption, we saw the EU and China leading this shift from gasoline to electric cars. This is now being led by more stringent emission norms in both regions, especially the EU, where the proposed mandate is to reduce CO2 emissions by 15% by 2025, and 37.5% by 2030 versus 2021 levels. Similarly, in China, we have seen the government putting a cap on new registration for gasoline cars in a number of cities to tackle the rising issue of pollution.

Figure 22: Total xEV penetration by region: Global adoption to reach close to 65% by 2030E



Source: Credit Suisse estimates (Global Auto Research team)

Figure 23: PHEV + BEV penetration by region: Global adoption to reach close to 40% by 2030E



Source: Credit Suisse estimates (Global Auto Research team)

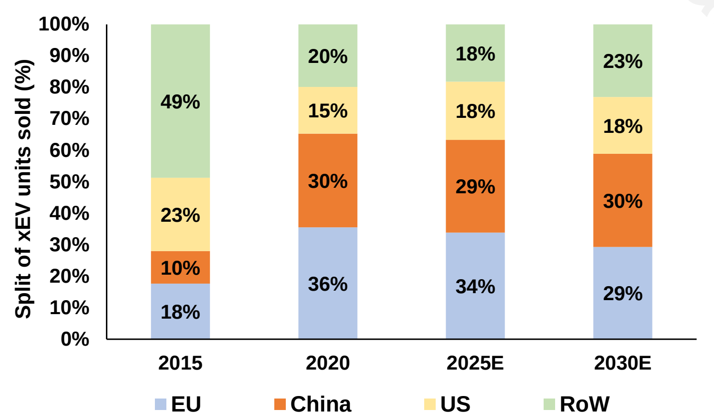
xEV penetration in EU could rise to >80% by 2030. Penetration of EV cars in the EU has grown from 5% in 2018 to 18% in 2020 (Figure 22). If we look at PHEV and BEV models only, then penetration has risen from 2% in 2018 to 9% in 2020. Both these data points clearly show the rapid pace at which EU carmakers and customers are embracing auto electrification. Combining this with strict emission norms and the increasing subsidy push from various EU countries, we believe the EU will continue to be the regional leader when it comes to xEV adoption. We model 81% of all cars sold in the EU by 2030 to be xEV enabled, of which slightly more than 50% will be either PHEV or BEV as we show in Figure 23.

China also driving a big push to EV. In October 2020, an academic entity (China Society of Automotive Engineers) announced its suggestions for EV adoption, forecasting that 20%/40%/50% of all cars sold in China by 2025/2030/2035 should be NEV enabled. Following that study, the China State Council announced in early November its long-awaited "New Energy Vehicle Industry Development Plan (2021-2035)" targeting the following:

- Change public charging pile/station tech from slow-charge to high-voltage fast charge;
- Reduce the requirement from 100% to 80% of NEV public buses, taxis and logistics vehicles in certain polluted areas;
- Reduce the NEV sales volume proportion target for 2025 from 25% to 20% – the reduction in the 2025 target was due to the slow uptake of EV in China during 2H19 and 1H20, first because of the impact from subsidy cuts, and then the impact of COVID-19;
- However, longer term, China is still aiming to stop new gasoline car sales by 2035, by when it expects NEV (includes BEV, PHEV and FCEV) and HEV (includes MHEV and HEV) to account for 50% of unit sales. Breaking this target down by years, China is aiming to get to 20% NEV/40% HEV by 2025, 40% NEV/45% HEV by 2030, and then 50% NEV/50% HEV by 2035.

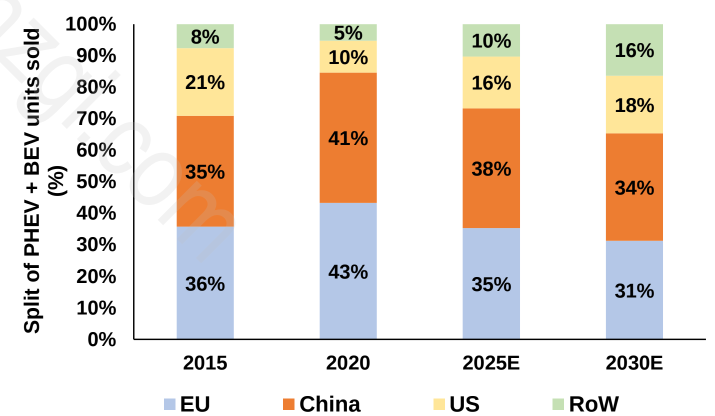
Note in our xEV model, we forecast China total xEV adoption to be 30% (22% NEV + 8% HEV) by 2025, and then 53% (40% NEV + 13% HEV) by 2030 as we show in Figure 22. As such, we argue there may be potential upside to our China assumptions.

Figure 24: Sales split of xEV by region – EU and China lead the way with over 65% of global unit sales in 2020



Source: Credit Suisse estimates (Global Auto Research team)

Figure 25: Sales split of PHEV + BEV by region – EU and China have also led here with nearly 85% of units sold in 2020

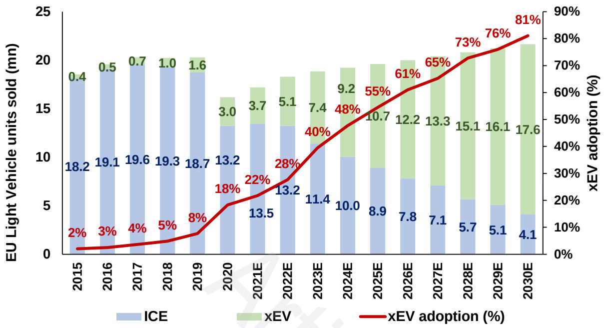


Source: Credit Suisse estimates (Global Auto Research team)

EU and China accounted for ~65% of xEV cars sold in 2020… Another way to judge the pace of adoption of xEV is by looking at the total volumes of xEV cars sold in a year and how it splits by region. In Figure 24, we can see that, of the total 8.3mn EV cars sold globally, 36% were in EU and another 30% were in China – so both these regions accounted for around two-thirds of the total market.

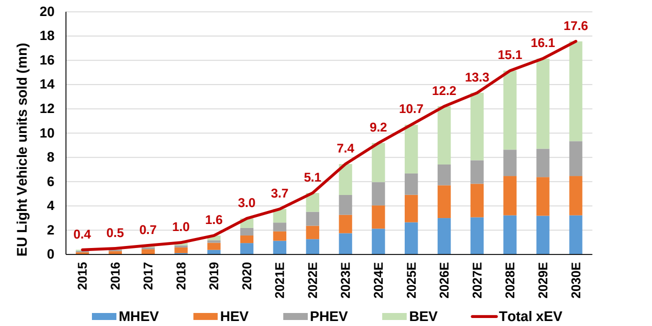
…and nearly 85% of PHEV + BEV global units in 2020. If we narrow that down further to look at only PHEV and BEV units, then EU (43%) and China (41%) accounted for nearly 85% of global shipments last year (Figure 25). While their contribution to the global units will decline as EV adoption in other regions (US, Latam and SE Asia) picks up, we expect the EU and China to still lead the way in EV adoption when looking at xEV as a proportion of total car sales.

Figure 26: xEV in EU to rise to ~55%/80% by 2025/2030…



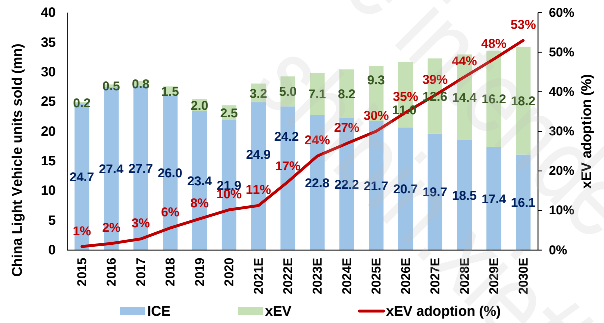
Source: Credit Suisse estimates (Global Auto Research team)

Figure 27: …leading to 18mn xEV cars in 2030 (3mn in 2020)



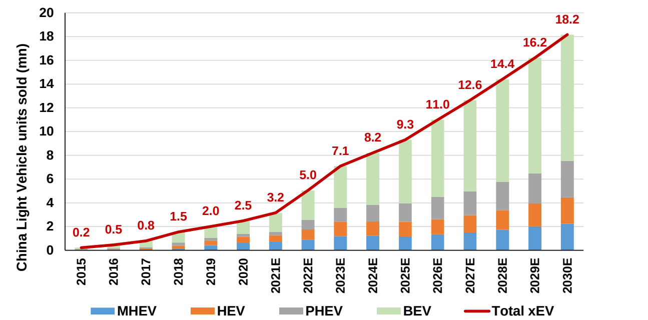
Source: Credit Suisse estimates (Global Auto Research team)

Figure 28: xEV in China to rise to ~30%/55% by 2025/2030…



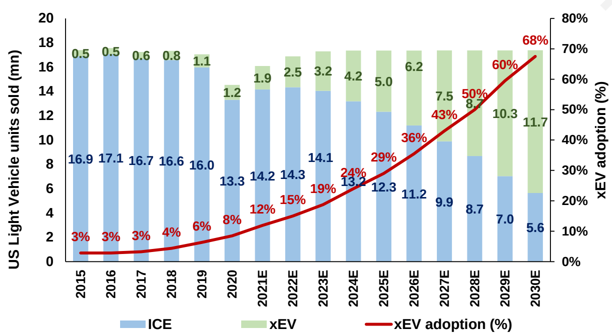
Source: Credit Suisse estimates (Global Auto Research team)

Figure 29: …leading to 18mn xEV cars in 2030 (2.5mn in 2020)



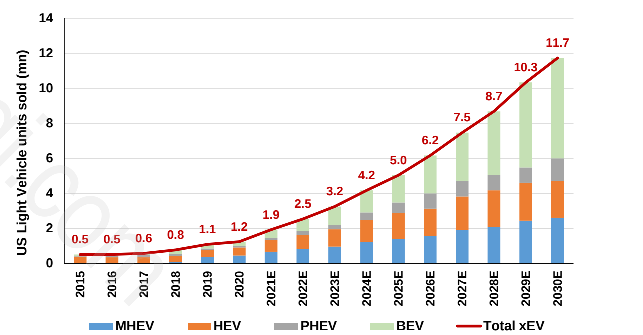
Source: Credit Suisse estimates (Global Auto Research team)

Figure 30: xEV in US to rise to ~30%/65% by 2025/2030…



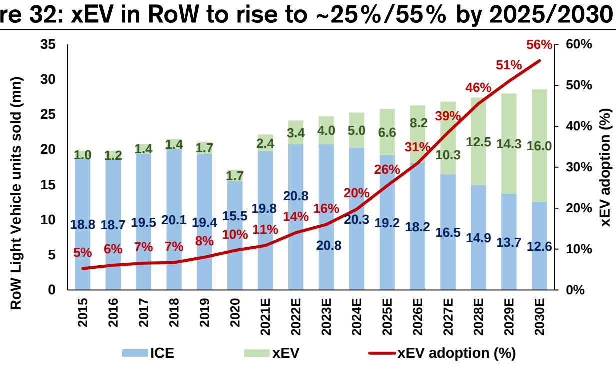
Source: Credit Suisse estimates (Global Auto Research team)

Figure 31: …leading to 12mn xEV cars in 2030 (1mn in 2020)



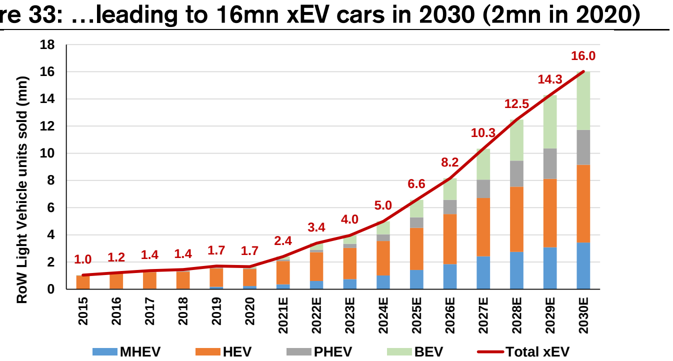
Source: Credit Suisse estimates (Global Auto Research team)

Figure 32: xEV in RoW to rise to ~25%/55% by 2025/2030…



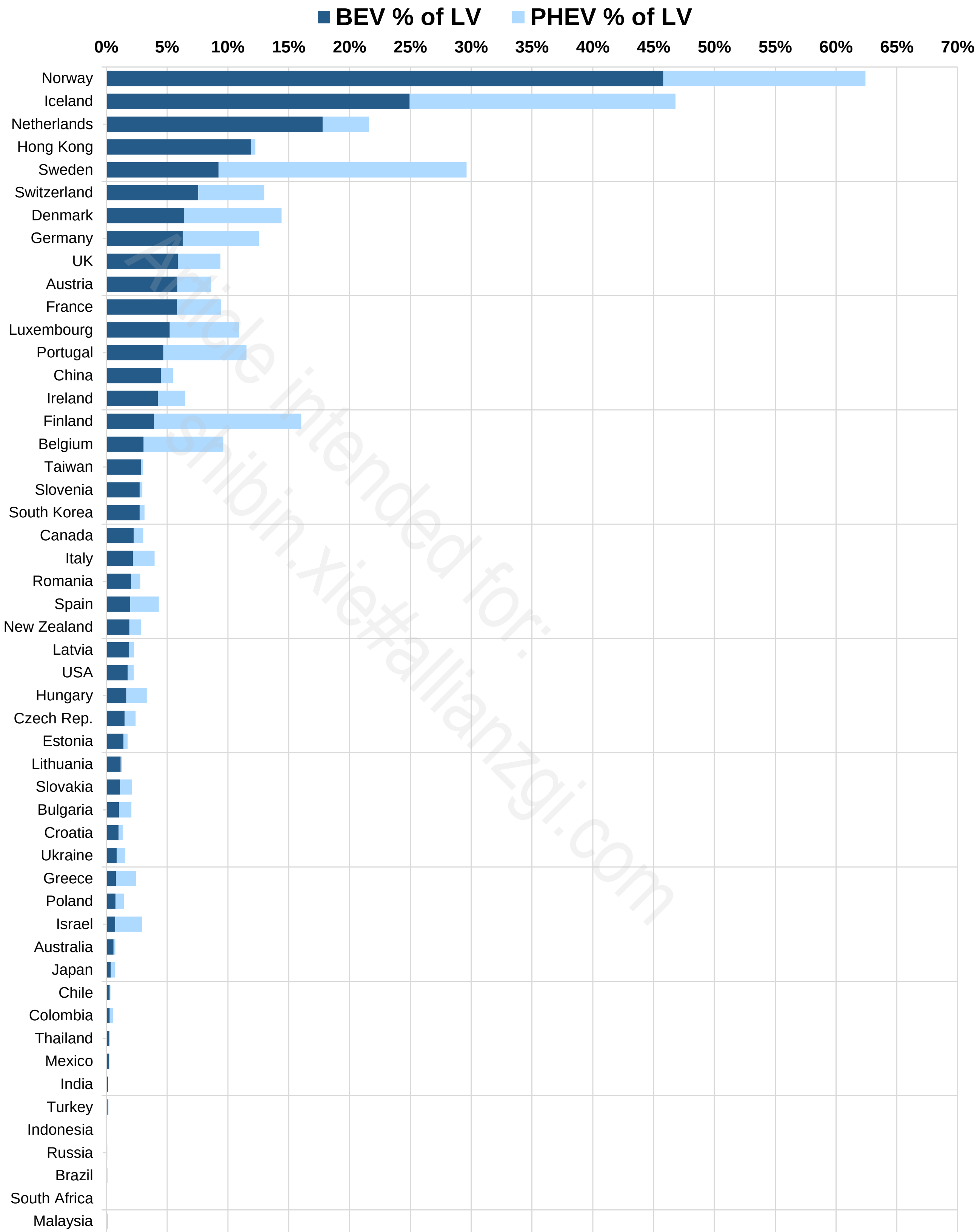
Source: Credit Suisse estimates (Global Auto Research team)

Figure 33: …leading to 16mn xEV cars in 2030 (2mn in 2020)



Source: Credit Suisse estimates (Global Auto Research team)

Figure 34: PHEV + BEV penetration in 2020 across different markets – EU countries are in the lead here

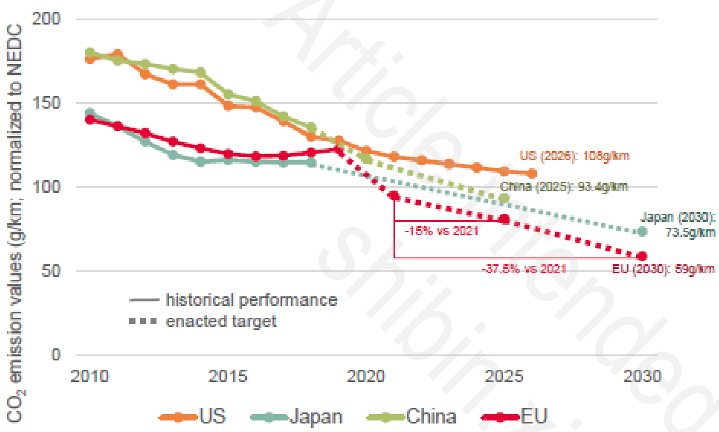


Source: Credit Suisse US Auto Research team

Multiple factors (push & pull) driving up the adoption

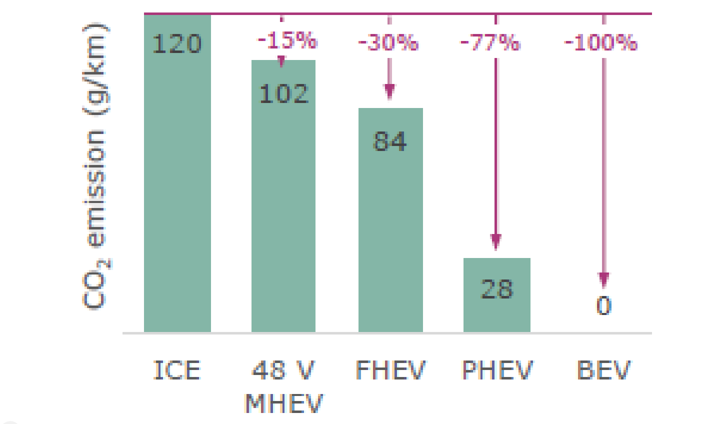
CO2 emission norms becoming more stringent. Even though regions/countries have different regulations around emission standards, there is a clear trend of moving to more stringent CO2 emission (g/km) regulations in all major geographical regions. According to ICCT data, the EU has one of the most stringent emission standards to reach 59g/km by 2030, representing a 37.5% decline from the desired level in 2021, while Japan is also targeting 73.5g/km by 2030. China and the US have shorter term and relatively less stringent targets, with China aiming to reach 93.4g/km by 2025 and US to reach 108g/km by 2026.

Figure 35: CO2 emission norms are getting more stringent: EU looking for 15%/37% reduction by 2025/2030 vs. 2021 levels



Source: ICCT (May 2020)

Figure 36: CO2 emission (tank to wheel): Typical reduction in emissions when moving from ICE to different types of xEV



Source: Infineon (Oct 2020)

Big subsidy push towards xEV. Over the last few months, a number of EU countries have increased and extended xEV incentive plans as one of the measures to boost economies, especially after COVID-19 (Figure 37). In fact, 4 of the 5 major EU countries (Germany, France, Spain, and Italy) have increased subsidies and extended the duration. It has been different from the responses in China and US. Despite China extending the EV incentive plan from 2020 to 2022, subsidy has been reduced by more than 10%, while the US has maintained same level of the tax credit since it was introduced in 2010.

Potential for increased push in the US under Biden administration. Under the leadership of President Joe Biden, who has made climate change a priority for his administration, we believe the US may become more aggressive in its push towards EV through a combination of fuel regulations, increased stimulus plans and consumer tax credits. Our US auto team has also published a note on the new US administration acting as a catalyst on EV adoption: US Autos & Auto Parts: New administration serves as catalyst to unlock US EV narrative.

- *Higher fuel efficiency for car fleets (CAFE)* – Corporate Average Fuel Economy (CAFE) is a metric to measure the fuel efficiency of the car fleet on an average. Under the Obama administration, carmakers were asked to increase this efficiency by 5% pa from 2021 to 2026, which was rolled back to 1.5% only by Trump administration. This resulted in fleet-wide gasoline usage of around 40.4mpg, well below the 46.7mpg target by 2026 set under Obama.
- *Cash for Clunkers* – Biden has expressed his support for 'cash for clunkers' rebate program which would encourage consumers to trade in their older ICE cars for new EVs.
- *Tax Credits* – Currently US consumers can get a federal tax credit of up to $7,500 (Figure 37) on the purchase of a BEV or PHEV model (although all models are not eligible), and also this incentive phases out once the car maker sells 200k EV units.
- *Infrastructure push* – Biden has promised $400bn in public investments around clean energy, which includes battery technologies and EVs. Lack of charging infrastructure and

slow charging times are one of the most common issues faced by prospective buyers. The US has only 29k public EV charging points, which is well below 136k gas stations.

- *Potential stimulus for start-up companies* – In addition to the above, the US government may also consider offering tax breaks, subsidized loans or R&D grants to new emerging companies in the space of EV as it hopes to close down the gap in EV adoption vs. both the EU and China.

Figure 37: Incentive plans for encouraging xEV adoption amongst consumers across some of the key countries

Country	Previous Incentive	Latest Incentive
Germany	From November 2020 to end of 2021: ▪ €6,000 for BEVs and FCEVs ▪ €4,500 for PHEVs and EREVs	From November 2020 to 2025: ▪ €9,000 for BEVs and FCEVs ▪ €6,750 for PHEVs and EREVs
France	▪ Up to €6,000 for vehicles emitting 20g CO2/km or less. ▪ €1,000 for PHEVs	From 1 June 2020: ▪ Up to €7,000 for vehicles emitting 20g CO2/km or less. ▪ €2,000 for PHEVs
Spain	From February 2019 (Plan: Move): ▪ Up to €5,500 for purely electric vehicles ▪ Up to €2,300 (up to a zero-emission range of 31.9 km), €3,600 (32 to 71.9 km) or €6,500 (from 72 km) for PHEVs	From July 2020 - waiting for official publishment (Plan: Move II): ▪ Up to €5,500 for purely electric vehicles and PHEVs
UK	▪ Up to £3,500 for BEVs ▪ No grant for PHEVs	From March 2020: ▪ Up to £3,000 for BEVs ▪ No grant for PHEVs
Italy	From March 2019: ▪ Up to €6,000 for BEVs ▪ Up to €2,500 for PHEVs	From 1 August 2020 to 31 December 2020: ▪ Up to €10,000 for BEVs ▪ Up to €6,500 for PHEVs
China	In 2019 (To be ended in end of 2020): ▪ Up to Rmb25,000 for BEVs ▪ Up to Rmb10,000 for PHEVs	From April 2020 (Extended from 2020 to 2022): ▪ Up to Rmb22,500 for BEVs ▪ Up to Rmb8,500 for PHEVs Subsidies will be decreased every year from 2020 to 2022
US	No incentive	From 2010: ▪ All federal taxes that depend on fuel consumption are waived for PEVs ▪ Up to $7,500 of federal tax credit for PEVs
Japan	From 2013: Up to JPY850,000 for BEVs	From 2015: Up to JPY400,000 for BEVs Up to JPY200,000 for PHEVs
Korea	From 2016: Up to KRW14mn for BEVs Up to KRW5mn for PHEVs	From 2020 to 2025: Up to KRW18.2mn for BEVs

Source: Credit Suisse research

Various governments also proposing outright bans on ICE cars in the future. EU countries have so far been more aggressive than China and NA on imposing ICE car bans in the near-term. For example, the UK is planning to ban the sale of all petrol/diesel cars from 2030 onwards, while Germany is also targeting 100% of new cars sales from xEV by 2030. France is also planning to ban all fossil fuel cars by 2040 (Figure 38).

Here again we believe that US states (barring a few recent examples) have remained well behind EU countries in taking that strict stance against gasoline cars. In September 2020, California became the first US state to announce a ban on fossil cars by 2035. This was followed by New Jersey's decision to reduce state emissions by 80% by 2050. And more recently Massachusetts (in January 2021) also declared its intention to ban gas-powered vehicles by 2035.

Figure 38: Targets set by different countries for EV installed base or EV as % of new car sales by 2025-2050; scope for US states to become more aggressive in their targets following recent announcements in California and New Jersey

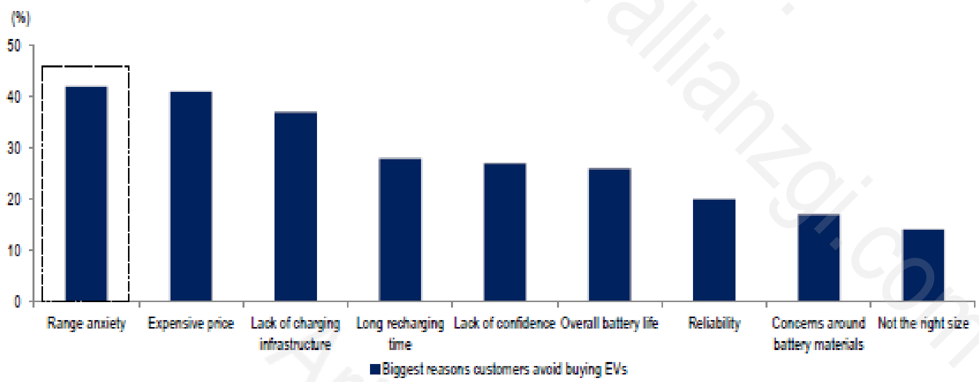
Country	Vehicle type	Target year	Targets (new sales or installed base)
Canada	Light duty vehicles	2025	10% EVs sold
		2030	30% EVs sold
		2040	100% EVs sold
China	Vehicles	2025	20% NEVs & 40% HEVs sold
		2030	40% NEVs & 45% HEVs sold
		2035	50% NEVs & 50% HEVs sold
Chile	Vehicles	2050	40% EVs sold
Costa Rica	Light duty vehicles	2035	25% EVs sold
		2050	100% ZEVs sold
Denmark	PVs	2030	No ICE sold; 1mn EVs on the road
		2035	No ICE or PHEVs sold
France	PVs & Light duty CVs	2023	500k PHEV & 660k BEV on the road
		2028	1.8mn PHEV & 3mn BEV on the road
		2040	No ICE sold
Germany	PVs	2030	7-10mn BEV/FCEV on the road
		2050	100% EVs sold
Iceland	PVs	2030	No ICE sold
India	PVs	2030	30% EVs sold
Ireland	PVs	2030	No ICE sold; 950k EVs on the road
Israel	PVs	2030	No ICE sold
Japan	PVs	2030	30-40% HEVs, 20-30% BEVs, 0-3% FCEVs sold

Country	Vehicle type	Target year	Targets (new sales or installed base)
Netherlands	PVs	2030	100% EVs sold
Norway	PVs	2025	100% EVs sold
	Light duty vans	2025	100% EVs sold
	Long distance coaches	2030	75% EVs sold
	Trucks	2030	50% EVs sold
Portugal	PVs	2040	No ICE sold
Scotland	PVs & Vans	2032	No ICE sold (may bring forward to 2025)
Singapore	Vehicles	2040	No ICE sold
Sri Lanka	Vehicles	2040	100% EVs or HEVs sold
Slovenia	PVs & Light duty CVs	2030	100% sold with less than 50g/km CO2
South Korea	PVs	2030	33% EVs sold
Spain	PVs	2030	100% EVs sold
Sweden	PVs	2030	No ICE sold
UK	PVs & Vans	2030	No ICE sold
California (US)	Vehicles	2030	5mn EVs on the road
		2035	100% EVs sold
New Jersey (US)	Light duty vehicles	2025	330k EVs sold
		2035	100% EVs sold
NY, Oregon, Rhode Island, Vermont, Washington, Connecticut, Maryland, Massachussets (US)	Vehicles	2050	100% EVs sold

Source: Credit Suisse research

Improvement in charging infrastructure availability. Looking at key areas of concern that a consumer has when looking to purchase an EV, we can see that range anxiety, price and lack of charging infrastructure are the top 3 concerns on the list (Figure 39). While improvements in IGBT technology and the ongoing shift from IGBT to SiC in premium models are likely to drive higher mileage in EVs, thereby alleviating some concerns around range anxiety, we are now starting to see renewed focus from governments on increasing the availability of charging infrastructure.

Figure 39: Lack of charging infrastructure still remains (at #3 from the top) a key area of concern for consumers looking to buy an EV car



Source: Autolist, Credit Suisse Korea research team

As per a study from IEA (International Energy Agency), the total number of charging points globally has increased from 2.3mn in 2016 to 7.3mn in 2019. But most of the growth has come from privately installed slow chargers at homes, with carports rising from around 2mn in 2016 to 6.5mn in 2019. Charging points in the public domain are still an area of work in progress with only around 860k in total globally, with ~60% of them being in China (50% of slow chargers and 80% of fast chargers installed for public use as we show in Figure 40).

Figure 40: Total of 7.3mn charging points installed globally (2019) – although still majority is privately installed showing need for fast charging points in public domain

Charging Infra	Private Slow Chargers	Public Slow Chargers	Public Fast Chargers
China	37%	50%	81%
Japan	3%	4%	3%
US	24%	11%	5%
UK	4%	4%	2%
Germany	5%	6%	1%
France	5%	4%	1%
Norway	5%	1%	2%
Netherlands	4%	8%	0%
Others	13%	12%	5%
Total charging points	**6.5 mn**	**0.60 mn**	**0.26 mn**

Source: IEA (International Energy Agency), Credit Suisse research

Auto OEMs now re-aligning their strategy to EVs. Given a combination of all the factors mentioned above, we have seen a number of car makers in the last few months either re-align their manufacturing/partnership strategy to help accelerate their EV production plans, or already announced a number of new model launches with an aim to participate in this ongoing EV transition theme.

Figure 41: List of top PHEV + BEV car makers globally: Tesla accounted for 15% of total sales in 2020 followed by VW at 13%

OEM (PHEV + BEV unit sales) ('000)	2018	mkt share (%)	2019	mkt share (%)	2020	mkt share (%)
Tesla Inc.	246	12%	367	16%	499	15%
VW Group	83	4%	142	6%	424	13%
R-N-M Alliance	197	9%	205	9%	247	8%
GM	83	4%	95	4%	215	7%
Hyundai Motor	83	4%	132	6%	206	6%
BMW Group	143	7%	151	7%	196	6%
BYD	234	11%	226	10%	184	6%
Daimler AG	38	2%	46	2%	182	6%
Volvo (+Geely)	107	5%	121	5%	160	5%
PSA Group	10	0%	9	0%	123	4%
SAIC	98	5%	78	3%	103	3%
GAC	24	1%	46	2%	62	2%
Toyota Motor	50	2%	60	3%	59	2%
Great Wall Motors	20	1%	39	2%	57	2%
Chery Automobile	66	3%	41	2%	46	1%
NIO Inc.	12	1%	21	1%	44	1%
Ford	12	1%	11	0%	37	1%
BAIC	165	8%	165	7%	37	1%
CHJ Automotive	0	0%	0	0%	33	1%
Changan Automobile	35	2%	39	2%	32	1%
Tata-JLR	16	1%	31	1%	32	1%
Xiaopeng	1	0%	14	1%	27	1%
Dongfeng Motor	41	2%	42	2%	27	1%
All Others	327	16%	194	9%	217	7%
Total	**2,091**	**100%**	**2,274**	**100%**	**3,251**	**100%**

Source: Credit Suisse research

Figure 42 shows where the leading global car OEMs are in terms of penetration as of 2020 (PHEV + BEV cars sold out of their total auto production units), and where they are aiming to reach over the next 5-10 years. A number of these car makers especially in the EU and China have noted an intent to go all electric (some form of electrification either hybrid or battery electric) by either 2025 (PSA, JLR, BAIC, SAIC) or 2030 (Volvo, Ford Europe).

Figure 42: PHEV + BEV penetration at leading car OEMs in 2020, and their long-term targets or plans for xEV adoption

Auto OEM	Total auto production units (2020)	PHEV + BEV sales unit (2020)	PHEV + BEV penetration (%)	Target (long term)
Toyota	9,470,177	59,147	0.6%	Aims to sell more than 5.5mn xEVs (incl. over 1mn BEV or FCEV) by 2030
Volkswagen	9,047,089	424,341	4.7%	70% of all VW group cars sold to be pure electric by 2030 (vs. old target of 50%)
Renault-Nissan-Mitsubishi	7,125,130	247,284	3.5%	Half of its EU launches will be pure-electric by 2025; Hybrid powertrains to account for 35% of sales (EVs at 30%)
Hyundai	6,299,290	205,802	3.3%	Hyundai & Kia plan to introduce 23 new EV models and sell 1mn units annually by 2025
General Motors	5,120,628	215,261	4.2%	Targeting 1mn EV sales by mid-2020; Aiming to go all-electric by 2035
Honda	4,428,172	19,920	0.4%	Aiming for 100% of its EU auto sales to be electric by 2025; Plans to achieve 2/3rd (15% EV + FCV & 50% HEV + PHEV) of its global sales to be electric by 2030
Ford	4,270,747	37,100	0.9%	All EU cars to be electrified (electric or hybrid) by mid-2026; All EU cars to be pure electric by 2030
FCA	3,828,448	22,913	0.6%	
PSA	2,684,807	123,342	4.6%	Aiming for 100% of its cars to offer some form of electric powertrain by 2025
Daimler	2,597,413	182,418	7.0%	Aims to have >50% of car sales coming from PHEV + BEV by 2030; carbon neutral (full EV) by 2039
Suzuki	2,532,812	2,409	0.1%	
BMW	2,359,304	195,979	8.3%	Aims to generate 1/4th of sales from electrified cars in 2021, rising to 1/3rd in 2025 and 50% by 2030
Geely	1,965,330	160,069	8.1%	Geely's Volvo aims to become 50% electric by 2025, and fully electric by 2030
SAIC-GM-Wuling	1,562,593	103,272	6.6%	Aims to electrify all models by 2025; 100 new EV models (incl. 20 PHEV and 10 FCEV) by then
Changan	1,467,044	32,270	2.2%	
Mazda	1,190,840	9,563	0.8%	
Great Wall	1,063,618	57,457	5.4%	
Subaru	862,945	2,304	0.3%	40% of all sales to have some form of electrification by 2030; all models to offer electrification by 2035
SAIC	794,633	103,272	13.0%	
Tata	705,695	34,210	4.8%	JLR to go full electric by 2025
BAIC	689,574	36,577	5.3%	Aims to go all electric by 2025
Dongfeng	573,162	26,747	4.7%	
Chery	571,274	46,361	8.1%	
Tesla	491,221	499,453	101.7%	Ambitions to reach as high as 20mn vehicles by 2030
BYD	428,004	183,769	42.9%	

Source: Credit Suisse research

xEV accelerating Auto Semis; Power to drive content per car to grow >2x by 2030

Auto production trends over time. The auto industry hit peak production of 95mn LV (light vehicles) in 2015. But since then it has fallen to the 75mn level in 2020 due to a number of issues such as EU WLTP (2018), China slowdown (2018-19) and finally COVID-19 (2020). With the industry now in a recovery mode, albeit still struggling with chip supply constraints, we expect the global auto production units to reach 91mn by 2023 and 95mn by 2025 (Figure 43).

