High-Voltage SiC Optimized for Megawatt Charging in EV Long-haul Trucking

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APEC February 29th, 2024

A New World Needs New EV Trucks

MAN Truck & Bus and ABB E-mobility, exclusive cooperation agreement. Jan ’24 [2]

Passenger EV adoption increasing:

USA: passenger EV forecast for 2030 up >2x[1]

Long-haul EV trucking: early days

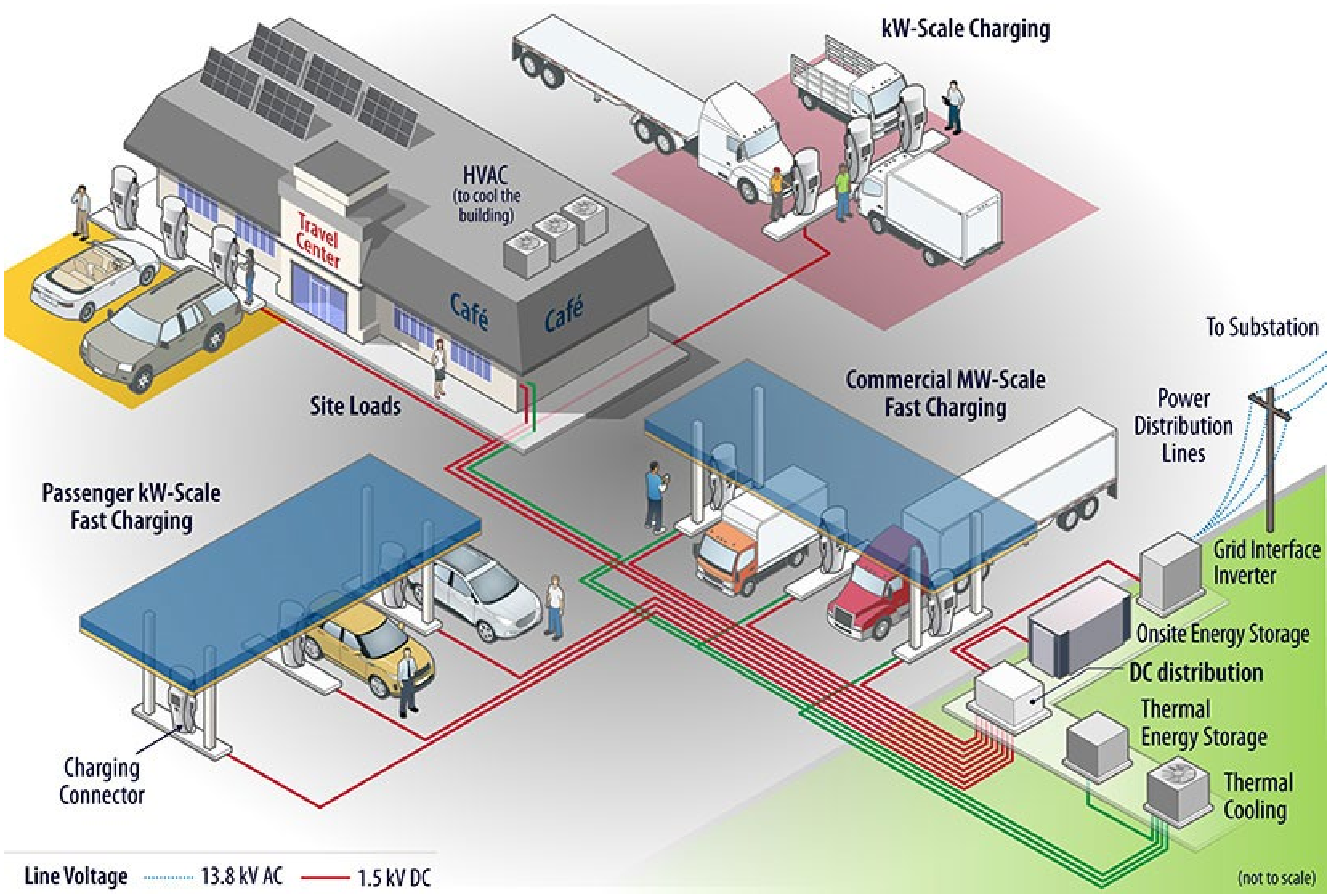
In 2022, 60k medium- and heavy-duty BEV trucks sold (~1% of total), 110 BEV truck models introduced

US and 26 other countries signed COP27 MoU:

30% ZEV sales by 2030 and 100% by 2040

1) Boston Consulting Group (BCG) forecasts, 21% in 2018, 53% in 2022 forecast
2) https://press.mantruckandbus.com/corporate/megawatt-charging-and-more-man-and-abb--e-mobility-announce-rd-cooperation/

