Efficient 400-800V Charging & Conversion with GaNFast™ Power ICs & GeneSiC™ Trench-Assisted Planar-Gate MOSFETs

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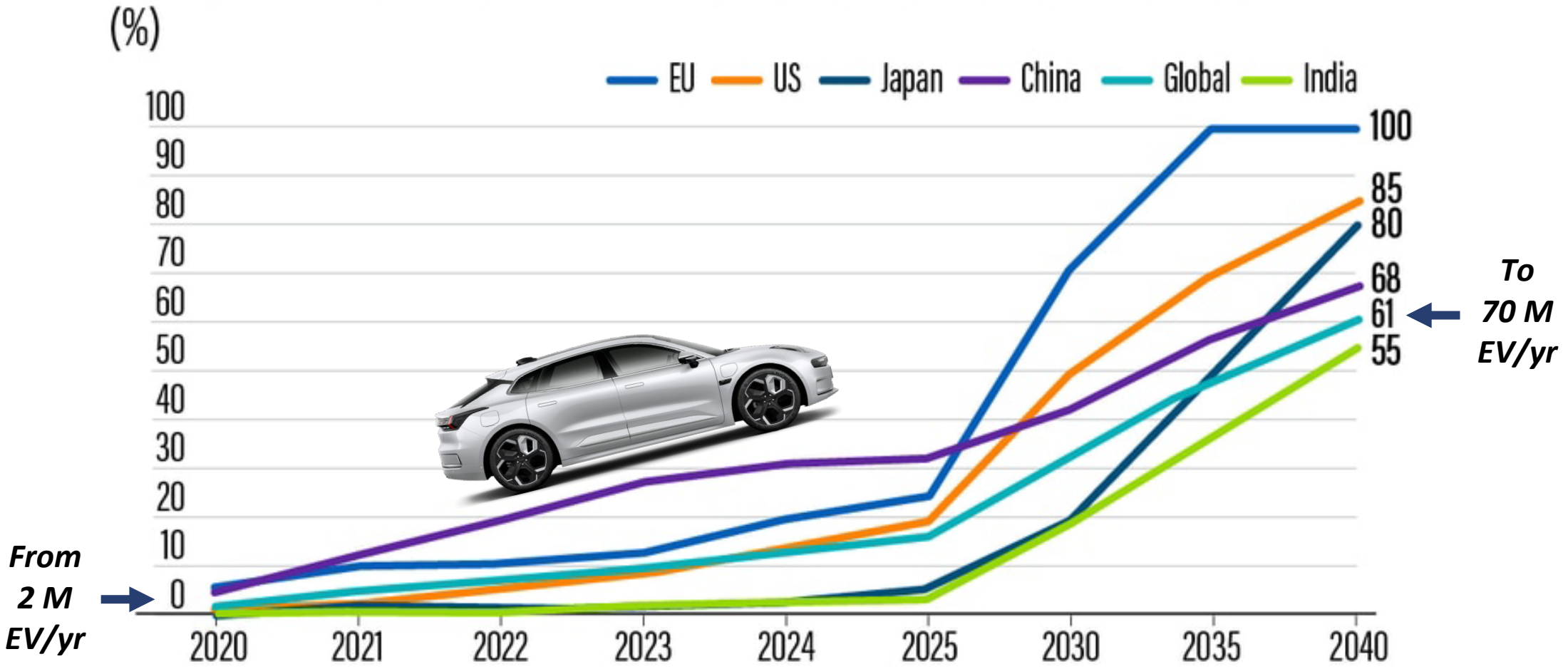
COO/CTO, Co-Founder
March 28th, 2023

Navitas
Energy • Efficiency • Sustainability

Contact: ir@navitassemi.com Information is as of the date specified only.

The Rise of EV



Source: IHS, Global Insight, Goldman Sachs Research, https://www.thenationalnews.com/business/economy/2023/02/13/electric-vehicles-to-account-for-half-of-global-car-sales-by-2035-amid-net-zero-push/