Figure 43: IHS forecasting global LVP units of 85mn in 2021 (+13% yoy) after seeing 16% decline in 2020

Auto production	CY06	CY07	CY08	CY09	CY10	CY11	CY12	CY13	CY14	CY15	CY16	CY17	CY18	CY19	CY20	CY21E	CY22E	CY23E	CY24E	CY25E
Europe	20.7	22.0	20.8	16.5	19.0	20.2	19.3	19.5	20.1	21.0	21.5	22.2	22.0	21.2	16.6	19.0	20.1	20.4	20.7	20.7
% change yoy	3%	6%	-6%	-21%	15%	6%	-4%	1%	3%	4%	3%	3%	-1%	-4%	-22%	14%	6%	2%	2%	0%
N America	15.3	15.1	12.6	8.6	11.9	13.1	15.4	16.2	17.0	17.5	17.8	17.1	17.0	16.3	13.0	16.2	16.8	16.7	16.5	16.5
% change yoy	-3%	-1%	-16%	-32%	39%	10%	18%	5%	5%	3%	2%	-4%	-1%	-4%	-20%	24%	3%	-1%	-1%	0%
China	7.0	8.4	8.8	13.1	17.1	17.6	18.6	21.3	23.0	24.0	27.4	28.0	26.9	24.7	23.6	25.0	26.0	27.0	28.2	29.5
% change yoy	23%	20%	5%	48%	31%	3%	5%	14%	8%	4%	14%	2%	-4%	-8%	-4%	6%	4%	4%	5%	4%
Japan + Korea *	10.9	11.0	10.9	7.6	9.1	7.9	9.4	9.0	9.2	8.8	8.7	13.3	13.2	13.1	11.2	12.1	12.2	12.1	12.2	12.4
% change yoy	6%	1%	-1%	-30%	20%	-13%	20%	-4%	2%	-5%	0%	52%	0%	-1%	-14%	8%	1%	0%	1%	1%
Rest of APAC	8.1	8.6	8.8	8.3	10.8	11.5	12.8	12.6	12.2	12.5	12.6	8.7	9.2	8.4	6.2	7.4	8.4	9.2	9.7	10.3
% change yoy	3%	7%	2%	-6%	31%	6%	11%	-1%	-3%	2%	1%	-31%	6%	-8%	-27%	20%	13%	10%	5%	6%
Latin America	3.0	3.6	3.8	3.7	4.2	4.3	4.3	4.5	3.8	3.1	2.7	3.3	3.4	3.3	2.2	3.0	3.3	3.5	3.6	3.8
% change yoy	7%	18%	5%	-2%	13%	4%	-1%	6%	-15%	-19%	-11%	20%	4%	-4%	-32%	33%	10%	6%	3%	5%
MEA	1.7	1.8	1.8	1.7	2.1	2.3	1.8	1.5	2.0	2.0	2.3	2.6	2.6	2.0	1.8	2.0	2.1	2.2	2.3	2.4
% change yoy	15%	3%	0%	-4%	22%	9%	-23%	-13%	28%	2%	15%	14%	-2%	-21%	-12%	14%	3%	5%	3%	6%
Global units (mn)	**66.8**	**70.6**	**67.5**	**59.4**	**74.3**	**76.9**	**81.5**	**84.7**	**87.4**	**88.8**	**93.1**	**95.2**	**94.2**	**89.0**	**74.6**	**84.6**	**88.7**	**91.1**	**93.3**	**95.5**
% change yoy	4%	6%	-4%	-12%	25%	3%	6%	4%	3%	2%	5%	2%	-1%	-6%	-16%	13%	5%	3%	2%	2%

*Japan + Korea * denotes that only Japan data till 2016, Japan + Korea after 2016*

Source: US Autos Research team (IHS), Credit Suisse research

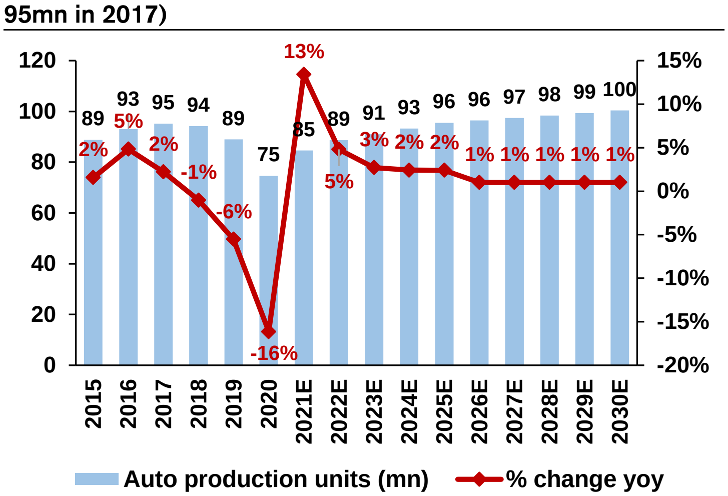
Figure 44: New car sales: China leading the auto demand recovery, US also showing decent recovery, but EU lagging well behind – overall we have seen yoy growth in monthly car sales in key markets we track for the last 5 out of 6 months now

	Units													
Units sold	**Jan-20**	**Feb-20**	**Mar-20**	**Apr-20**	**May-20**	**Jun-20**	**Jul-20**	**Aug-20**	**Sep-20**	**Oct-20**	**Nov-20**	**Dec-20**	**Jan-21**	**Feb-21**
Europe	**1,134,898**	**1,066,794**	**853,077**	**292,182**	**623,812**	**1,131,843**	**1,281,740**	**884,394**	**1,300,048**	**1,129,223**	**1,049,409**	**1,214,581**	**842,835**	**828,899**
yoy % change	-7%	-7%	-52%	-78%	-57%	-24%	-4%	-18%	1%	-7%	-13%	-4%	-26%	-22%
Germany	246,300	239,943	215,119	120,840	168,148	220,272	314,938	251,044	265,170	274,303	290,150	311,394	169,754	194,000
yoy % change	-7%	-11%	-38%	-61%	-49%	-32%	-5%	-20%	8%	-4%	-3%	10%	-31%	-19%
France	134,229	167,782	62,668	20,997	96,310	233,818	178,981	103,637	168,291	171,049	126,048	186,323	126,381	132,637
yoy % change	-13%	-3%	-72%	-89%	-50%	1%	4%	-20%	-3%	-9%	-27%	-12%	-6%	-21%
UK	149,279	79,594	254,684	4,321	20,247	145,377	174,887	87,226	328,041	140,945	113,781	132,682	90,249	51,312
yoy % change	-7%	-3%	-44%	-97%	-89%	-35%	11%	-6%	-4%	-2%	-27%	-11%	-40%	-36%
Italy	155,528	163,124	28,326	4,279	99,711	132,457	135,992	88,801	156,132	156,569	138,405	119,454	134,001	142,998
yoy % change	-6%	-9%	-85%	-98%	-49%	-23%	-11%	0%	10%	0%	-8%	-15%	-14%	-12%
Spain	86,442	94,618	37,644	4,163	34,337	82,651	117,929	66,925	70,729	74,228	75,708	105,841	41,966	58,279
yoy % change	-8%	-6%	-69%	-97%	-73%	-37%	1%	-10%	-13%	-21%	-19%	0%	-51%	-38%
Russia	**99,369**	**119,073**	**162,321**	**38,922**	**63,033**	**122,622**	**141,924**	**137,517**	**154,409**	**154,164**	**157,580**	**166,666**	**95,213**	**120,081**
yoy % change	-1%	-2%	4%	-72%	-52%	-15%	7%	-1%	3%	7%	6%	-2%	-4%	1%
Asia (top 4)	**2,330,539**	**1,010,278**	**1,928,600**	**1,935,864**	**2,057,701**	**2,396,847**	**2,391,368**	**2,411,268**	**2,978,563**	**2,885,653**	**3,126,511**	**3,173,964**	**2,832,417**	**1,977,055**
yoy % change	-17%	-51%	-37%	-16%	-12%	-5%	4%	3%	6%	9%	10%	9%	22%	96%
China	1,590,968	225,001	1,032,819	1,500,097	1,635,035	1,728,686	1,631,702	1,721,538	2,052,466	2,071,169	2,257,964	2,328,341	2,027,801	1,134,788
yoy % change	-20%	-81%	-48%	-2%	6%	2%	9%	6%	8%	9%	12%	7%	27%	404%
Japan	360,103	430,185	581,438	270,393	218,285	347,371	396,346	326,436	469,705	407,000	411,601	380,000	384,442	432,300
yoy % change	-12%	-10%	-9%	-29%	-45%	-23%	-14%	-16%	-14%	29%	7%	10%	7%	0%
India	262,226	256,645	143,014	0	36,860	116,969	197,523	234,343	292,883	249,860	286,436	276,544	303,904	308,611
yoy % change	-6%	-6%	-51%	-100%	-85%	-48%	-2%	20%	31%	-9%	9%	17%	16%	20%
Korea	117,242	98,447	171,329	165,374	167,521	203,821	165,797	128,951	163,509	157,624	170,510	189,079	116,270	101,356
yoy % change	-14%	-18%	10%	7%	9%	41%	10%	-6%	23%	0%	5%	8%	-1%	3%
North America	**1,257,432**	**1,186,291**	**1,086,449**	**756,660**	**1,224,947**	**1,266,750**	**1,390,546**	**1,485,465**	**1,521,519**	**1,518,709**	**1,343,616**	**1,723,312**	**1,200,468**	**1,308,662**
yoy % change	1%	-14%	-39%	-50%	-28%	-25%	-11%	-19%	6%	1%	-14%	4%	-5%	10%
US	1,147,444	1,061,232	990,332	710,827	1,111,723	1,111,311	1,225,526	1,319,628	1,351,643	1,361,858	1,214,891	1,616,577	1,109,578	1,196,008
yoy % change	1%	-16%	-38%	-47%	-30%	-26%	-12%	-20%	6%	1%	-14%	5%	-3%	13%
Canada	109,988	125,059	96,117	45,833	113,224	155,439	165,020	165,837	169,876	156,851	128,725	106,735	90,890	112,654
yoy % change	1%	3%	-47%	-75%	-44%	-16%	-5%	-9%	2%	-2%	-10%	-3%	-17%	-10%
Brazil	**154,581**	**165,150**	**131,276**	**39,501**	**50,290**	**107,872**	**140,229**	**147,917**	**166,219**	**173,648**	**182,799**	**199,912**	**130,804**	**128,111**
yoy % change	-5%	2%	-23%	-79%	-75%	-41%	-28%	-25%	-12%	-15%	-7%	-7%	-15%	-22%
Key Markets	**4,976,819**	**3,547,586**	**4,161,723**	**3,063,129**	**4,019,783**	**5,025,934**	**5,345,808**	**5,066,562**	**6,120,758**	**5,861,397**	**5,859,915**	**6,478,434**	**5,101,737**	**4,362,808**
yoy % change	-10.4%	-27.5%	-40.1%	-44.4%	-30.6%	-16.7%	-3.4%	-9.3%	4.3%	2.6%	-1.5%	4.2%	2.5%	23.0%
US + China + EU5	**3,510,190**	**2,031,294**	**2,621,592**	**2,365,524**	**3,165,511**	**3,654,572**	**3,779,955**	**3,638,799**	**4,392,472**	**4,250,121**	**4,216,947**	**4,800,612**	**3,699,730**	**2,910,022**
yoy % change	-11.6%	-37.8%	-46.8%	-38.1%	-23.9%	-14.9%	-1.2%	-8.5%	5.6%	3.4%	-2.1%	4.4%	5.4%	43.3%

Source: Credit Suisse (China & US Auto Research team)

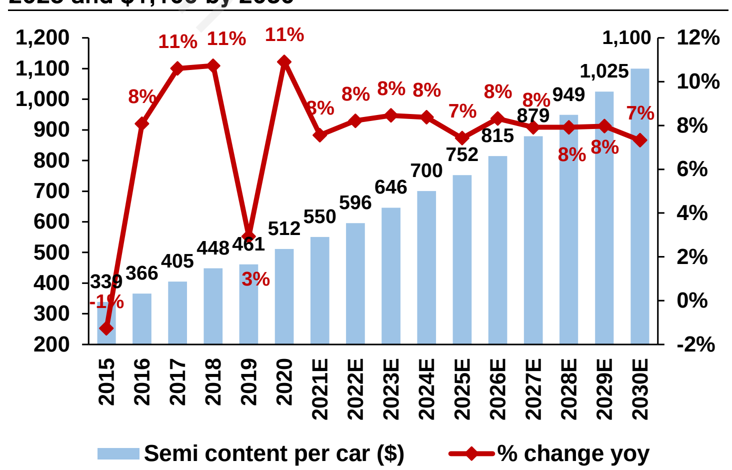
Auto unit + Semis content growth ahead. After meaningful correction in auto units over 2017-2020, units are on track to recover for the next 3 years before likely to stabilize. At the same time, we have seen that semi content per car has seen a significant acceleration from 3% CAGR over 2010-2015 to 9% CAGR over 2015-2020. This has resulted in continued growth in the auto semis market (except 2019/20). Now with auto units recovering along with continued acceleration in content per car, we believe that the auto chip market may see growth of 10%+ p.a. over 2021-2025 and around 9% CAGR over 2025-2030.

Figure 45: Global Auto production – we model global units to reach 91mn in 2023 and 96mn by 2025 (previous peak was 95mn in 2017)



Source: IHS, Credit Suisse US Auto Research team, Credit Suisse estimates

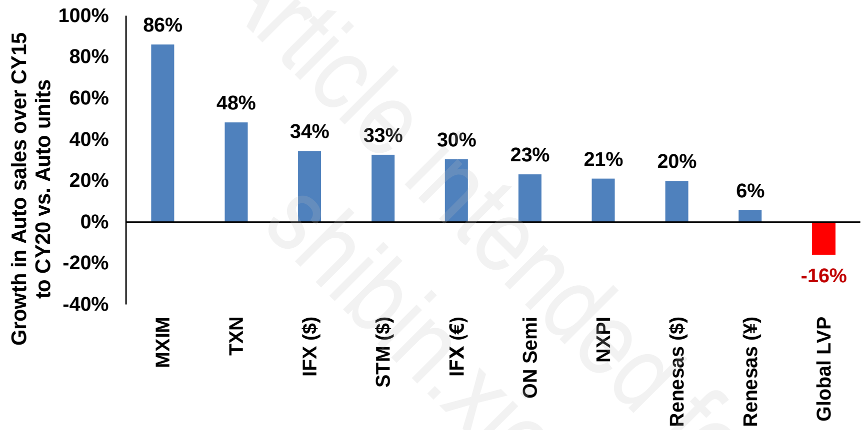
Figure 46: Semi content per car can grow by over 2x in the next decade – around $510 per car in 2020 to nearly $750 by 2025 and $1,100 by 2030



Source: Gartner, Credit Suisse estimates

Chip vendors significantly outgrowing LVP units… All the leading chip vendors globally have continued to outgrow the auto production units by a significant margin given rising content per car along with smaller vendors continuing to lose share over time, especially in faster growing areas of EV (electrification), advanced sensors and connectivity. For example, Maxim, TXN, IFX and STM have significantly benefitted from these trends. IFX's auto related sales have cumulatively grown at 34% (in USD terms excluding M&A benefits) over last the 5 years during CY15 to CY20, when global LVP has declined from 89mn to 75mn (or 16% lower) during the same period as we show in Figure 47. Even in 2020, when LVP was down 16% yoy, we believe the global auto semis market was only down around 7-8% yoy based on full year revenues reported by leading semis suppliers.

Figure 47: Cumulative growth in Auto related sales for key chip vendors over CY2015 to CY2020, when global auto production units have fallen by 16% over that period…



Source: Company data, Credit Suisse research

… the trend may even accelerate as semi content story remains intact. As we show in Figure 48, average semi content per car continues to rise, driven by new features around electrification, safety and connectivity. For example, semi content per car has grown at 6% CAGR from around $300 in 2010 to $510 in 2020 although the rate of growth has been higher than 6% in recent years. As such, we continue to model semis content to continue to grow to around $750 by 2025 and $1,100 by 2030 (8% CAGR over 2020-2030).

Figure 48: Over the last decade, growth in Auto semis sales has outperformed LVP unit growth by 6ppt per year on average; this has been higher at 7ppt over 2015-2020, and we expect an average of 8ppt of outperformance over 2021-2030

Auto (Light Vehicles)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production units (mn)	**66.8**	**70.6**	**67.5**	**59.4**	**74.3**	**76.9**	**81.5**	**84.7**	**87.4**	**88.8**	**93.1**	**95.2**	**94.2**	**89.0**	**74.6**
% change yoy		6%	-4%	-12%	25%	3%	6%	4%	3%	2%	5%	2%	-1%	-6%	-16%
Auto Semis revenue ($ bn)	**18.0**	**20.0**	**20.0**	**15.8**	**22.0**	**24.2**	**25.0**	**27.1**	**30.0**	**30.1**	**34.1**	**38.5**	**42.2**	**41.0**	**38.2**
% change yoy		11%	0%	-21%	39%	10%	3%	8%	11%	0%	13%	13%	10%	-3%	-7%
Semi content per car ($)	**270**	**283**	**296**	**267**	**297**	**315**	**307**	**320**	**343**	**339**	**366**	**405**	**448**	**461**	**512**
% change yoy		5%	4%	-10%	11%	6%	-3%	4%	7%	-1%	8%	11%	11%	3%	11%
Auto Semis growth O/P vs. LV units		**5%**	**4%**	**-9%**	**14%**	**6%**	**-3%**	**5%**	**7%**	**-1%**	**8%**	**11%**	**11%**	**3%**	**9%**

												CAGR		
Auto (Light Vehicles)	**2020**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**2028E**	**2029E**	**2030E**	**2010-15**	**2015-20**	**2010-20**
Production units (mn)	**74.6**	**84.6**	**88.7**	**91.1**	**93.3**	**95.5**	**96.5**	**97.4**	**98.4**	**99.4**	**100.4**	3.6%	-3.4%	0.0%
% change yoy	-16%	13%	5%	3%	2%	2%	1%	1%	1%	1%	1%			
Auto Semis revenue ($ bn)	**38.2**	**46.6**	**52.8**	**58.8**	**65.3**	**71.8**	**78.6**	**85.7**	**93.4**	**101.8**	**110.4**	6.4%	4.9%	5.7%
% change yoy	-7%	22%	13%	11%	11%	10%	9%	9%	9%	9%	8%			
Semi content per car ($)	**512**	**550**	**596**	**646**	**700**	**752**	**815**	**879**	**949**	**1,025**	**1,100**	2.7%	8.6%	5.6%
% change yoy	11%	8%	8%	8%	8%	7%	8%	8%	8%	8%	7%			
Auto Semis growth O/P vs. LV units	**9%**	**9%**	**9%**	**9%**	**9%**	**8%**	**8%**	**8%**	**8%**	**8%**	**7%**	**5%**	**7%**	**6%**

Source: Gartner (Auto Semis sales till 2019), IHS (LVP units till 2020), Credit Suisse estimates

Power to drive >25% of incremental growth in Auto semis over the next 5 years. Rising semi content in Autos will result in the Auto semis market growing from $38bn in 2020 to $72bn by 2025, and further to $110bn by 2030 on our estimates. Of this, we expect Power semis to account for over 20% of total Auto semis in the long term. Over the next 5 years (2020-2025), we expect Auto Power semis market to grow by an additional $7bn in revenues, accounting for 21% of the incremental $33bn growth we expect to see in the overall Auto semis market (Figure 49). With the traditional auto (ICE cars) market likely to decline longer term, power semis going into the xEV market should account for nearly 25% of the incremental growth in overall Auto semis, and over 100% of the growth in Auto Power semis. Here, IGBT will remain the key technology platform, driving the bulk of the growth in xEV power semis till 2025, but with SiC gradually rising in the mix, we expect SiC to contribute much higher percentage of growth from 2025-2030.

Figure 49: Power semis accounts for ~20% of the overall Auto semis market; nearly 25% of incremental growth in Auto semis over the next 10 years to be driven by Power semis used in xEV cars

																	Incremental growth ($ bn)		
Market size ($ bn)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2026E**	**2027E**	**2028E**	**2029E**	**2030E**	**2015-2020**	**2020-2025**	**2025-2030**
Auto Semis market	**30.1**	**34.1**	**38.5**	**42.2**	**41.0**	**38.2**	**46.6**	**52.8**	**58.8**	**65.3**	**71.8**	**78.6**	**85.7**	**93.4**	**101.8**	**110.4**	**8.1**	**33.7**	**38.5**
% change yoy	0%	13%	13%	10%	-3%	-7%	22%	13%	11%	11%	10%	9%	9%	9%	9%	8%			
Auto Power Semis	**6.7**	**7.1**	**7.5**	**7.8**	**7.6**	**7.1**	**8.4**	**9.8**	**11.4**	**12.7**	**14.2**	**15.8**	**17.6**	**19.6**	**21.6**	**23.6**	**0.4**	**7.1**	**9.4**
% change yoy	2%	6%	5%	4%	-2%	-8%	18%	17%	16%	12%	11%	11%	11%	12%	10%	9%			
Power as % of Auto semis	22%	21%	19%	18%	19%	19%	18%	19%	19%	20%	20%	20%	21%	21%	21%	21%	5%	21%	24%
ICE Power Semis	**6.1**	**6.3**	**6.4**	**6.3**	**5.8**	**4.6**	**5.0**	**4.8**	**4.5**	**4.2**	**3.9**	**3.5**	**3.1**	**2.7**	**2.4**	**2.0**	**(1.4)**	**(0.7)**	**(1.9)**
xEV Power Semis	**0.6**	**0.8**	**1.1**	**1.5**	**1.9**	**2.4**	**3.4**	**5.0**	**6.9**	**8.5**	**10.2**	**12.2**	**14.4**	**16.9**	**19.3**	**21.6**	**1.8**	**7.8**	**11.4**
% change yoy	12%	27%	35%	40%	24%	31%	38%	48%	39%	23%	20%	20%	18%	17%	14%	12%			
IGBT Power	0.6	0.8	1.1	1.4	1.7	2.1	2.8	4.1	5.4	6.4	7.3	8.3	9.1	9.9	10.3	10.6	1.5	5.2	3.3
SiC Power	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.9	1.5	2.1	2.9	4.0	5.3	7.0	9.0	11.0	0.3	2.6	8.1

Source: Gartner, Company data, Credit Suisse estimates

Growing importance of BMS in EV adoption. The battery management system (BMS) is critically important for electric vehicles given their task of monitoring and modulating the charge levels of the battery. Wireless BMS works the same way as traditional BMS (and serves the same function), but each module is interconnected via a wireless connection instead of a cable/wire – thereby providing the additional benefit of lessening the weight of the vehicle and also increasing the battery range. These systems are important for 3 main reasons – protecting the battery, the job of an electronic 'fuel gauge', and monitoring health and safety of the battery pack – in addition to other things such as optimizing battery performance, regulating the temperature of the engine, data aggregation and error correction.

Bottom-up TAM sizing for the BMS market. It is estimated that current BMS content in a vehicle ranges from $30-$100/unit but should grow to $60-$200/unit with increased unit electrification and wBMS capabilities. This implies that the potential TAM could be ~$4-5bn – with 30-40m EV units or ~35-40% penetration of CY25 total Auto SAARs. In other words, BMS TAM by CY25 could surpass the total CY20 Auto revenues of NXPI, ADI, and MXIM combined.

Figure 50: Sensitivity analysis for bottom-up TAM for the BMS market

CY20	
EV/HEV Units (m)	9.5
Total Units (m)	75
% Penetration	12.7%

CY25 CS Estimates	
EV/HEV Units (m)	41.5
Total Units (m)	95.5
% Penetration	43.5%

CY25 BMS TAM Sensitivity ($m)					
BMS Content/Unit ($)	# of EV Vehicles (m units)				
	20.0	30.0	40.0	50.0	60.0
$30	$600	$900	$1,200	$1,500	$1,800
$60	$1,200	$1,800	$2,400	$3,000	$3,600
$100	$2,000	$3,000	$4,000	$5,000	$6,000
$130	$2,600	$3,900	$5,200	$6,500	$7,800
$160	$3,200	$4,800	$6,400	$8,000	$9,600
$200	$4,000	$6,000	$8,000	$10,000	$12,000

Source: Credit Suisse estimates

SiC has now replaced IGBT as the technology of choice

In this section, we examine the key requirements for power-related chips used in the EV market, and why Silicon Carbide (SiC) is replacing insulated gate bipolar transistors (IGBT) as the technology of choice, especially in premium model launches.

SiC starting to take center stage from IGBT

Here, we focus on the benefits of SiC as a material over Silicon (Si). Given its unique properties, SiC has several advantages in high-power applications when using SiC-based transistors (MOSFETs) vs. IGBT transistors based only on Si.

Unique properties of SiC

SiC – band gap ~3x higher than Si. Band gap is the energy required to move an electron from its non-conductive state (valence band) to a conductive state. With a band gap of around 3.3, which is ~3x higher than Si (as shown in Figure 51), SiC results in low leakage at high voltage and higher temperatures. This makes SiC a more efficient material for making chips to be used in high-power applications such as xEV and electricity grids.

Figure 51: High band gap, electric field and electron velocity properties are good for applications requiring high frequency and high voltage; High conductivity and electric field are good for applications needing high power and high voltage

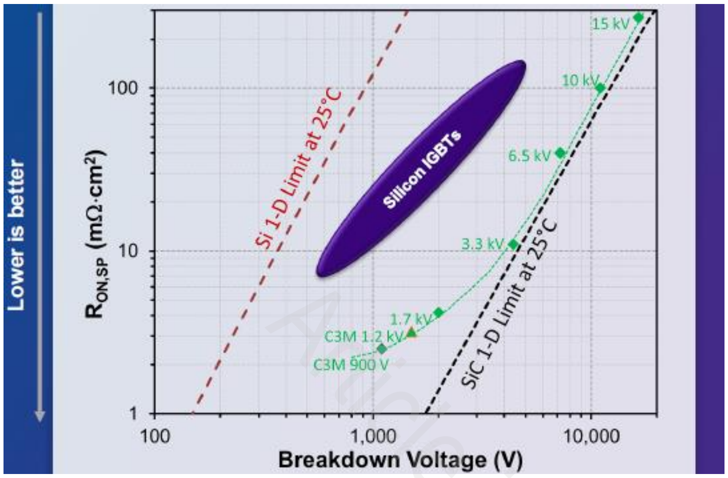
Property	SiC advantage		
E_g (eV) - band gap	x3	Si	1.1
		SiC	3.3
v_{sn} (cm/s) – electron saturation velocity	x2	Si	1x10^7
		SiC	2x10^7
μ_n (cm²/Vs) – electron mobility	~	Si	1350
		SiC	950
e_r - dielectric constant	~	Si	11.8
		SiC	9.7
E_c (V/cm) - critical electric field	x15	Si	2x10^5
		SiC	3x10^6
k (W/cm K) - thermal conductivity	x3	Si	1.5
		SiC	5

Source: Company data (STM – Sep 2019)

SiC's critical electric field up to 15x higher than Si. SiC also has properties to withstand up to a 10-15x higher electric field than Si. This property is useful when looking to configure transistors at higher voltage (600V to a few kV) through a thin drift layer and higher impurity concentration. Given that most of the resistance in any transistor is located in the drift layer, having a thin drift layer makes it possible to allow higher voltages to flow through the device with an extremely low ON-resistance per unit area.

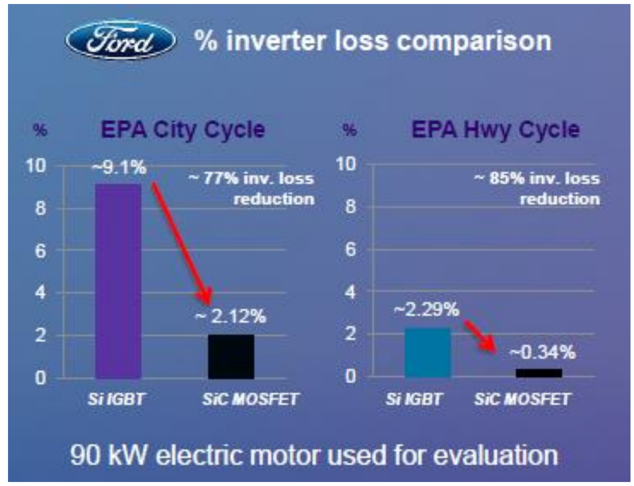
Si-based chips also try to achieve a minimal increase in ON-resistance at a higher voltage using IGBT technology, but this results in higher switching losses, which then leads to higher heat dissipation and limited ability to operate at higher frequency.

Figure 52: SiC offers much lower ON-resistance at higher voltage than both Si and IGBT…



Source: Company data (CREE – Nov 2019)

Figure 53: …which allows for significantly lower inverter losses (75-85% lower) than IGBT-based electric cars



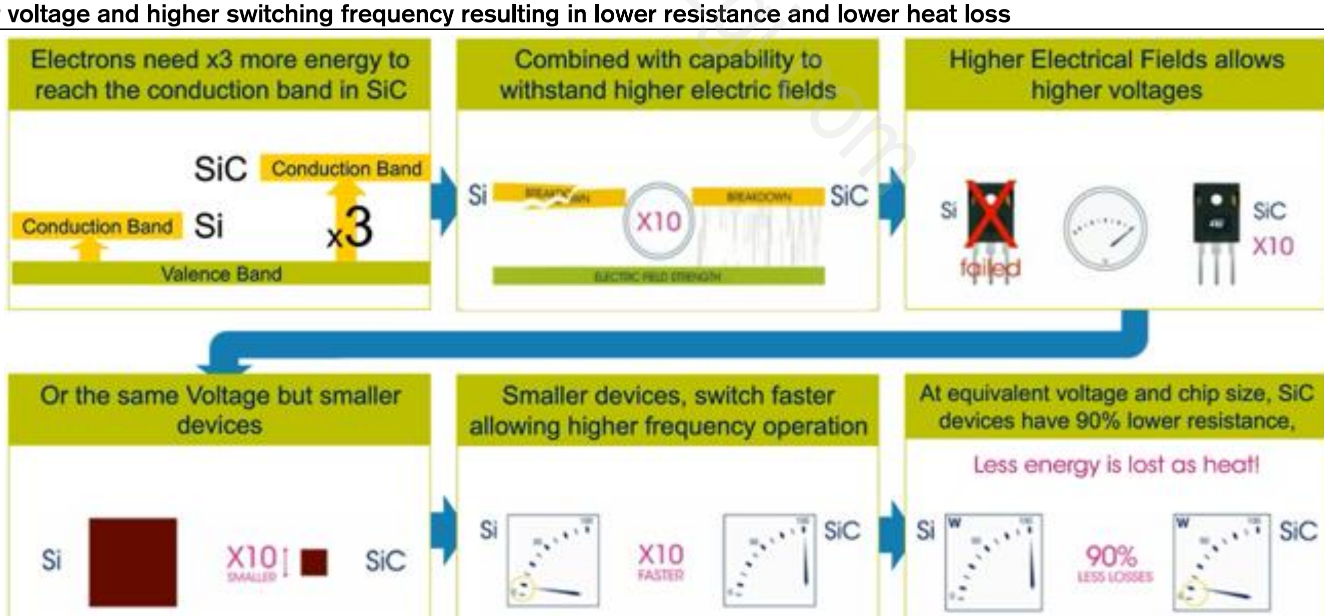
Source: Company data (CREE – Nov 2019)

SiC has ~3x the thermal conductivity of Si. Another key feature of SiC is its high thermal conductivity, as a higher number here represents the ease with which heat caused by the power loss can be removed, which is necessary to cool down the device. Operating a device at a high temperature without cooling it down may result in performance degradation.

Advantages of SiC MOSFETs over IGBTs

Lower resistance, lower losses. A higher band gap (3x vs. Si) and critical electric field (10-15x vs. Si) values for SiC means that MOSFETs (transistors) designed using SiC material can result in either higher voltages to be passed through the device, or the device size to be materially smaller for the same amount of voltage. A smaller device form factor along with faster switching can result in as high as 80-90% lower resistance in a SiC-based chip than one based on Si (Figure 54).

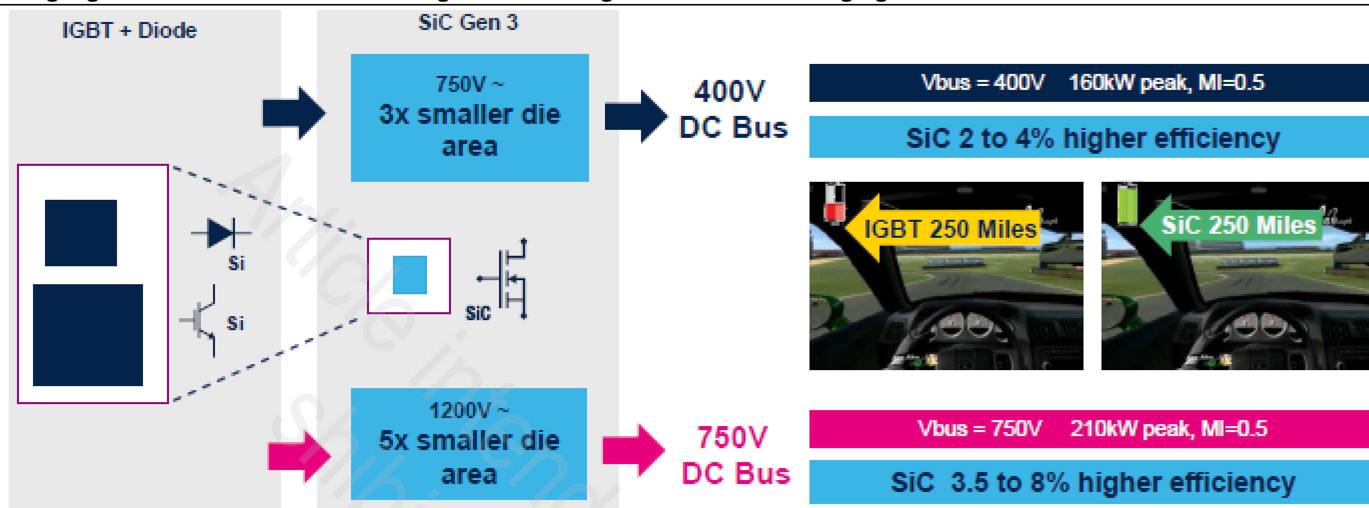
Figure 54: Benefits of SiC-based chips (transistors & diodes) over those based on Si – ability to withstand higher electrical fields, higher voltage and higher switching frequency resulting in lower resistance and lower heat loss



Source: Company data (STM – Sep 2019)

Smaller and lighter. Another benefit of SiC-based MOSFETs is a smaller die area than Si IGBT. STM recently noted that its latest SiC (third generation) product has one-third the die area versus Si-based IGBT for a 750V MOSFET and a one-fifth for a 1200V MOSFET (Figure 55).

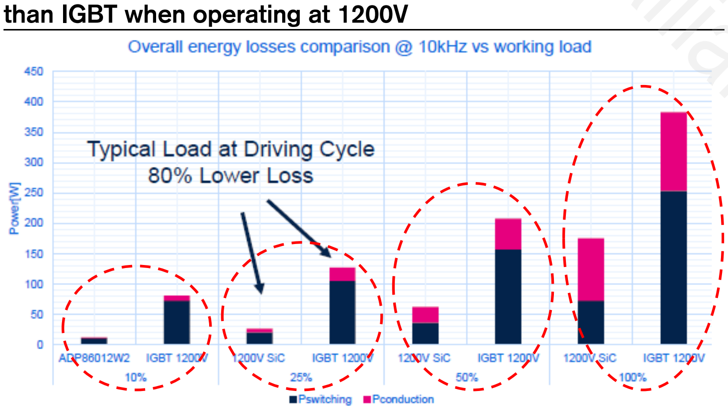
Figure 55: SiC offers significantly smaller die area than IGBT-based solutions leading to a range of 2-8% higher efficiency providing significant benefits in areas of higher car mileage and/or lower charging time



Source: Company data (STM – Mar 2020)

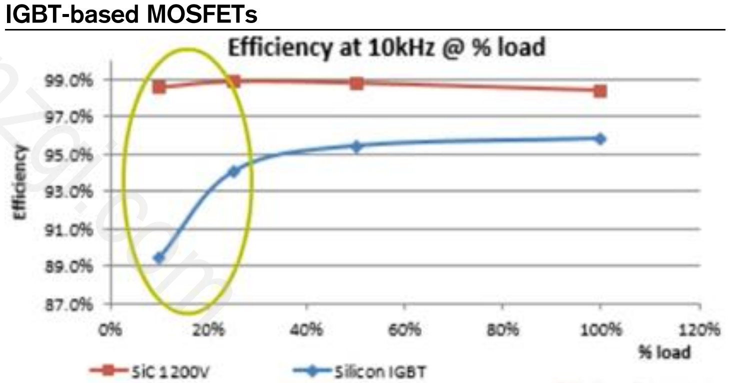
Up to 10% efficiency improvement. This benefit then translates into lower weight when used in products such as xEV car and industrial machines. Benefits of a smaller size and lower weight can then result in an efficiency improvement of 2-10%.

Figure 56: SiC-based chips are likely to 80% less power loss than IGBT when operating at 1200V



Source: Company data (STM – Sep 2019)

Figure 57: SiC MOSFETs are 2-10% more efficient than Si IGBT-based MOSFETs



Source: Company data (STM – Mar 2020)

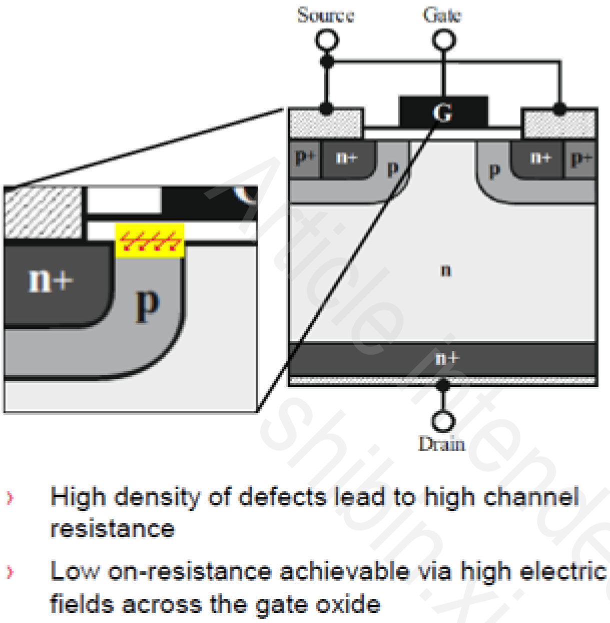
Within SiC MOSFET there are two design architectures (Planar and Trench). During the early years of SiC adoption, all suppliers focused on developing Planar SiC MOSFET technology. However, in the past 12-18 months, we have seen existing suppliers shift their focus also towards Trench technology. Infineon, Rohm, Mitsubishi and Fuji have already launched trench variants in the market while still working on making further improvements in future versions.

We note the following key differences in SiC Trench vs. Planar MOSFET, which provides an advantage to the trench architecture:

- Trench allows cells to be placed densely in substrate trenches rather than mounting gate electrodes on the substrate; this reduces the ON-resistance by as much as half in certain cases, thereby leading to lower heat generation and also allowing for a reduction in chip size and use of smaller cooling solutions.

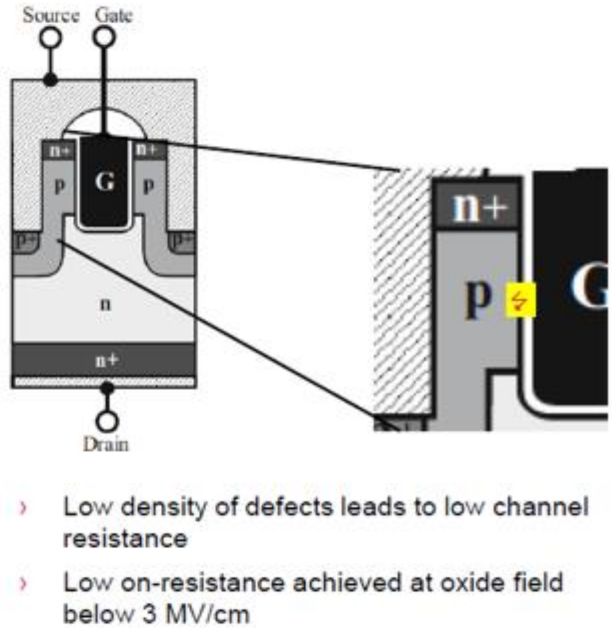
- Current flow in Trench MOSFET is in the vertical direction as opposed to vertical followed by horizontal (so current direction needs to be changed) in Planar design; this allows better control on the current flow in a Trench architecture (Figure 58).
- Option to shrink the chip design is limited in Planar architecture.

Figure 58: Design of Planar SiC MOSFET



Source: Company data (Infineon)

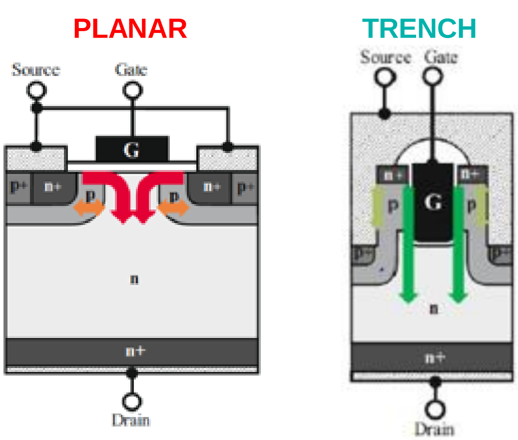
Figure 59: Design of Trench SiC MOSFET



Source: Company data (Infineon)

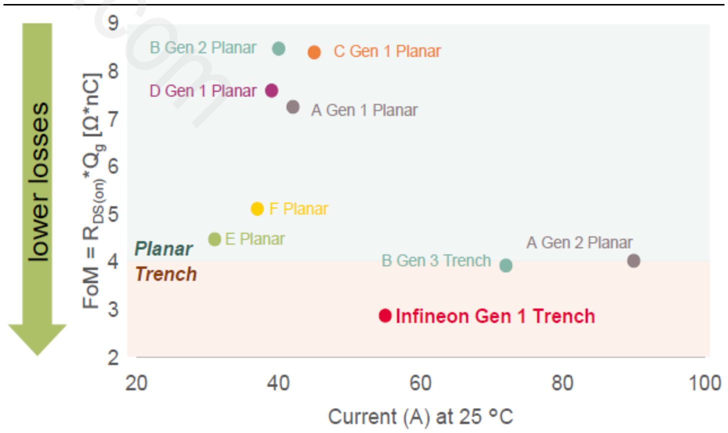
IFX looking to come back strongly with focus on SiC Trench. Although any research study looking at the performance metrics of MOSFETs from different chip companies is not going to be exhaustive and conclusive, a recent study from an independent consultancy firm showed that Infineon's Gen1 Trench offering has lower losses than both trench and planar offerings from competition (Figure 61).

Figure 60: Current flow in a Planar vs. Trench SiC MOSFET – easier to control current flow in vertical direction



Source: Company data (Infineon)

Figure 61: IFX looking to forge ahead in SiC vs. competition with the launch of Trench MOSFET



Source: Company data (Infineon – Feb 2021 earnings)

Net benefits to Auto OEMs and Consumer

Up to $500 cost savings per car from SiC for the car maker. SiC remains a more costly technology owing to high wafer prices, limited supply, a more complex manufacturing process, and lower production yields (remember SiC is still on 6" wafer vs. 8" and 12" for Si chips). This can result in a higher cost of around $200 for the SiC MOSFET-based traction inverter than one based on Si IGBT. However, the cost savings in adjacent areas, particularly in the battery cost, more than compensate for the higher SiC cost.

- Here, assuming 5-10% higher efficiency in a SiC-based battery electric car (BEV) that uses a 60kWh battery at a cost of around $115 per kWh, this would translate into cost savings of $350-$700 for the battery.
- In addition, given that SiC chips have a significantly smaller die area (one-fifth to one-third compared to IGBT chips), it results in cost savings because the battery and inverter solutions in the car are smaller and lighter.
- Furthermore, given its high thermal conductivity, SiC can also materially reduce costs relating to cooling systems.