Roadside Charging: Many HV SiC Opportunities



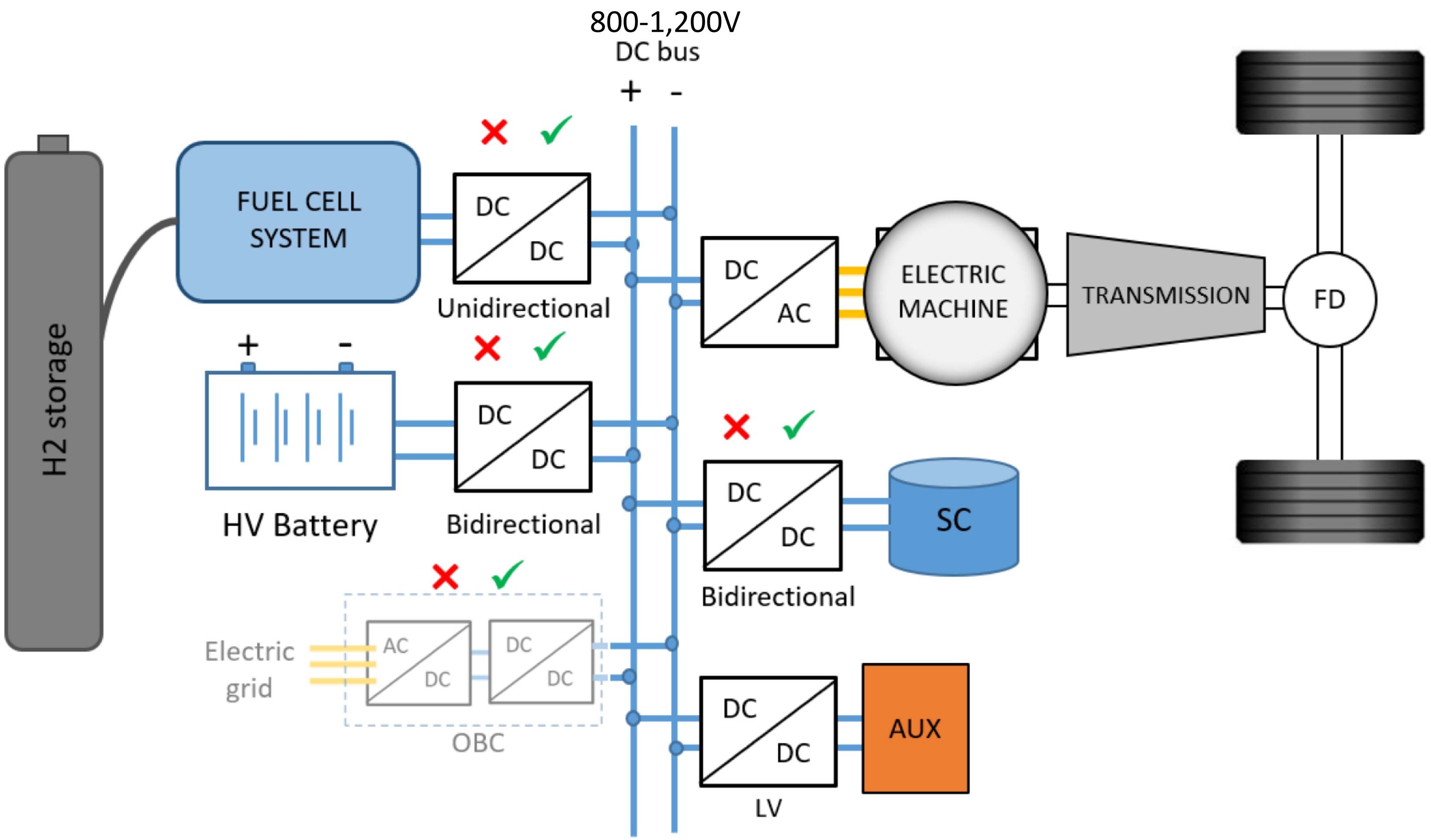
https://www.nrel.gov/transportation/medium-heavy-duty-vehicle-charging.html

Nikola BEV vs H2 Fuel Cell

Spec	Nikola BEV[1]	Nikola Fuel-Cell[2]
Max Speed (mph)	70	70
Range (miles)	Up to 330	Up to 500
Battery (kWh)	733	164
Fuel Cell Power Module (kWh)	-	200
Continuous Power (kW)	480	400
Instantaneous Power (kW)	797	575
Charging / Refueling Time (mins)	90 (@350 kW) *<< @ 1MW?*	20

1) https://nikolamotor.com/the-nikola-tre-bev-reinventing-short-haul-transportation/
2) https://nikolamotor.com/tre-fcev/

Hydrogen Fuel-cell: Still More Power, Still High Voltage



"A Review of Fuel Cell Powertrains for Long-Haul Heavy-Duty Vehicles: Technology, Hydrogen, Energy and Thermal Management Solutions", Pardhi, et al, Energies 2022, 15(24), 9557; https://doi.org/10.3390/en15249557