The Rise of EV = The Rise in WBG

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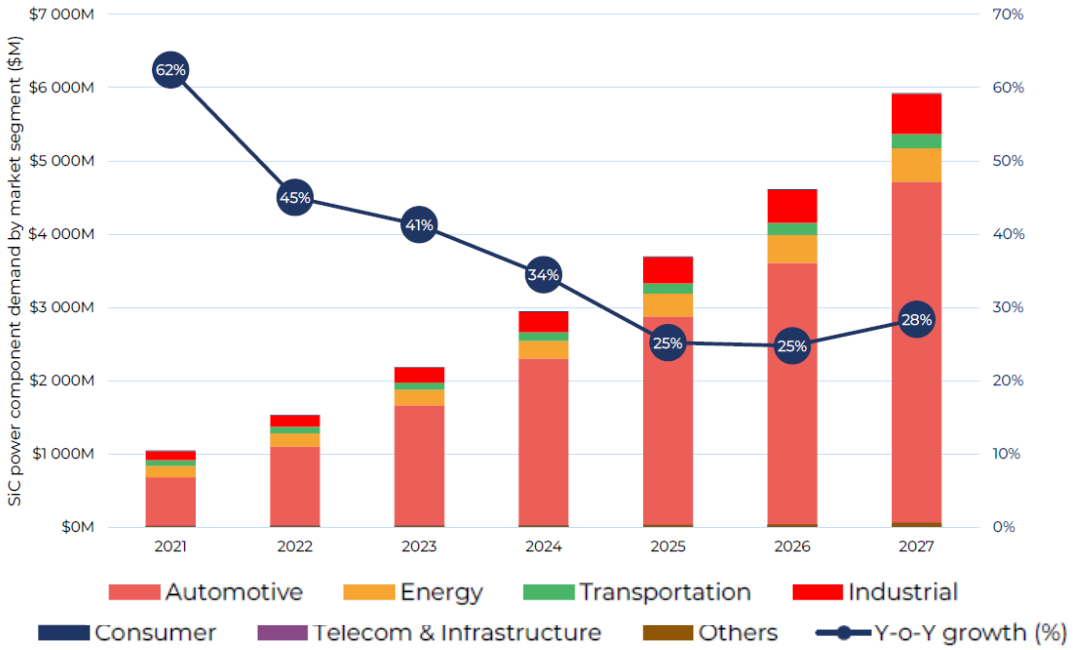
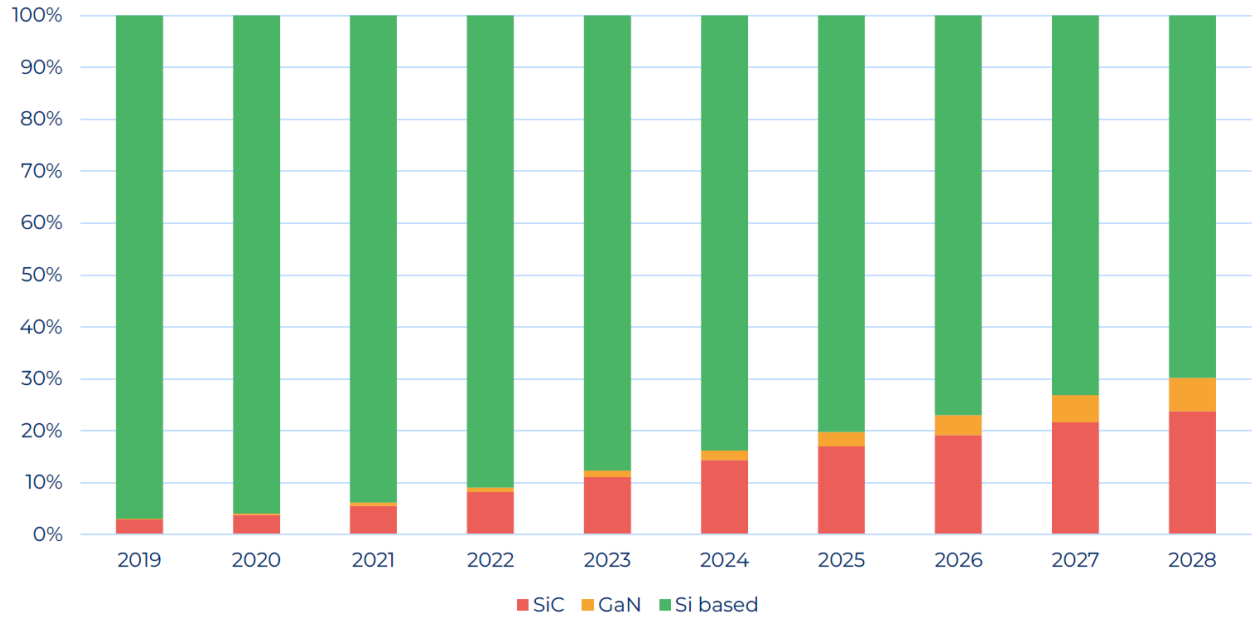
SiC Revenue Forecast
(Yole, Nov'22)



YOLE Intelligence

SiC EV ~$4.6B/yr by 2027

SiC+GaN Share of Market
(Yole, March'22)



YOLE Intelligence

SiC+GaN ~30% by 2028

Life Can Be Unpredictable.