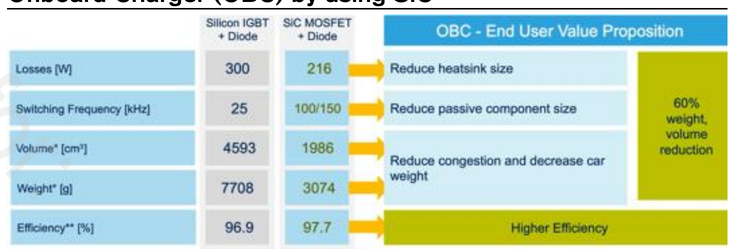
Although it is difficult to quantify the cost savings from the latter benefits, we see a scenario where SiC can lower the overall solution cost by ~$150-500 compared to IGBT (Figure 62).

Figure 62: Over $150-500 of net savings from use of SiC in a traction inverter for a BEV

Areas of savings (SiC over IGBT)	$ savings
~5-10% battery cost savings from using SiC assuming 60kWh battery x $115/kWh battery cost	~$350 - $700
Space / Weight related cost savings (battery + inverter)	$ can vary
Cooling system cost savings	$ can vary
Incremental cost of using SiC	~$200
Net savings per BEV car	**> ~$150 - $500**

Source: Credit Suisse estimates

Figure 63: ~60% reduction in weight and volume of an Onboard Charger (OBC) by using SiC

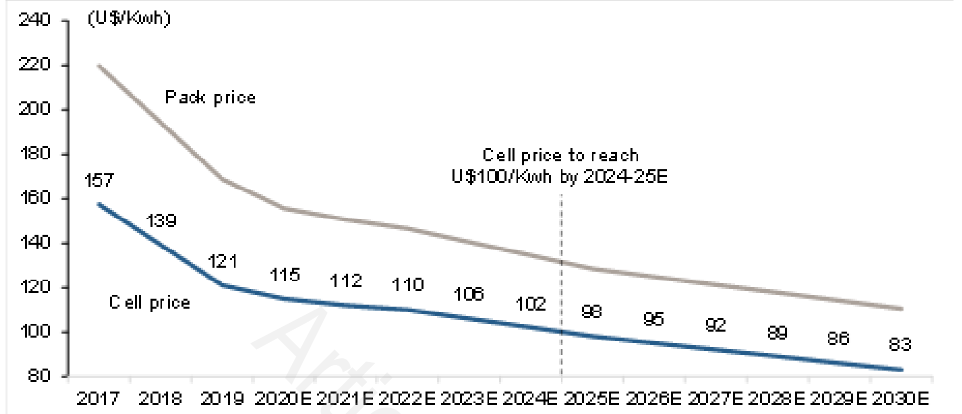


Source: Company data (STM – Sep 2019)

Battery is the biggest contributor to xEV cost. Our Global Automotive team focusing on battery makers believes that tier-1 battery makers' cost curve has continued to improve thanks to advancements in battery technology and pre-emptive capex spending, underpinned by an ample order book. That said, with ongoing chemistry innovation and better scale-effect, we expect the battery industry's average "cell" cost curve to reach US$100/kWh by 2025E (vs. US$115/kWh in 2020), while leading cell makers can differentiate themselves by offering high energy density battery with lower cost. For more details, please refer to our report ***Global xEV Battery Sector: Reaching the next inflection point***, in which our team illustrates what kind of developments are ongoing including form factor and upgrades in material chemistry, such as high nickel cathode, silicon additive anodes and changes in electrolytes.

But even at US$100/kWh of battery cost in the mid-term, and with most new BEV models coming with at least 75-100kWh of battery, it would still mean that battery will account for at least $7.5k to $10k (or 20-25%) of the total cost of a typical BEV. This is why we believe SiC as a technology is starting to gain widespread adoption despite the chip/module cost of SiC being much higher than a comparable IGBT solution. Use of SiC allows car OEMs to save cost in other areas such as battery, inverter, and cooling systems in addition to lower weight and smaller size.

Figure 64: Battery price to see gradual declines – reaching $100 per kWh by mid-2025 driven by battery cell migration, improving manufacturing and economies of scale



Source: Credit Suisse Global Automotive & Chemical research teams' estimates

~60% reduction in volume and weight for an onboard charger (OBC). In addition to traction inverters, SiC also has significant benefits when used in an OBC used in any PHEV and BEV car. Apart from lower losses and higher switching frequency enabling improved performance, it can offer up to a 60% reduction in both volume and weight of an OBC (Figure 63). Another compound technology, GaN (Gallium Nitride), also has proven advantages for OBC-type applications given its performance in a high switching frequency environment. However, we do not explore this area in this report.

Increasing interest from car OEMs and tier-1 suppliers in SiC. Driven by the benefits mentioned above, we have seen increasing levels of interest from global car OEMs and tier-one suppliers around SiC MOSFET technology across varying voltage configurations. Here we note that STM, CREE and Infineon have been leaders looking at these partnership announcements as we show in Figure 65.

Figure 65: List of publicly announced SiC partnerships in Automotive– rising interest in the supply chain

Date	Auto OEM / Tier-1 supplier	SiC Partner	Details
Dec 2020	Toyota	Denso	Produces SiC power chips (diodes & transistors) for fuel cell vehicles (FCEV); product used in Toyota's new Mirai model (launched in Dec 2020)
Jul 2020	Delphi + China car OEM	CREE	Win for a 800V SiC inverter (to be developed by Delphi in partnership with CREE) for a new BEV platform for a China car OEM
Jun 2020	Vitesco (Continental)	Rohm	Developing and testing SiC technology in an 800V inverter concept (also working on 400V technology); Vitesco aims to start production of its first SiC inverter from 2025
May 2020	Yutong	StarPower & CREE	Planning to use CREE's 1200V SiC devices in a StarPower power module for its new, high-efficiency powertrain system for electric buses
Feb 2020	BYD	BYD Semiconductor	Launches BYD Han EV model, which is based on its internal SiC technology; in Dec 2020, BYD noted that it has developed 3rd gen of SiC MOSFET, and is on track to launch the 4th gen
Nov 2019	ZF	CREE	ZF expects to make SiC electric drivelines available to the market by 2022
Oct 2019	Hyundai	Infineon	Selects IFX's HybridPACK CoolSiC (trench) products for their next gen EVs; Launched E-GMP platform in Dec 2020, which is dedicated to BEV models which can provide over 500km range and faster charging (upto 80% in 18mins)
Sep 2019	Renault-Nissan-Mitsubishi	STM	Selected to supply high efficiency SiC power chips for advanced on-board chargers (OBC) in its next-gen EVs; OBCs are expected to enter volume production in 2021
Sep 2019	Delphi + Premium global car OEM	CREE	Partnering on 800V technology with launch timeframe in 2022; Delphi scored a $2.7bn 8-year contract win with a premier global car OEM
May 2019	Volkswagen	Infineon	Chosen as a new partner for VW's strategic supplier network called FAST (Future Automotive Supply Tracks); VW aims to launch 70 xEV models over the next 10 years with aim to build 22mn xEV cars (most of them on MEB platform)
May 2019	Volkswagen	CREE	Selected as the exclusive SiC partner for VW's strategic supplier network called FAST (Future Automotive Supply Tracks); Both companies to work with tier-1 and power module suppliers to engineer SiC-based solutions for future VW vehicles
Feb 2019	Hyundai	STM	Joint R&D lab (ADSL) with Hyundai-Autron for new products aimed at EV models, with focus on powertrain controllers
May 2018	Innolectric	STM	Joint R&D on use of SiC for developing on-board chargers (OBC); Production started for 22kW OBC using 400V and 800V in Jan 2020, with deliveries from mid 2020
Aug 2017	Tesla	STM	Selected as supplier for SiC MOSFET (650V) chips for inverter in Model 3; 24 SiC MOSFETs were packaged together in a customized solution for Model 3; extended that partnership for other Tesla models since then

Source: Company data, Credit Suisse research

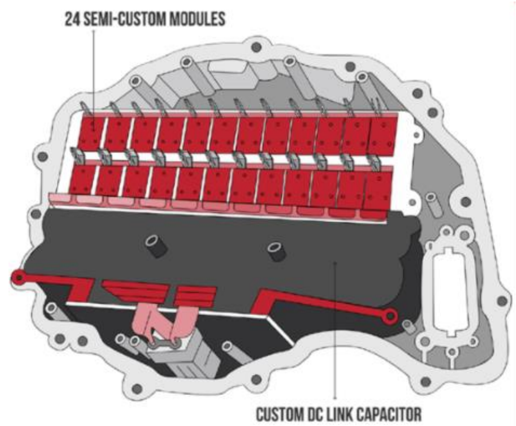
- **Tesla** has already announced a couple of models for future launch – Roadster and Cybertruck – which are aimed at offering driving ranges of 620 miles and 500 miles, although both models will be equipped with a 200kWh battery. Even its Model 3 (Long Range version) has a range of over 350 miles with a battery size of only 75kWh. In addition, all of them have quick acceleration, allowing them to go from 0-60mph within 2-4 seconds depending on the model. These metrics are all well ahead of most other models from competition.

Figure 66: List of publicly disclosed SiC customers for STM (note this is not the full customer list)

bel
BYD
DELTA
enel x
HYUNDAI
inmotion TECHNOLOGIES
innolectric

Source: STM Auto & Discrete Group presentation (Nov 2020)

Figure 67: Tesla using 24 SiC modules (semi-custom made by STM) for the inverter in Model 3

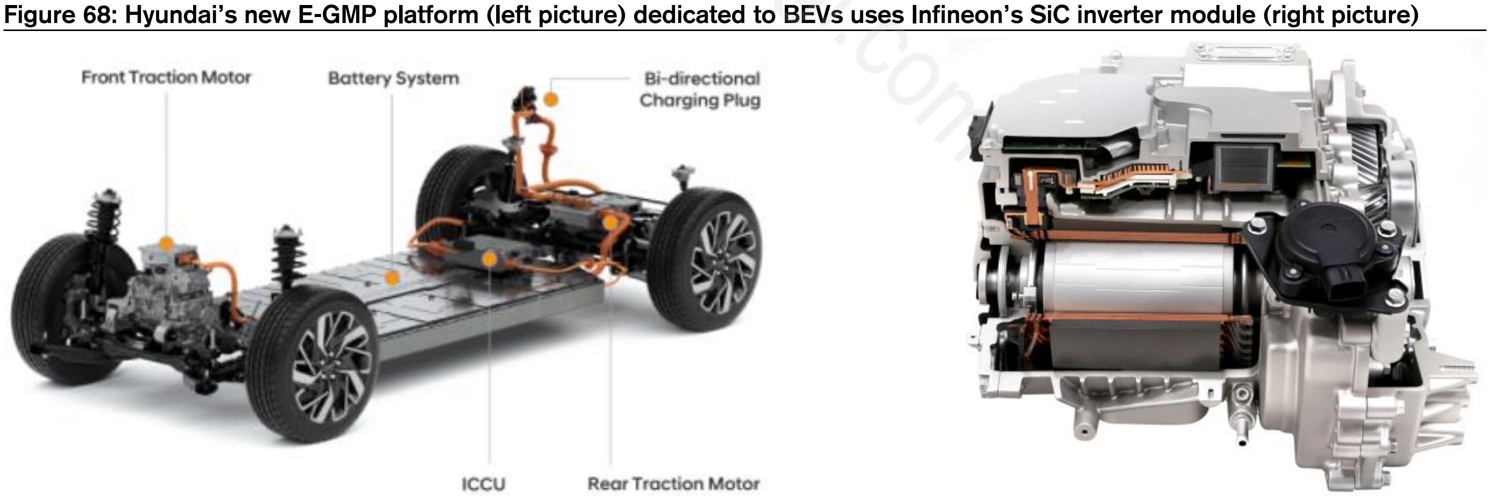


Source: Company data

- **BYD** launched Han, its first ever SiC inverter-based electric car, in 2020. Given that STM recently noted BYD as one of its SiC customers, we believe it is likely that BYD is using SiC chips from STM for this particular model. BYD has recently noted plans to launch a self-built SiC production line in 2021 as it is making progress on R&D to develop the fourth generation of its SiC MOSFET chip.

- **Lucid** also announced its Air model last year with plans to launch the vehicle in spring of 2021. The car has a driving range of 406 miles with 0-60mph acceleration in 2.5 seconds, and is powered by its SiC inverter solution.

Figure 68: Hyundai's new E-GMP platform (left picture) dedicated to BEVs uses Infineon's SiC inverter module (right picture)



Source: Company data (Hyundai), Credit Suisse research

- Recently, we have seen **Hyundai** launch its first SiC solution (we believe only the second global auto OEM to launch a SiC powered car after Tesla), which will power its new E-GMP platform (Figure 68). Hyundai is aiming to launch a total of 23 EV models (including 11 BEVs) by 2025, which would offer i) a driving range of ~300 miles; ii) up to 232kW electric charging supported by an 800V battery system to charge 10-80% capacity in 18mins; iii) two-way charging to use the 800V system to charge other electronic devices; iv) a modular and highly standardised structure to reduce manufacturing complexity; and v) a SiC power module to allow a 2-3% improvement in system efficiency, which can allow for 5% higher range with the same battery charge. With this E-GMP platform, Hyundai is aiming to sell more than one million EVs and become the #3 EV name by 2025.

Figure 69: List of BEV models that offer mileage of around 300 miles or more; SiC starting to see increased adoption in newer launches aimed at a 350+ miles range (BYD, Lucid, Hyundai and Nio being the latest to follow Tesla in using SiC)

Auto OEM	Model	Launch year	Range (miles)	Charging time	Acceleration time	Battery (kWh)	IGBT / SiC?
Tesla	Tesla Roadster	2022E	620	10 hrs 45 mins (full charge at home); 44 mins (rapid charge)	0 - 60mph in 1.9 secs	200	SiC
Tesla	Tesla Cybertruck	2021E	500	10 hrs 45 mins (full charge at home); 44 mins (rapid charge)	0 - 60mph in 2.9 secs	200	SiC
Nio	ET7	2022E	435	10 hrs (full charge at home); 45 mins (rapid charge)	0 - 62mph in 3.9 secs	100	SiC
Lucid	Lucid Air	2021E	406	17 hrs 30 mins (full charge at home); 25 mins (rapid charge)	0 - 60mph in 2.5 secs	113	SiC
Tesla	Model S (Long Range)	2020	402	15 hrs 15 mins (full charge at home); 44 mins (rapid charge)	0 - 60mph in 3.7 secs	100	SiC
Nio	ES6	2019	380	10 hrs (full charge at home); 45 mins (rapid charge)	0 - 62mph in 4.7 secs	100	IGBT
BYD	Han	2020	376	11 hrs (full charge at home); 25 mins (rapid charge)	0 - 62mph in 3.9 secs	77	SiC
BMW	i4	2021E	375	10 hrs 30 mins (full charge at home); 44 mins (rapid charge)	0 - 62mph in 4 secs	80	IGBT
Ford	Mustang Mach E (ER) RWD	2020	379	14 hrs (full charge at home); 50 mins (rapid charge)	0 - 62mph in 3.7 secs	96	IGBT
Tesla	Model 3 (Long Range)	2019	353	11 hrs 45 mins (full charge at home); 22 mins (rapid charge)	0 - 60mph in 4.4 secs	75	SiC
Tesla	Model X (Long Range)	2019	370	11 hrs 30 mins (full charge at home); 22 mins (rapid charge)	0 - 60mph in 3 secs	100	SiC
Volkswagen	ID.3 (Tour)	2020	336	12 hrs 15 mins (full charge at home); 39 mins (rapid charge)	0 - 62mph in 7.9 secs	77	IGBT
Volkswagen	ID.4	2021E	325	12 hrs 15 mins (full charge at home); 39 mins (rapid charge)	0 - 62mph in 8.5 secs	77	IGBT
Tesla	Model Y (Long Range)	2020	326	11 hrs 45 mins (full charge at home); 22 mins (rapid charge)	0 - 60mph in 3.5 secs	75	SiC
Hyundai	Ioniq 5	2021E	310	11 hrs 45 mins (full charge at home); 36 mins (rapid charge)	0 - 62mph in 5.2 secs	73	SiC
Porsche	Taycan 4S	2020	301	11 hrs 30 mins (full charge at home); 35 mins (rapid charge)	0 - 62mph in 4 secs	79	IGBT
Jaguar	i-Pace	2018	292	13 hrs 30 mins (full charge at home); 44 mins (rapid charge)	0 - 62mph in 4.5 secs	90	IGBT
Polestar	Polestar 2	2020	292	12 hrs (full charge at home); 38 mins (rapid charge)	0 - 62mph in 4.7 secs	78	IGBT

Note: SiC-based models are highlighted in green.

Source: Company data, Credit Suisse research

- **Nio in China** also launched its first SiC-based BEV model called ET7 in January 2021. The model will start shipping in 2H22 with battery options of 70kWh and 100kWh offering a driving range of 310 miles and 435 miles, respectively, with the possibility of launching 130kWh in the future with an increased range of 620 miles.

What is in it for the consumer? Higher mileage and/or lower charging time. Apart from price, three key considerations for a consumer are mileage offered per charge, total time taken for charging the vehicle, and pace of acceleration. Looking at the recent BEV model launches from various car OEMs, we can see that a number of companies are now launching models with a driving range of close to or more than 300 miles. What is obvious here is that Tesla continues to lead the pack on all the three metrics (Figure 69) – how much of that is driven entirely by the use of SiC MOSFETs vs. a combination of other things such as battery size, tighter supply chain integration allowing better design and improved performance, that is difficult to tell. However, with more auto makers, such as Hyundai, BYD, Lucid and Nio, starting to adopt SiC for their premium model launches, it is clear that SiC remains on track to become the mainstream power technology for BEV models over the next few years.

IGBT – enough room to grow despite cannibalization from SiC

IGBT is a three-terminal voltage-controlled power semiconductor device, constructed through a fusion of BJT (bipolar junction transistor) and MOSFET (metal-oxide-semiconductor field-effect transistor), and used primarily in high-voltage inverter and cyclo-converter currently. In simple terms, IGBTs are better equipped to handle high-power, but lower-frequency applications (such as automotive, welding machine and solar/wind inverter) than Si MOSFET, which has been the traditional way of building power semi chips. The latter performs better at low-power applications (like consumer electronics, servers, traditional areas of autos and industrial demand).

We expect IGBT to remain an attractive solution in areas where there is increasing need to balance performance and cost for any high-power applications (600V or higher) owing to less conduction loss than Si MOSFET. Therefore, IGBT technology seems well positioned to benefit from growing power semiconductor demand, driven mainly by EVs, renewable energy generation, rail traction, high-voltage industrial applications, among others.

We see strong growth ahead in IGBT despite SiC cannibalization. Even though we believe SiC will gradually cannibalize the use of IGBT in the power semis market (especially for xEV applications), we think IGBT should continue to see robust growth at least until 2025 and potentially even beyond. We show in detail our assumptions driving SiC and IGBT sales for the xEV market in a later section of this report (Figure 93), but below we present a summary of our overall view on the IGBT market (including Auto and non-Auto applications). We estimate that the size of the overall IGBT market was around $6.1bn in 2020 (CAGR of 8% since 2015), but we expect the growth to accelerate driven by the increasing adoption of xEV vehicles. Therefore, we model the IGBT market to grow to $12.9bn by 2025 (CAGR of 16% over the next five years).

Figure 70: Despite SiC cannibalization, we estimate the IGBT Power market can grow from $6.1bn in 2020 to $12.9bn by 2025 (CAGR of 16% over that period)

												CAGR	
IGBT Power chip market ($ mn)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2015-2020**	**2020-2025E**
IGBT Power - Auto	622	792	1,073	1,424	1,662	2,147	2,837	4,052	5,428	6,382	7,348	28.1%	27.9%
% change yoy	12%	27%	35%	33%	17%	29%	32%	43%	34%	18%	15%		
IGBT Power - Non-Auto	3,607	3,718	4,182	4,800	4,678	3,976	4,413	4,722	5,053	5,305	5,571	2.0%	7.0%
% change yoy	-8%	3%	12%	15%	-3%	-15%	11%	7%	7%	5%	5%		
IGBT Power - Total ($ mn)	**4,229**	**4,510**	**5,255**	**6,224**	**6,340**	**6,123**	**7,250**	**8,774**	**10,481**	**11,687**	**12,919**	**7.7%**	**16.1%**
% change yoy	-5%	7%	17%	18%	2%	-3%	18%	21%	19%	12%	11%		

Source: Infineon, Credit Suisse estimates

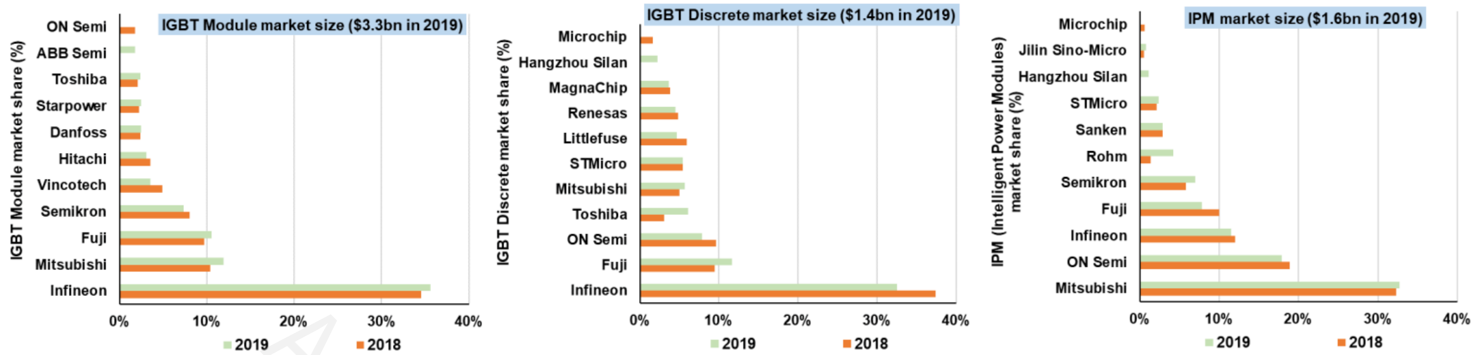
IGBT market dominated by European and Japanese companies. If we look at the history of market shares in IGBT, suppliers from Europe and Japan have dominated this market with Infineon, Mitsubishi, Fuji Electric and Semikron maintaining their positions in the Top 5 supplier list. Between 2015 and 2020, Infineon was able to grow its market share from 25% to 30% owing to its higher share in faster-growing areas such as xEV and Renewables (wind/solar) energy. Mitsubishi and Fuji Electric have been the #2 and #3 names here with around 15% and 10% shares, respectively, driven mainly by higher adoption of xEV cars at Japanese car OEMs in the earlier years of auto electrification, and a stronger presence in home appliance markets.

Figure 71: IGBT market share: IFX leads with around 30% share followed by Mitsubishi and Fuji at #2 and #3

												CAGR	
IGBT vendors	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**2015-2020**	**2020-2025E**
Infineon ($ mn)	1,074	1,168	1,424	1,780	1,829	1,806	2,277	2,808	3,354	3,740	4,186	11.0%	18.3%
market share (%)	25%	26%	27%	29%	29%	30%	31%	32%	32%	32%	32%		
Mitsubishi ($ mn)	871	767	862	946	996	918	1,160	1,316	1,572	1,753	1,938	1.1%	16.1%
market share (%)	21%	17%	16%	15%	16%	15%	16%	15%	15%	15%	15%		
Fuji Electric ($ mn)	529	550	562	604	640	612							
market share (%)	13%	12%	11%	10%	10%	10%							
ON Semi ($ mn)	207	320	405	448	431	429	580	768	969	1,169	1,292	15.6%	24.7%
market share (%)	5%	7%	8%	7%	7%	7%	8%	9%	9%	10%	10%		
Semikron ($ mn)	321	298	294	355	353	367							
market share (%)	8%	7%	6%	6%	6%	6%							
All Others ($ mn)	1,226	1,407	1,708	2,091	2,090	1,990	2,037	2,391	2,804	3,039	3,307	10.2%	10.7%
market share (%)	29%	31%	33%	34%	33%	33%	28%	27%	27%	26%	26%		
IGBT Power - Total ($ mn)	**4,229**	**4,510**	**5,255**	**6,224**	**6,340**	**6,123**	**7,250**	**8,774**	**10,481**	**11,687**	**12,919**	**7.7%**	**16.1%**
% change yoy	-5%	7%	17%	18%	2%	-3%	18%	21%	19%	12%	11%		

Source: Infineon, Credit Suisse estimates

Figure 72: Market shares in different parts of the IGBT market (Modules, Discretes and IPMs)



Source: Infineon, Credit Suisse research

Companies in China trying to catch up in IGBT, but a wide gap ahead. China has limited presence in the IGBT market as is evident from market shares in different parts of IGBT market (modules, discretes and IPMs) (Figure 72). The Chinese government has identified this as an area of weakness, and has been increasing R&D efforts and support for domestic manufacturers. In the industrials and consumer electronics part of the IGBT market, where technological and entry barriers are relatively lower, many Chinese companies have started to see some early signs of success. In the auto-grade IGBT segment, which is more difficult to enter, some Chinese companies have narrowed the technology gap and are trying to catch up, although there is still a long way to go. For details on China's progress in the IGBT space, please refer to the detailed report, ***Dual Circulation 1.5: Technology Self-Reliance – Switching Power***, recently published by our China research team.

In this report, our China team flagged that there are three types of business models for IGBT suppliers in China: (1) integrated device manufacturer, (2) fabless + packaging, and (3) pure module.

- **Integrated Device Manufacturers (IDMs)** include BYD, Zhuzhou CRRC, Silan, Sino-Micro, Yangjie, and CR Micro, to name a few. These companies have full capabilities throughout the IGBT chip-making process, including IC design, wafer fabrication, and packaging. Power semiconductor products are differentiated by the front-end process, back-end process and application/system expertise, unlike standard CMOS products, which are differentiated by more factors like IP-blocks, design flow and software. Hence, the IDM business model could help these companies to better develop and differentiate their products and serve product customization requirements.

- **Tee Fabless + Packaging business model** has been adopted by companies such as StarPower, NCE power and Sun.King. These companies leverage the expertise of foundries, namely Hua Hong, CR Micro and ASMC, to seek help in manufacturing internally designed IGBT chips. Notably, Hua Hong, the world's largest 8" foundry for power semis, is the main foundry for many of China's IGBT fabless companies including StarPower and NCE Power. Hua Hong is also trying to manufacture IGBT on 12" fab (to compete with established companies, e.g. Infineon), which could further facilitate IGBT fabless development in China. For packaging, these companies have built their own lines to enhance product competence and assure capacity, as packaging technology could significantly affect the performance/reliability of IGBT modules.

- **The module approach** is being adopted by Singa and Silver Micro, for instance, which procure IGBT dies from third parties and sell final module product. These companies have also established their distinctive expertise, as packaging technology is critical for IGBT's heat dissipation and electromagnetic shielding, significantly affecting module performance and reliability.

Figure 73: Key IGBT names in China

Company	CR Micro	StarPower	Silan	Sino-Micro	Yangjie	Zhuzhou CRRC	BYD	Sun King	NCE Power	Singa	Silver Micro
Product	Discrete and module (under qualification)	Module	Discrete and module	Discrete and module	Discrete and module	Discrete and module	Discrete and module	Discrete and module	Discrete and module	Module	Module
Application	Consumer, Industrial control, Solar/wind	Consumer, Industrial control, Solar/wind, Automotive	Consumer, Industrial control, Solar/wind	Consumer, Industrial control, Solar/wind	Industrial control	Railway, Subway, Power system, Solar/Wind, Automotive	Industrial control, Automotive	1200V R&D completed, qualification in progress	Consumer, Industrial control, Solar/wind	Industrial control	Consumer, Industrial control, Solar/wind
Business model	IDM + foundry+ OSAT	Fabless + packaging	IDM	IDM	IDM	IDM	IDM	Fabless + packaging	Fabless + packaging	Packaging	Packaging
- IC design	√	√	√	√	√	√	√	√	√		
- Wafer fabrication	√		√	√	√	√	√				
- Back-end	√	√	√	√	√	√	√	√	√	√	√

Source: Company data, Credit Suisse research (China Semiconductor research team)

In general, our China team sees higher potential for domestic substitution in industrials and consumer electronics given a lower barrier to entry, while auto-grade IGBT has a longer way to go. Here, by application, we flag the following development for IGBT chips in China:

- **High-voltage IGBT.** There is only one Chinese company, Zhuzhou CRRC Electric, for IGBT above 3,300V. Its high-voltage IGBT has been widely adopted by traction units in China's locomotives and metros, and, more recently, it has started to penetrate into high-speed rail. Global competitors in the high-voltage IGBT market include Mitsubishi, Hitachi, ABB and Infineon. Considering China's strong localization ambitions and Zhuzhou CRRC's proven technological capabilities, we think CRRC may be better positioned to grow in the high-voltage IGBT market in China.

- **Auto-grade IGBT.** Global auto-grade IGBT is still dominated by global giants such as Infineon, Mitsubishi and Semikron. In the China market, BYD Semiconductor, StarPower and Zhuzhou CRRC are ramping up. BYD is the leader in China, thanks to its aggressiveness in adopting its own IGBT on its own EVs. BYD's EV sales ranked #2 in China in 2020. StarPower's IGBT module has been adopted by China OEMs in small volumes, but mainly on low-end models. Zhuzhou CRRC is trying to migrate its IGBT knowledge from high-voltage products to mid- and low-voltage products, and is in the early stages of automotive IGBT shipment. Despite high interest in IGBT from a number of Chinese suppliers, we believe that the auto-grade IGBT market in the country may remain concentrated among a few capable names given high entry barriers.

    - **StarPower looking to raise capital:** On 2 March 2021, StarPower announced its private placement plan to raise no more than Rmb3.5bn through issuing no more than 16m shares. The money raised would be used for: (1) Rmb2bn for high-voltage (above 3300V) IGBT and SiC fab for a capacity of 30k wafers per month; (2) Rmb0.7bn for power semis module line automation upgrade for a module capacity of 333,000/month; and (3) Rmb0.8bn for working capital requirements. Given that the building of fab and production ramp may take 2-3 years, we believe StarPower will continue to rely on Wolfspeed's SiC MOSFET to make SiC modules for its customers in China.

    - **StarPower's ambition in IGBT:** This placement demonstrates StarPower's ambition to become a major IGBT supplier in China by ensuring enough capacity to meet demand in the medium term. That said, its major foundry partner, Hua Hong Semi, has been ramping up 8" and 12" IGBT production rapidly in recent years; so this placement may raise concerns from its major foundry partner. Currently, Zhuzhou CRRC Electric is the leader among China suppliers for IGBT above 3,300V. However, given the rapidly expanding market for IGBT, we believe both companies should benefit from growth potential in the mid-term.

- **IGBT for industrials and consumer electronics.** The import substitution for IGBT in the industrials and consumer electronics space has shown some good progress in China in recent times. Many IGBT companies in China have registered quick growth in these areas. There might be more competition in the industrials and consumer electronics IGBT market given the lower entry barrier. However, considering China's currently low IGBT self-sufficiency rate, we expect significant potential for China suppliers in these segments.

SiC opportunity – supply ramping up to meet growing demand

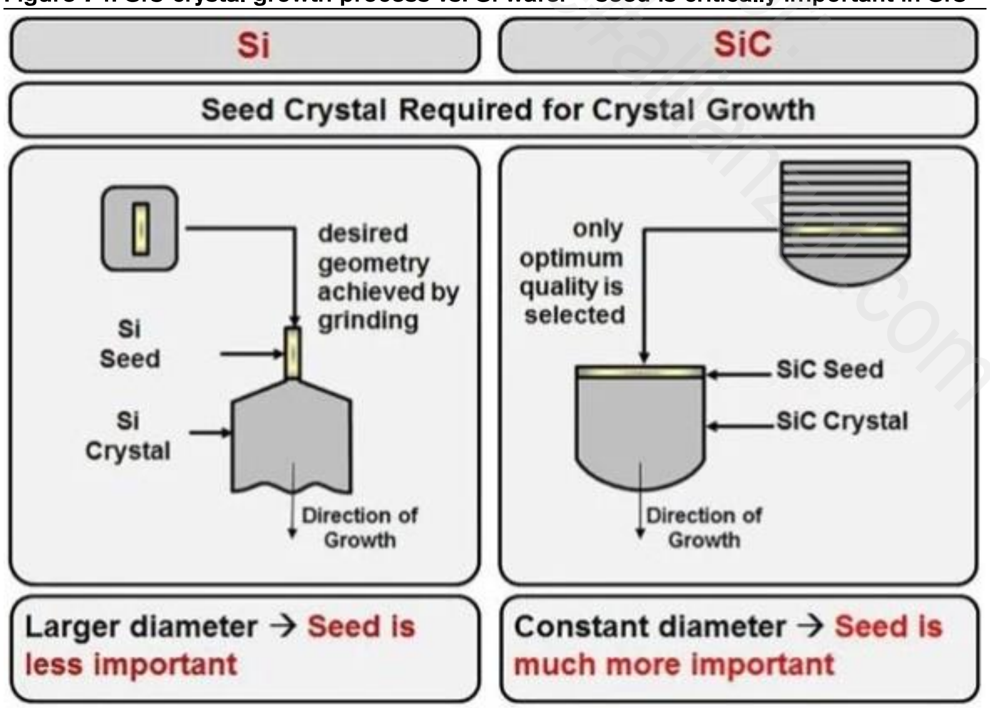
In this section, we look at the existing challenges in the SiC supply chain, and industry action being taken to resolve these issues over time, leading to higher production capacity and better cost structure.

SiC supply chain – ongoing challenges

Why is SiC wafer manufacturing so difficult? SiC wafers were first commercially produced in 1991, but it was only in 2005 that the industry was able to produce these wafers on 100mm (or 4" diameter), and then expanded to 150mm (or 6") in 2012 after overcoming a number of manufacturing challenges. Even today, SiC wafers are restricted to 150mm in size, with various companies aiming to move to 200mm (8" diameter) in 2021/22. Here we highlight the key challenges in manufacturing SiC wafers:

- **Material hardness –** SiC is a very hard material, second only to diamond, requiring high temperatures (2200°C for SiC vs. 1500°C for Si wafer in a furnace) and a longer time to grow and process crystals.
- **Complex seeding process –** For normal Si wafers, the seed crystal used is relatively small. As it is pulled from the rotating furnace, molten Si sticks to the seed and starts to solidify, resulting in a single crystal ingot of around 2m long with a target diameter of 100-300mm. For SiC wafers, the quality of the seed is extremely important and needs to have the same diameter as the ingot. As increasing the seed crystal diameter takes a lot of time, the whole seeding process for SiC wafers is much more complex than for Si wafers.

Figure 74: SiC crystal growth process vs. Si wafer – seed is critically important in SiC

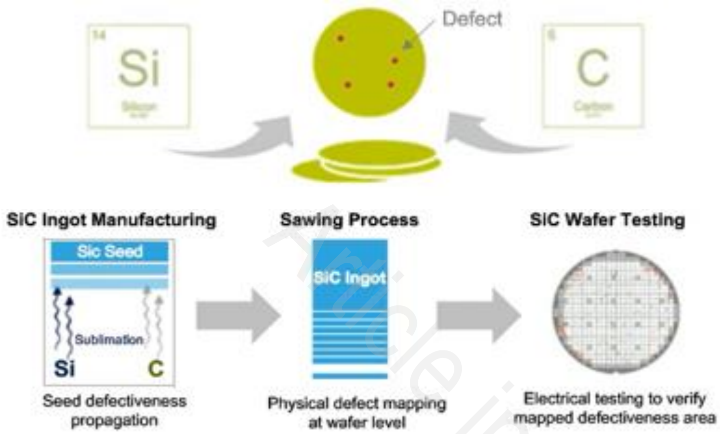


Source: Company data

- **Low production yields –** Given the above issues, production yield for SiC wafers is significantly lower than for Si wafers. For example, 35-50 SiC wafers can be produced from a typical boule of 35-50mm length vs. 2,000 silicon wafers from a Si boule typically two metres long.

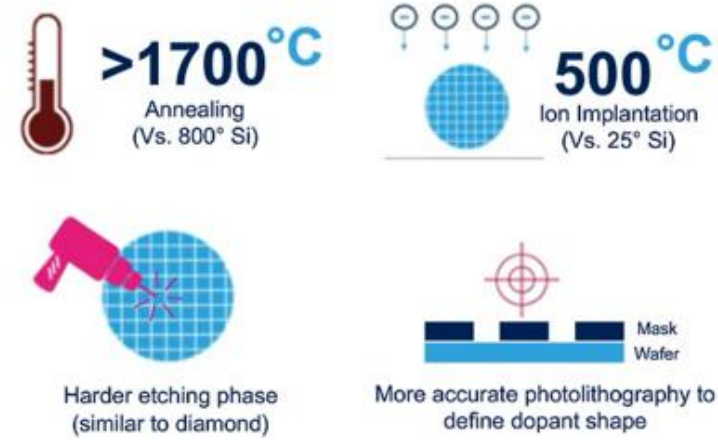
- **More defects –** SiC substrates are prone to various defect types and scratches. These defects can be crystalline stacking faults, micro-pipes, pits, stains and surface particles.

Figure 75: SiC has high intrinsic defectiveness which makes the wafer manufacturing process quite complex



Source: Company data (STM – Sep 2019)

Figure 76: High temperatures (for annealing, ion implantation) and difficult etching all are challenges to SiC manufacturing

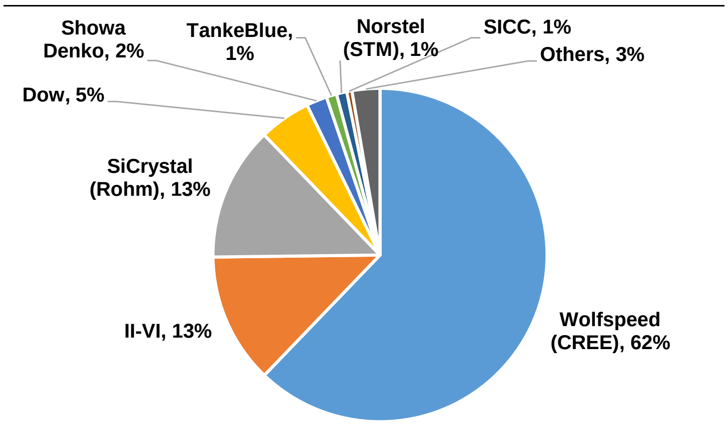


Source: Company data (STM – Sep 2019)

- **Difficulties in grinding and sawing –** Once the crystal is grown, the cylindrical ingot is pulled from the crucible, and then goes through a number of steps, such as grinding, sawing, rounding of the edges, polishing, and lapping, to get the desired wafers. Given the hardness of SiC as a material (value of 9 on the Mohs hardness scale where diamond is valued at the upper limit of 10), it requires extremely high precision in grinding, sawing and rounding off the edges.

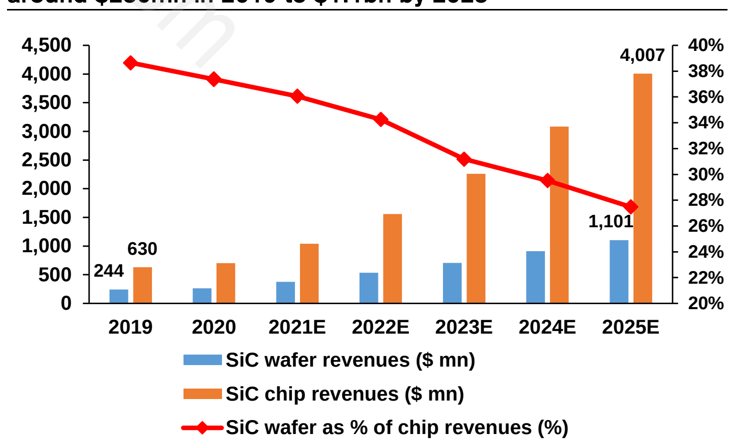
Different steps involved in SiC wafer making. There are a number of key steps in SiC wafer production including: i) in the production of SiC materials: high-purity SiC can be produced from silicon and carbon at high temperatures and in an inert gas atmosphere; ii) in ingot manufacturing: high-purity SiC materials are lowered into a crucible and heated above 2200°C, followed by the seeding process; iii) in annealing: the SiC crystal is placed in an annealing furnace under high temperature (>1700°C) to eliminate stress and reduce injection defects; and iv) in the deposition of the epitaxial layer: a thin epitaxial layer is grown on the substrate using a deposition process.