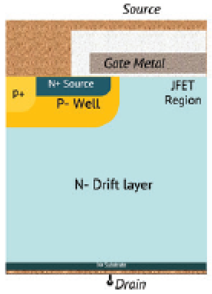
Full BEV: More Power, Higher Voltage

"Megawatt Charging System": SAE J3271[1,2], up to 3.75 MW via 1,250 V cable

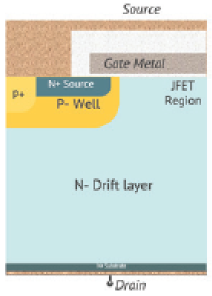
DC Fast-Charger Specifications	Passenger / LDV	HDV J3721 (non-cooled)	HDV J3721 (actively-cooled)
Power (max, kW)	350	440	3,750
Voltage (max, V)	920	1,250	1,250
Current (max, A)	500	350	3,000
Vehicle Battery (nom, V)	400 / 800	800, 1200	800, 1200
SiC Device Voltage (nom, V)	**750 / 1,200**	**1,200 / 1,700**	**1,700**

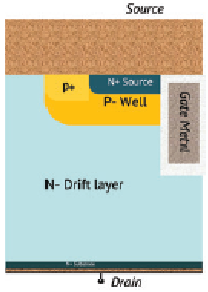
1) SAE J3271 specification, https://standardsworks.sae.org/standards-committees/j3271-megawatt-charging-system-electric-vehicles-tf
2) https://www.anl.gov/reference/faq-charging-for-heavyduty-electric-trucks

The Planar Problem

	Planar 
Manufacturability	» *Repeatable* » *High yield* » *Low cost*
Performance	» *High $R_{DS(ON)}$ / area* » *Slow switching* » *High $R_{DS(ON)}$ / Δ temp*
Reliability	» *Rugged gate oxide (stable V_{TH})*

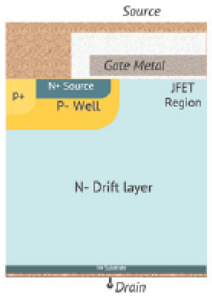
The Trouble with Trench

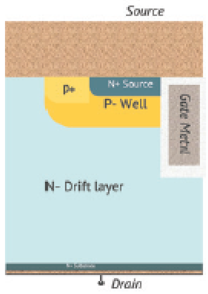


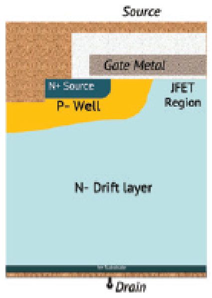


	Planar	*Trench*
Manufacturability	» *Repeatable* » *High yield* » *Low cost*	» *Inconsistent trench etch* » *Lower yields* » *High cost*
Performance	» *High $R_{DS(ON)}$ / area* » *Slow switching* » *High $R_{DS(ON)}$ / Δ temp*	» *Lower $R_{DS(ON)}$ / area* » *Faster switching* » *High $R_{DS(ON)}$ / Δ temp*
Reliability	» *Rugged gate oxide (stable V_{TH})*	» *Failures due to non-uniform gate oxide* » *Lower short-circuit capability*