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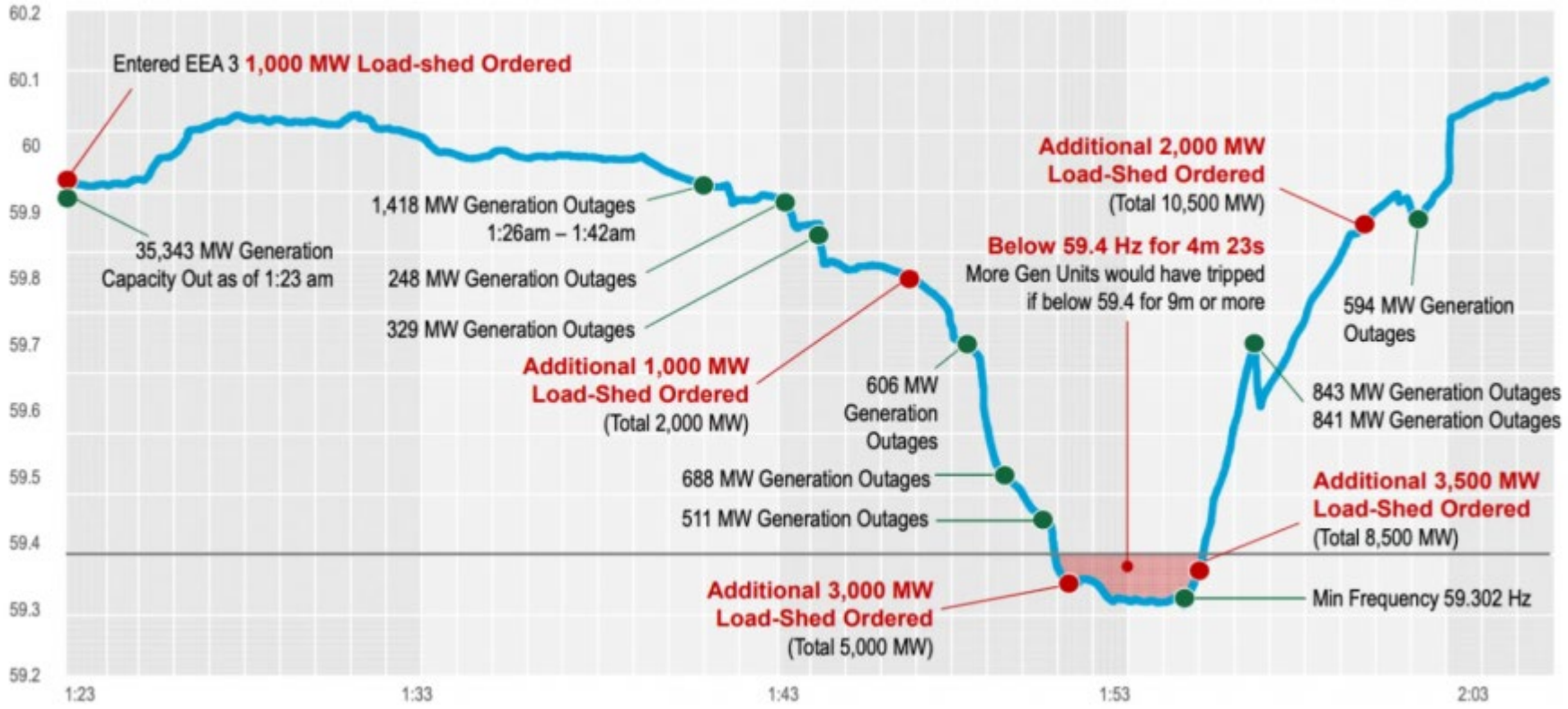
Texas Power Grid, February 21st 2021