Figure 77: SiC wafer market share (2020) – Wolfspeed, II-VI and Rohm lead with combined revenue share of close to 90%



Source: Company data, Credit Suisse research

Figure 78: We expect SiC wafer market to grow in sales from around $250mn in 2019 to $1.1bn by 2025

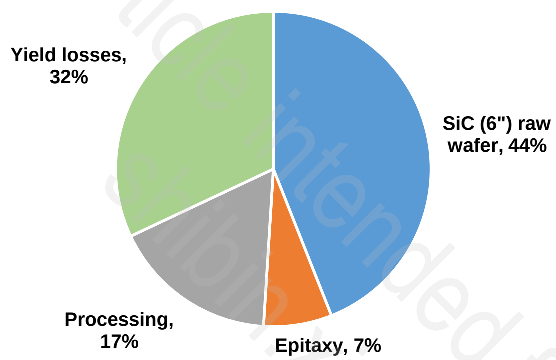


Source: Company data, Credit Suisse estimates

Estimating the SiC wafer (substrate) market size

The SiC wafer market was around $260m in revenues in 2020. With increasing adoption of SiC across industrial and automotive applications, we estimate the SiC wafer market could grow from around $0.26bn in 2020 to $1.1bn in 2025 (+33% CAGR). This would likely result in SiC substrate as a percentage of the SiC power chip market declining from 37% in 2020 to 27% by 2025. Note that today around 40-45% of the front-end cost of a SiC MOSFET is linked to SiC wafer cost (Figure 79), although it has been reducing over time (it was around 55% a couple of years back). We expect this trend to continue, driven by a likely improvement in wafer manufacturing yields (migration from 150mm or 6" to 200mm or 8" diameter wafers) and lower waste/losses.

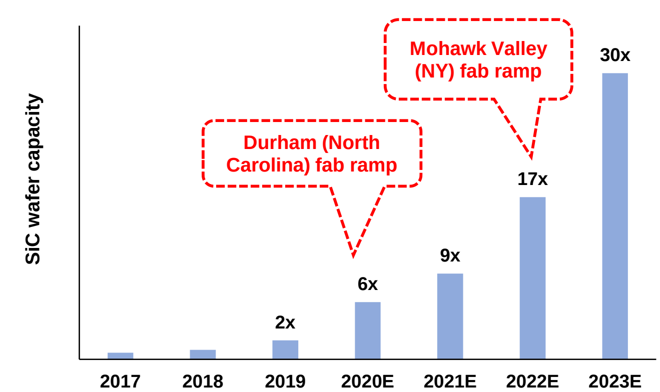
Figure 79: Typical cost breakdown (front-end cost only, so excludes back-end costs like packaging) of SiC MOSFET – raw wafer accounts for the biggest portion



Source: Credit Suisse research

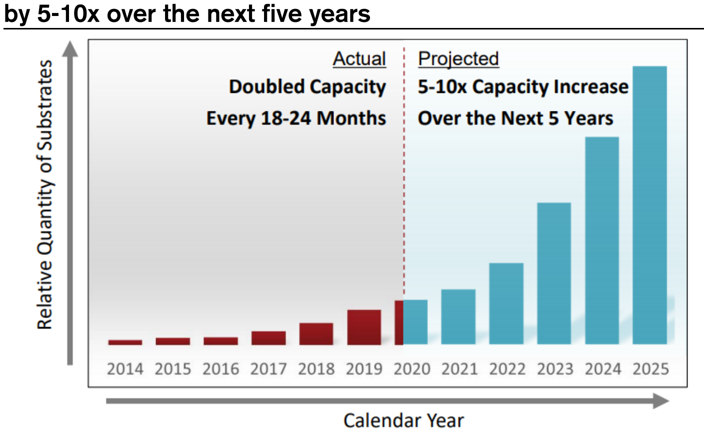
Wolfspeed leads in SiC wafers. Wolfspeed (CREE) has a dominant position in the SiC wafer market with a 60-65% share, followed by II-IV and Rohm at a c13% share each (Figure 77). Among its competitors, Wolfspeed also has the longest history in wide-band-gap material (like SiC and GaN) wafer production. In 2019, it announced plans to invest $1bn in SiC materials growth and fab expansion (two fabs including a mega fab) aimed at producing 200mm (8") SiC wafers in 2022 and increase capacity by 30x in 2023 vs. 2018 (Figure 80). Beyond the ongoing SiC capacity investment, the company has stated that it will consider building a second mega fab for SiC production in 2024/25 depending on demand trends. With the current market position and near-term development plan, Wolfspeed is likely to maintain its dominant market position in SiC wafer manufacturing (we assume a share of more than 50% even in 2025).

Figure 80: Wolfspeed has been investing ($1bn in total) to increase SiC wafer capacity by 30x in 2023 vs. 2018 levels



Source: Company data (Wolfspeed), Credit Suisse research

Figure 81: II-VI is also planning to increase SiC wafer capacity by 5-10x over the next five years



Source: II-VI (May 2020 presentation)

II-IV planning to scale up SiC wafer capacity by 5-10x; also focus on 200mm volume production. II-IV has a long history in SiC wafer production, achieving 100mm (4") production in 2007, 150mm (6") production in 2013 and demonstrating the world's first 200mm (8") wafer in 2015. Since 2016, II-IV has been expanding its presence in SiC driven by:

- Plans to increase its 150mm SiC wafer capacity by 5-10x (Figure 81) while focusing on scaling production for a differentiated 200mm SiC wafer;
- Signed an agreement with GE in Jun 2020 to license GE's technology to manufacture SiC devices;
- In August 2020, announced the acquisition of Ascatron, a Swedish SiC epitaxial wafer company with 3DSiC technology, with the deal closing in October 2020;
- In October 2020, it also acquired Colorado Springs-based INNOViON Corp, which is focused on ion implantation to help doping across variety of semis materials (including SiC and GaN).

Rohm also adding SiC wafer capacity for 200mm (8") in 2022. SiCrystal was formed in 1996 in Germany, and Rohm acquired it in 2009 with an aim to become more vertically integrated in SiC market. SiCrystal continues to operate as a subsidiary of Rohm, and sells SiC wafers both internally to Rohm and externally to other customers (like STM). SiCrystal started the commercial production of 4" SiC wafers in 2011, followed by 6" in 2014. It is also aiming to have 8" production available in 2022.

GlobalWafers also getting into 150mm SiC wafers. GWC is a major name in the traditional silicon wafer market (#3 with a 17% market share). In August 2019, it signed an LTA with GTAT to help it source SiC boule from the latter, and produce 150mm SiC wafers using those boules.

Wafer Works – ambition to get into SiC substrates. Wafer Works is a specialty raw wafer supplier with 6" and 8" capacity in Taiwan and China, and is now targeting 12". 6" raw wafers currently contribute ~30% of sales, with the remaining ~70% coming from 8". The company is a leader in the 6" and 8" heavy doped wafers for power discrete and IGBT mainly for automotive and industrial applications. It has also been expanding its customer base over the past two decades with a proven record including IDM customers in Europe, US and China (some customers include Infineon, STM, Diodes and Vishay) and foundry customers (TSMC, UMC, SMIC and Hua Hong). For automotive, Wafer Works has a high exposure in the market, which contributes 40-50% of its 8" business mostly for the power applications.

- **Investing in SiC wafer business.** Wafer Works is also investing in SiC wafer as it believes the technology is suitable for applications requiring high frequency, high voltage, high power efficiency and radio-resistance applications including 5G, EV and wind energy, which are the Chinese government's key focus areas.
- **Planned IPO of its China business rejected.** The company had announced plans to list its China business on the STAR market in 2020, saying it aimed to invest Rmb203mn for the 6" SiC technology development, according to the prospectus. However, the IPO was rejected late in 2020 as local authorities required more evidence of the independent operation for the China entity from the Taiwan business.

Infineon also buying boules from GTAT in addition to its CREE deal. In November 2018, Infineon signed a strategic long-term agreement to purchase SiC wafers (150mm) from CREE. In the same month, it also bought a start-up company called Siltectra in Germany for €124mn. Also in November 2020, Infineon signed a 5-year deal (initial term) with GTAT to buy SiC boules from the company, planning to use Siltectra's technology (Cold Split) to slice wafers from the SiC boule being bought from GTAT (Figure 83). This will allow Infineon to increase significantly the number of SiC wafers it can get from one boule, and thereby reduce waste/losses.

Figure 82: SiC wafer and boule agreements signed in the past 2-3 years

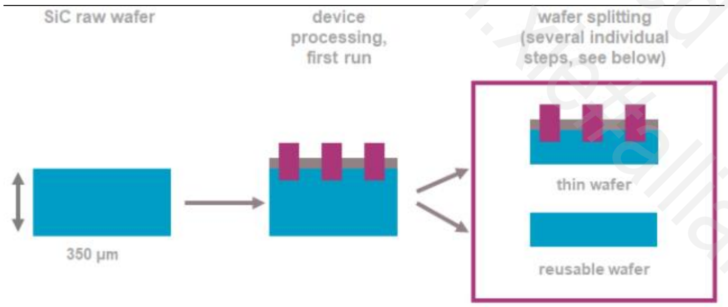
Date	SiC wafer supplier	SiC wafer buyer	Deal Summary
Nov 2020	GTAT	Infineon	5-year (initial term) supply agreement for SiC boules
Mar 2020	GTAT	ON Semi	5-year agreement with potential for $50mn for CrystX (SiC boules)
Mar 2020	GTAT	GlobalWafers	GWC will now add 150mm SiC to its offering, manufactured from SiC boule from GTAT
Jan 2020	SiCrystal (Rohm)	STM	For supply of over $120mn worth of advanced 150mm SiC wafers
Nov 2019	Wolfspeed (CREE)	STM	Expanded and extended an existing multi-year, long-term SiC wafer supply agreement to more than $500mn; Original agreement worth $250mn announced in Jan 2019 for 150mm SiC bare and epitaxial wafers
Aug 2019	Wolfspeed (CREE)	ON Semi	Agreement valued at over $85mn for supply of CREE's advanced 150mm SiC and epitaxial wafers
Feb 2018	Wolfspeed (CREE)	Infineon	Long term supply agreement worth over $100mn for the provision of SiC wafers (150mm only)

Source: Company data, Credit Suisse research

STM trying to become vertically integrated in addition to LT supply deals. STM is adopting two parallel approaches, an external supply arrangement and ramping up its internal production. So far, it has relied on CREE and SiCrystal (Rohm) for the supply of SiC substrates. In fact, STM signed a multi-year $250mn deal with CREE in January 2019 for procuring SiC raw wafers (both bare and epitaxial). This deal was then expanded and extended to over $500mn (doubling in value) in November of the year. It also has a long-term deal with SiCrystal (Rohm) for SiC wafer supply worth $120mn for several years, which was signed in January 2020.

In addition, STM acquired a 55% stake in Norstel (a small SiC wafer maker in Sweden) in February 2019, and the remaining 45% in Q419 (for a total consideration of $137.5m for a full 100% stake) in order to become vertically integrated.

Figure 83: Infineon is using Siltectra's Cold Split technology to slice wafers from a boule and allow some level of re-use



Source: Company data (Infineon)

Figure 84: STM (using Norstel technology) plans to start SiC wafer production at a small scale later in 2021

	Today	2021 addition	Mid-term
External qualified suppliers	4 suppliers		
External supply agreements	LTSA with CREE and SiCrystal (Rohm)		
Internal plans	ST-Norstel integration and R&D	ST-Norstel small scale production	New wafer plant Evolution to 200mm

Source: Company data, Credit Suisse research

SK Siltron bought DuPont's SiC wafer business. Korean wafer maker SK Siltron (#5 vendor in the traditional wafer market with around 12% share) signed an agreement with DuPont to acquire its SiC wafer division for US$450mn in September 2019, with the deal closing in February 2020. DuPont offers both 100mm and 150mm SiC wafers, as well as SiC epitaxy service.

Figure 85: Disco's KABRA!zen's advantage over existing process in SiC wafer making

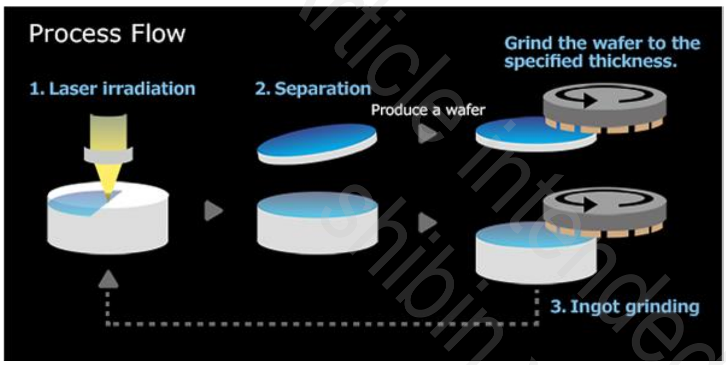
	Existing process*1·2 Wire saw + Lapping grind	KABRA!zen Fully automatic process
Material loss (per wafer) (Kerf loss + lapping/ grinding loss)	Approx. 260 µm	Approx. 80 µm
Kerf loss (per wafer)	180 µm	0 µm
Lapping/ grinding loss (per wafer)	Approx. 80 µm	Approx. 80 µm
Number of wafers produced from one ingot	32 wafers	46 wafers
Wafer pickup per hour*3	1.2 wafers	6 wafers
Ingot processing hours*4	100 hours	31 hours
Lapping grind	Approx. 16 hours	Not required

*1: Wafers with a designated thickness of 350 µm are produced from an SiC ingot with a diameter of 6 inches and a thickness of 20 mm.
*2: Lapping is performed after cutting using a loose abrasive-type diamond wire saw. All values are standard values based on those acquired from users.
*3: When four ingots are processed concurrently.
*4. Grind the upper surface of the ingot for the next laser irradiation. Repeat processes 1 to 3 and slice the wafer.

Source: Company data, Credit Suisse research

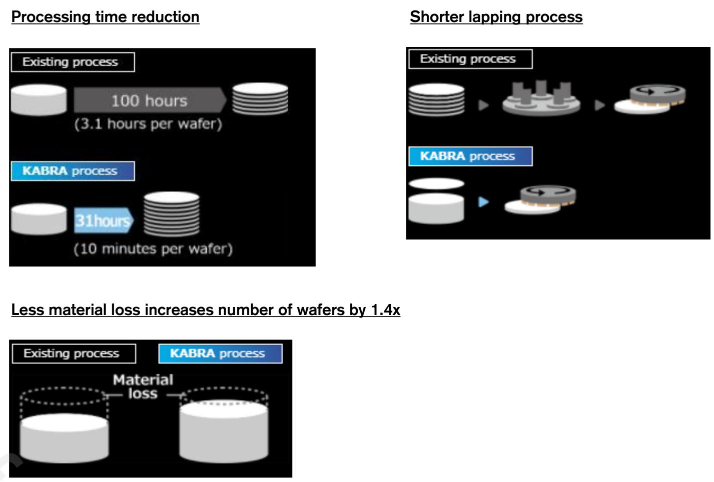
- **Disco has developed a low-cost manufacturing process using KABRA!zen.** Disco has been working to develop SiC ingot slicing equipment and has launched manual equipment named “KABRA” and a fully-automated machine “KABRA!zen” that integrates a few processes such as surface treatment of ingots to grinding. Compared with conventional wire saws, KABRA!zen boosts the wafer yield from a single ingot by 40% and reduces ingot slicing time from 100 hours per ingot to 31 hours. The company has already started mass production of manually operated machines for leading SiC wafer makers, while its fully automated machines are being evaluated at major SiC wafer makers. SiC wafer makers are looking for ways to reduce the manufacturing costs significantly.

Figure 86: Disco’s KABRA!zen – process flow



Source: Company data (Disco)

Figure 87: KABRA!zen – advantages in SiC wafer making



Source: Company data (Disco)

SiC device market size – material runway ahead

Estimating the size of xEV Power market (and SiC Power within that) long term. To estimate the size of the total xEV market for Power semis, we try to forecast the following key variables: i) Total number of cars sold per year globally, ii) xEV adoption by type (MHEV, HEV, PHEV and BEV) over time as a percentage of new cars sold every year, and iii) Power semis content by car (ICE and all four types of xEV vehicles). For the purpose of this report, we focus on the xEV part of the market only. Once we have the size of the total xEV Power semis market, we split that market into IGBT and SiC chips depending on our assumption for increasing levels of adoption of SiC in BEV models to begin with and then also in PHEV models over time.

xEV penetration to hit 62% by 2030; PHEV + BEV penetration of 38% by 2030, on our estimates. As we explained in an earlier section in detail, we forecast xEV penetration to rise from 11% in 2020 to 34% by 2025, and to 62% by 2030 at a global level (we also acknowledge that these forecasts may have potential upside driven by scope for even stricter regulations around emissions and aggressive push from various governments). This should result in total xEV cars sold increasing from 8m in 2020 to 63m by 2030 (Figure 88). Within this, we expect PHEV + BEV adoption to rise from 4.5% in 2020 to 18%/38% by 2025/2030, resulting in the number of cars sold growing from slightly over 3m in 2020 to nearly 40m by 2030.

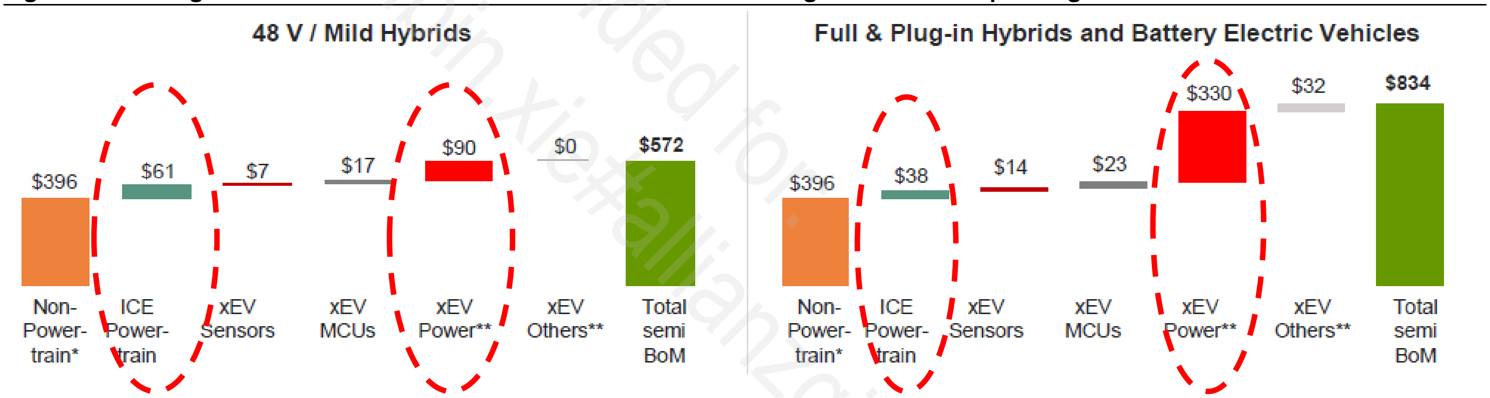
Figure 88: Split of xEV by MHEV, HEV, PHEV and BEV: BEV + PHEV adoption to rise from 4% in 2020 to 18%/38% by 2025/2030

	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Global LV sales (mn)	**80.7**	**84.9**	**86.8**	**86.6**	**83.9**	**72.3**	**83.5**	**88.6**	**90.8**	**92.3**	**93.8**	**95.3**	**96.9**	**98.5**	**100.2**	**101.9**
% change yoy	2%	5%	2%	0%	-3%	-14%	16%	6%	2%	2%	2%	2%	2%	2%	2%	2%
MHEV	0.00	0.03	0.05	0.32	1.34	2.23	2.83	3.55	4.63	5.56	6.62	7.75	8.89	9.78	10.71	11.48
MHEV adoption (%)	0.0%	0.0%	0.1%	0.4%	1.6%	3.1%	3.4%	4.0%	5.1%	6.0%	7.1%	8.1%	9.2%	9.9%	10.7%	11.3%
HEV	1.60	1.84	2.16	2.33	2.74	2.87	3.71	4.89	5.99	6.93	8.07	9.21	10.42	11.76	12.33	13.28
HEV adoption (%)	2.0%	2.2%	2.5%	2.7%	3.3%	4.0%	4.4%	5.5%	6.6%	7.5%	8.6%	9.7%	10.7%	11.9%	12.3%	13.0%
MHEV + HEV adoption (%)	2.0%	2.2%	2.5%	3.1%	4.9%	7.1%	7.8%	9.5%	11.7%	13.5%	15.7%	17.8%	19.9%	21.9%	23.0%	24.3%
PHEV	0.22	0.28	0.42	0.64	0.58	0.98	1.24	2.38	3.41	4.26	4.70	5.52	6.17	7.36	7.96	9.83
PHEV adoption (%)	0.3%	0.3%	0.5%	0.7%	0.7%	1.4%	1.5%	2.7%	3.8%	4.6%	5.0%	5.8%	6.4%	7.5%	7.9%	9.6%
BEV	0.32	0.51	0.84	1.44	1.68	2.25	3.44	5.20	7.71	9.79	12.23	15.04	18.29	21.81	25.96	28.88
BEV adoption (%)	0.4%	0.6%	1.0%	1.7%	2.0%	3.1%	4.1%	5.9%	8.5%	10.6%	13.0%	15.8%	18.9%	22.1%	25.9%	28.3%
PHEV + BEV adoption (%)	0.7%	0.9%	1.5%	2.4%	2.7%	4.5%	5.6%	8.6%	12.3%	15.2%	18.0%	21.6%	25.2%	29.6%	33.9%	38.0%
Total xEV	**2.14**	**2.66**	**3.47**	**4.73**	**6.34**	**8.33**	**11.23**	**16.02**	**21.74**	**26.54**	**31.61**	**37.53**	**43.77**	**50.71**	**56.96**	**63.47**
xEV adoption (%)	2.7%	3.1%	4.0%	5.5%	7.6%	11.5%	13.4%	18.1%	24.0%	28.8%	33.7%	39.4%	45.2%	51.5%	56.8%	62.3%
Total ICE	78.57	82.25	83.38	81.92	77.55	63.93	72.29	72.57	69.03	65.75	62.19	57.82	53.16	47.83	43.24	38.43

Source: Credit Suisse US Auto Research team (until 2020), Credit Suisse estimates

Power semis content per car – range of $160 for MHEV to $450 for BEV. Typical power semis content in an ICE (petrol/diesel) car is around $50-100 depending on the model. This is based on a combination of normal silicon-based MOSFETs and diodes used for powertrain. However, when we move from an ICE car to a PHEV or BEV car, the use of Traction Inverter (Electric Motor), OnBoard Charger (OBC) and Battery Management System (BMS) drives the bulk of the increase in power semis content.

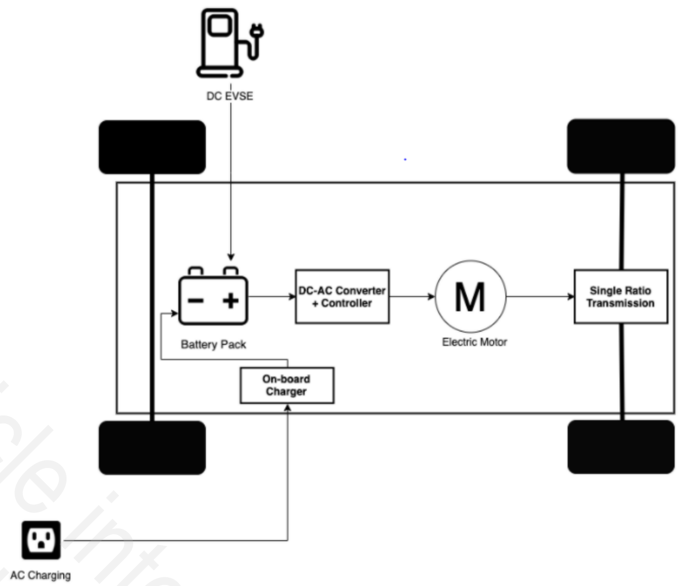
Figure 89: Average Power Semis content in an electric car – varied range of content depending on MHEV to BEV



Source: Company data (Infineon – Feb 2021 earnings)

OBC is critical to converting AC current from a charging socket (in a car port or charging station) to DC current, and then controlling the flow of that DC current into the battery before it is saved there. From the battery, DC current flows to a DC-AC converter as an electric motor needs that current in AC, along with deciding what frequency and magnitude that current needs to flow into the motor, which is determined by the driver's driving intentions. This electrical energy is converted into mechanical energy by the motor and transmitted into wheels. All of these need a combination of MOSFETs and IC drives along with MCU and Sensors. Therefore, we see such a substantial increase in Power semis content when migrating from an ICE to xEV engine.

Figure 90: Electric Motor and OnBoard Charger (OBC) drive the bulk of the increase in power semis content in an xEV



Source: Company data, Credit Suisse research

As we show in Figure 91, we assume that Power semis content for an ICE car is around $70 on an average, and we model a gradual decline over time. Similarly, for an electric vehicle we assume this number to vary – $160 for MHEV, $250 for HEV, $350 for PHEV and $450 for BEV. We assume these content numbers will remain more or less constant in the future because although we think pricing may decrease over time (a declining cost curve due to scale and improving yields especially on SiC), it would likely be compensated by an increase in more power content to drive a further improvement in performance (charging time and/or driving range).

Figure 91: Power Semis content for an xEV – we assume a range of $160 for MHEV and $450 for BEV

	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Global LV sales (mn)	**80.7**	**84.9**	**86.8**	**86.6**	**83.9**	**72.3**	**83.5**	**88.6**	**90.8**	**92.3**	**93.8**	**95.3**	**96.9**	**98.5**	**100.2**	**101.9**
% change yoy	2%	5%	2%	0%	-3%	-14%	16%	6%	2%	2%	2%	2%	2%	2%	2%	2%
Global LV production (mn)	**88.8**	**93.1**	**95.2**	**94.2**	**89.0**	**74.6**	**84.6**	**88.7**	**91.1**	**93.3**	**95.5**	**96.5**	**97.4**	**98.4**	**99.4**	**100.4**
% change yoy	2%	5%	2%	-1%	-6%	-16%	13%	5%	3%	2%	2%	1%	1%	1%	1%	1%
ICE units (mn)	86.6	90.4	91.7	89.4	82.6	66.3	73.4	72.6	69.3	66.7	63.9	58.9	53.7	47.7	42.4	36.9
Total xEV units (mn)	**2.1**	**2.7**	**3.5**	**4.7**	**6.3**	**8.3**	**11.2**	**16.0**	**21.7**	**26.5**	**31.6**	**37.5**	**43.8**	**50.7**	**57.0**	**63.5**
MHEV units (mn)	0.00	0.03	0.05	0.32	1.34	2.23	2.83	3.55	4.63	5.56	6.62	7.75	8.89	9.78	10.71	11.48
HEV units (mn)	1.60	1.84	2.16	2.33	2.74	2.87	3.71	4.89	5.99	6.93	8.07	9.21	10.42	11.76	12.33	13.28
PHEV units (mn)	0.22	0.28	0.42	0.64	0.58	0.98	1.24	2.38	3.41	4.26	4.70	5.52	6.17	7.36	7.96	9.83
BEV units (mn)	0.32	0.51	0.84	1.44	1.68	2.25	3.44	5.20	7.71	9.79	12.23	15.04	18.29	21.81	25.96	28.88
Average Auto Power Semis content ($)	**75**	**77**	**79**	**82**	**86**	**95**	**99**	**111**	**125**	**137**	**148**	**164**	**180**	**199**	**218**	**235**
Average ICE Power Semis content ($)	70	70	70	70	70	70	68	67	65	63	62	60	59	57	56	54
Average xEV Power Semis content ($)	**290**	**298**	**309**	**318**	**293**	**292**	**300**	**310**	**317**	**321**	**323**	**326**	**329**	**333**	**338**	**340**
MHEV Power content ($)	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160
HEV Power content ($)	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
PHEV Power content ($)	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
BEV Power content ($)	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Total Auto Power Semis ($ mn)	**6,687**	**7,121**	**7,491**	**7,765**	**7,642**	**7,069**	**8,371**	**9,798**	**11,400**	**12,741**	**14,163**	**15,788**	**17,562**	**19,623**	**21,629**	**23,599**
Total ICE Power Semis ($ mn)	6,065	6,330	6,418	6,261	5,783	4,638	5,008	4,834	4,497	4,221	3,941	3,544	3,146	2,726	2,364	2,005
Total xEV Power Semis ($ mn)	**622**	**792**	**1,073**	**1,504**	**1,859**	**2,431**	**3,363**	**4,964**	**6,902**	**8,520**	**10,222**	**12,244**	**14,416**	**16,897**	**19,265**	**21,594**
MHEV Power ($ mn)	0	4	8	52	215	356	453	567	741	889	1,059	1,240	1,422	1,565	1,714	1,837
HEV Power ($ mn)	401	460	540	581	685	717	928	1,223	1,497	1,732	2,017	2,303	2,604	2,939	3,082	3,321
PHEV Power ($ mn)	76	99	145	225	202	344	435	834	1,195	1,492	1,644	1,932	2,159	2,577	2,787	3,441
BEV Power ($ mn)	145	228	380	646	757	1,013	1,546	2,340	3,470	4,407	5,502	6,768	8,231	9,817	11,681	12,995

Source: Company data, Credit Suisse estimates

The xEV Power semis market likely to grow from $2.4bn in 2020 to nearly $22bn by 2030. Based on the above assumptions for xEV adoption by type and average power semis content for each of the different types of xEV vehicle, we believe the xEV Power semis market grew from $0.6bn in 2015 to $2.4bn in 2020 (CAGR of 31%). Furthermore, we expect this market to grow to $10.2bn by 2025 (CAGR of 33% over 2020-2025), and to $21.6bn by 2030 (CAGR of 16% over 2025-2030) as we show in Figure 91.

Figure 92: xEV Power semis market to be split at around 75%/25% for IGBT/SiC by 2025, and 50%/50% by 2030 as SiC rises in the mix especially in BEV and in PHEV to some extent

	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Total Auto Power Semis ($ mn)	**6,687**	**7,121**	**7,491**	**7,765**	**7,642**	**7,069**	**8,371**	**9,798**	**11,400**	**12,741**	**14,163**	**15,788**	**17,562**	**19,623**	**21,629**	**23,599**
Total ICE Power Semis ($ mn)	6,065	6,330	6,418	6,261	5,783	4,638	5,008	4,834	4,497	4,221	3,941	3,544	3,146	2,726	2,364	2,005
Total xEV Power Semis ($ mn)	**622**	**792**	**1,073**	**1,504**	**1,859**	**2,431**	**3,363**	**4,964**	**6,902**	**8,520**	**10,222**	**12,244**	**14,416**	**16,897**	**19,265**	**21,594**
MHEV Power ($ mn)	0	4	8	52	215	356	453	567	741	889	1,059	1,240	1,422	1,565	1,714	1,837
HEV Power ($ mn)	401	460	540	581	685	717	928	1,223	1,497	1,732	2,017	2,303	2,604	2,939	3,082	3,321
PHEV Power ($ mn)	76	99	145	225	202	344	435	834	1,195	1,492	1,644	1,932	2,159	2,577	2,787	3,441
BEV Power ($ mn)	145	228	380	646	757	1,013	1,546	2,340	3,470	4,407	5,502	6,768	8,231	9,817	11,681	12,995
Split by IGBT and SiC:																
IGBT Power Semis ($ mn)	**622**	**792**	**1,073**	**1,424**	**1,662**	**2,147**	**2,837**	**4,052**	**5,428**	**6,382**	**7,348**	**8,280**	**9,100**	**9,898**	**10,252**	**10,643**
% change yoy	12%	27%	35%	33%	17%	29%	32%	43%	34%	18%	15%	13%	10%	9%	4%	4%
MHEV	0	4	8	52	215	356	453	567	741	889	1,059	1,240	1,422	1,565	1,714	1,837
% of IGBT in MHEV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
HEV	401	460	540	581	685	717	928	1,223	1,497	1,732	2,017	2,303	2,604	2,939	3,082	3,321
% of IGBT in HEV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
PHEV	76	99	145	225	202	344	435	834	1,195	1,447	1,521	1,691	1,781	1,958	1,951	2,237
% of IGBT in PHEV	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%	93%	88%	83%	76%	70%	65%
BEV	145	228	380	565	560	729	1,020	1,427	1,995	2,314	2,751	3,046	3,293	3,436	3,504	3,249
% of IGBT in BEV	100%	100%	100%	88%	74%	72%	66%	61%	58%	53%	50%	45%	40%	35%	30%	25%
SiC Power Semis ($ mn)	**0**	**0**	**0**	**81**	**197**	**284**	**526**	**913**	**1,475**	**2,138**	**2,874**	**3,964**	**5,317**	**6,999**	**9,013**	**10,951**
% change yoy	NM	NM	NM	NM	144%	44%	85%	74%	62%	45%	34%	38%	34%	32%	29%	21%
MHEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% of SiC in MHEV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% of SiC in HEV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PHEV	0	0	0	0	0	0	0	0	0	45	123	242	378	618	836	1,204
% of SiC in PHEV	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	8%	13%	18%	24%	30%	35%
BEV	0	0	0	81	197	284	526	913	1,475	2,094	2,751	3,723	4,939	6,381	8,177	9,746
% of SiC in BEV	0%	0%	0%	13%	26%	28%	34%	39%	43%	48%	50%	55%	60%	65%	70%	75%

Source: Company data, Credit Suisse estimates

Split of IGBT and SiC in xEV power semis market – around 75%/25% by 2025, but nearly 50%/50% by 2030. SiC remains a relatively new technology with a number of challenges around substrate supply constraints, yield issues, and scale challenges as production continues to be on 6" wafers for now (upcoming plans for 8" wafers but still no 12" wafers in sight), in addition to design challenges. However, we think MHEV and HEV vehicles will continue to use IGBT technology for powertrain, while SiC is being increasingly adopted in BEV for now and should be adopted in PHEV from 2024.

In Figure 92, we show our forecasts for the split of both the BEV and PHEV markets by IGBT and SiC technologies over time. For BEV where we believe the use case for SiC is most justified given benefits of higher mileage, we assume that SiC adoption will rise from 28% in 2020 (driven by Tesla) to 50% by 2025, and to 75% by 2030. For PHEV, we model SiC penetration rising from 3% in 2024 to 35% by 2030.

This should result in the SiC power market for xEV to grow from around $300m in 2020 to $2.9bn by 2025, and $11.0bn by 2030. Over the same period, we expect IGBT for the xEV market to grow from $2.1bn in 2020 to $7.3bn/$10.6bn by 2025/2030.

Figure 93: Power Semis market for xEV to grow from $2.4bn in 2020 to $10.2bn by 2025 (33% CAGR 2020-25) and $21.6bn by 2030 (16% CAGR 2025-30); within this we expect SiC to grow from $300mn in 2020 to $2.9bn/$11.0bn by 2025/2030

																	CAGR		
	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E	2015-2020	2020-2025E	2025E-2030E
Global LV sales (mn)	**80.7**	**84.9**	**86.8**	**86.6**	**83.9**	**72.3**	**83.5**	**88.6**	**90.8**	**92.3**	**93.8**	**95.3**	**96.9**	**98.5**	**100.2**	**101.9**	**-2.2%**	**5.4%**	**1.7%**
% change yoy	2%	5%	2%	0%	-3%	-14%	16%	6%	2%	2%	2%	2%	2%	2%	2%	2%			
Global LV production (mn)	**88.8**	**93.1**	**95.2**	**94.2**	**89.0**	**74.6**	**84.6**	**88.7**	**91.1**	**93.3**	**95.5**	**96.5**	**97.4**	**98.4**	**99.4**	**100.4**	**-3.4%**	**5.1%**	**1.0%**
% change yoy	2%	5%	2%	-1%	-6%	-16%	13%	5%	3%	2%	2%	1%	1%	1%	1%	1%			
ICE units (mn)	86.6	90.4	91.7	89.4	82.6	66.3	73.4	72.6	69.3	66.7	63.9	58.9	53.7	47.7	42.4	36.9	-5.2%	-0.7%	-10.4%
Total xEV units (mn)	**2.1**	**2.7**	**3.5**	**4.7**	**6.3**	**8.3**	**11.2**	**16.0**	**21.7**	**26.5**	**31.6**	**37.5**	**43.8**	**50.7**	**57.0**	**63.5**	**31.2%**	**30.6%**	**15.0%**
MHEV units (mn)	0.00	0.03	0.05	0.32	1.34	2.23	2.83	3.55	4.63	5.56	6.62	7.75	8.89	9.78	10.71	11.48			
HEV units (mn)	1.60	1.84	2.16	2.33	2.74	2.87	3.71	4.89	5.99	6.93	8.07	9.21	10.42	11.76	12.33	13.28			
PHEV units (mn)	0.22	0.28	0.42	0.64	0.58	0.98	1.24	2.38	3.41	4.26	4.70	5.52	6.17	7.36	7.96	9.83			
BEV units (mn)	0.32	0.51	0.84	1.44	1.68	2.25	3.44	5.20	7.71	9.79	12.23	15.04	18.29	21.81	25.96	28.88			
Average Auto Power Semis content ($)	**75**	**77**	**79**	**82**	**86**	**95**	**99**	**111**	**125**	**137**	**148**	**164**	**180**	**199**	**218**	**235**	**4.7%**	**9.4%**	**9.7%**
Average ICE Power Semis content ($)	70	70	70	70	70	70	68	67	65	63	62	60	59	57	56	54			
Average xEV Power Semis content ($)	**290**	**298**	**309**	**318**	**293**	**292**	**300**	**310**	**317**	**321**	**323**	**326**	**329**	**333**	**338**	**340**	**0.1%**	**2.1%**	**1.0%**
MHEV Power content ($)	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160	160			
HEV Power content ($)	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250			
PHEV Power content ($)	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350			
BEV Power content ($)	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450			
Total Auto Power Semis ($ mn)	**6,687**	**7,121**	**7,491**	**7,765**	**7,642**	**7,069**	**8,371**	**9,798**	**11,400**	**12,741**	**14,163**	**15,788**	**17,562**	**19,623**	**21,629**	**23,599**	**1.1%**	**14.9%**	**10.8%**
Total ICE Power Semis ($ mn)	6,065	6,330	6,418	6,261	5,783	4,638	5,008	4,834	4,497	4,221	3,941	3,544	3,146	2,726	2,364	2,005	-5.2%	-3.2%	-12.6%
Total xEV Power Semis ($ mn)	**622**	**792**	**1,073**	**1,504**	**1,859**	**2,431**	**3,363**	**4,964**	**6,902**	**8,520**	**10,222**	**12,244**	**14,416**	**16,897**	**19,265**	**21,594**	**31.3%**	**33.3%**	**16.1%**
MHEV Power ($ mn)	0	4	8	52	215	356	453	567	741	889	1,059	1,240	1,422	1,565	1,714	1,837	NM	24.3%	11.6%
HEV Power ($ mn)	401	460	540	581	685	717	928	1,223	1,497	1,732	2,017	2,303	2,604	2,939	3,082	3,321	12.3%	23.0%	10.5%
PHEV Power ($ mn)	76	99	145	225	202	344	435	834	1,195	1,492	1,644	1,932	2,159	2,577	2,787	3,441	35.1%	36.7%	15.9%
BEV Power ($ mn)	145	228	380	646	757	1,013	1,546	2,340	3,470	4,407	5,502	6,768	8,231	9,817	11,681	12,995	47.6%	40.3%	18.8%
Split by IGBT and SiC:																			
IGBT Power Semis ($ mn)	**622**	**792**	**1,073**	**1,424**	**1,662**	**2,147**	**2,837**	**4,052**	**5,428**	**6,382**	**7,348**	**8,280**	**9,100**	**9,898**	**10,252**	**10,643**	**28.1%**	**27.9%**	**7.7%**
% change yoy	12%	27%	35%	33%	17%	29%	32%	43%	34%	18%	15%	13%	10%	9%	4%	4%			
MHEV	0	4	8	52	215	356	453	567	741	889	1,059	1,240	1,422	1,565	1,714	1,837			
% of IGBT in MHEV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%			
HEV	401	460	540	581	685	717	928	1,223	1,497	1,732	2,017	2,303	2,604	2,939	3,082	3,321			
% of IGBT in HEV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%			
PHEV	76	99	145	225	202	344	435	834	1,195	1,447	1,521	1,691	1,781	1,958	1,951	2,237			
% of IGBT in PHEV	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%	93%	88%	83%	76%	70%	65%			
BEV	145	228	380	565	560	729	1,020	1,427	1,995	2,314	2,751	3,046	3,293	3,436	3,504	3,249			
% of IGBT in BEV	100%	100%	100%	88%	74%	72%	66%	61%	58%	53%	50%	45%	40%	35%	30%	25%			
SiC Power Semis ($ mn)	**0**	**0**	**0**	**81**	**197**	**284**	**526**	**913**	**1,475**	**2,138**	**2,874**	**3,964**	**5,317**	**6,999**	**9,013**	**10,951**	**NM**	**58.9%**	**30.7%**
% change yoy	NM	NM	NM	NM	144%	44%	85%	74%	62%	45%	34%	38%	34%	32%	29%	21%			
MHEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
% of SiC in MHEV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%			
HEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
% of SiC in HEV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%			
PHEV	0	0	0	0	0	0	0	0	0	45	123	242	378	618	836	1,204			
% of SiC in PHEV	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	8%	13%	18%	24%	30%	35%			
BEV	0	0	0	81	197	284	526	913	1,475	2,094	2,751	3,723	4,939	6,381	8,177	9,746			
% of SiC in BEV	0%	0%	0%	13%	26%	28%	34%	39%	43%	48%	50%	55%	60%	65%	70%	75%			

Source: Company data, Credit Suisse estimates

The SiC Power market has potential to record a 40%+ CAGR. In addition to the xEV Auto market, we also layer on the revenue contribution for the SiC market coming from Industrial applications. This results in the total SiC Power market growing from \$700m in 2020 to \$4.0bn by 2025 (CAGR of 42%). Of this \$4.0bn, we model \$2.9bn coming from Auto markets and \$1.1bn coming from various Industrial applications.