Best of Both: Trench-Assisted Planar Gate



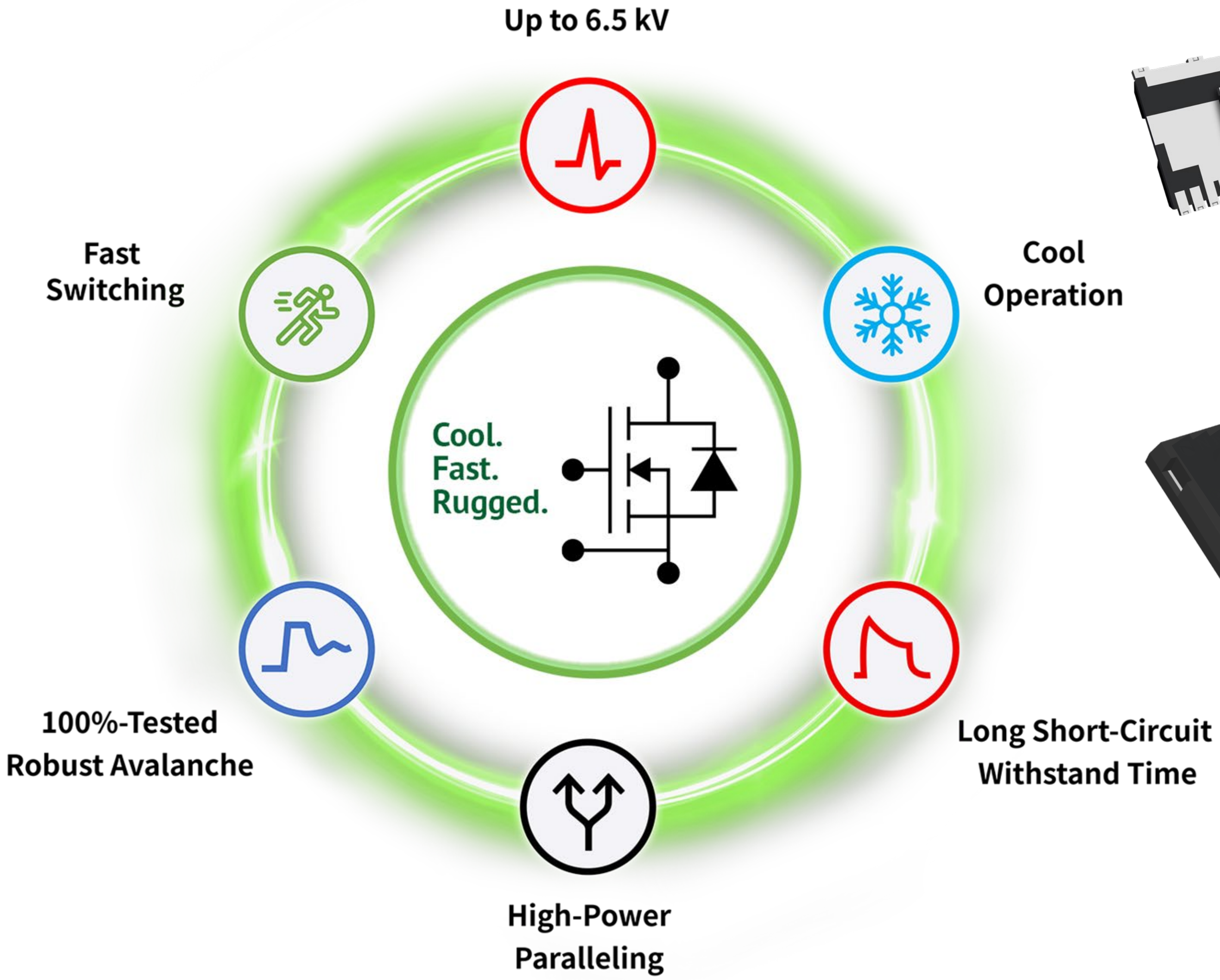


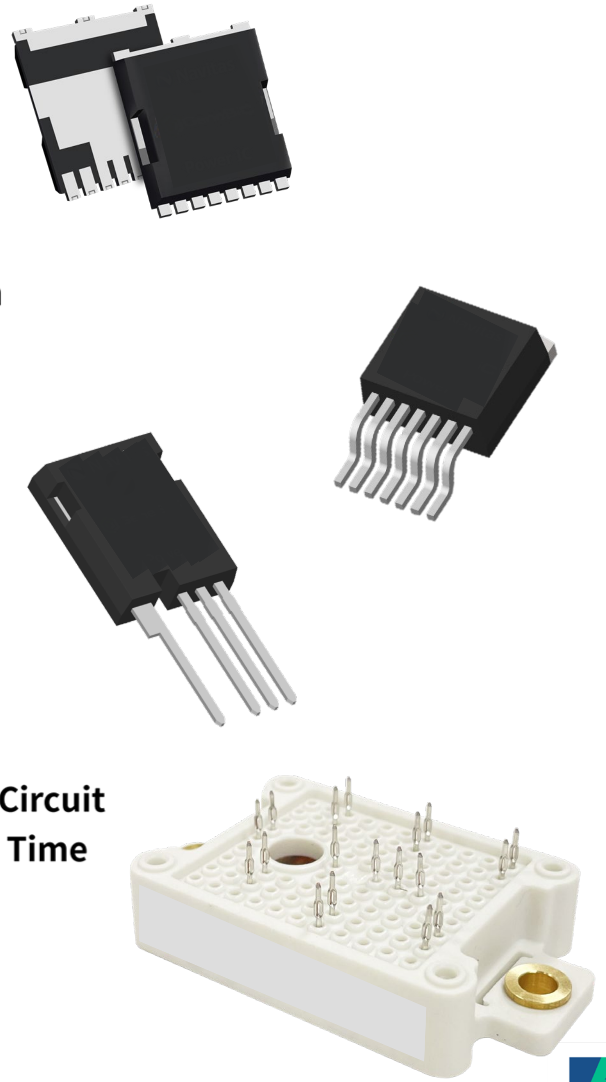


	Planar	Trench	Trench-Assisted Planar Gate
Manufacturability	» Repeatable » High yield » Low cost	» Inconsistent trench etch » Lower yields » High cost	» Repeatable » High yield » Low cost
Performance	» High $R_{DS(ON)}$ / area » Slow switching » High $R_{DS(ON)}$ / Δ temp	» Lower $R_{DS(ON)}$ / area » Faster switching » High $R_{DS(ON)}$ / Δ temp	» Lower $R_{DS(ON)}$ / area » Fastest switching » Lowest $R_{DS(ON)}$ / Δ temp
Reliability	» Rugged gate oxide (stable V_{TH})	» Failures due to non-uniform gate oxide » Lower short-circuit capability	» Highest 100% tested avalanche » Long short-circuit withstand time » Rugged gate oxide (stable V_{TH})

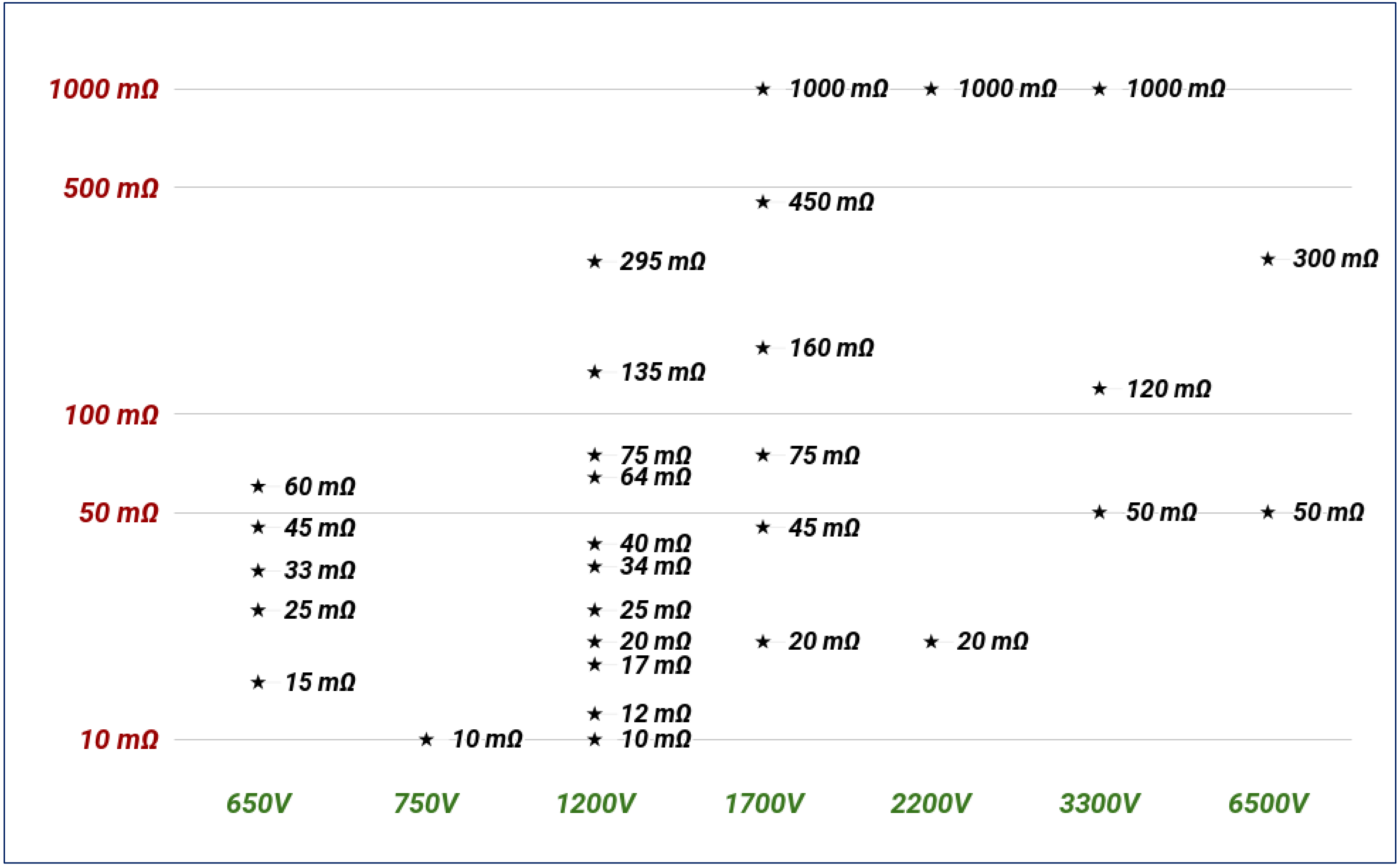
Highest Performance, Voltage Range & Ruggedness