Figure 94: We estimate the SiC Power market to grow from \$700mn in 2020 to \$4bn by 2025 (CAGR of 42%)

SiC Power chip market ($ mn)	2019	2020	2021E	2022E	2023E	2024E	2025E
SiC Power - Auto ($ mn)	197	284	526	913	1,475	2,138	2,874
% change yoy		44%	85%	74%	62%	45%	34%
SiC Power - Non-Auto ($ mn)	433	418	514	647	787	944	1,132
% change yoy		-4%	23%	26%	22%	20%	20%
SiC Power - Total ($ mn)	**630**	**701**	**1,040**	**1,560**	**2,262**	**3,082**	**4,007**
% change yoy		11%	48%	50%	45%	36%	30%

Source: Company data, Credit Suisse estimates

Market share trends in SiC – the top four companies to account for ~85% of the market. Looking at the size of the SiC market (Auto + Industrial) of around \$700m in 2020, we estimate that STM has been the leader so far with around 40% share – helped by a design win at Tesla across all models (starting with Model 3 at the end of 2017, and penetrating into other models since then). The next three key companies in SiC are Wolfspeed (CREE), Rohm and Infineon, with each having a market share of around 15%, followed by ON Semi and Mitsubishi (c5% share each).

Figure 95: STM had a ~40% share in the SiC Power market in 2020 given its relationship with Tesla; As SiC is adopted by more OEMs, we expect STM's high share to stabilize in the low-30% range over time

SiC Power chip market ($ mn)	2019	2020	2021E	2022E	2023E	2024E	2025E
STMicro	205	275	480	651	851	1,074	1,298
market share (%)	33%	39%	46%	42%	38%	35%	32%
Wolfspeed (CREE)	110	108	139	218	328	493	681
market share (%)	18%	15%	13%	14%	15%	16%	17%
Rohm	97	92	104	187	294	431	601
market share (%)	15%	13%	10%	12%	13%	14%	15%
Infineon	70	97	185	328	520	770	1,002
market share (%)	11%	14%	18%	21%	23%	25%	25%
ON Semi	41	38	31	47	68	92	120
market share (%)	7%	5%	3%	3%	3%	3%	3%
Mitsubishi Electric	32	31	31	47	68	62	80
market share (%)	5%	4%	3%	3%	3%	2%	2%
Others	75	60					
market share (%)	12%	8%					
Total	**630**	**701**	**1,040**	**1,560**	**2,262**	**3,082**	**4,007**
% change yoy		11%	48%	50%	45%	36%	30%

** Others include Fuji Electric, Semikron, Danfoss, etc.*

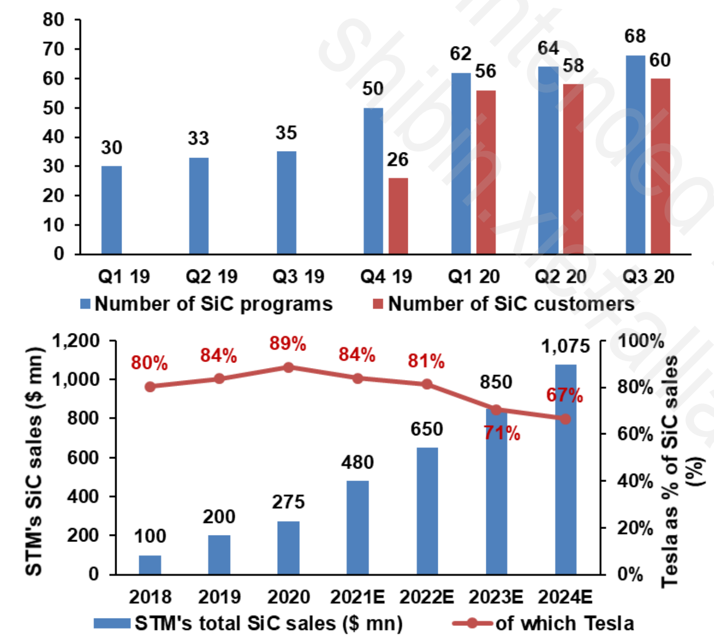
Source: Company data, Credit Suisse estimates

- **STM could remain the market leader given its Tesla relationship.** As more car OEMs start to adopt SiC, we believe STM's high market share of close to 40% in 2020 and likely even higher at ~45% in 2021 may start to decline as more car OEMs adopt SiC technology using solutions from other chip makers. A recent example was the announcement from Hyundai, which has selected Infineon as the SiC supplier for inverters in its new e-GMP platform for BEV models. Hence, we believe STM's share in SiC should stabilize at around the low-30%'s over time (Figure 95).

- STM's SiC customer list has more than doubled in the past year. Over the past few quarters, we note that STM has increased its SiC customer count from 26 (in Q419) to 60 (in Q320), although we still believe that Tesla accounts for ~85% of STM's SiC sales (Figure 96). In terms of SiC customers publicly announced for STM, we note Tesla, Hyundai, Renault-Nissan-Mitsubishi, Innolectric and BYD as some of its key customers for either inverter or OBC applications.

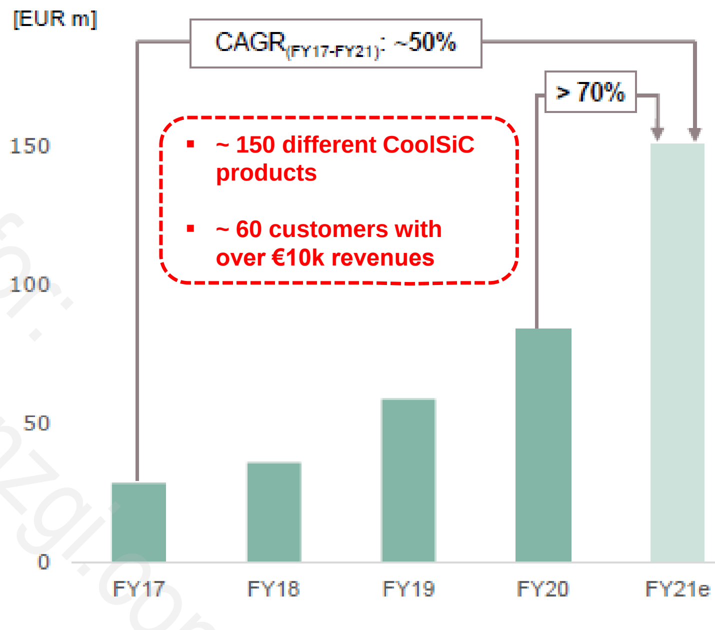
- **STM targeting $450-500mn SiC sales in 2021.** Having grown from a base of ~$100m of SiC chip sales in 2018 to ~$275m in 2020, we believe STM can reach $480m in 2021 (company target is $450-500m for 2021 with 2H > 1H). We also believe that STM's SiC sales can reach around $1.1bn/$1.3bn by 2024/2025. Therefore, STM is working on expanding its manufacturing presence for SiC chips for both the front and back-end. Currently STM has a 150mm front-end fab in Catania (Italy), and plans to add incremental capacity for 150mm in Singapore in 2021. For back-end manufacturing, it has a fab in Shenzhen (China) currently, with plans to add another fab in Bouskoura (Morocco) this year.

Figure 96: STM is expanding its list of SiC customers and projects beyond Tesla, but Tesla still ~85% of its SiC sales



Source: Company data (STM), Credit Suisse estimates

Figure 97: IFX aiming for 70%+ growth in its SiC business reaching at least €150m of sales in FY21



Source: Infineon (Feb 2021 slides)

- **Infineon should benefit from new high-volume wins.** Infineon had been lagging in SiC momentum for automotive applications. Nearly all of its SiC sales until FY20 were coming from Industrial applications (we believe mainly from PV inverters used in the renewable energy market). However, we are now starting to see signs of traction with auto OEMs with Hyundai using its SiC trench MOSFET for its new E-GMP platform for a range of BEV models starting with IONIQ 5. Including Hyundai, it now has three SiC customers for inverter products in the automotive market. At its most recent earnings, IFX noted it now has around 60 customers (with more than €10k sales contribution) and expects above 70% yoy growth in its SiC business in FY21 resulting in over €150m sales (Figure 97). The majority of this incremental growth in FY21 is expected to come from the Auto market. We expect IFX's SiC sales to reach $1.0bn (or €830mn) by 2025.

- **Wolfspeed aiming to reach €900m of SiC + GaN chip sales by June 2024.** Wolfspeed (CREE) had $471m of sales in FY20 (year ending June 2020), which we assume was roughly split 50/50 between wafers and chips. Furthermore, both wafers and chip sales were split between the two wide-band-gap technologies (SiC and GaN).

Therefore, we assume Wolfspeed would have around $250m of SiC sales (wafers + chips) in FY20 – split as around $150m for SiC wafers and around $100m for SiC chips.

Wolfspeed is aiming to reach $1.5bn of sales by FY24, of which $600m will be linked to materials (SiC + GaN wafers) and another $900m will come from devices (SiC + GaN chips) based on its expectations that it will have a c60% share in SiC wafers and a 20% share in SiC chips over time. Wolfspeed has also noted a $10bn opportunity pipeline (combination of Award Letters and MoUs from customers) over 2020-2025.

- **Rohm targeting full-scale SiC ramp-up from 2024, ¥50bn sales contribution in 2025.** Rohm's old guidance (as of FY18) called for FY25 SiC device sales of ¥70bn, equal to 30% of the projected market (¥230bn premised on 5m EVs; FY18 market share: 20%). However, with the COVID-19 pandemic likely to hamper market growth for around two years, we think the company now assumes an FY25 market of ¥150–200bn and targets sales of about ¥50bn (30% market share). This plan assumes that in FY25, full SiC power modules will be used only in large and luxury EVs with battery capacity of 50kWh or more.

  - **Mass production of fourth-gen SiC MOSFET.** At its results briefing last May, Rohm said it was initiating mass production of its fourth-gen SiC-MOSFET with world-leading performance (40% reduction in on-resistance vs. previous generation) in 2Q20. It also expects strong sales growth from 2024 citing xEV-related inquiries from more than 30 companies. Sales of SiC-Schottky barrier diodes (SBDs) for EV onboard chargers are already growing, but the company expects sales of full SIC-MOSFET/SBD power modules to pick up from 2024. Rohm's strategy is to expand SiC-MOSFET sales by bundling them with insulated gate drivers manufactured in-house.

  - **Partnership with Vitesco (Continental).** Within the customer base, we note Vitesco Technologies, a powertrain technology provider in the Continental group, selected Rohm as a preferred supplier of SiC technology in June 2020. The two companies also announced that they had agreed to form an EV power electronics development partnership. Vitesco said it had selected Rohm as a preferred supplier to maximize the efficiency of its automotive inverters and motors. Both Vitesco and Rohm have bases in Nuremberg, close to Vitesco's head office, affording a geographical advantage. Vitesco indicated that it would collaborate on SiC inverter solutions for 400V batteries, in addition to 800V batteries, and plans to start production of its first SiC inverter in 2025. For customers other than Vitesco, Rohm started shipping full SiC power modules for inverters in 2H 2020, and we note that EVs equipped with Rohm's full SiC power modules are likely to hit markets from 2021 onwards.

  - **SiC wafer supply agreement with STM.** In January 2020, the company signed a multi-year SiC wafer supply contract with STMicroelectronics. The agreement is to supply over $120m worth of SiC wafers. The switch to 6" wafers was completed later than initially planned, but the company is now shifting to larger, 8" wafers, and expects to complete the transition within 1-2 years.

  - **SiC capex of ¥60bn by FY25.** Rohm's plans for SiC device-related capex calls for a total outlay of ¥60bn by FY25 (¥40bn by FY21), comprising ¥15bn for SiC wafer substrates and ¥45bn for front-end processes. The company began construction of a new building at its Apollo Chikugo facility in February 2019, and completed it in December 2020. Rohm has issued plans to increase SiC device production capacity by 6x in FY3/21 and 16x in FY3/25 (current capacity is up 3x) and insulated gate driver production capacity by 5x in FY3/21 and 11x in FY3/25 (all vs. FY3/17 levels). We note that the company plans to install 8" manufacturing equipment at the Chikugo facility, which will enable it to switch from production of 6" SiCs initially to 8" SiCs as market conditions warrant.

Figure 98: Rohm aiming to grow its SiC device sales by 5x over the next four years

Source: Rohm (October 2020 slides)

- **One of the very few vertically integrated names.** Rohm stands out for its vertical integration of production processes (along with Wolfspeed, and also STM in the future) from wafers through to back-end processes, but it appears even more vertically integrated in SiC devices than in silicon devices. SiC wafers are harder than Si wafers and difficult to process but producing them in-house gives Rohm structural control of internal wafer design, which we think has led to differentiation in the development of front-end processes including for trench structures.

- **Toshiba developing SiC devices mainly for in-house use.** Toshiba manufactures SiC power devices for in-house use on its 4" and 6" lines, and has already introduced inverters based on 3.3kV all-SiC power devices for new model rail cars. SiC devices developed by Toshiba range up to 650V–3.3kV. The company plans to launch its second-gen SiC devices for railway applications in 2022.

- **Fuji Electric targeting 20% share of SiC power module market by 2025-2026.** Fuji Electric has rolled out SiC power modules and aims to grow annual sales to over a billion yen by FY3/24. The company is mass-producing its first-gen trench gate MOSFET at its plant for 6" devices and is currently developing a second-gen product. Improving on its first-gen device, Fuji Electric has achieved a 23% lower power loss on the second-gen trench gate MOSFET, and started providing samples in 2020. The company plans to complete development of the third-gen trench gate MOSFET by around 2025. It targets a 20% share of the SiC power module market in 2025–26 with sales of ¥10–15bn (or US$90-140mn). Although on our SiC device market estimate of $4.0bn in 2025 (up from $0.7bn in 2020), this ¥10-15bn sales target would imply only 2-4% global share.

- **Mitsubishi Electric targets SiC adoption in Auto in 2022-23.** Mitsubishi Electric produces SiC power devices in volumes on 4" and 6" lines. In-house air conditioner and railway applications currently account for the bulk of the company's SiC power modules, which make up around 5% (¥6-7bn) of its power semiconductor sales. In the future, the company expects growth in demand for installation of SiC power modules in automotive motors. It aims for adoption of its products in cars to take place in 2022–23 at the earliest. The company also launched a second-gen all-SiC power module for industrial applications in January 2021. SiC-MOSFET and SiC-SBD (SBDs are schottky barrier diodes) chips boast low-loss properties and high carrier frequency, which should boost the efficiency of various industrial equipment, thereby contributing to their size and weight reduction. These chips reduce power loss by 70% compared with Si-IGBT modules.

Figure 99: List of publicly announced SiC partnerships on the Automotive front – rising interest in the supply chain

Date	Auto OEM / Tier-1 supplier	SiC Partner	Details
Dec 2020	Toyota	Denso	Produces SiC power chips (diodes & transistors) for fuel cell vehicles (FCEV); product used in Toyota's new Mirai model (launched in Dec 2020)
Jul 2020	Delphi + China car OEM	CREE	Win for a 800V SiC inverter (to be developed by Delphi in partnership with CREE) for a new BEV platform for a China car OEM
Jun 2020	Vitesco (Continental)	Rohm	Developing and testing SiC technology in an 800V inverter concept (also working on 400V technology); Vitesco aims to start production of its first SiC inverter from 2025
May 2020	Yutong	StarPower & CREE	Planning to use CREE's 1200V SiC devices in a StarPower power module for its new, high-efficiency powertrain system for electric buses
Feb 2020	BYD	BYD Semiconductor	Launches BYD Han EV model, which is based on its internal SiC technology; in Dec 2020, BYD noted that it has developed 3rd gen of SiC MOSFET, and is on track to launch the 4th gen
Nov 2019	ZF	CREE	ZF expects to make SiC electric drivelines available to the market by 2022
Oct 2019	Hyundai	Infineon	Selects IFX's HybridPACK CoolSiC (trench) products for their next gen EVs; Launched E-GMP platform in Dec 2020, which is dedicated to BEV models which can provide over 500km range and faster charging (upto 80% in 18mins)
Sep 2019	Renault-Nissan-Mitsubishi	STM	Selected to supply high efficiency SiC power chips for advanced on-board chargers (OBC) in its next-gen EVs; OBCs are expected to enter volume production in 2021
Sep 2019	Delphi + Premium global car OEM	CREE	Partnering on 800V technology with launch timeframe in 2022; Delphi scored a $2.7bn 8-year contract win with a premier global car OEM
May 2019	Volkswagen	Infineon	Chosen as a new partner for VW's strategic supplier network called FAST (Future Automotive Supply Tracks); VW aims to launch 70 xEV models over the next 10 years with aim to build 22mn xEV cars (most of them on MEB platform)
May 2019	Volkswagen	CREE	Selected as the exclusive SiC partner for VW's strategic supplier network called FAST (Future Automotive Supply Tracks); Both companies to work with tier-1 and power module suppliers to engineer SiC-based solutions for future VW vehicles
Feb 2019	Hyundai	STM	Joint R&D lab (ADSL) with Hyundai-Autron for new products aimed at EV models, with focus on powertrain controllers
May 2018	Innolectric	STM	Joint R&D on use of SiC for developing on-board chargers (OBC); Production started for 22kW OBC using 400V and 800V in Jan 2020, with deliveries from mid 2020
Aug 2017	Tesla	STM	Selected as supplier for SiC MOSFET (650V) chips for inverter in Model 3; 24 SiC MOSFETs were packaged together in a customized solution for Model 3; extended that partnership for other Tesla models since then

Source: Company data, Credit Suisse research

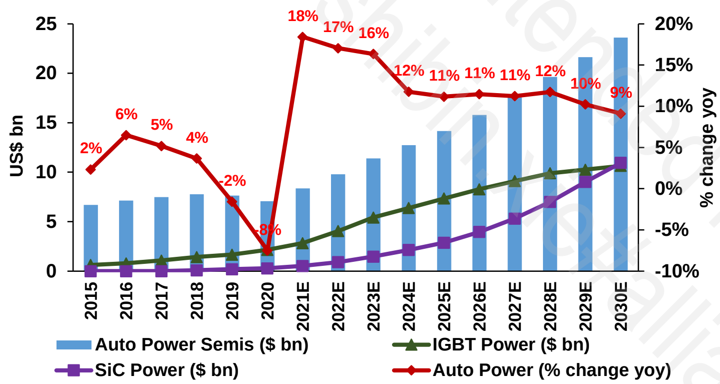
Sector and supply chain positioning

In this section, we focus on the key product areas that stand to benefit from the rising xEV theme and on companies globally that could benefit from this trend.

Power Semis should fuel the EV revolution

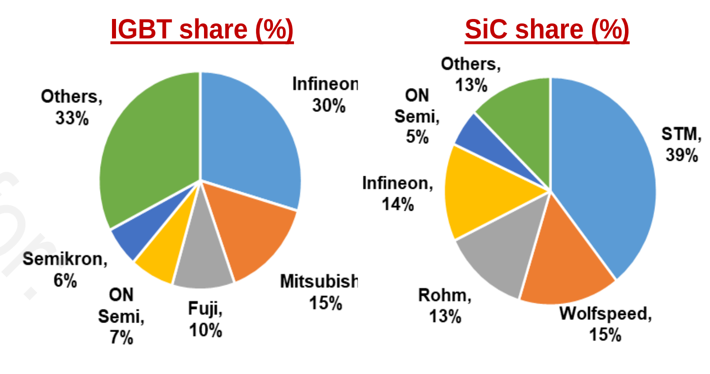
Given the increasing importance of power-related semis in the EV market, we believe that Power Semis for the xEV market will account for nearly 30% of incremental growth in the total Auto semis market over the next decade. Within this, we believe companies with a strong presence in the IGBT market will continue to benefit from this trend – this includes Infineon (30% share in IGBT devices in 2020), Mitsubishi (15%), Fuji (10%) and ON Semi (7%). However, with SiC now emerging as a technology of choice for high-voltage applications within an EV, we believe companies with a presence in SiC technology are even better positioned to benefit from xEV adoption. Given that SiC is still a relatively new technology, we see limited competition here for now, with STM (~40% share in SiC devices in 2020), Wolfspeed, Rohm and Infineon (all around 15% share each) being the key companies.

Figure 100: Rising xEV adoption means Power Semis market can grow from $7bn in 2020 to $24bn by 2030 (13% CAGR)



Source: Gartner, Company data, Credit Suisse estimates

Figure 101: IFX leads in IGBT devices with a ~30% share (2020), while STM leads in SiC with ~40%



Source: Company data, Credit Suisse research

Growing importance of BMS in EV adoption

What is BMS? The battery management system (BMS) is critically important for electric vehicles given their task of monitoring and modulating the charge levels of the battery. Wireless BMS works the same way as traditional BMS (and serves the same function), but each module is interconnected via a wireless connection instead of a cable/wire, providing the additional benefit of lessening the weight of the vehicle and increasing the battery range. These systems are important for three main reasons:

- **Protecting the battery** from being over-charged (cell voltages getting too high) or over-discharged (cell voltages getting too low), thus extending the life of the battery pack. Essentially, it monitors every cell in the battery pack and calculates how much current can safely go in/out without damaging it. These calculated current limits are then sent to the source (usually a battery charger) and load (motor controller, power inverter, etc.), which are responsible for modulating within these limits.

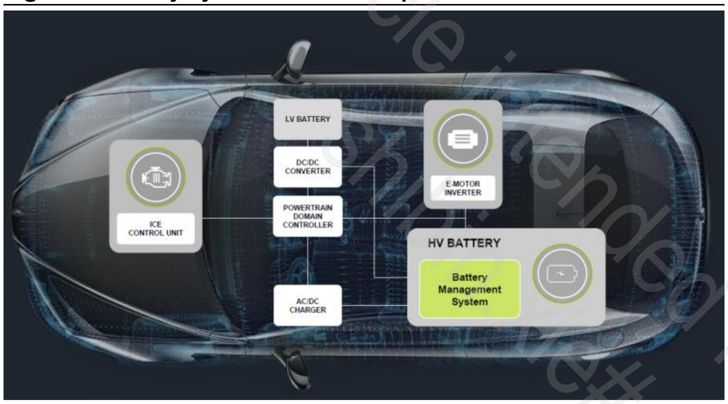
- **An electronic "fuel gauge"** as BMS calculates the "State of Charge" (the amount of energy remaining in the battery) – a value that can be thought of as a fuel gauge indicating how much battery power is left in the pack.

- **Monitoring the health/safety of the battery pack** by constantly checking for shorts, loose connections, breakdowns in wire insulation, and weak or defective battery cells that need to be replaced.

There are also secondary, but equally significant, functions that the BMS performs:

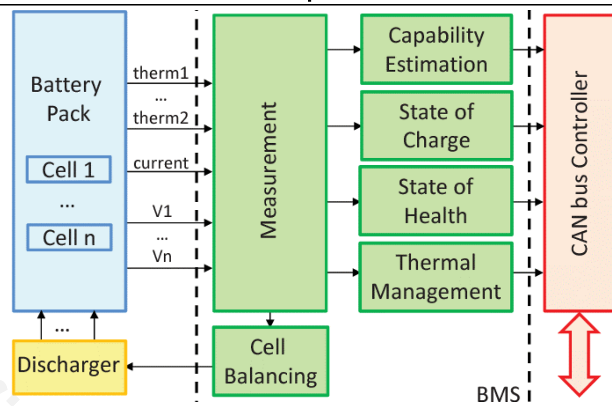
- **Optimizing battery performance** – Balances all the cells in the battery pack by intelligently dissipating excess energy from cells that are charged more than others. This provides the maximum amount of usable energy (capacity) from the battery pack since the pack is only as strong as the weakest cell.
- **Regulating the temperature of the engine** – Monitors the temperature of the battery pack and controls the fan to regulate the temperature. It also constantly monitors the output of the fan to make sure it is working properly.
- **Data aggregation and error correction** – Provides real-time information to send to devices such as motor controllers, chargers, displays etc. using several different methods (CANBUS, analog outputs, and digital outputs). This allows for storage of error codes/diagnostic info to help fix any problems that might arise.

Figure 102: Key systems in an xEV powertrain



Source: Company data (NXPI)

Figure 103: The role of BMS in powertrain



Source: EV reporter

Bottom-up total addressable market (TAM) sizing for the BMS market. It is estimated that current BMS content in a vehicle ranges from $30 to $100/unit but should grow to $60-200/unit with increased unit electrification and wBMS capabilities. This implies that the potential TAM could be ~$4-5bn – with 30-40m EV units or CS estimated ~35-40% penetration of CY25 total Auto SAARs. In other words, BMS TAM by CY25 could surpass the total CY20 Auto revenues of NXPI, ADI, and MXIM combined.

Figure 104: Sensitivity analysis for bottom-up TAM for the BMS market

CY20	
EV/HEV Units (m)	9.5
Total Units (m)	75
% Penetration	12.7%

CY25 CS Estimates	
EV/HEV Units (m)	41.5
Total Units (m)	95.5
% Penetration	43.5%

CY25 BMS TAM Sensitivity ($m)	# of EV Vehicles (m units)				
BMS Content/Unit ($)	20.0	30.0	40.0	50.0	60.0
$30	$600	$900	$1,200	$1,500	$1,800
$60	$1,200	$1,800	$2,400	$3,000	$3,600
$100	$2,000	$3,000	$4,000	$5,000	$6,000
$130	$2,600	$3,900	$5,200	$6,500	$7,800
$160	$3,200	$4,800	$6,400	$8,000	$9,600
$200	$4,000	$6,000	$8,000	$10,000	$12,000

Source: Credit Suisse estimates

Extending battery capacity and range. One of the most significant benefits of BMS is its ability to extend battery life, improve capacity, and therefore extend the miles per charge. Here we note that BMS could extend useful capacity/operation hours of an EV battery pack by ~10-15% over three years (Smart Battery Pack for Electric Vehicles) and ADI estimates that its BMS systems can extend vehicle range by up to ~20% per charge. Some OEMs are estimated to charge ~$10-20k per vehicle for over-the-air updates to extend the range of a battery pack – which in reality is equivalent to a ~10-15 kWh capacity improvement, achieved with a BMS system costing ~$60-100. This could significantly incentivize OEMs to invest in the technology that enables useful capacity improvements. Although the relationship between capacity and range depends on the design and weight of the vehicle, it is clear that improving both will lessen the cost for the consumer, and reduce the need for highly concentrated EV charging networks. This, in turn, would accelerate penetration of EVs to more geographies.

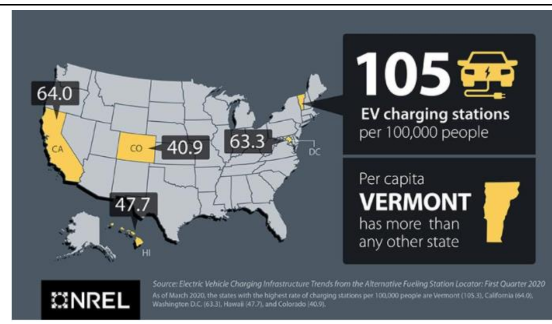
Importance of BMS for Auto OEMs and consumers: In addition, since the battery of most EVs is ~75% of its powertrain cost (Real-world study for the optimal charging of electric vehicles), one of the biggest issues for the EV consumer is this high purchase cost. Although some expect the average price of Lithium-ion battery packs to fall from $200-250/kWh (International Energy Agency) to $100/kWh by 2025, the importance of maintaining an EV battery using BMS, not only to resell the car but also for extended usage, could help reduce both the battery cost for EV manufacturers and the TCO for customers.

Figure 105: Range of cost savings based on the average cost of electricity per kWh

Cost for Full Charge Based on BMS Improvements					
	% Longer Range of EV with BMS				
Cost of Electricity (per kWh)	0%	5%	10%	15%	20%
$0.13	$ 7.80	$ 8.19	$ 8.58	$ 8.97	$ 9.36
$0.15	$ 9.00	$ 9.45	$ 9.90	$ 10.35	$ 10.80
$0.17	$ 10.20	$ 10.71	$ 11.22	$ 11.73	$ 12.24
$0.19	$ 11.40	$ 11.97	$ 12.54	$ 13.11	$ 13.68
$0.21	$ 12.60	$ 13.23	$ 13.86	$ 14.49	$ 15.12
$0.23	$ 13.80	$ 14.49	$ 15.18	$ 15.87	$ 16.56

Source: Credit Suisse estimates

Figure 106: Current concentration of EV network varies greatly by region in the US



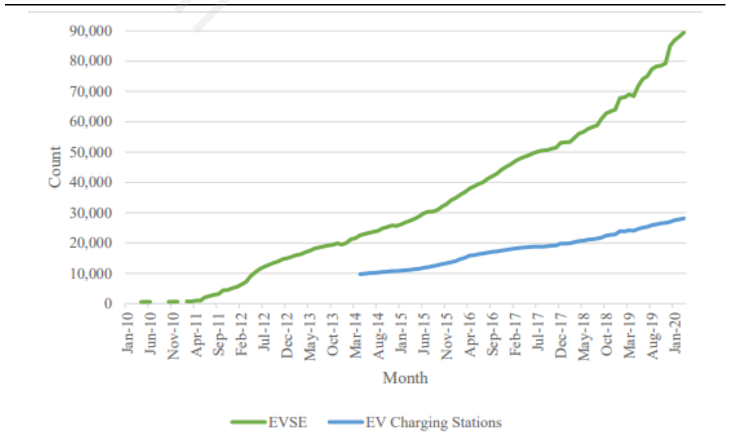
Source: National Renewable Energy Laboratory (NREL)

Lessening the burden on the EV charging network. Based on NREL's National Plug-In Electric Vehicle Infrastructure Analysis, which estimated how much Level 2 and DC fast-charging infrastructure would be required in the US to meet charging demand by CY30, ~12%/50% of the necessary Level 2/DC charging has been installed as of CY1Q21. However, 56% of public DC-fast charging tracked is on the TSLA network and therefore only readily accessible to TSLA drivers. Through BMS-extended EV ranges, this could significantly lower the number of stations needed and boost consumer confidence in EV longevity.

Figure 107: Driving route from NYC to SF in the US requires >20 full recharges for BEV

Source: Alternative Fuels Datacenter (median EV range ~150 miles/charge)

Figure 108: EV charging stations in the US have grown ~2x over 2015-19

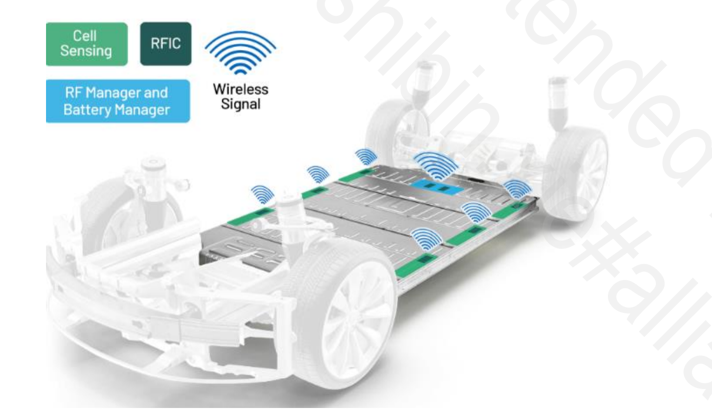


Source: NREL.gov (US data); EVSE = EV servicing equipment

Main BMS names. BMS, similar to other Analog/Diversified markets, is relatively fragmented, with market leaders (NXPI, ADI, ST, Renesas, SLAB, IFX, and TXN) still only having ~10-15% total market share and competing against multiple other companies in the market – i.e. Elithion, Nuvation Engineering, Orion, Vecture, Ventec, etc. We would highlight the following companies for BMS in our US coverage:

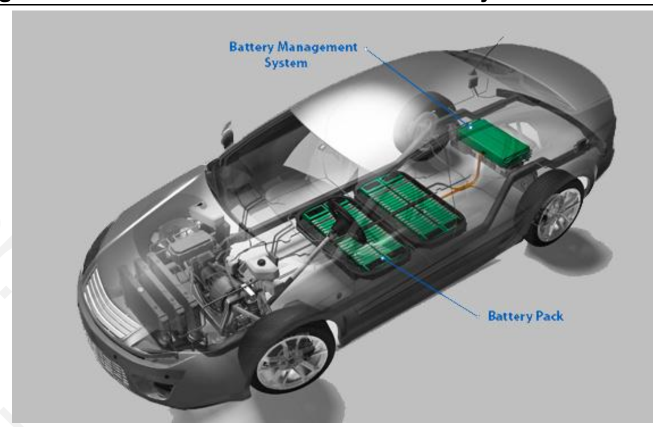
- **Analog Devices (ADI) adding wireless to BMS.** In September 2020, ADI had announced a collaboration with GM for the industry's first wireless BMS (wBMS) to debut on all GM EVs with Ultium batteries starting with model-year 2021/22. From a financial perspective, we note that:
  - BMS is roughly ~10% of ADI's Automotive sales (~15% of group sales) with potential for a strong, double-digit sales CAGR going forward in the mid-term;
  - wBMS could double content per EV from a range of $30-100 per EV to $60-200 per EV; and
  - wBMS removes up to 90% of wiring and 15% of battery volume saving significant weight/space – every ~10% reduction in weight improves MPG by ~5% – thereby providing significant economic benefits to auto OEMs and consumers.

Figure 109: ADI Introduces first wBMS for Production EVs



Source: Company data (ADI)

Figure 110: wBMS Removes ~15% of Battery Volume



Source: Company data (ADI)

In addition, we note the following for wBMS:

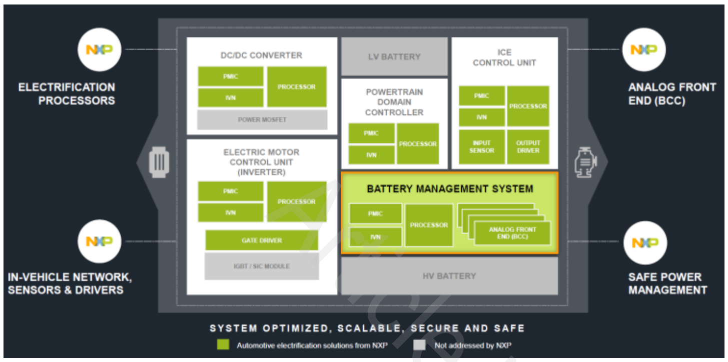
- It allows for a modular design to quickly and economically scale fleet across different car models/designs – it is unclear if GM's collaboration with NKLA includes Ultium;
- It is easily reconfigurable for battery reuse/secondary life; and
- It also allows for additional system measurement and performance features – increasing early failure detection and enabling optimized battery pack assembly.

wBMS should solidify an already strong market position as ADI's BMS solution given: (1) wBMS is now used in >50% of the top 10 selling EV cars globally, (2) it has best-in-class vehicle range, mile per charge performance (~20% greater than peers), and (3) it also has all the functional safety features, including module-level security and ASIL-D. We view GM/wBMS collaboration as very positive for ADI's Auto business, as the company continues to gain share across EVs with innovative products/solutions like wBMS and the new road-noise-cancelling solution (also reducing weight) more than doubling semi content/vehicle over the next 2-3 years.

- **NXP Semiconductors (NXPI) growing its BMS footprint.** NXP's scalable battery management systems have also been gaining traction (est. ~15% market share or #3 player in BMS today). They were recently adopted across the entire MEB platform of the Volkswagen Group, including ID.3 and ID.4 models, and in the luxury and performance models, Audi e-tron and Porsche Taycan. Currently, NXPI BMS business has a run rate of

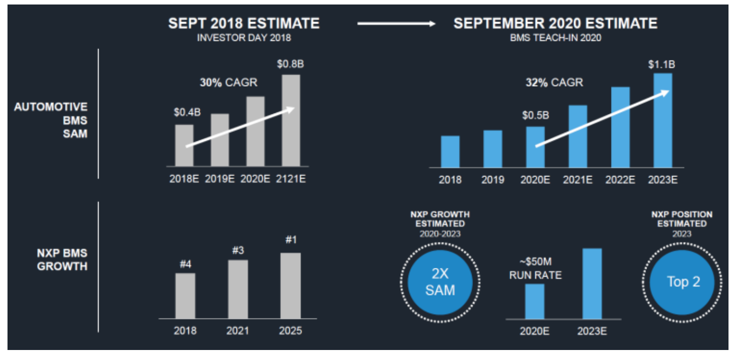
~$50m (CY20) and the company believes it can grow at 2x SAM, at a ~30% CAGR or a ~60% CAGR for next 3/5 years to ~$1.1bn by CY23 – to the #2 position in the BMS market. By CY23, the company estimates that one out of every four xEVs will use NXPI's BMS solution based on BMS project design wins with 16 out of top 20 global OEMs.

Figure 111: NXPI's BMS portfolio



Source: Company data (NXPI)

Figure 112: NXPI forecasts 32% CAGR for BMS SAM



Source: Company data (NXPI)

Outsourced manufacturing for Auto semis

The mainstream foundries have not been as active in ramping up their foundry services for the emerging SiC market, which has been led by IDM companies such as Infineon, STM, Wolfspeed and Rohm with their own proprietary processes that closely couple design and manufacturing. For the mainstream foundries, they do have a larger presence in the traditional, lower-cost MOSFET and IGBT analog power devices used in adapters and power supplies. However, MOSFET and IGBT devices lack the efficiency and power density offered by compound devices such as SiC and GaN. Several smaller foundries including X-FAB (6" in Texas), Episil (4" and 6" in Taiwan) and Sanan (6" in China) are offering foundry services for SiC. We believe several chip OEMs, such as ABB, GeneSiC, Global Power, Microchip, Monolith, and UnitedSiC, are using foundry services to make SiC devices.

Auto exposure remains low (~5-10%) for most Asian companies. For the outsourced manufacturers, revenue exposure to the Automotive market remains low and ranges 5-10% for most companies, with back-end supplier Amkor (~20%) and back-end equipment supplier ASM Pacific (~10%) being at the higher end. However, even these numbers are low relative to most of the outsourced foundries with high exposure to the PC, Datacenter, Smartphones, Smart home and Consumer segments. That said, we expect healthy growth in Auto semis to result in rising Auto exposure for these foundry companies over time.

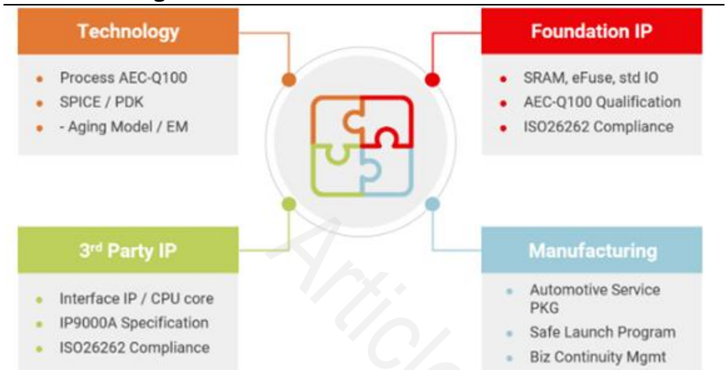
Figure 113: Automotive accounts for 5-10% of sales for most Asian manufacturers, albeit higher for ASMPT and Amkor

Company	Auto Contribution	Description
TSMC	**4%**	Foundry for ADAS, RF, MCUs, CIS, PMIC
UMC	**5%**	Foundry for MCUs, PMIC, infotainment, radar
Vanguard	**8%**	Foundry for Power management and Display Ics
SMIC	**3%**	Foundry for MCUs and CIS
Amkor	**20%**	Back-end for broad based vehicle electronics
ASE	**8%**	Back-end for broad based vehicle electronics
ASM Pacific	**10%**	Back-end and SMT equipment supplier for auto

Source: Company data, Credit Suisse estimates

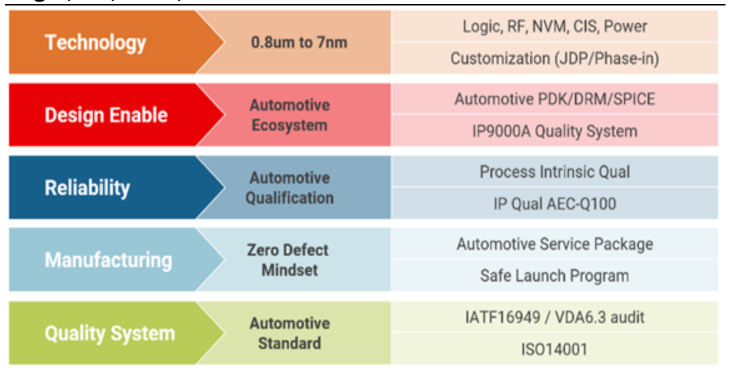
TSMC's Auto platform focuses on Logic, MCU, CIS and Power. TSMC's automotive ecosystem contains four elements: technology, foundation IP, third-party IP and manufacturing all certified based on AEC-Q100 auto grade specifications. Automotive-grade silicon requires additional qualification, extended temperature range, durability tests and additional traceability of designs through the fab. The foundry process enables multiple chip types including: i) advanced nodes for autonomous driving processing, ii) RF for 5G and mmWave radar, iii) non-volatile memory for MCUs and AI, iv) CMOS image sensors for automotive vision, and v) BiCMOS/DMOS (BCD) for power management.

Figure 114: TSMC's Auto platform: Technology, IP & Manufacturing



Source: TSMC

Figure 115: TSMC Auto program focuses on products such as Logic, RF, NVM, CIS and Power



Source: TSMC

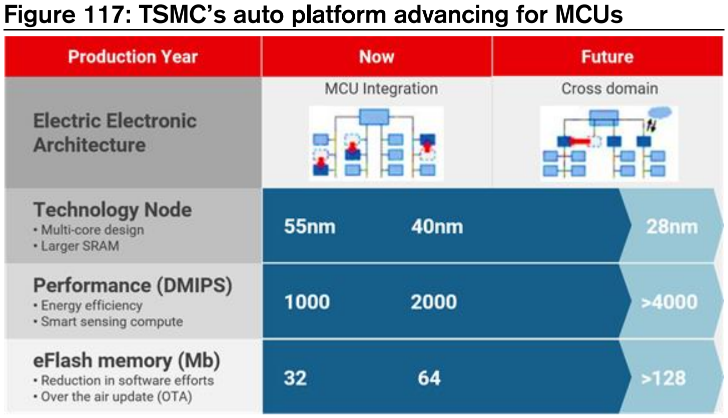
- **Need for more processing and advanced sensing.** The vehicle electronic processing and control system is migrating to more advanced nodes to incorporate highly capable microcontrollers (MCUs) to ensure handling more vehicle controls and AI applications requiring multiple CPU cores and higher memory density leveraging TSMC's embedded flash or automotive-grade MRAM. For CMOS sensors, the company now enables global shutter (moving objects), high resolution, high dynamic range (contrast to detect objects), and near Infrared (NIR) sensitivity for low light and LiDAR use.

Figure 116: TSMC's BCD analog for electronics and EV/HEV performance

Source: TSMC

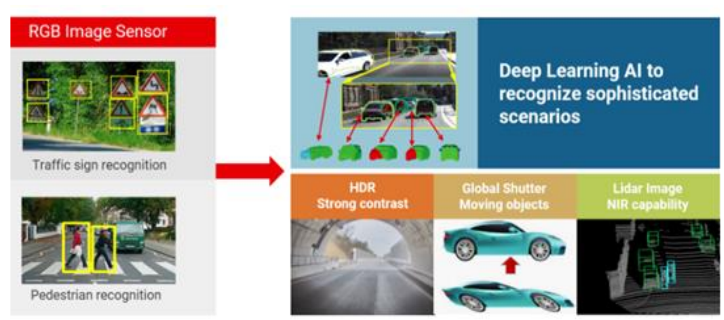
- **7nm transition in 2020, 5nm coming next year.** The company's dedicated automotive design platform had already expanded to 7nm in 2020, with an aim to introduce 5nm from 2022 onwards. TSMC also offers the BCD analog process for faster battery charging time and >70V high-voltage devices for a 12V battery automotive power system.

Figure 117: TSMC's auto platform advancing for MCUs



Source: TSMC

Figure 118: TSMC CIS technology for automotive vision



Source: TSMC

- **TSMC's customer collaboration with Auto chip suppliers growing.** TSMC has announced collaboration with several industry leaders. In addition to MCUs used across multiple functionalities in a car, TSMC is also scaling flash memory to advanced nodes by offering its resistive RAM on its 40/22nm, and planning risk production for MRAM on 16nm in 4Q21, which the foundry claims would offer 10-year retention at 125°C and 10,000 endurance cycles.
  - **Renesas:** TSMC has collaborated with Renasas on MCUs with on-chip flash memory since 90nm through to 28nm. MCUs have been used in ADAS sensor control, coordinated control of electronic control units (ECUs), engine control and motor inverter control for EVs.
  - **NXP:** NXP also announced an agreement for TSMC's 5nm process for its next-generation automotive platform, advancing from its collaboration on 16nm. NXP plans to use TSMC's 5nm with first samples in 2021 for connected cockpits, domain controllers, ADAS, advanced networking hybrid propulsion control and integrated chassis management.
  - **Socionext:** This company was formed by combining the LSI businesses of Fujitsu and Panasonic in 2015. In February 2021, it announced plans to adopt TSMC's 5nm process for next-generation autonomous driving for risk production in 2022.
  - **STM:** STM has also announced plans to sample its GaN power devices on TSMC's GaN on Silicon process technology. According to Knowmade's GaN on Silicon patent analysis, TSMC has 12 key inventions narrowly relating to power applications back to 2021. TSMC also has used the fab process for GaN systems for power technology for 100V to 650V devices extending to EVs.
  - **VisIC:** Israel-based VisIC Technologies also has announced 1,200V GaN modules for production at TSMC for small efficient xEV chargers and uninterruptible power systems. The devices offer reduced gate charge and capacitance so less switching energy is required.
  - **Intel's Mobileye:** Beyond these chip companies, Intel's Mobileye is also shifting to TSMC for its EyeQ5 chipset on 7nm FinFET. Although this chip was first announced in May 2016, it is entering mass production in March 2021. Older generations of EyeQ chips were being manufactured at STM's fabs using its FD-SOI process.
  - **Nvidia:** TSMC has also produced Nvidia's DRIVE AGX platform for autonomous driving through the 16nm Parker and the 12nm Xavier and is now launching the 7nm Orin chipsets. The 7nm chipset features 17bn transistors (vs. Apple's A14 processor used in iPhone12 at 11.8bn transistors), four 10GbE hosts and up to 8k at 30fps encoding.

Figure 119: TSMC's Auto sales corrected from 5% to 2% of sales by Q320, leading to auto chip shortages as car OEMs cut production plans during the early phase of the pandemic

Sales (US$mn)	3Q18	4Q18	1Q19	2Q19	3Q19	4Q19	1Q20	2Q20	3Q20	4Q20	2020
Automotive	**$424**	**$402**	**$355**	**$349**	**$417**	**$416**	**$417**	**$363**	**$279**	**$317**	**$1,377**
Smartphone	$3,819	$4,961	$3,335	$3,486	$4,623	$5,488	$5,022	$4,839	$5,523	$6,465	$21,849
High Performance Computing	$2,801	$2,773	$2,044	$2,504	$2,748	$2,962	$3,064	$3,444	$4,430	$4,056	$14,994
IoT	$509	$501	$511	$586	$792	$884	$948	$903	$1,117	$824	$3,792
Digital Consumer	$509	$413	$497	$480	$473	$363	$524	$476	$364	$470	$1,833
Others	$849	$750	$710	$691	$760	$697	$748	$723	$704	$861	$3,036
Total	**$8,486**	**$9,398**	**$7,096**	**$7,746**	**$9,396**	**$10,394**	**$10,306**	**$10,385**	**$12,138**	**$12,676**	**$45,505**
% of sales	**3Q18**	**4Q18**	**1Q19**	**2Q19**	**3Q19**	**4Q19**	**1Q20**	**2Q20**	**3Q20**	**4Q20**	**2020**
Automotive	**5.0%**	**4.3%**	**5.0%**	**4.5%**	**4.4%**	**4.0%**	**4.1%**	**3.5%**	**2.3%**	**2.5%**	**3.0%**
Smartphone	45.0%	52.8%	47.0%	45.0%	49.2%	52.8%	48.7%	46.6%	45.5%	51.0%	48.0%
High Performance Computing	33.0%	29.5%	28.8%	32.3%	29.3%	28.5%	29.7%	33.2%	36.5%	32.0%	33.0%
IoT	6.0%	5.3%	7.2%	7.6%	8.4%	8.5%	9.2%	8.7%	9.2%	6.5%	8.3%
Digital Consumer	6.0%	4.4%	7.0%	6.2%	5.0%	3.5%	5.1%	4.6%	3.0%	3.7%	4.0%
Others	10.0%	8.0%	10.0%	8.9%	8.1%	6.7%	7.3%	7.0%	5.8%	6.8%	6.7%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

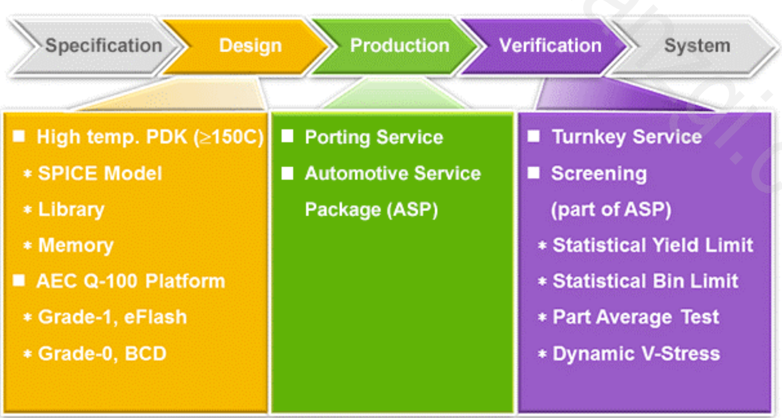
Source: Company data, Credit Suisse research

- **TSMC's Auto sales dwarfs its other platforms, but should ramp up in the coming years.** TSMC has elevated the status of Automotive as an end market, when it switched disclosures to quantify its four growth platforms of Smartphones, high-performance Computing (HPC), Internet of Things (IoT) and Automotive. The Automotive business for TSMC was at a cUS$400m quarterly run rate (5% of sales) through 2019 and early 2020, but corrected to sub-US$300m through mid-2020 (reaching a trough level of 2.3% of its Q320 sales) as auto makers cut back on production. Auto is now being prioritized by the foundries to ramp up production and resolve bottlenecks around component shortages. With a much smaller run rate and prioritization to carve out a small additional slice relative to the overall capacity, we expect the most severe bottlenecks to ease by mid-2021. Over the mid-to-longer term, TSMC's auto sales growth should outpace the robust automotive semiconductor growth as more of the advanced silicon including high-end MCUs, networking (Ethernet, Wi-Fi, Cellular), infotainment, CIS/ISPs and autonomous driving chips are outsourced to foundries.

UMC – doubling its Auto/general products to 10% of sales since 2015. UMC classifies automotive in its other category, which includes auto and general MCUs/power management and accounts for ~10% of its revenue (~5% is Auto related). This is well below its exposure to other end markets such as Communications (~50%), Consumer (~25%) and Computer (~15%).

- **Auto growing in UMC's mix.** While Auto has been a small contributor to UMC's sales, it has been gaining more prominence and has doubled as a percentage of sales since 2015 when the company announced its UMC Auto technology platform. That platform marked a more aggressive push into automotive including design kits, IP and a qualified foundry process to meet AEC-Q100 automotive standards along with the ISO 15408 and 22301 certifications necessary for the higher quality, reliability and security protection required in automotive. The foundry has also licensed Microchip subsidiary SST's embedded flash on its UMC's 55nm platform suitable for these MCUs. In addition, its automotive spans peripheral chips including radar, sensors, motor drivers and CIS.

Figure 120: UMC's automotive platform for design, production and verification

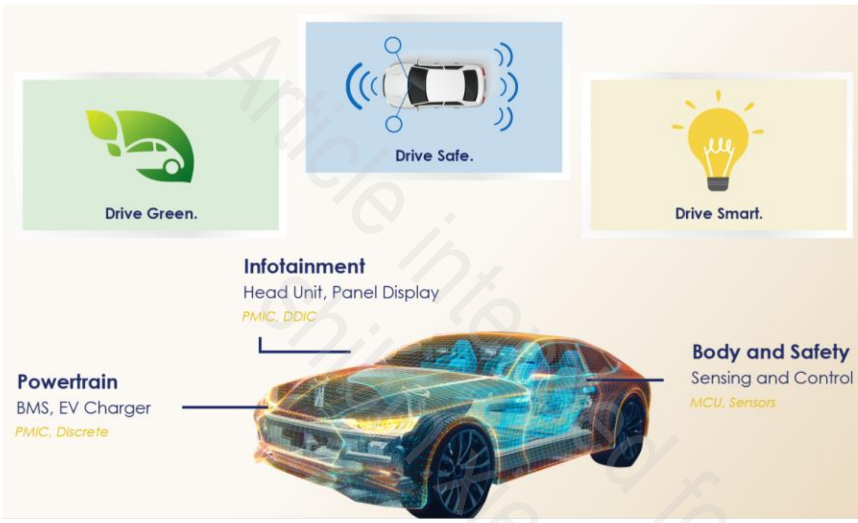


Source: Company data

- **Increasing customer base across regions.** UMC provides foundry services for a number of the leading IDMs including NXP, ON Semi, Infineon, STM and also fabless companies such as Silergy for power management ICs. Its acquisition of Fujitsu's MIE 12" fab in 2019 also gives it a 12" facility and manufacturing expertise down to 40nm to serve its customers in Japan, including Renasas, Fujitsu, Shindengen, TDK, New Japan Radio and Rico Electronic devices for applications including infotainment, heads-up display, ADAS controllers and mmWave radar.

Vanguard Semiconductor (VIS) – high-single-digit exposure to Auto. VIS (specialty 8" foundry) has Auto exposure through products such as power management, discretes and display drivers while also having GaN on Silicon in the development phase. VIS has about 8% of sales coming from Auto through its partnerships with leading IDMs including ADI, Renasas, Infineon, NXP, STM, TI and ON Semi. The company's platform is available from 800nm through to 110nm for high voltage, BCD and SOI, and has IATF 16949 automotive quality certification, Sony Green certification, ISO 26262 (road vehicle functional safety), and AEC-Q100 reliability test qualifications.

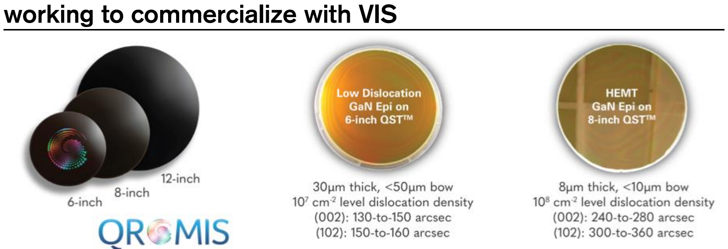
Figure 121: Vanguard's Automotive platform is focused on PMIC, Sensors, MCU and Discrete



Source: Company data

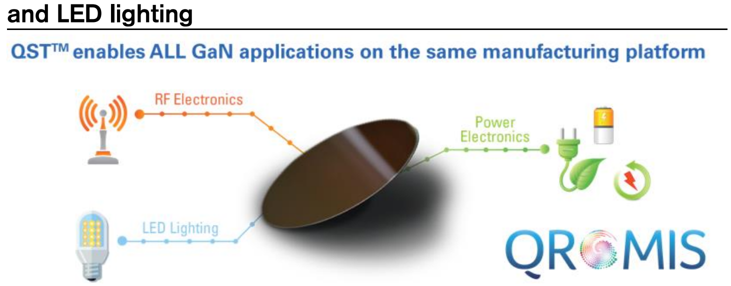
- **Partnerships around GaN on Silicon technology.** Vanguard has also been in partnership for four years with Qromis, a Silicon Valley fabless spin-off from Micron developing substrates (QST – Qromis Substrate Technology) and epi wafers for GaN on Silicon with a licensing agreement to Shin-Etsu Chemical. Imec and Qromis have also been collaborating with Aixtron on GaN on QST development. The company's substrates deposit several additional layers and a top thin silicon interface that closely matches the thermal expansion of the GaN to reduce cracks and achieve thickness similar to bulk silicon. The company has released 6" and 8" GaN-ready substrates for power charging first, but eventually capable of scaling to 900V/1200V, suitable for electric vehicle charging.
- Vanguard has licensed the technology, GaN power epitaxy and processes for use in its foundry process for foundry devices. Qromis CEO has said that the demand from VIS could reach wafer volume in the tens of thousands over the next few years to address demand for GaN power, RF, LED and EV power. Qromis has been backed by the Mirai Creation Fund backed by Toyota, Sumitomo Mitsui and Spark to develop key enabling technologies.

Figure 122: Qromis developing 6" and 8" GaN epi substrates working to commercialize with VIS



Source: Company data

Figure 123: Qromis is targeting products such as Power, RF and LED lighting



Source: Company data

- **Mobile chargers now, EV charging in the future.** After several years of developing mobile charging solutions, Vanguard started volume production in Q420 and could reach 1-2% of sales, targeting mobile chargers first as it can scale up to only 800-900V vs. SiC over 1000V, although long term it could also be used for EV charging.

Episil – a niche Taiwan-based SiC foundry and epi maker. Episil is the parent company of fabless IC supplier Hestia power, SiC/GaN epi wafer maker Episil Precision and SiC/GaN foundry Episil Technologies. Founded in 1985, Episil Technologies is a compound semiconductor foundry with close to US$200m annualized sales in Taiwan with 2k WPM 4" fab, 10k WPM 5" fab, and 50k 6" capacity in two fabs, with all of its capacity in Hsinchu. It offers GaN and SiC foundry services, supplying power devices up to 600V for schottky barrier diodes and MOSFETs, but is now scaling up to 1700V used in EV charging. The company is making SiC MOSFETs for BYD Semiconductor to supply China EV maker BYD to allow better tolerance for high voltage, strong current and heat dissipation. In total, the company has 45 clients and more than 300 products in production including 16949 automotive certification.

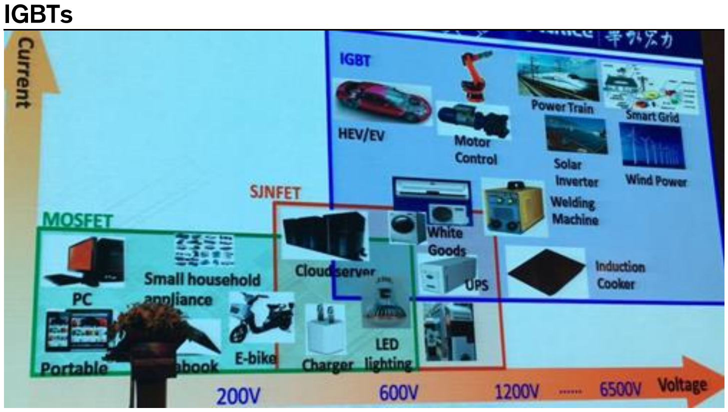
Episil also holds a 60% stake in Episil-Precision which offers a 6" SiC and GaN/Silicon epitaxy with US$135m annual sales and counts GlobalWafers as a key customer. Overall, Episil Group can offer a full process for customers including epitaxy, device manufacturing, backside grinding and metallization, and chip probe testing.

Hua Hong – specialty China foundry with ~10% automotive exposure from IGBTs, PMIC and MCUs. Hua Hong is the second largest foundry in China founded in 1997 as a partnership between Hua Hong and NEC Corp, and later merged with Grace Semiconductor providing 8" and mature 12" technologies for RF, mixed signal, power management, MCUs and automotive ICs. For automotive, the company has 10% of sales targeting EV/HEV power, MCUs, infotainment, battery management and infotainment systems.

- **Multiple product offering.** The company has several solutions for automotive: i) discretes (IGBT, super-junction MOSFETs), ii) analog/power management (BCD and high voltage CMOS), and iii) MCUs (16-bit and 32-bit with embedded flash). Management believes its fabs can differentiate in energy-saving applications including electric vehicles (DC-DC converter, DC-AC inverter, generator, battery charger and a fuel car start-stop module).

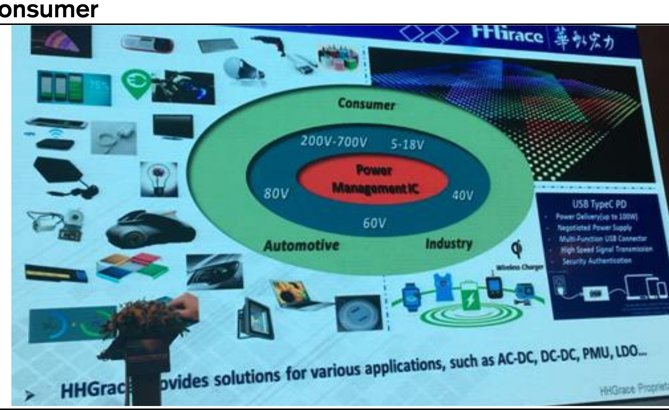
- **MOSFETs and IGBTs across a wide range of voltages.** Hua Hong's foundry process supports voltage ranging from 8V through 1,700V for electricity generation, transmission, distribution and consumption. Key applications are: i) **8V:** portable device protection, ii) **200V:** e-bike, motor control, iii) **600V:** LED lighting, AC-DC drivers, cloud/server power management, and iv) **1200-6500V:** EVs and green energy inverters. Hua Hong now offers MOSFET up to 600V, Super junction MOSFET from 200-900V and IGBT from 600-1700V, with 3300-6500V products also expected to come soon. The company offers an MCU solution with higher reliability flash cell, error correction and redundancy, AEC-Q100 qualification of its flash and a wide temperature range from -40° to 175°C.

Figure 124: Hua Hong addressing a wide voltage range of IGBTs



Source: Company data

Figure 125: Hua Hong's PMIC for auto, industrial and consumer



Source: Company data

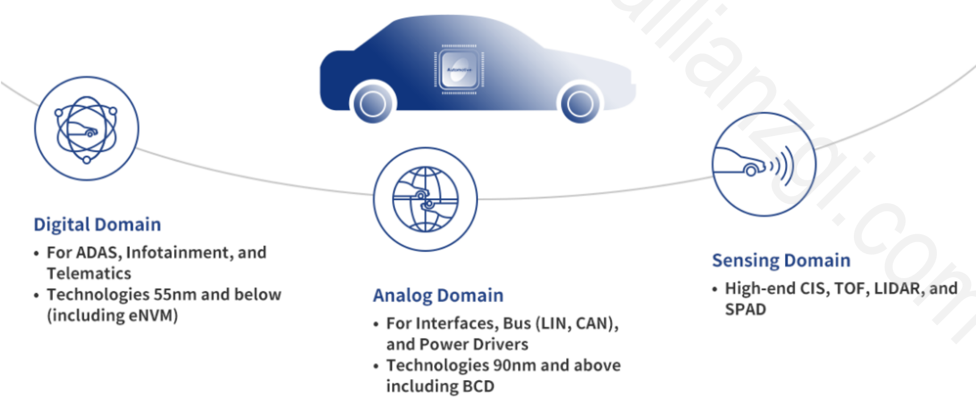
- **Moving into higher voltage.** The company has been moving into higher voltage processes, introducing super-junction and IGBT technology in 2011 and higher density technologies in the past few years. Hua Hong believes it is now the largest power device foundry, with 35% of its sales from discretes, including 9% of sales from super-junction MOSFETs and 5% from IGBT. The IGBT products have seen wider use case in charging stations and inverters for EVs which doubled in 2019 before declining in 2020 due to auto production cuts seen during COVID-19.

- The company is seeing increased IGBT discrete demand from the power grid including electric vehicles, motors, transmission, wind turbines and solar/PV. The company has passed AEC Q100 Qualification and has automotive grade IPs with designs for engine control, airbag control, engine data control and oil pump systems. The company has been in production since 2005 for engine control with 14mn chips shipped and also has an embedded flash technology for car radio and navigation systems since 2005.

- Hua Hong also addresses a range of power management solutions (AC-DC, DC-DC, Power management, LDOs) for consumer, auto and industry ranging from 5V through 700V. The company has shipped over 100,000 wafers with its 700V BCD technology and now offers either a high performance or a low cost platform for customers, with 0.11 micron BCD platform compatible with embedded flash oriented toward automotive power supply while the 90nm is suited more for digital power and motor drives.

SMIC – modest automotive contribution. SMIC's automotive sales are a low to mid-single digit percentage of group sales currently, having declined after it sold its LFoundry fab in Italy, which was a primary foundry for ON Semi's CMOS image sensors. The foundry still is expanding its automotive offering with AEC-Q100 stress test qualifications from 180nm down to 40nm. Target applications include digital (ADAS, infotainment, MCUs), analog (BCD power management), and sensing (CIS, ToF, LiDAR and SPAD).

Figure 126: SMIC's automotive target applications



Source: Company data

Assembly/Testing (OSAT) another area to benefit

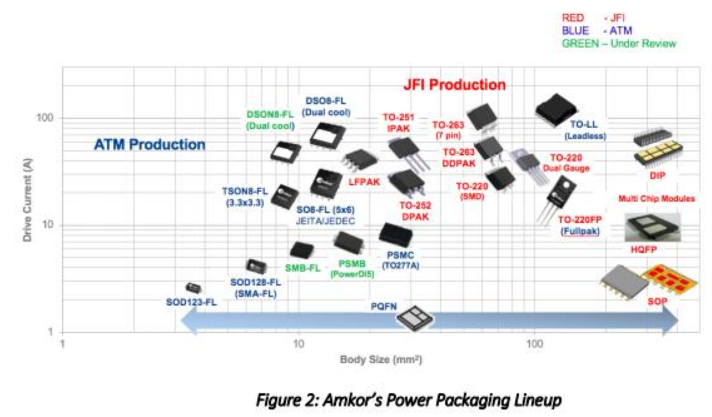
Amkor – leading OSAT for automotive electronics. Amkor is the leading OSAT in automotive semiconductor packaging & testing with highest exposure among the group at around 20% of group sales following its acquisition of J-Devices (a consolidated back-end supplier spun out from the Japanese semiconductor makers). Amkor offers over 40 packaging families that are qualified for automotive, with 40 years of engagement in automotive across 11 automotive production facilities and power packaging supported by its Malaysia and Japan Fukui plants.

- The company has a large toolkit of lead frame, wafer level packaging, flip chip, discrete, laminate, system in packaging and MEMS/sensor packaging tailored for automotive chassis, xEV, safety, body electronics, infotainment, ADAS and powertrain. For automotive, packaging differentiators include advanced lead frame technology, copper clip interconnects, aluminum wedge bonding and space-saving surface-mount flat lead devices with dual-side cooling. The solutions are able to perform assembly and test across MCU, sensor, transceivers, connectors, SoCs, CIS, mmWave radar, Lidar, PMICs, LED drivers, touch controllers, RFICs, amplifiers, inertial measurement units and analog ICs.

Figure 127: Amkor offers an array of packaging for automotive

Source: Amkor

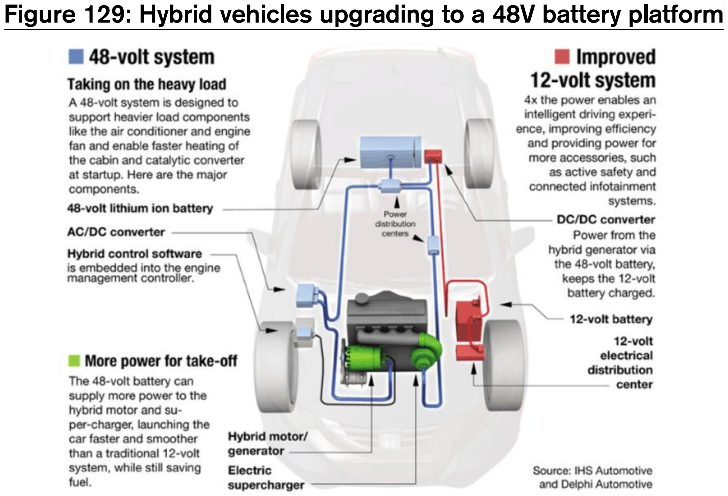
Figure 128: Amkor's power packaging line-up



Source: Amkor

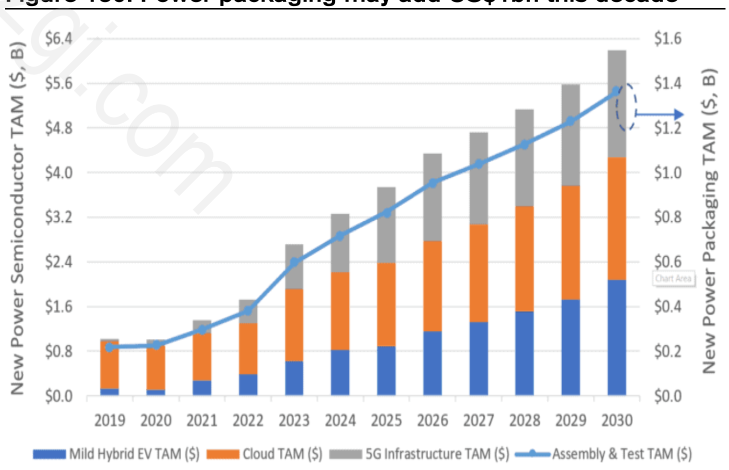
- Amkor sees a big opportunity as auto makers are shifting from a power tree powered by a 12V battery to a car platform powered by a 48V battery that can create an MHEV solution. The 48V battery can supply more power to a hybrid motor and super charger to launch a car faster and smoother and support the heavier-load A/C and engine fans. The company expects a similar upgrade in the data center for greater power density and efficiency. Amkor expects this migration for mild hybrids to add US$75/vehicle and US$40 to the power device bill in data centers. For power device packaging, this could create an incremental US$1bn TAM by 2030.

Figure 129: Hybrid vehicles upgrading to a 48V battery platform



Source: Company data (Delphi)

Figure 130: Power packaging may add US$1bn this decade

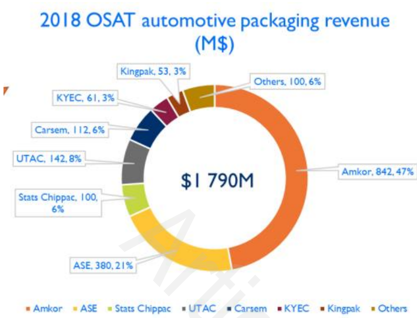


Source: Company data (Amkor)

- **Growth in Auto packaging, with OSATs gaining share.** Yole forecasts the overall automotive packaging market to grow from US$5.1bn in 2018 to US$9.0bn in 2024, with 94% using mature wirebond packages and 6% using advanced packages (flip chip, fan-out, and wafer-level CSP). Yole believes that OSAT share will grow from 35% or US$1.8bn of a US$5.1bn market in 2018 to 47% or US$4.4bn of a US$9.0bn market by

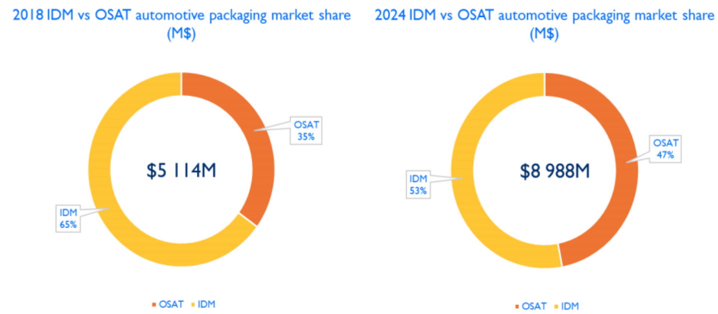
2024 owing to higher volumes and more package diversity and complexity. Among the OSATs, Amkor leads with close to 50% share followed by ASE at slightly over 20%.

Figure 131: Amkor leads in the OSAT market with close to 50% share, followed by ASE at over 20%



Source: Yole

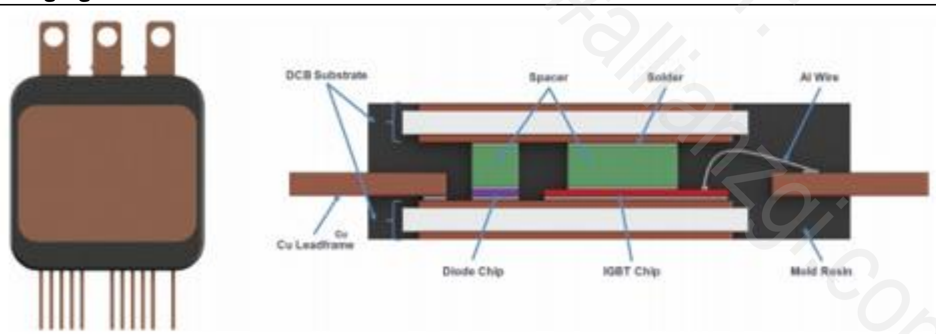
Figure 132: Yole projects OSAT's market share in Auto packaging to rise from 35% to 47% by 2024



Source: Yole

- **Packaging more challenging for compound semiconductors.** Amkor has indicated MOSFETs and IGBTs play a major role, with maturity, manufacturability and an established supply chain covering 200V to 600V+ and can usually use power discrete packages, with high power systems also having half-bridge or full-bridge modules. For SiC and GaN wide-band-gap materials, packaging will need to be upgraded to handle challenging mechanical, thermal and electrical issues. Amkor has developed molded modules with superior thermal and electrical performance and dual-sided cooling that can be integrated into electric motor architectures.

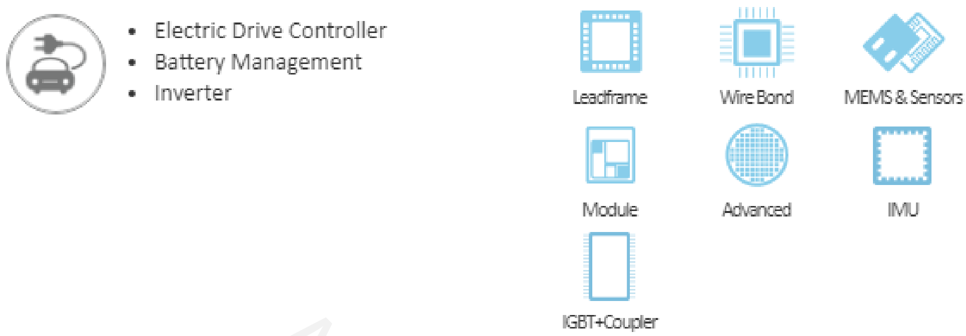
Figure 133: Amkor's DSC molded module package is suitable for EV power IC packaging



Source: Amkor

ASE – broad base of automotive solutions. As the largest global back-end assembly and test supplier with 25% industry share, ASE also has a strong position in Automotive, which contributed about 8% to revenue in 2020. ASE provides an array of automotive packaging spanning lead frame, wirebond, flip chip, wafer-level packaging, MEMS/sensor packaging, SiP module, advanced packaging to address applications spanning safety, ADAS, body, infotainment, chassis, EV/HEV, instrumentation, powertrain and after-market systems. The company has achieved certifications such as TS16949 and ISO26262 along with AEC-Q100 certification.

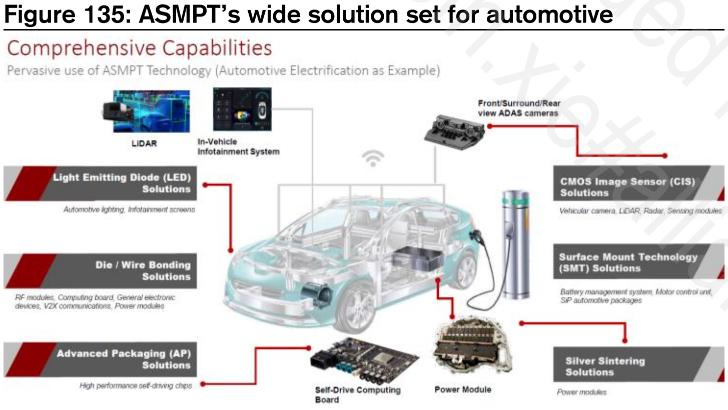
Figure 134: ASE packaging solutions for EV/HEV



Source: ASE

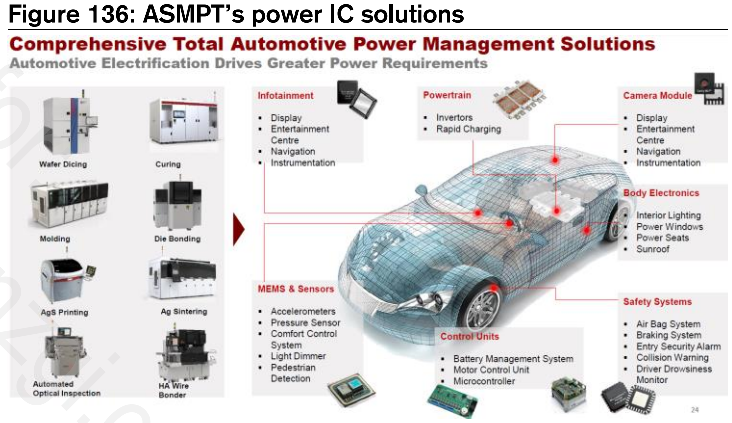
ASM Pacific – SMT and back-end equipment both targeting growth from automotive. ASM Pacific generates ~15% of sales from automotive electronics, with solutions spanning both its surface mount technology (SMT) and back-end packaging divisions. The company established its SMT unit through the acquisition of the business from Siemens and still retains a strong position with the European automakers. The group has solutions spanning die/wire bonding, advanced packaging, LED, SIS, SMT and silver sintering for power modules. The company is noting a surge in bookings this year as the automotive production rebounds and from new content drivers from electrification and autonomous driving.