Patented Trench-Assisted Planar-Gate SiC MOSFETs





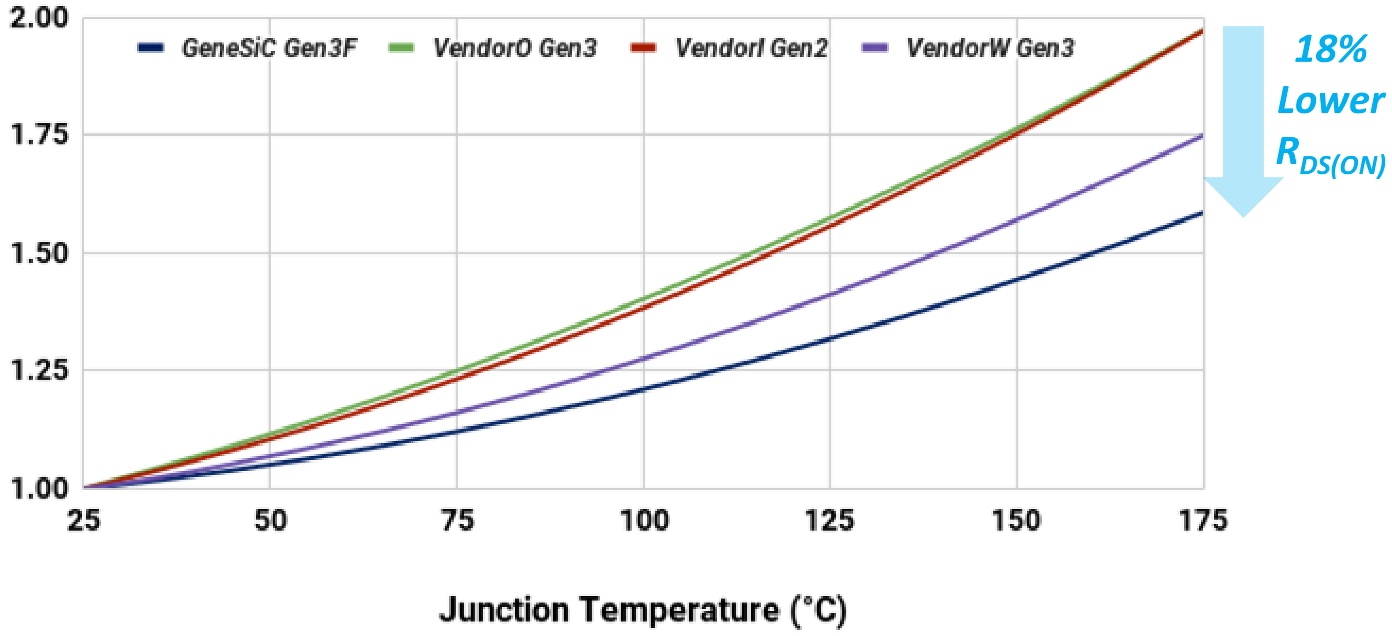
Broad SiC Portfolio (650 V → 6,500 V)