Figure 135: ASMPT's wide solution set for automotive



Source: ASM Pacific

Figure 136: ASMPT's power IC solutions



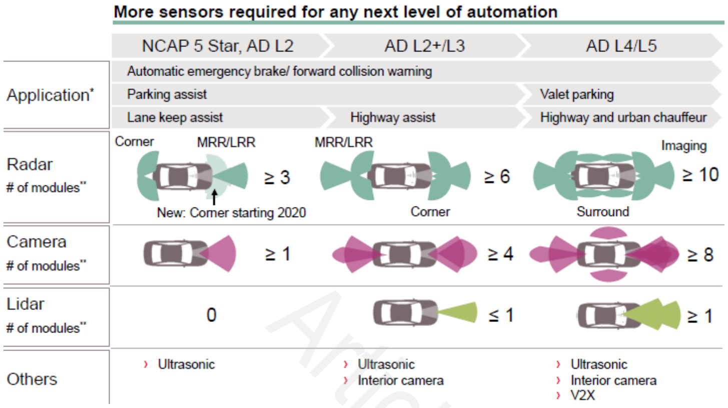
Source: ASM Pacific

PCB – Autos rising in PCB mix driven by xEV

The rising demand for car electrification has been driving the Auto PCB market to outgrow the overall PCB market, with an increasing contribution from 5% of the total PCB production value in 2010 to 11% in 2019. While the auto PCB market was badly hurt by weak global auto demand and COVID-19 during 2020, one interesting trend post-pandemic has been the rising demand for individual mobility. Another interesting observation is rising HDI adoption rates in automotive, given that a growing number of xEV brands treat EV as a large-sized PC and thus are more willing to adopt IT-type technology, e.g. HDI. According to Chin Poon, the leading auto PCB maker, it has witnessed rising HDI adoption in auto PCB to 10-15% in 2019.

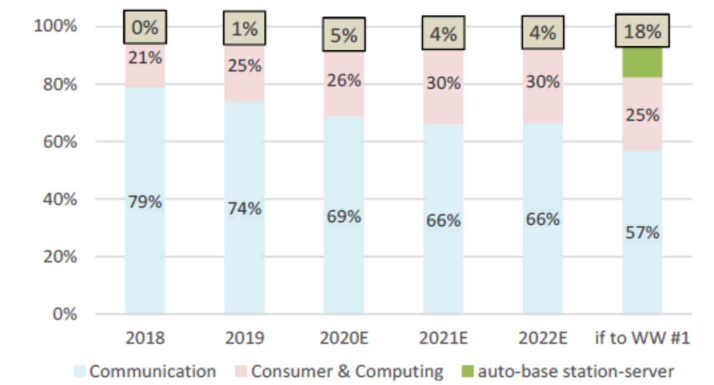
ZDT – growing auto exposure through Boardtek acquisition. While automotive contribution is at low single-digit for ZDT (Zhen Ding Technology), its product offerings to Autos has been expanding from ECU, camera module, powertrain, chassis, lighting, interior & exterior parts, to radar boards (through the acquisition of Boardtek in 2020). We think the further increase in car electrification, auto brands' localization supply chain strategy, and rising level of autonomous driving should help ZDT to further expand its market share in the auto PCB market. We estimate every 1% market share gains in automotive will add 1-2% of ZDT's sales.

Figure 137: Rising demand for Radars for the next level of autonomous driving



Source: Company data (Infineon)

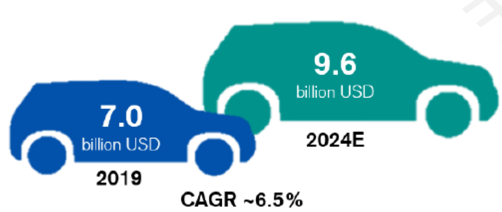
Figure 138: ZDT's sales mix – Boardtek's acquisition has added exposure to auto, base station, server/data center



Source: Company data (ZDT)

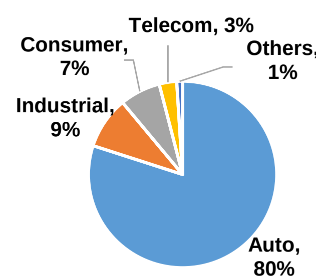
Chin Poon – rising PCB dollar content from xEV. Being the world's leading auto PCB maker with ~80% exposure to the auto market, we expect Chin Poon to benefit from the auto market recovery and rising car electrification. Chin Poon is also making decent progress with top EV brands in US/EU, with small volumes starting from late 2020. Given our view that auto PCB content is around US$100+ for EV vs. US$60-70 for ICE, we expect the rising xEV adoption rate and its EV order wins to provide new growth opportunity. However, we also profit recovery for the sector to lag revenue recovery, given rising cost headwinds esp. from copper.

Figure 139: Auto PCB outgrowing the overall PCB market



Source: Company data

Figure 140: Chin Poon's sales mix



Source: Company data, Credit Suisse research

Key stocks exposed to the xEV megatrend

In this section, we look at the list of companies (in alphabetical order) that are highly exposed to xEV trend across our global semis coverage universe.

Allegro MicroSystems (O/P, TP US$36): 10-15% Auto sales CAGR ahead

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- **Highly levered to Autos.** ALGM has core IP in magnetic sensors and power ASICs and is the most levered semi company to Autos (~70% of sales vs. an average of 15-20% for most semis companies in the US). ALGM has both macro and company-specific drivers that should enable relative outperformance including: (1) Long duration end markets in Auto/Industrial (~85% of Rev) with 3+ year design cycles followed by 7+ years of highly visible revenue streams, (2) Accelerating content in Auto from a ~5% CAGR to 7-9% CAGR allowing ALGM to grow its Auto revenues at 10-15% CAGR, and (3) Strong cyclical recovery in Autos after two consecutive years of unit decline in CY19 and CY20. This combined with ongoing content growth means that our Auto sales growth for ALGM of +13%/+11% in CY21/22 may appear conservative.
- **Modeling the Automotive opportunity.** In CY21/22/23, we model ALGM Auto revenues to grow at 12.9%/11.2%/13.0% respectively. The basic components underwriting this Auto growth are (1) Auto unit sales, (2) Mix of Auto sales between standard ICE engines vs. Hybrid/EV – because there are different magnitudes of content between ICE/Hybrid/EV, and (3) Content growth potential in each segment. For CY21, our 13% yoy growth should be relatively conservative given CY21 will see robust cyclical recovery in units. However, layering on the impact of mix shift yields an incremental ~3.5% growth from sensor content/vehicle mix just due to EV mix going from 4% to 6% and Hybrid from 13% to 19%. Lastly, we note that over a longer period of time magnetic sensors per vehicle should grow at a ~4-5% CAGR through to CY24 driven by increasing need for content in (1) Powertrain, (2) Safety & Control, and (3) Interior functionality.

Figure 141: Baseline Mix Adjusted Content Growth

ALGM Product Segments	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
Magnetic sensors (MS)	$353.4	$397.8	$435.2	$481.6	11%
Auto	$244.2	$275.6	$306.6	$346.5	12%
Industrial	$58.4	$65.3	$78.6	$80.3	11%
y/y		12.9%	11.2%	13.0%	

Auto Units Sold	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
Total	75,265,979	85,027,558	92,334,637	97,100,632	9%
y/y		*13.0%*	*8.6%*	*5.2%*	

Vehicle Mix Breakdown	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	62,271,856.2	64,003,727.4	62,596,765.6	63,880,733.8	1%
Hybrid	10,034,842.3	15,951,172.1	22,118,099.2	24,396,689.9	34%
EV	2,959,280.7	5,072,658.5	7,619,771.8	8,823,208.1	44%
Total	75,265,979.2	85,027,558.0	92,334,636.6	97,100,631.7	9%

Vehicle Mix Breakdown %	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	83%	75%	68%	66%	-7%
Hybrid	13%	19%	24%	25%	24%
EV	4%	6%	8%	9%	32%
Total	100%	100%	100%	100%	0%

# of Sensors Per Vehicle	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	25	25	25	25	0%
Hybrid	35	35	35	35	0%
EV	45	45	45	45	0%
Total	27.1	28.1	29.0	29.3	3%
y/y		*3.5%*	*3.5%*	*1.0%*	

Total Sensors in Market	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	1,556,796,405	1,600,093,185	1,564,919,141	1,597,018,345	1%
Hybrid	351,219,479	558,291,023	774,133,471	853,884,146	34%
EV	133,167,633	228,269,633	342,889,730	397,044,362	44%
Total	2,041,183,516	2,386,653,840	2,681,942,343	2,847,946,853	12%
y/y		*16.9%*	*12.4%*	*6.2%*	

Source: Company data, IHS, Credit Suisse estimates

Figure 142: Upside with only ~4% Content Growth

ALGM Product Segments	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
Magnetic sensors (MS)	$353.4	$397.8	$435.2	$481.6	11%
Auto	$244.2	$275.6	$306.6	$346.5	12%
Industrial	$58.4	$65.3	$78.6	$80.3	11%
y/y		12.9%	11.2%	13.0%	

Auto Units Sold	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
Total	75,265,979	85,027,558	92,334,637	97,100,632	9%
y/y		*13.0%*	*8.6%*	*5.2%*	

Vehicle Mix Breakdown	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	62,271,856.2	64,003,727.4	62,596,765.6	63,880,733.8	1%
Hybrid	10,034,842.3	15,951,172.1	22,118,099.2	24,396,689.9	34%
EV	2,959,280.7	5,072,658.5	7,619,771.8	8,823,208.1	44%
Total	75,265,979.2	85,027,558.0	92,334,636.6	97,100,631.7	9%

Vehicle Mix Breakdown %	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	83%	75%	68%	66%	-7%
Hybrid	13%	19%	24%	25%	24%
EV	4%	6%	8%	9%	32%
Total	100%	100%	100%	100%	0%

# of Sensors Per Vehicle	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	25	26	27	28	3.8%
Hybrid	35	36	38	39	3.8%
EV	45	47	48	50	3.8%
Total	27.2	29.1	31.3	32.9	6.6%
y/y		*6.9%*	*7.7%*	*5.1%*	

Total Sensors in Market	CY2020	CY2021	CY2022	CY2023	2020-2023 CAGR
ICE	1,560,793,193	1,657,257,034	1,686,764,323	1,791,277,669	5%
Hybrid	352,311,440	578,362,822	834,429,412	957,749,551	40%
EV	133,619,446	236,538,987	369,782,939	445,340,345	49%
Total	2,046,724,079	2,472,158,842	2,890,976,674	3,194,367,564	16%
y/y		*20.8%*	*16.9%*	*10.5%*	

Source: Company data, IHS, Credit Suisse estimates

- **The impact of EV.** As the world continues to pivot away from ICE towards xEV, we see ALGM especially positioned to outperform. We estimate that magnetic sensor IC content alone increases from about $17 in an ICE vehicles to $24 in Hybrid Vehicles and $30 in Fully Electric Vehicles. Based on increasing units/content, we believe ALGM can increase its (1) xEV TAM from ~$273mn in CY20 to $1.5bn in CY25 at >30% CAGR and (2) general powertrain TAM, from $866mn in CY20 to $1.7bn in CY25 at 6% CAGR. Given this backdrop, we expect ALGM to capitalize on accelerating content growth across ICE/Hybrid/EV which embed ~25/35/45 sensors today – moving to >30/45/55 over time. As the #1 player in the Sensor market, we see these industry trends supporting ~$1.00 of EPS by CY22/23. In fact, assuming (1) Target GM/OM of 55%/30% and (2) A 100% saturated EV market yields earning power in excess of $1.85 vs. $0.45 in CY20.

- **Advanced Driver Assistance Systems (ADAS) and Autonomous Vehicles.** As ADAS features become more sophisticated, and adoption increases, we expect demand for sensor and power ICs to expand from steering into additional braking and new radar and LiDAR applications. ALGM solutions address the critical "act" function, i.e. reacting to system inputs to enable collision avoidance, lane keeping, or self-park features through automatic steering and braking. A steering system equipped with even a modest degree of Automation utilizes products across ALGM's entire portfolio – including sensors, power management ICs and motor driver ICs. To date, AGLM has shipped >100mn devices for ADAS compatible vehicles. In aggregate, we expect this transition to enable ALGM to expand ADAS/Safety & Chassis TAM from ~$692mn in CY20 to $1.1bn in CY24, or ~11% CAGR.

Amkor (O/P, TP US$23): Most leveraged in package and test to Auto

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- **Back-end packaging leader in Automotive.** Amkor is the global leader in outsourced packaging and test for automotive, following its acquisition of J-Devices, and merging its own US/Europe auto exposure with J-Devices' Japan presence. The company has 40 years' engagement in auto with over 40 packaging families in 11 production facilities for package and test in key electronic systems including EV/HEV, body electronics, infotainment, powertrain, chassis and ADAS.
- **Auto opportunity fueled by electronic content growth.** Yole projects automotive packaging to grow from US$5.1bn in 2018 to US$9bn in 2024, with the outsourced share rising from 35% to 47%, growing that market from US$1.8bn to US$4.4bn. Among OSATS, Amkor leads with close to 50% share in automotive, with ASE 2nd at 20-25%.
- **Automotive now 20% of sales.** Amkor has outsized revenue at 20% of sales following its J-Devices acquisition vs 10% for global semis, supplying auto semi leaders including Toshiba, Renesas, TI, STM, NXP, ON Semi and IFX. We believe Automotive should see a cyclical recovery supplement content growth to supplement its solid position in 5G smartphones, HPC and consumer markets and growing SiP presence.
- **Good leverage to semiconductor growth areas.** We maintain an Outperform rating and TP of US$23 (based on 11x 2022E P/E and 2x P/B). We expect the positive turn to continue to be driven by: (1) rising content in the flagship smartphone adding modem assembly and testing; (2) growing SiP pipeline, including wearables, AiP and RF front-end; and (3) higher leverage to the auto recovery (20% of sales) to fill mainstream capacity.

Analog Devices (O/P, TP $200): BMS opportunity ahead with EV

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- **Automotive opportunities via BMS.** Despite only having only 15% Auto exposure, ADI is well levered to Battery Management Systems (BMS). We estimate that by 2025 the BMS market could be $7.4bn and at ~20% share ADI could see its BMS sales approaching $1.5bn, which would be significantly greater than its entire Auto sales in CY20 with BMS at only 10% of sales. In Sep-20, ADI had announced a collaboration with GM for the industry's first wireless BMS (wBMS) to debut on all GM EV's with Ultium batteries starting with model year 2021/22.

Figure 143: ADI – Summary of Results and Expectations

ADI-US	F4Q20	F1Q21				F2Q21E			FY2021E		FY2022E	
	Reported	Actual	CS	Cons	Guidance	CS	Cons	Guidance	CS	Cons	CS	Cons
Revenue	**$1,526**	**$1,558**	**$1,500**	**$1,511**	***$1,430m to $1,570m***	**$1,600**	**$1,602**	***$1,550m to $1,650m***	**$6,508**	**$6,495**	**$6,885**	**$6,922**
% Q/Q chng	*4.8%*	*2.1%*	*-1.7%*	*-1.0%*	*-6.3% to +2.9%*	*2.7%*	*6.0%*	*-0.5% to +5.9%*				
Seasonal ADI + LLTC (5-year)	*5.7%*	*-3.5%*	*-3.5%*			*1.2%*						
% Y/Y chng	*5.8%*	*19.6%*	*15.1%*	*15.9%*		*21.5%*	*21.6%*		*16.2%*	*15.9%*	*5.8%*	*6.6%*
Gross Margin	**70.0%**	**70.0%**	**70.0%**	*69.7%*		**70.0%**	*70.1%*		**70.5%**	*70.2%*	**71.0%**	*71.1%*
Operating Expenses	**$431**	**$456**	**$450**	**$445**		**$464**	**$469**		**$1,850**	**$1,863**	**$1,890**	**$1,933**
Operating Margin	**41.7%**	**40.7%**	**40.0%**	*40.2%*	*39% to 41%*	**41.0%**	*40.8%*	*~40% to ~42%*	**42.1%**	*41.5%*	**43.5%**	*43.2%*
Net Income	**$534**	**$537**	**$484**			**$539**			**$2,274**		**$2,482**	
Net Margin	**35.0%**	**34.4%**	**32.2%**			**33.7%**			**34.9%**		**36.0%**	
EPS (Non-GAAP ex-SBC)	**$1.54**	**$1.55**	**$1.41**			**$1.55**			**$6.53**		**$7.08**	
EPS (Non-GAAP w/ SBC)	**$1.44**	**$1.44**	**$1.30**	**$1.33**	***$1.20 to $1.40***	**$1.44**	**$1.45**	***$1.36 to $1.52***	**$6.10**	**$6.05**	**$6.65**	**$6.69**
Fully diluted shares	372.3	373.1	372.3			373.1			373.1		373.1	

Source: Company data, Credit Suisse estimates, Consensus (FactSet)

- **Importance of BMS.** From a financial perspective, we would note that: i) wBMS could double content per EV from a range of $30-$100 per EV to $60-$200 per EV; and ii) wBMS removes up to 90% of wiring and 15% of battery volume saving significant weight/space – every ~10% reduction in weight improves MPG by ~5% – thereby providing significant economic benefits to auto OEMs and consumers. We would also highlight that:
  - It allows for a modular design to quickly and economically scale fleet across different car models/designs – it is unclear if GM's collaboration with NKLA includes Ultium; and
  - It is easily reconfigurable for battery reuse/secondary life; it also allows for additional system measurement and performance features – increasing early failure detection and enabling optimized battery pack assembly.

  wBMS should solidify an already strong market position as ADI's BMS solution given:
  - wBMS is now used in >50% of the top 10 selling EV cars globally;
  - It has best-in-class vehicle range, mile per charge performance (~20% greater than peers); and
  - It also has all the functional safety features, including module-level security and ASIL-D. We view the GM/wBMS collaboration as very positive for ADI's Auto business, as the company continues to gain share across EVs with innovative products/solutions like wBMS and the new road-noise cancelling solution (also reducing weight) more than doubling semi content/vehicle over the next 2-3 years.
- **Automotive opportunity set.** In addition to BMS/wBMS, ADI also has opportunities within vehicle electrification – especially within power solutions and onboard charging systems. These solutions improve power/energy efficiency and are being rapidly adopted across xEV platforms. Given these factors we have a high level of conviction in ADI's ability to execute against the current and future Automotive S-D backdrop.

ASM Pacific (O/P, TP HK$133): Leading equipment supplier for EMS and back-end auto packaging

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- **Automotive a key growth driver for its SMT and back-end equipment.** ASM Pacific generates ~15% of sales from automotive electronics, with solutions spanning both its surface mount technology (SMT) and back-end packaging divisions. The company established its SMT unit through the acquisition of the business from Siemens and still retains a strong position with the European automakers.
- **Wide solution set for the automotive market.** ASM Pacific offers equipment solutions spanning die/wire bonding, advanced packaging, LED, CIS, SMT and silver sintering for power modules. The company's machines cover all parts of the process including wafer dicing, curing, molding, wire and die bonding, silver printing and sintering, CIS packaging for ADAS cameras, optical inspection as well as SMT for power modules and ADAS computing boards.
- **2021 outlook remains solid.** Growth drivers are diverse, including broad-based semiconductor growth, automotive and industrial market recovery and rebounding smartphone shipments. The company is positive on automotive, factoring rising semiconductor and electronic content would drive its equipment across ICs, LED, CMOS image sensors and SMT equipment.
- **We rate the stock Outperform as it supplies an industry with structural drivers also trying to catch-up to demand.** We maintain Outperform with HK$133 target based on 25x 2021E EPS. We expect strong orders with upside to pricing from the tight environment, better mix (mini-LED, CIS, automotive and advanced packaging), cost down initiatives and rebound of developed markets sales for in auto/industrial.

Infineon (O/P, TP €42.50): Accelerating EV adoption and design wins to drive upside to mid-term targets

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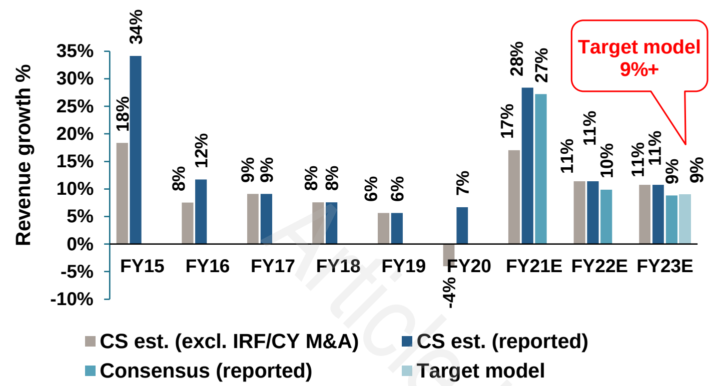
- **Raising estimates and TP; Upgrade to Outperform from Underperform.** In a company report also published today, we show that based on our detailed analysis of xEV adoption trends and semis content growth opportunity especially in Power, we believe that IFX can exceed its mid-term targets for sales (9% growth) and margins (19% EBIT). Further, we see signs that IFX is now seeing increased traction in SiC technology, along with its existing pipeline of IGBT wins. This leads us to raise our sales and EPS estimates for IFX by 1-4% and 2-7% respectively over FY21-23. Hence, we upgrade shares to Outperform with new TP of €42.50 (€31.0 previously). Our FY21/FY22/23 EPS estimates are €1.16/€1.42/ €1.70, which are 6%10%/16% above consensus.
- **Powering the EV revolution.** The increasing push for electrification means that xEV adoption can rise from 11.5% (8mn xEV units) in 2020 to 62% by 2030 (63mn xEV units, of which 29mn BEV). Given a typical BEV has 2x semi content at $800 vs. gasoline car, with ~75% of incremental content coming from Power, we estimate that average semis content per car can grow from ~$510 in 2020 to $1,100 by 2030 driving Auto semis market to grow from $38bn to $110bn over the next decade (11% CAGR). Within that, we believe that xEV power semis can grow from $2.4bn in 2020 to $22bn by 2030 (25% CAGR). As such, we model IFX's IGBT/SiC sales to grow from €1.7bn in FY20 to €3.2bn in FY23 accounting for ~40% of incremental growth. This supports our sales growth forecast of 28% in FY21 (17% adjusted for M&A) followed by 11% in both FY22/23.
- **Upside potential for margins.** With falling fab idle charges, we model adjusted GM to improve to 40% in FY21 followed by 1ppt improvement each year reaching 42% by FY23.

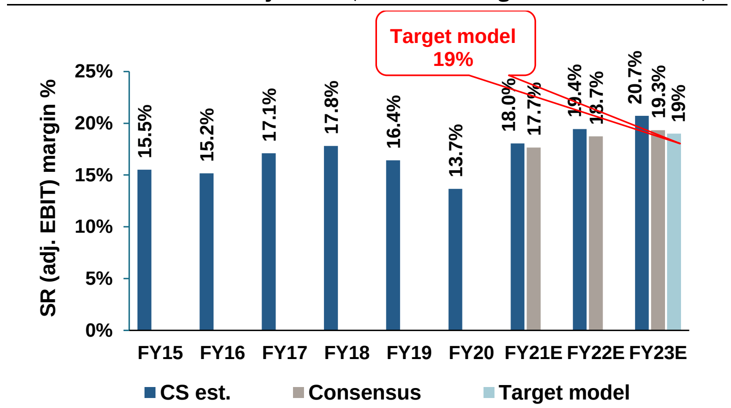
Even assuming ~10% opex CAGR along with targeted €140mn of opex savings from the Cypress deal means that EBIT margins can rise from 18% in FY21E to 21% by FY23E.

Figure 144: IFX sales: Our sales growth estimates are 1-2ppt above consensus for FY21 to FY23



Source: Company data, Credit Suisse estimates, Consensus (VARA)

Figure 145: IFX margins: We model SR margins to rise from 14% in FY20 to 21% by FY23 (above its target model of 19%)



Source: Company data, Credit Suisse estimates, Consensus (VARA)

■ **Raising TP to €42.50.** Our TP is based on 25x P/E on our FY23 estimate (vs. 17x EV/EBIT we used previously, the change in methodology being driven by improving FCF – we estimate €3.5bn over the next three years). **Catalysts** include news around future EV design wins (especially in SiC) and F2Q earnings on 4 May. **Risks** include slowdown in demand for Auto/Industrial products, slowing design win momentum in new EV launches and FX headwinds (strong EUR/USD).

Microchip (O/P, TP US$180): Stronger, sustainable cyclical recovery ahead

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■ **Well-positioned MCU and Analog portfolio.** MCHP has a well-positioned Analog/MCUs portfolio for a variety of Auto applications—Infotainment, Powertrain/EV/HEV, Body Electronics and ADAS. Notably, in the wake of recent semi shortages (C4Q20), they launched the PSP program (Preferred Supply Program) which would offer customers the ability to receive prioritized capacity in the 2H21/1H22, by placing 12 months of orders – all non-cancellable and non-reschedulable – increasing visibility and consistency of bookings.

■ **Cyclical recovery benefits after 2 years of inventory depletion.** More broadly, we believe MCHP will benefit from a cyclical recovery that is stronger and more sustainable than most expect, helped by 2 years of inventory depletion culminating in COVID panic depletion as well as significant supply rationalization over the 10+ years with over 200 M&As in the sector. We continue to argue semis are mid-stream in a value capture not seen since the late 1990s.

Figure 146: MCHP: We model 15% sales growth in CY21, followed by 5% in CY22

MCHP-US	Dec-20	Mar-21E			June-21E		FY2021E		FY2022E		CY2021E		CY2022E	
	Reported	CS	Cons	Guidance	CS	Cons	CS	Cons	CS	Cons	CS	Cons	CS	Cons
Revenue	$1,352	$1,454	$1,454	$1,420m to $1,487m	$1,500	$1,503	$5,425	$5,425	$6,160	$6,126	$6,064	$6,126	$6,365	$6,461
% Q/Q chng	3.3%	7.5%	7.5%	+8.4% to +13.6% q/q	3.2%	3.3%								
% Y/Y chng	5.0%	9.6%	9.6%		14.5%	14.7%	2.9%	2.9%	13.6%	12.9%	14.5%	15.6%	5.0%	6.6%
5YR Median	-1.8%	2.4%			7.7%									
Gross Margin	63.0%	63.5%	63.4%	63.3% to 63.7%	63.5%	63.5%	62.6%	62.6%	63.6%	63.8%	63.6%	63.8%	63.9%	63.9%
Operating Expenses	$314.3	$340.0	$339.3	23.2% to 23.6%	$345.0	$345.3	$1,257	$1,254	$1,400	$1,400	$1,385.0		$1,410.0	
Operating Margin	39.8%	40.1%	40.1%	39.7% to 40.5%	40.5%	40.6%	39.4%	39.4%	40.8%	41.0%	40.7%		41.7%	
Net Income	$444.9	$485.4			$504.2		$1,749		$2,105					
Net Margin	32.9%	33.4%			33.6%		32.2%		34.2%		34.0%		35.3%	
EPS (Non-GAAP ex-SBC)	$1.62	$1.73	$1.74	$1.67 to $1.79	$1.80	$1.80	$6.47	$6.47	$7.50	$7.46	$7.35	$7.46	$8.00	$8.15
EPS (Non-GAAP w/SBC)	$1.43	$1.55			$1.61		$5.75		$6.77		$6.62		$7.27	
Fully diluted shares	275.4	280.7			280.7		270.4		280.7		280.7		280.7	

Source: Company data, Credit Suisse estimates, Consensus (FactSet)

- **TP of $180.** Our 12-month TP of $180 is based on ~24.5x CY21 EPS estimate of $7.35. We see MCHP as well positioned and relatively cheap with (1) a clear path to de-leverage ($1.04 of CY21 EPS in interest expenses), and (2) OM to 45%+ (+100 bps of OM is ~40 cents of EPS) – F1Q/F2Q OM of ~39% at trough revenue levels is clearly supportive of upside to target ~42%.

NXP Semiconductors (O/P, TP US$215): Significant auto leverage

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- **Significant Auto Leverage.** NXPI is one of the most levered companies to Auto in our US semis universe, with Auto ~45% of sales. We see two strong vectors of growth for NXPI – (1) Cyclical as auto industry recovers from the negative impact of COVID-19, and (2) Structural as semi content is poised to accelerate in coming years due to more advanced ADAS and the mix shift from ICE to xEV. In addition, as RADAR, Smart BMS and Domain Compute continue to ramp, we see significant TAM expansion that should enable relative outperformance and support an Auto CAGR of 7-10% vs. trailing 3-yr CAGR of -4%.

Figure 147: NXPI – Summary of results and expectations

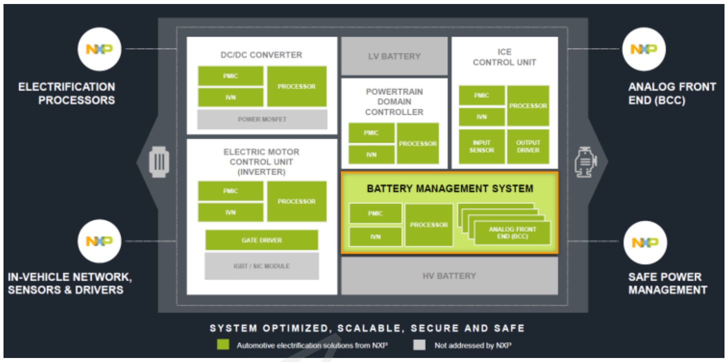
NXPI	Sep-20	Dec-20				Mar-21E			CY2021E		CY2022E	
	Reported	Reported	CS	Cons	Guidance	CS	Cons	Guidance	CS	Cons	CS	Cons
Revenue	**$2,267.0**	**$2,507.0**	**$2,450.0**	**$2,462.9**	**$2,375m-$2,525m**	**$2,550.0**	**$2,555.0**	**$2,475m-$2,625m**	**$10,570.0**	**$10,436.4**	**$11,100.0**	**$10,983.2**
% Q/Q chng	24.8%	10.6%	8.1%	8.6%	+4.8% to +11.4%	1.7%	3.7%	-1% to +5%				
% Y/Y chng	0.1%	9.0%	6.5%	7.0%	6.5%	26.2%	26.4%		22.7%	21.2%	5.0%	5.2%
Seasonality	5.1%	1.6%	1.6%	1.6%		-4.0%	-4.0%					
Gross Margin (ex-SBC)	**50.1%**	**52.9%**	**52.7%**	**52.7%**	**52.4% to 53.0%**	**53.5%**	**53.4%**	**53.2% to 53.8%**	**54.3%**	**54.3%**	**55.8%**	**55.0%**
Operating Expenses (ex-SBC)	**$549.0**	**$562.0**	**$563.0**	**$564.9**	**$563.00**	**$590.0**	$593.7	**~$590m**	**$2,395.0**	$2,426.0	**$2,475.0**	$2,486.8
Operating Margin (ex-SBC)	**25.8%**	**30.5%**	**29.7%**	**29.7%**	**29.7%**	**30.4%**	**30.2%**	**29.8% to 30.9%**	**31.6%**	**31.0%**	**33.5%**	**32.4%**
Net Income (ex-SBC)	**$443.0**	**$633.0**	**$599.0**			**$624.3**			**$2,698.1**		**$2,979.5**	
Net Margin (ex-SBC)	**19.5%**	**25.2%**	**24.4%**			**24.5%**			**25.5%**		**26.8%**	
EPS (Cont. Ops. ex-SBC)	**$1.56**	**$2.22**	**$2.09**	**$2.11**	**Implied $1.97-$2.23**	**$2.20**	**$2.21**	**Implied $2.06 - $2.33**	**$9.45**	**$9.35**	**$10.45**	**$10.46**
Fully diluted shares	284.4	285.3	286.0		286.0	284.0		284.0	285.5		286.0	

Source: Company data, Credit Suisse estimates, Consensus (FactSet)

- **Opportunities within Automotive.** New products in the Power market should allow NXPI to address 40% of EV market hitherto unaddressed. The power market has been growing at a >30% CAGR since 2017 and has expanded NXPI's SAM by more than $2bn. Aside from Power solutions, we would also note that ADAS and EV have the potential to drive semi content per car from $510/car today to well over $1,000/car in the long term (around 2035 timeframe). We see these tailwinds enabling NXPI to outperform especially given company-specific solutions across (1) High performance domain computing and (2) Secure Network processing, while simultaneously leveraging (3) a scalable and secure network architecture.

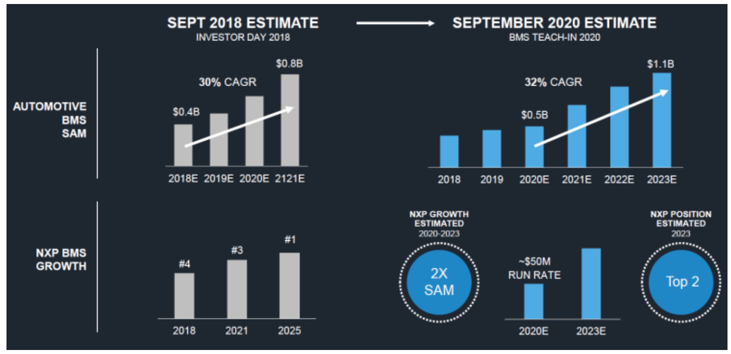
- **NXP growing its BMS footprint.** NXP's scalable battery management systems have been gaining traction (est. ~15% market share or #3 player in BMS today). It was recently adopted across the entire MEB platform of the Volkswagen Group, including ID.3 and ID.4 models, and also in the luxury and performance models, Audi e-tron and Porsche Taycan. Currently, NXPI BMS business has a run rate of ~$50mn (CY20) and the company believes they can grow at 2x SAM growing at ~30% CAGR or a ~60% CAGR for next 3/5 years to ~$1.1bn by CY23 – to the #2 position in BMS market. By CY23, the company estimates that 1 out of every 4 xEVs will use NXPI's BMS solution based on BMS project design wins with 16 out of top 20 global OEMs. By 2025, we see the BMS market at $7.4bn and with ~30% share NXPI could have BMS revenues exceeding $2.2bn vs. ~$300mn today vs. CY20 total Auto revenues of $3.8bn.

Figure 148: NXPI's BMS portfolio



Source: Company data (NXPI)

Figure 149: NXPI forecasts 32% CAGR for BMS SAM



Source: Company data (NXPI)

ON Semiconductor (U/P, TP US$17): Waiting for an updated financial model

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- **One of the most exposed semis companies in our US coverage.** ON is one of the most Auto exposed Semis in our coverage with ~32% of sales (5 year sales CAGR of ~8%). Their auto portfolio includes ADAS/AV, Powertrain, BMS, Lighting/Interior, In-Vehicle Networking, as well as innovations in SiC technology (for power management). Specifically, ON is the top supplier of CMOS image sensors for ADAS and ICs for Advanced Front Lighting Systems (AFLS) – with >10,000 automotive grade (AEC) products. To date, they have partnered with Subaru using their latest sensor technology for developing AV/ADAS applications and with Formula-E to implement powertrain systems under demanding perf and efficiency requirements.

- **Waiting for an updated financial model.** A full updated financial model will likely be provided on 5th Aug Analyst Day – though newly appointed CEO Hassane El-Khoury has clearly noted GM/OM expansion above old targets of 43%/22% based on: (1) Shift to a fab-light model, (2) Portfolio pruning, (3) Increased efficiency, and (4) M&A. We expect new management to be well equipped to lead ON though its continued cost cutting efforts while addressing company-specific headwinds including: (1) Substitution risk for ON being greater than most peers, (2) Integration risk from Quantenna, (3) Outsized profits from CMOS image sensors, and (4) GF East Fishkill acquisitions.

Figure 150: ON Semi: We model 17% sales growth in CY21, followed by 5% in CY22

ON-US	Dec-20	Mar-21E			Jun-21E		CY2021		CY2022E	
	Reported	CS	Cons	Guidance	CS	Cons	CS	Cons	CS	Cons
Revenue	**$1,446**	**$1,460**	**$1,462**	***$1,410m-$1,510m***	**$1,525**	**$1,492.4**	**$6,150**	**$5,982**	**$6,455**	**$6,228**
% Q/Q chng	*9.8%*	*0.9%*	*1.1%*	*-2.5% to +4.4%*	*4.5%*	*2.2%*				
% Y/Y chng	*3.2%*	*14.2%*	*14.4%*		*25.7%*	*23.0%*	*17.0%*	*8.4%*	*5.0%*	*4.1%*
Seasonal	*-1.0%*	*0.0%*			*4.4%*					
Gross Margin	**34.4%**	**35.1%**	*35.1%*	*34.1% to 36.1%*	**35.5%**	*35.9%*	**35.5%**	*36.4%*	**37.1%**	*38.6%*
Operating Expenses	**$292.4**	**$320.0**	**$319.6**	*$313m-$237m*	**$325.0**	**$319.5**	**$1,305**	**$1,283**	**$1,382**	**$1,317**
Operating Margin	**14.2%**	**13.2%**	*13.3%*		**14.2%**	*14.5%*	**14.3%**	*15.0%*	**15.7%**	*17.5%*
Net Income	**$147.1**	**$140.7**		*Tax $18m-$24m*	**$161.6**		**$666**		**$798**	
Net Margin	**10.2%**	**9.6%**			**10.6%**		**10.8%**		**12.4%**	
EPS (Non-GAAP ex-SBC)	**$0.39**	**$0.36**			**$0.41**		**$1.69**		**$2.08**	
EPS (Non-GAAP w/SBC)	**$0.35**	**$0.33**	**$0.33**	***Implied $0.28 to $0.38***	**$0.37**	**$0.39**	**$1.55**	**$1.60**	**$1.85**	**$1.97**
FCF/sh	**$0.25**	**$0.68**			**$0.11**		**$1.17**		**$1.62**	
Fully diluted shares	416.8	431.0			431.0		431.0		422.9	

Source: Company data, Credit Suisse estimates, Consensus (FactSet)

- **Maintain Underperform.** While we maintain our U/P rating on the stock, we acknowledge these recent positive developments and continue to reiterate our structural view on the industry that Semis are midstream in a revaluation higher based upon a value-capture that looks to be accelerating versus historic trends.

Rohm (O/P, TP ¥12,100): Full SiC ramp from 2024

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- **Targets SiC device sales of around ¥50bn in 2025.** Rohm is apparently targeting a global market share in SiC devices of 30% in FY25 (up from 20% in FY18), which it expects will produce sales of around ¥50bn. It already supplies SiC-SBD for EV onboard chargers and began shipping SiC full modules with embedded SiC-MOSFET in the second half of 2020, which are likely to be fitted to EVs planned for launch in 2021. It expects full production startup from 2024–25 as part of its partnership with Vitesco Technologies, as announced in May 2020.
- **Unified SiC production structure from wafers to assembly and testing.** Rohm utilizes vertical integration in SiC devices too, but will apparently utilize an even higher-level unified production structure in this area. From a technical standpoint, the shift to in-house manufacture of wafers allows for control of the trench construction in SiC-MOSFET from the wafer internally, which increases the competitiveness of product development. Moreover, the plan is to supply high-performance SiC products through combination with an insulating gate driver IC.
- **Analog semiconductors, discrete, SiC the three growth pillars in the automotive sphere.** Sales of automotive products account for 36% of total sales in FY3/21. In the automotive sphere, the company previously had a high sales weighting for conventional audio and car navigation applications, but has been working to expand in areas such as analog semiconductors for powertrains and bodies & chassis, discrete, and SiC.
- **Valuation.** Our ¥12,100 target price for Rohm is derived using a zero growth ROIC model (EV/IC = ROIC/WACC) based on our FY3/23 forecasts (beta = 1.1, Rf = 0.03%, Rp = 5.03%, WACC = 5.36%, ROIC = 5.72%).