Trench-Assisted Planar Gate Performance

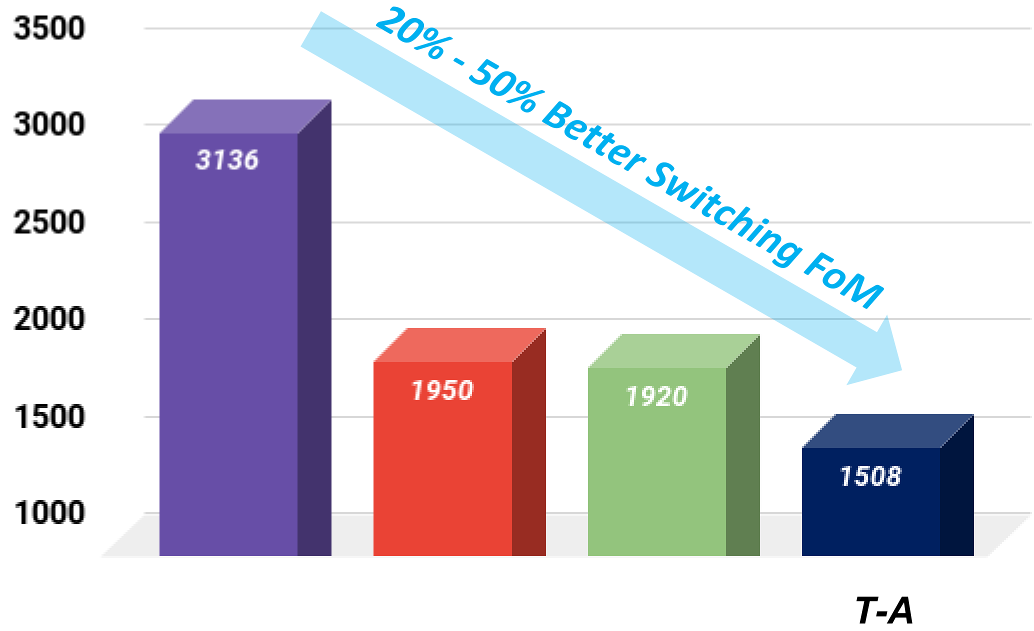
Static Performance *(1200 V)*

On-Resistance vs. Temperature



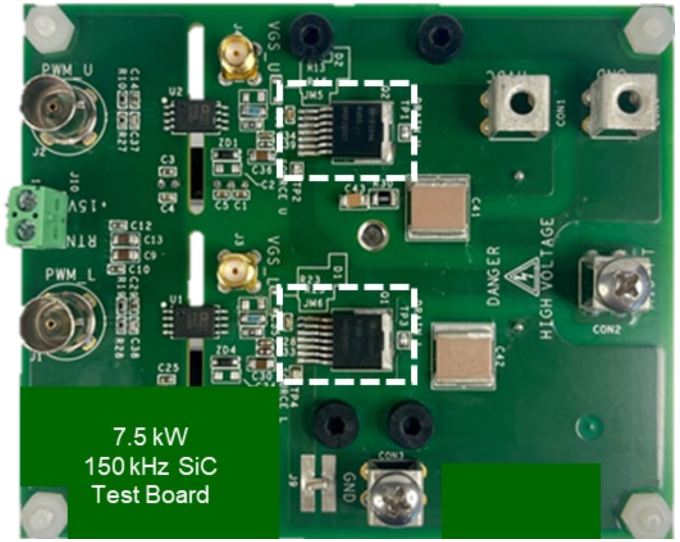
Switching Performance *(1200 V)*

R_{ON} x E_{OSS} at 125°C (mΩ-µJ)



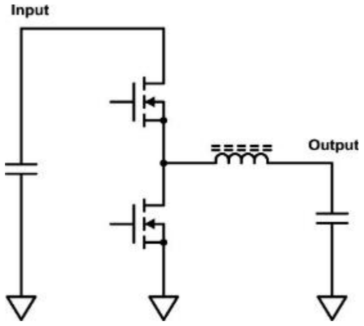
- ❑ ***Tr-assisted planar gate*** offers **10% -18% lower on-resistance** at 175°C
- ❑ **20% - 50% better switching** figure-of-merit
- ❑ Enables lower losses and cooler operation
  - ✓ Better system efficiency
  - ✓ Longer lifetime

Faster, Cooler, Longer Lifetime

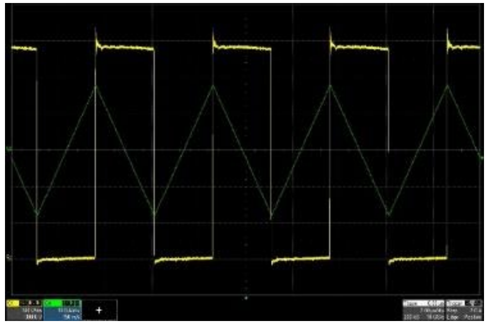


Test Board

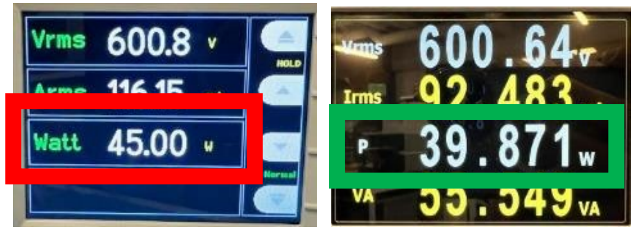
- Trench-assisted planar FET vs. Competitor SiC FET
  - 1,200 V, 40 mΩ, D2pak in half-bridge
  - Represents 7.5 kW DC-DC converter (e.g. data center, EV)
  - 150 kHz switching = ~10x faster than Si IGBT example
- **>80% energy savings (>3,000 kWh/yr)** ***vs Si IGBTs***
  -25°C cooler = 3x longer life ***vs other SiC***
  (reduced maintenance / repair costs)



Test Circuit
(1-phase of 3-phase motor drive)