STMicroelectronics (O/P, TP €39): Leading in SiC

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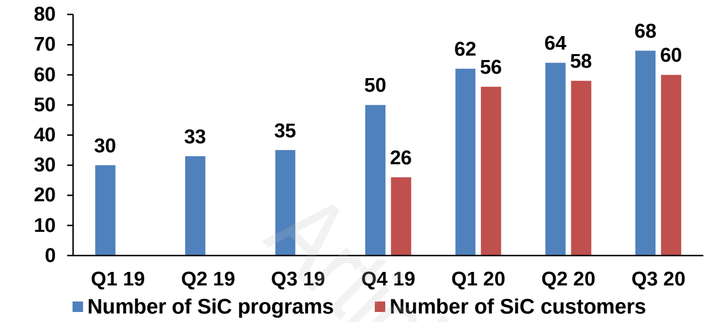
- **Estimates and TP unchanged; maintain O/P.** Based on our analysis of xEV adoption trends and the semis content growth opportunity especially in Power, we believe that STM can significantly exceed its SiC sales target of $1bn by 2025 (we model $1.1bn in 2024). At its last ADG session in November 2020, STM had flagged the following: i) Aim to continue to outgrow the auto semis market similar to the last 3 years; ii) Higher exposure to Electrification & Digitization (60%+ of ADG's Auto in 2022 vs. 35% in 2019); and iii) IGBT to grow from $150mn to $300mn+ by 2025. While our estimates for its Auto revenues are unchanged (we model 19%/10%/9% growth in 2021/22/23), increasing pace of EV adoption and SiC wins could provide potential upside to these forecasts. We reiterate our O/P rating with TP of €39.0.
- **Significant outperformance vs. Auto semis peers since 2016.** STM has outgrown the auto semis industry in the last 4 years by 2x (6% CAGR over 2016-2020 vs. industry growth of 3%), and management aim to extend this trend. While a large part of this outperformance was Tesla-driven ($245mn sales in 2020 vs. zero in 1H17), we note that STM's Auto business (excl. Tesla) grew by 3% CAGR since 2016 (in-line with the industry). While the pace of outperformance may decelerate as SiC competition increases, we still believe that STM can continue to outperform most peers given increasing adoption of SiC across car OEMs and its first-mover advantage.
- **Upside to SiC target of $1bn by 2025.** With 60+ SiC customers so far, STM is targeting to reach $1bn SiC sales (~$3bn TAM) by 2025, however we model $1.1bn/$1.3bn by 2024/25 given: i) we estimate SiC TAM of at least $4bn by 2025; ii) $240mn Tesla-linked sales in 2020 to grow to $700mn+ by 2024; and iii) assuming

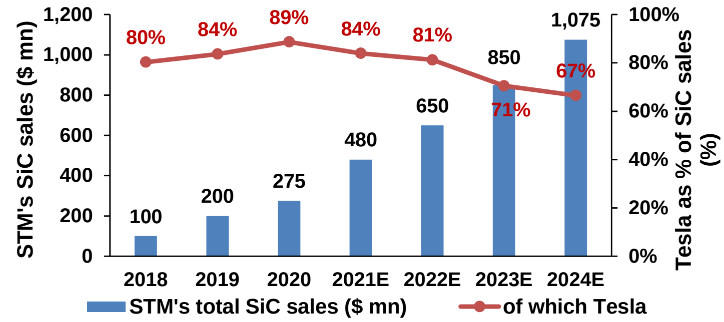
<$10mn sales per customer per year in outer years, it should result in $500mn SiC sales from the remaining 59 SiC customers.

Figure 151: STM has been growing its customer base for SiC products (over 2x in the last year)…



Source: Company data, Credit Suisse research

Figure 152: …which should allow it to exceed its $1bn SiC sales target in 2025 (we model $1.1bn by 2024)



Source: Company data, Credit Suisse estimates

- **Recent de-rating due to Apple socket loss concerns.** Concerns of potential socket loss at Apple – wireless charging ($1.5 chip) and FaceID ($4 chip) – has led to de-rating in shares (trading at P/E of 20x/18x on our 2022/23), which we hope to get clarity on upcoming Q1 earnings. However, we remain confident that STM continues to see increasing traction in key areas of Auto electrification, MCU and Connectivity.

Texas Instruments (O/P, TP US$200): Benefiting from broad-based Auto exposure

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- **Broad-based Auto exposure.** Automotive accounts for ~20% of TXN sales (and has grown at 12% CAGR over the last 5 years) and in the recent tight supply environment has benefited from its IDM model and shift to direct distribution strategy – i.e. availability of product when others are short. TXN's portfolio in Auto is broad-based: (1) powertrain systems – i.e. xEVs, (2) infotainment and cluster displays, (3) ADAS systems, (4) safety systems, and (5) body electronics and lighting.

- **Focus on long lifecycle and high duration products.** The company generally focuses on selling products with long lifecycles into high-duration markets – thus, Auto/Industrial has been a strategic asset for many years. TXN has cited that 45 out of their 65 different product lines ship into the Auto industry – serving >1,000 automotive OEMs, mostly Tier 1. While TXN has market leadership in overall Analog/Diversified with ~15-20% share, the Auto space remains highly diversified and at its recent Capital Management Day (February 2021), the company noted that any potential acquisition would likely be a highly strategic company with Auto/Industrial exposure (i.e. further consolidation). Most recently, new updates in wBMS technology were released by TXN during CES 2021 (Wireless Battery Management to increase Driving Range in EVs).

Figure 153: TXN: We expect 15% sales growth for 2021, followed by 5% in 2022

TXN	Dec-20	Mar-21E			Jun-21E		CY21E		CY22E	
	Reported	CS	Cons	Guidance	CS	Cons	CS	Cons	CS	Cons
Revenue	$4,076	$3,950	$3,977	$3,790m-$4,110m	$4,190	$4,137	$16,635	$16,599	$17,475	$17,377
% Q/Q chng	*6.8%*	*-3.1%*	*-2.4%*	***-7.0% to +0.8%***	*6.1%*	*4.0%*				
% Y/Y chng	*21.7%*	*18.7%*	*19.5%*		*29.4%*	*27.7%*	*15.0%*	*14.8%*	*5.0%*	*4.5%*
Seasonal	*-8.9%*	*-3.3%*			*6.0%*					
Gross Margin	64.9%	64.5%	64.4%		64.8%	64.7%	64.8%	65.2%	65.2%	0.657304
R&D Expense	$388	$410			$425		$1,705		$1,760	
SG&A Expense	$398	$405			$415		$1,655		$1,660	
Operating Expenses (GAAP)	$833	$862	$869		$887	$890	$3,548	$3,514	$3,608	$3,646
Operating Margin (GAAP)	44.5%	42.7%	42.6%		43.6%	43.2%	43.5%	44.1%	44.5%	0.4475025
Net Income (GAAP)	$1,688	$1,446			$1,558		$6,171		$6,644	
Net Margin (GAAP)	41.4%	36.6%			37.2%		37.1%		38.0%	
Operating EPS (w\o options)	$1.86	$1.61			$1.74		$6.88		$7.43	
GAAP EPS	$1.80	$1.55	$1.57	$1.44-$1.66	$1.67	$1.66	$6.60	$6.71	$7.15	$7.20
Fully Diluted Sharecount	932	930			930		930		925	

Source: Company data, Credit Suisse estimates, Consensus (FactSet)

- **Reiterate O/P with TP of $200.** We would highlight the company's consistent focus on shareholder value – returning 109% of CY20 FCF ($5.5bn) with 57% dividends, 43% buyback, and accelerating FCF growth in CY21 that should drive further buybacks. Our TP of $200 is ~28x CY22E EPS of $7.15 (street at $7.20) vs. 3/5-year averages of ~23x.

Valuation Methodology and Risks

Target Price and Rating
Valuation Methodology and Risks: (12 months) for ASM Pacific Technology Ltd (0522.HK)

Method: Our target price of HK$133 for ASM Pacific Tech reflects 25x upcycle P/E (price-to-earnings) and 2021E EPS (earnings per share). We have an OUTPERFORM rating on the stock. We like its structural trend and we believe CIS (CMOS image sensing), backend and SMT (surface mount technology) equipment would benefit from macro recovery in 2021. Besides, hetergeneous integration will continue to drive advanced packaging demand while 5G infrastructure roll-out will drive SMT demand and mini-LED (Light Emitted Diode) picking up from 2H21 also support ASMPT structural growth outlook, in addition to increase of production capacity in SEA (south-east Asia) and India, and localisation of China supply chain.

Risk: Risks to our HK$133 target price and OUTPERFORM rating for ASM Pacific include execution of transformation, slowing/improving orders, lower/higher multi-cam adoption, inventory correction cycle, weaker/improving macro demand, continuous pandemic impact and forex risks.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for Allegro Microsystems, Inc. (ALGM.OQ)

Method: Our Outperform rating and $36 target price for ALGM are based on 45x times CY22 EV/FCF. We rate ALGM Outperform given its leading share position in Auto and incumbency status with industry leading OEMs.

Risk: Risks to our $36 target price and Outperform rating for ALGM are (1) competitive pressures in the auto market, (2) failure to secure future design wins, and (3) a slower than expected recovery in the Auto market.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for Amkor Technology Inc. (AMKR.OQ)

Method: Our target price of US$23 for Amkor Technology is based on 11x 2022E P/E based on Amkor's mid-cycle range. Valuation is at the lower-end, at 0.8x EV/sales vs its 0.5x-1.2x range and 3.2x EV/EBITDA vs its 2.5x-5x range. We thus rate Amkor OUTPERFORM.

Risk: Downside risks to our US$23 target price and OUTPERFORM rating for Amkor Technology include: the share price could perform worse due to slower-than-expected premium smartphones, and worse-than-expected opex control leading to low profitability.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for Analog Devices Inc. (ADI.OQ)

Method: Our $200 target price and Outperform rating for ADI are based on ~32 times CY21 P/E. We rate ADI Outperform as we expect it to appreciate more than its peers.

Risk: Risks to our $200 target price and Outperform rating for ADI are: (1) competitive pricing pressure in the analog universe by new entrants and Chinese semiconductor companies and (2) market share loss in amplifiers, data converters, power management, due to new entrants and new technologies being introduced.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for Infineon Technologies AG (IFXGn.DE)

Method: For our TP of €42.50, we apply a 25x P/E multiple (top-end of the peer group range) to our fiscal 2023 EPS estimates. We rate the stock Outperform as we believe that Infineon is well placed to benefit from rising adoption trends of electric cars, industrial automation and proliferation of connected devices.

Risk: The main risks to our TP of €42.50 and Outperform rating include: (1) overall macroeconomic slowdown in 2021/2022 leading to demand slowdown in automotive and industrial, along with inventory destocking, (2) strong depreciation in USD vs. EUR FX rate given higher net exposure to USD, and (3) slower than expected uptake of electric/hybrid cars with Infineon losing significant market share in this market.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for Microchip Technology Inc. (MCHP.OQ)

Method: Our $180 target price and Outperform rating for MCHP are based on ~24.5x our estimated CY21 P/E. We believe MCHP should trade near the high end of the group given our structural favorable view of the company. We rate MCHP Outperform rating as we continue to see it as one of the most diversified and well run companies in the Semi Industry - with consistent execution, as well as its strong track record of successful M&A to augment organic growth. We expect MCHP to return more than its peers.

Risk: Risks to our $180 target price and Outperform rating for MCHP are a slowdown in the overall economy, as its revenue is spread over a large number of customers (none over ~2% of revenue) and tends to be tied to the macroeconomic environment, failure to meet the long-term gross margin target, share loss in the MCU market, failure to show good revenue growth in the 16-bit MCU market and a slowdown in auto sales (auto is about 15% of revenue).

Target Price and Rating
Valuation Methodology and Risks: (12 months) for NXP Semiconductors N.V. (NXPI.OQ)

Method: Our Outperform rating and $215 target-price for NXPI are based on 20.0x CY21 EV/FCF. Along with growth, margin expansion and cash return should close the valuation gap. We rate NXPI Outperform as we expect it to appreciate more than its peers.

Risk: Risks to our $215 target-price and Outperform rating for NXPI are (1) below-industry revenue growth rate, (2) execution of new businesses and (3) loss of market share.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for ON Semiconductor Corp. (ON.OQ)

Method: Our TP of $17 represents ~13x P/E on CY21. We maintain our Underperform rating as we see shares as fully valued, ON has historically underperformed post y/y Rev peaks, and we see longer-term structural competitive issues without an M&A bid. We see higher quality assets at similar multiples with better risk/reward.

Risk: Major Risks to our $17 target price and our Underperform rating for ON include successful execution towards its LT EPS target and better than expected content gains in Autos and Mobile.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for ROHM (6963.T)

Method: We calculate our ¥12,100 target price for Rohm using our zero-growth ROIC model (EV/IC=ROIC/WACC) for FY3/23 (beta 1.1, RFR 0.03%, ERP 5.03%, WACC 5.36% and ROIC 5.72%). We are upbeat on Rohm's potential for medium-term growth centering on automotive applications. Our OUTPERFORM rating is based on a comparison of the 12-month projected total returns for the company's shares and our coverage universe.

Risk: Risks to our ¥12,100 target price and OUTPERFORM rating for Rohm include adjustments in automotive/industrial equipment, a stronger yen, and weaker Japanese OEM auto output.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for STMicroelectronics NV (STM.PA)

Method: For our TP of €39.0, we apply P/E multiple of 22x (well above 14x average for FY3 P/E seen since 2012) for STM on our 2023 EPS plus current net cash, which we believe is warranted given material re-rating in the sector along with STM's improving product portfolio in Auto, Industrial and Sensors, and ongoing improvement in EBIT margins. We rate the stock Outperform given upside potential to our target price from current share price levels.

Risk: Main risks to our TP of €39.0 and Outperform rating include: (1) slower growth in automotive and industrial and risk of contract losses in Radars and Electric Cars; (2) losing existing sensor sockets at Apple and/or Samsung; and (3) strong appreciation in EUR vs. USD FX rate given higher net (sales minus costs) exposure to USD, which means appreciation in EUR would be a negative for STM's earnings.

Target Price and Rating
Valuation Methodology and Risks: (12 months) for Texas Instruments Inc. (TXN.OQ)

Method: Our $200 PT represents ~30.0x P/E on CY21. Our Outperform rating is based upon: (1) Street Estimates that are under modeling both Rev Growth and OpM Leverage, (2) Continued dominant franchise position which skews risk to duration not fundamentals, and (3) Solid downside support at ~$100.

Risk: The primary risk factors to our Outperform rating and our $200 price target are weak end-market demand, share loss in the embedded or analog businesses, less than normal seasonality, and overall company execution. TXN has a broad based business which is affected by many macro economic conditions, any one of which could impact the stock price.

Companies Mentioned *(Price as of 18-Mar-2021)*

ABB (ABBN.S, SFr28.95)
AIXTRON (AIXGn.DE, €18.79)
ASE Industrial Holdings (3711.TW, NT$106.5)
ASM Pacific Technology Ltd (0522.HK, HK$100.4, OUTPERFORM, TP HK$133.0)
Allegro Microsystems, Inc. (ALGM.OQ, $26.07, OUTPERFORM[V], TP $36.0)
Amkor Technology Inc. (AMKR.OQ, $23.11, OUTPERFORM[V], TP $23.0)
Analog Devices Inc. (ADI.OQ, $149.45, OUTPERFORM, TP $200.0)
Apple Inc (AAPL.OQ, $120.53)
BAIC Motor Corporation Limited (1958.HK, HK$2.79)
BMW (BMWG.DE, €86.12)
BYD Co Ltd (002594.SZ, Rmb178.55)
BYD Co Ltd (1211.HK, HK$192.0)
CR Micro (688396.SS, Rmb55.51)
Chin-Poon Industrial Co., Ltd. (2355.TW, NT$34.15)
Continental (CTCN.BO, Rs20.75)
Cree (CREE.OQ, $105.42)
DISCO (6146.T, ¥34,950)
Daimler (DAIGn.DE, €74.33)
Delta Electronics (2308.TW, NT$288.0)
Denso (6902.T, ¥7,750)
Dongfeng Motor Group Company Limited (0489.HK, HK$7.69)
DuPont de Nemours, Inc. (DD.N, $78.37)
Enel (ENEI.MI, €8.06)
Fiat Chrysler Automobiles N.V. (STLA.MI, €15.39)
Ford Motor Company (F.N, $12.49)
Fuji Electric (6504.T, ¥4,790)
GT Advanced Tech (GTAT.PK, $4,790)
Geely Automobile Holdings Ltd (0175.HK, HK$24.7)
General Electric (GE.N, $13.25)
General Motors Company (GM.N, $59.27)
Globalwafers (6488.TWO, NT$740.0)
Great Wall B&R (0524.HK, HK$0.23)
Hitachi (6501.T, ¥5,395)
Hua Hong Semiconductor Limited (1347.HK, HK$43.95)
Hyundai Motor Company (005380.KS, W234,000)
II-VI (IIVI.OQ, $68.43)
Infineon Technologies AG (IFXGn.DE, €33.94, OUTPERFORM, TP €42.5)
Intel Corp. (INTC.OQ, $63.73)
Maxim Integrated Products (MXIM.OQ, $88.03)
Melexis (MLXS.BR, €85.35)
Microchip Technology Inc. (MCHP.OQ, $145.49, OUTPERFORM, TP $180.0)
Micron Technology Inc. (MU.OQ, $89.82)
Mitsubishi Electric (6503.T, ¥1,770)
Mitsubishi Motors (7211.T, ¥315)
Monolithic Power (MPWR.OQ, $335.76)
NGK Spark Plug (5334.T, ¥1,995)
NVIDIA Corporation (NVDA.OQ, $508.9)
NXP Semiconductors N.V. (NXPI.OQ, $198.59, OUTPERFORM, TP $215.0)
Nichias (5393.T, ¥2,887)
Nio Inc (NIO.N, $41.63)
Nissan Motor (7201.T, ¥605)
Nuvation Bio (NUVB.N, $14.01)
ON Semiconductor Corp. (ON.OQ, $39.14, UNDERPERFORM[V], TP $17.0)
Osram (OSRn.DE, €51.98)
QUALCOMM Inc. (QCOM.OQ, $129.75)
ROHM (6963.T, ¥10,860, OUTPERFORM, TP ¥12,100)
Renault (RENA.PA, €40.075)
Renesas Electronics (6723.T, ¥1,267)
SAIC Motor (600104.SH, Rmb20.42)
SAIC Motor Corp Ltd (600104.SS, Rmb20.42)
STMicroelectronics NV (STM.PA, €30.4, OUTPERFORM, TP €39.0)
Sanken Electric (6707.T, ¥5,210)
Semiconductor Manufacturing International Corp. (0981.HK, HK$26.45)
Shindengen Elec (6844.T, ¥3,370)
Showa Denko (4004.T, ¥3,230)
Silicon Laboratories Inc. (SLAB.OQ, $142.29)
Sony (6758.T, ¥11,630)
StarPower (603290.SS, Rmb179.21)
Sumitomo Mitsui Financial Group (8316.T, ¥4,260)
TDK (6762.T, ¥15,880)
Taiwan Semiconductor Manufacturing (2330.TW, NT$602.0)
Tata Motors Ltd. (TAMO.BO, Rs306.9)
Tesla Inc (TSLA.OQ, $653.16)
Texas Instruments Inc. (TXN.OQ, $174.36, OUTPERFORM, TP $200.0)
Toshiba (6502.T, ¥3,795)
Toyota Motor (7203.T, ¥8,650)
UMC Corp (UMC.N, $8.24)
United Microelectronics (2303.TW, NT$47.05)
Vanguard International Semiconductor (5347.TWO, NT$109.0)
Vishay Intertech (VSH.N, $24.36)
Volkswagen (VOWG_p.DE, €223.05)
Volvo (VOLVb.ST, Skr238.8)
Wafer Works (6182.TWO, NT$42.2)
X-FAB (XFAB.PA, €6.76)
ZDT (4958.TW, NT$127.5)
Zhuzhou CRRC Times Electric Co., Ltd (3898.HK, HK$33.55)

Disclosure Appendix

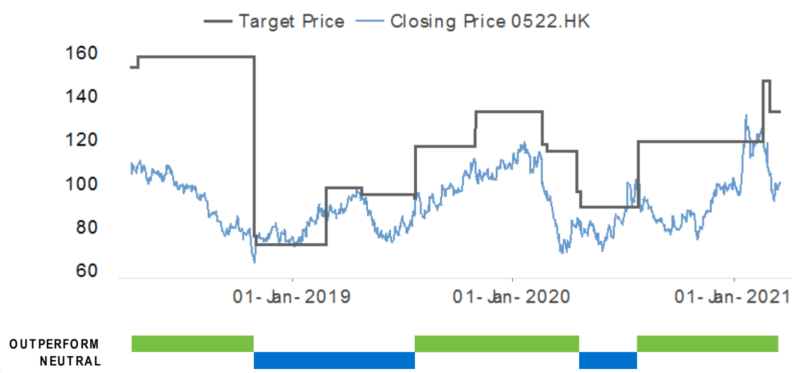
Analyst Certification

Achal Sultania, John W. Pitzer, Randy Abrams, CFA, Akinori Kanemoto, Hideyuki Maekawa, Pauline Chen, Chaolien Tseng, Patrick Chan, CFA and Haas Liu each certify, with respect to the companies or securities that the individual analyzes, that (1) the views expressed in this report accurately reflect his or her personal views about all of the subject companies and securities and (2) no part of his or her compensation was, is or will be directly or indirectly related to the specific recommendations or views expressed in this report.

3-Year Price and Rating History for ASM Pacific Technology Ltd (0522.HK)

0522.HK Date	Closing Price (HK$)	Target Price (HK$)	Rating
09-Apr-18	104.30	153.00	O
20-Apr-18	108.60	158.00	
29-Oct-18	65.15	76.00	N
02-Nov-18	75.25	72.00	
25-Feb-19	84.15	98.00	
25-Apr-19	94.35	95.00	
22-Jul-19	85.35	93.00	
24-Jul-19	94.40	117.00	O
31-Oct-19	109.70	133.00	
19-Feb-20	100.30	118.00	
26-Feb-20	93.20	115.00	
16-Apr-20	81.50	96.00	
22-Apr-20	82.65	89.00	N
27-Jul-20	99.75	119.00	O
18-Feb-21	122.30	147.00	
01-Mar-21	104.30	133.00	

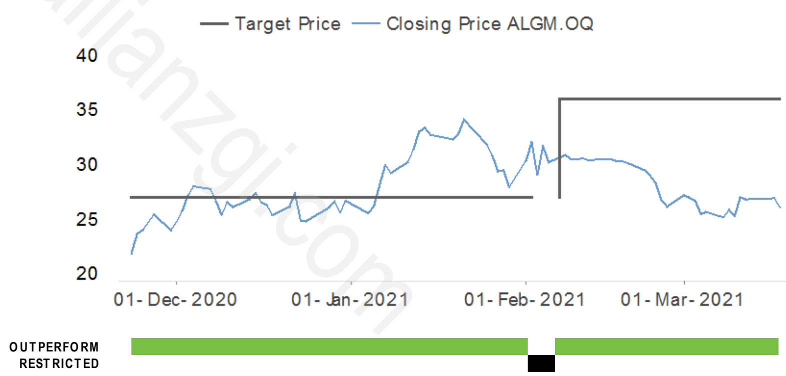
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for Allegro Microsystems, Inc. (ALGM.OQ)

ALGM.OQ Date	Closing Price (US$)	Target Price (US$)	Rating
23-Nov-20	21.86	27.00	O *
02-Feb-21	32.01		R
07-Feb-21	30.19	36.00	O

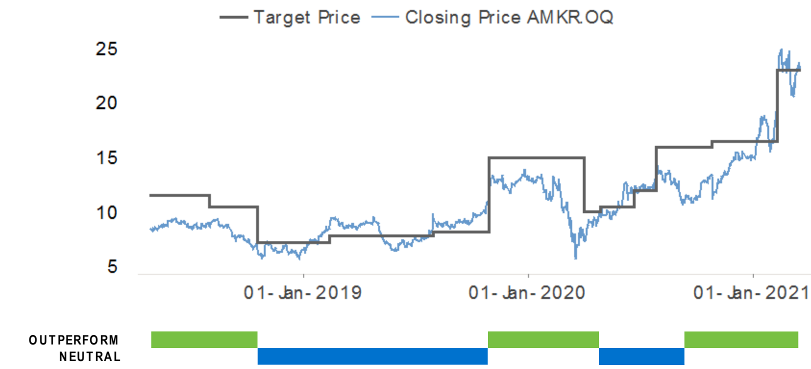
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for Amkor Technology Inc. (AMKR.OQ)

AMKR.OQ Date	Closing Price (US$)	Target Price (US$)	Rating
27-Apr-18	8.45	11.50	O
31-Jul-18	8.68	10.50	
18-Oct-18	6.28	7.20	N
12-Feb-19	8.92	7.80	
30-Jul-19	9.78	8.20	
29-Oct-19	14.92	15.00	O
02-Apr-20	7.50	10.00	
28-Apr-20	9.57	10.50	N
22-Jun-20	12.02	12.00	
28-Jul-20	14.33	16.00	
14-Sep-20	11.54	16.00	O
27-Oct-20	11.25	16.50	
09-Feb-21	19.38	23.00	

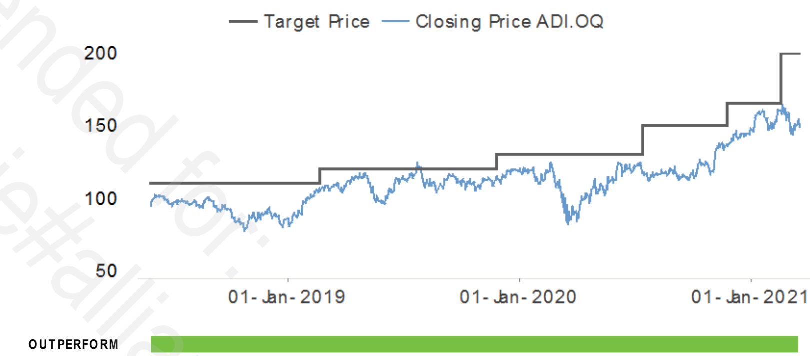
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for Analog Devices Inc. (ADI.OQ)

ADI.OQ Date	Closing Price (US$)	Target Price (US$)	Rating
30-May-18	94.98	110.00	O
21-Feb-19	105.28	120.00	
26-Nov-19	114.89	130.00	
13-Jul-20	117.25	150.00	
24-Nov-20	136.89	165.00	
17-Feb-21	159.75	200.00	

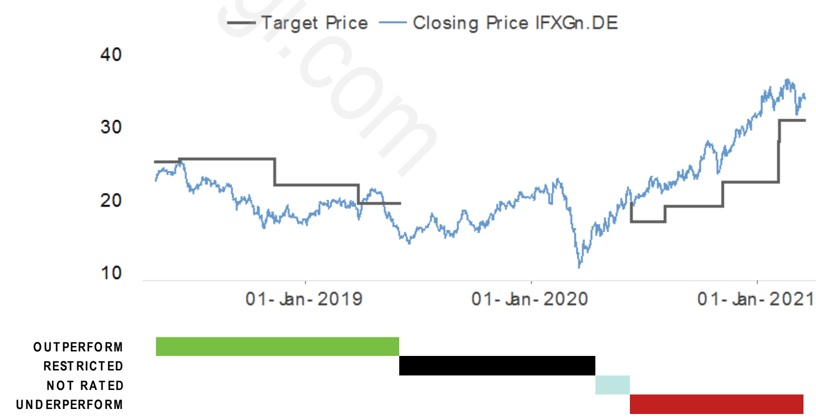
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for Infineon Technologies AG (IFXGn.DE)

IFXGn.DE Date	Closing Price (€)	Target Price (€)	Rating
04-May-18	22.73	25.30	O
11-Jun-18	25.12	25.60	
13-Nov-18	17.46	22.00	
28-Mar-19	17.42	19.50	
03-Jun-19	14.79		R
16-Apr-20	15.53		NR
11-Jun-20	19.67	17.00	U
05-Aug-20	21.82	19.20	
05-Nov-20	26.38	22.50	
03-Feb-21	33.83	28.00	
05-Feb-21	34.11	31.00	

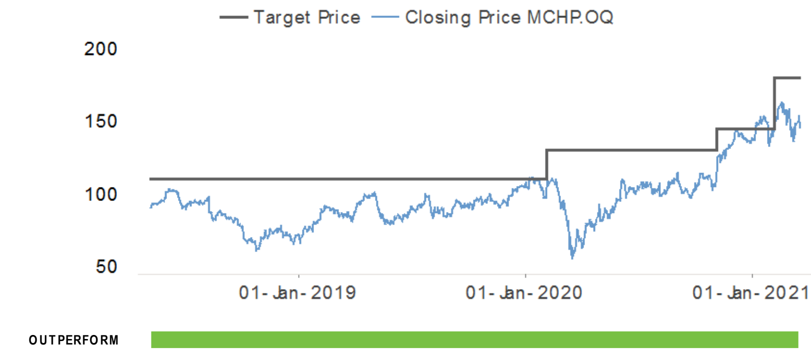
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for Microchip Technology Inc. (MCHP.OQ)

MCHP.OQ	Closing Price	Target Price	
Date	(US$)	(US$)	Rating
08-May-18	90.65	110.00	O
04-Feb-20	101.71	130.00	
05-Nov-20	118.38	145.00	
05-Feb-21	145.44	180.00	

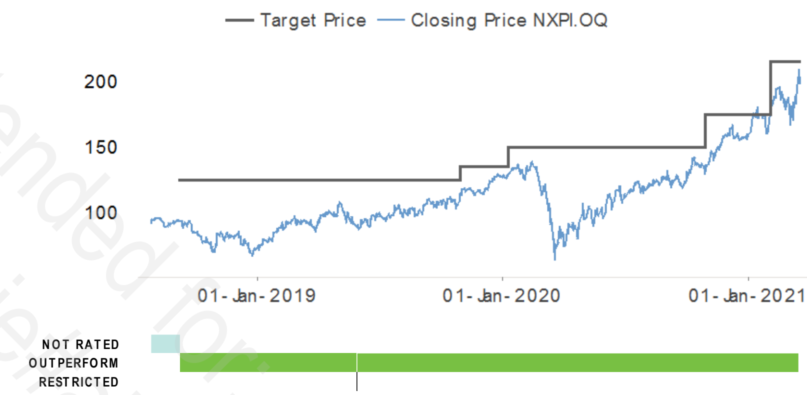
* *Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for NXP Semiconductors N.V. (NXPI.OQ)

NXPI.OQ	Closing Price	Target Price	
Date	(US$)	(US$)	Rating
26-Jul-18	92.81		NR
07-Sep-18	94.02	125.00	O
29-May-19	89.12		R
30-May-19	90.88	125.00	O
29-Oct-19	114.41	135.00	
09-Jan-20	129.18	150.00	
28-Oct-20	129.77	175.00	
02-Feb-21	177.21	215.00	

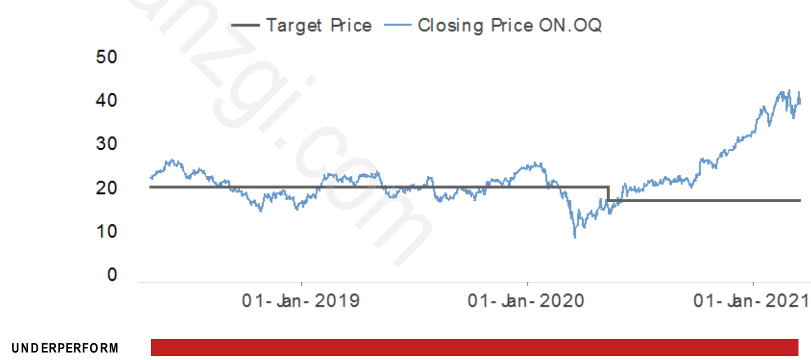
* *Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for ON Semiconductor Corp. (ON.OQ)

ON.OQ	Closing Price	Target Price	
Date	(US$)	(US$)	Rating
01-May-18	22.16	20.00	U
11-May-20	15.66	17.00	

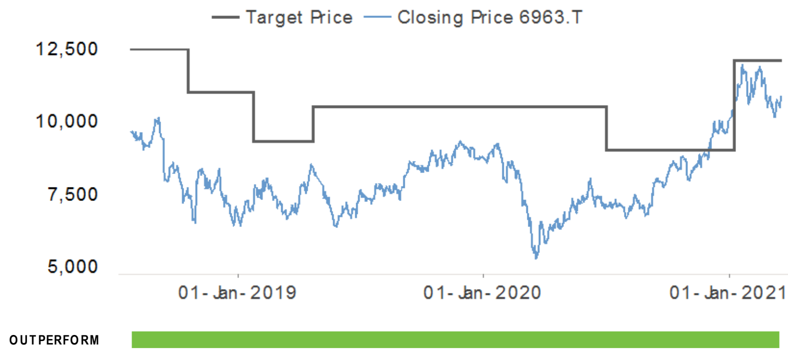
* *Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for ROHM (6963.T)

6963.T Date	Closing Price (¥)	Target Price (¥)	Rating
26-Jul-18	9,630	12,500	O
18-Oct-18	7,510	11,000	
24-Jan-19	7,340	9,300	
22-Apr-19	8,410	10,500	
01-Jul-20	7,120	9,000	
08-Jan-21	10,610	12,100	

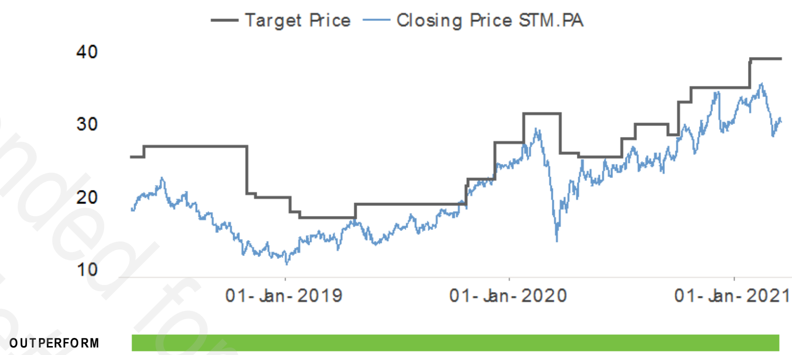
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for STMicroelectronics NV (STM.PA)

STM.PA Date	Closing Price (€)	Target Price (€)	Rating
26-Apr-18	18.34	25.50	O
16-May-18	20.16	27.00	
31-Oct-18	13.42	20.50	
14-Nov-18	12.45	20.00	
09-Jan-19	12.01	18.00	
25-Jan-19	14.37	17.20	
25-Apr-19	16.56	19.00	
22-Oct-19	19.02	21.50	
25-Oct-19	20.21	22.50	
09-Dec-19	23.11	27.50	
24-Jan-20	27.74	31.50	
24-Mar-20	18.32	26.00	
23-Apr-20	22.36	25.50	
02-Jul-20	24.01	28.00	
24-Jul-20	25.89	30.00	
15-Sep-20	26.60	28.50	
02-Oct-20	27.74	33.00	
23-Oct-20	28.61	35.00	
27-Jan-21	31.72	38.50	
28-Jan-21	33.03	39.00	

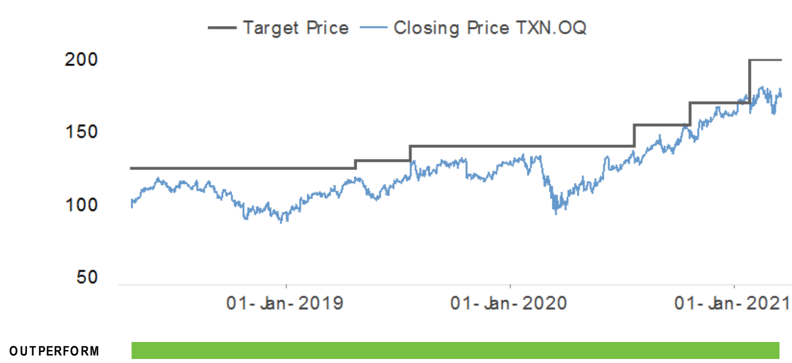
** Asterisk signifies initiation or assumption of coverage.*



3-Year Price and Rating History for Texas Instruments Inc. (TXN.OQ)

TXN.OQ Date	Closing Price (US$)	Target Price (US$)	Rating
24-Apr-18	98.42	125.00	O
24-Apr-19	118.43	130.00	
23-Jul-19	120.07	140.00	
22-Jul-20	132.53	155.00	
21-Oct-20	146.13	170.00	
26-Jan-21	171.47	200.00	

** Asterisk signifies initiation or assumption of coverage.*



As of December 10, 2012 Analysts' stock rating are defined as follows:
Outperform (O) : The stock's total return is expected to outperform the relevant benchmark* over the next 12 months.
Neutral (N) : The stock's total return is expected to be in line with the relevant benchmark* over the next 12 months.

Underperform (U) : The stock's total return is expected to underperform the relevant benchmark* over the next 12 months.

**Relevant benchmark by region: As of 10th December 2012, Japanese ratings are based on a stock's total return relative to the analyst's coverage universe which consists of all companies covered by the analyst within the relevant sector, with Outperforms representing the most attractive, Neutrals the less attractive, and Underperforms the least attractive investment opportunities. As of 2nd October 2012, U.S. and Canadian as well as European (excluding Turkey) ratings are based on a stock's total return relative to the analyst's coverage universe which consists of all companies covered by the analyst within the relevant sector, with Outperforms representing the most attractive, Neutrals the less attractive, and Underperforms the least attractive investment opportunities. For Latin America, Turkey and Asia (excluding Japan and Australia), stock ratings are based on a stock's total return relative to the average total return of the relevant country or regional benchmark (India - S&P BSE Sensex Index); prior to 2nd October 2012 U.S. and Canadian ratings were based on (1) a stock's absolute total return potential to its current share price and (2) the relative attractiveness of a stock's total return potential within an analyst's coverage universe. For Australian and New Zealand stocks, the expected total return (ETR) calculation includes 12-month rolling dividend yield. An Outperform rating is assigned where an ETR is greater than or equal to 7.5%; Underperform where an ETR less than or equal to 5%. A Neutral may be assigned where the ETR is between -5% and 15%. The overlapping rating range allows analysts to assign a rating that puts ETR in the context of associated risks. Prior to 18 May 2015, ETR ranges for Outperform and Underperform ratings did not overlap with Neutral thresholds between 15% and 7.5%, which was in operation from 7 July 2011.*

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Analysts' sector weightings are distinct from analysts' stock ratings and are based on the analyst's expectations for the fundamentals and/or valuation of the sector* relative to the group's historic fundamentals and/or valuation:

Overweight : The analyst's expectation for the sector's fundamentals and/or valuation is favorable over the next 12 months.

Market Weight : The analyst's expectation for the sector's fundamentals and/or valuation is neutral over the next 12 months.

Underweight : The analyst's expectation for the sector's fundamentals and/or valuation is cautious over the next 12 months.

**An analyst's coverage sector consists of all companies covered by the analyst within the relevant sector. An analyst may cover multiple sectors.*

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Global Ratings Distribution

Rating	Versus universe (%)	Of which banking clients (%)
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Neutral/Hold*	35%	(27% banking clients)
Underperform/Sell*	11%	(21% banking clients)
Restricted	2%	

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**For purposes of the NYSE and FINRA ratings distribution disclosure requirements, our stock ratings of Outperform, Neutral, and Underperform most closely correspond to Buy, Hold, and Sell, respectively; however, the meanings are not the same, as our stock ratings are determined on a relative basis. (Please refer to definitions above.) An investor's decision to buy or sell a security should be based on investment objectives, current holdings, and other individual factors.*

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See the Companies Mentioned section for full company names

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