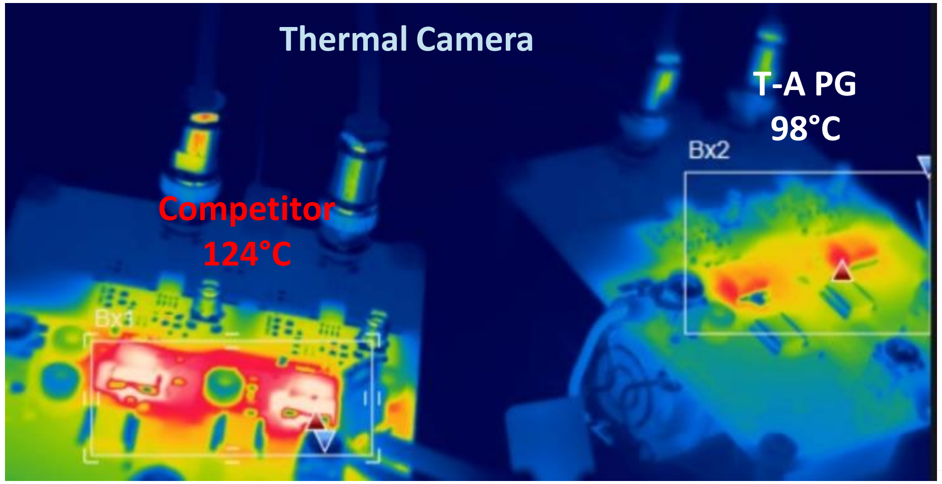


Switching Waveforms
(40 A pk-pk, 20 A turn-off}

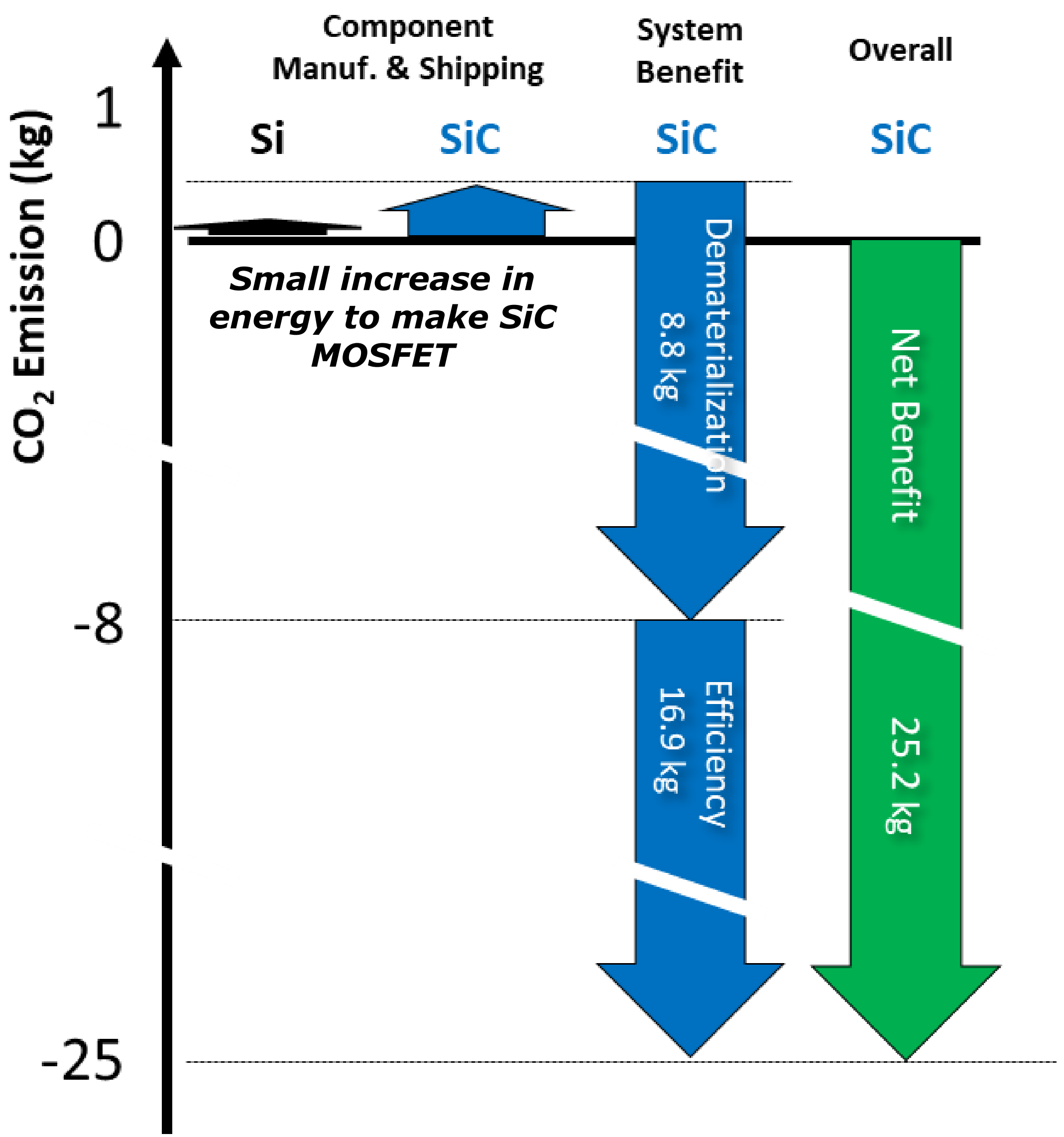


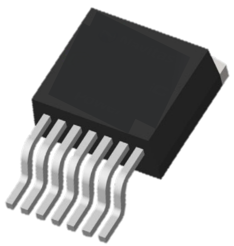
Competitor SiC
45 W system loss

T-A PG
40 W *system* loss
-30% *SiC* loss



Every T-A PG MOSFET Saves Over 25 kg CO_2





Huge benefit in application use

From EV Trucks to EVTOLs: Same Challenges, Same SiC Solutions

Battery Voltages: Archer 800V[1], Lilium 900V[2] Joby 1000V[3]

Require SiC: 1,200V, 1,700V

1) https://archer.com/technologies
2) https://lilium.com/newsroom-detail/first-high-voltage-electrical-harnesses-roll-off-the-line-for-the-all-electric-lilium-jet
3) https://joby-site.cdn.prismic.io/joby-site/5f82ea34-645e-4468-8e3f-14a16e298941_Joby-Charging-GEACS-final.pdf

Thank you for your interest.

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Emerging Applications for Power Electronics