Electric Reliability Corporation of Texas (ERCOT) December 2022, link

...and though Solar is a Growing Source of Power

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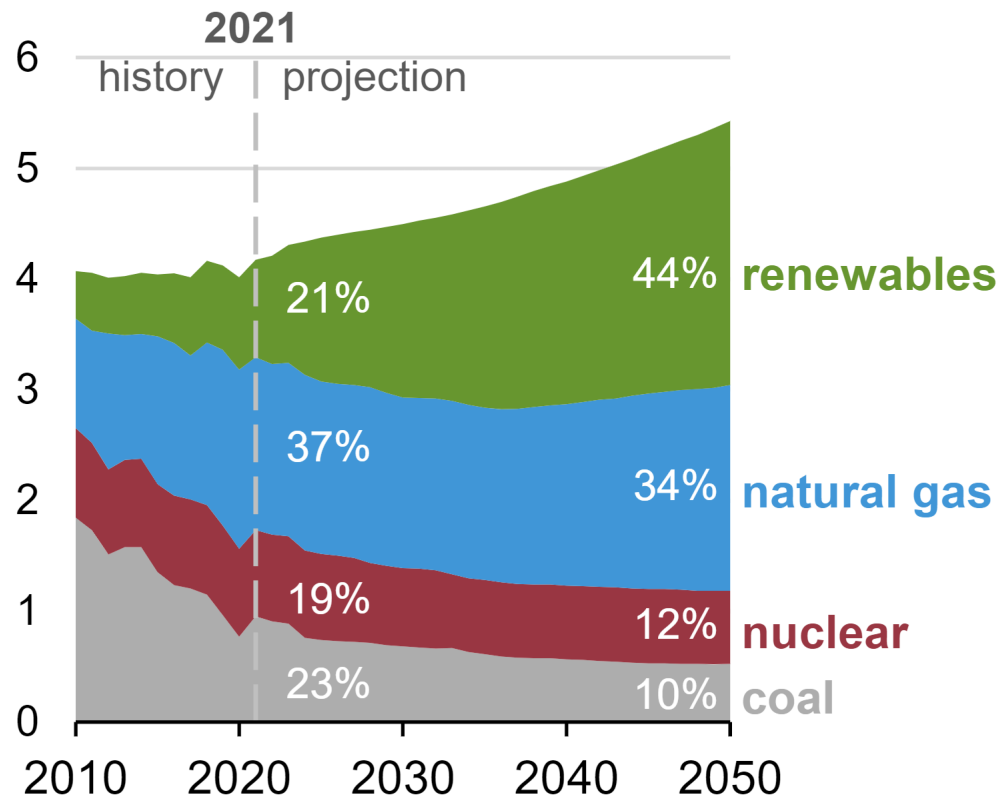
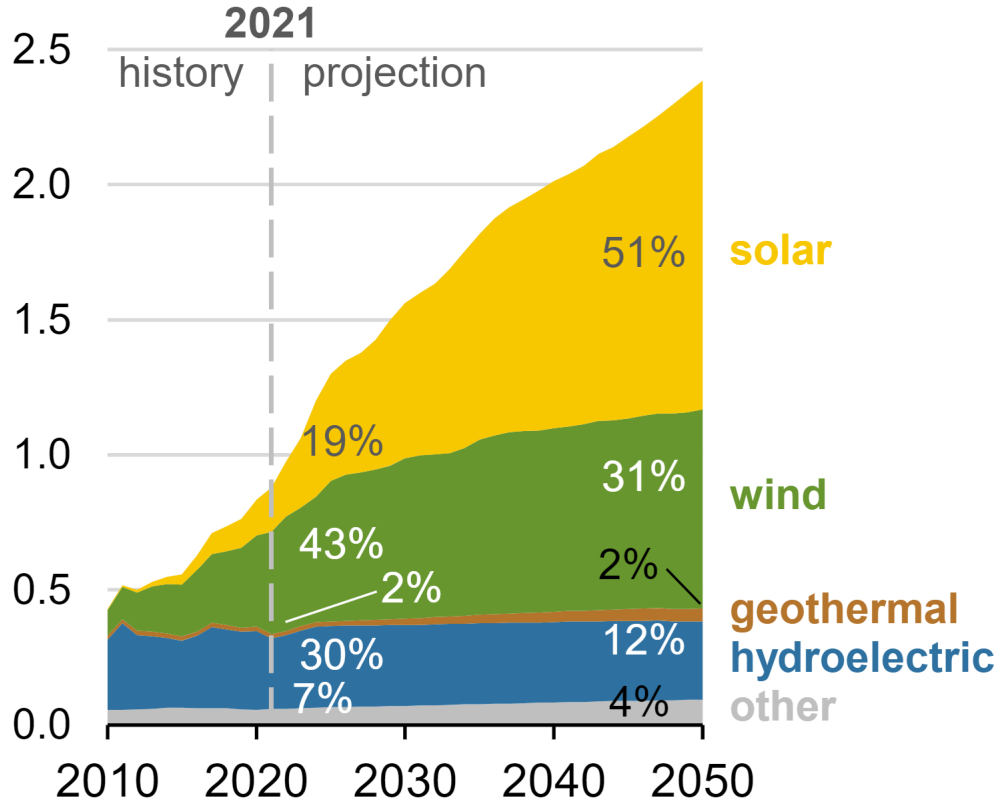
U.S. electricity generation
AEO2022 Reference case
trillion kilowatthours



U.S. renewable electricity generation including end use
trillion kilowatthours

eia



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022* (AEO2022)
Note: Biofuels are both shown separately and are included in petroleum and other liquids.

...Supply & Demand Don't Match

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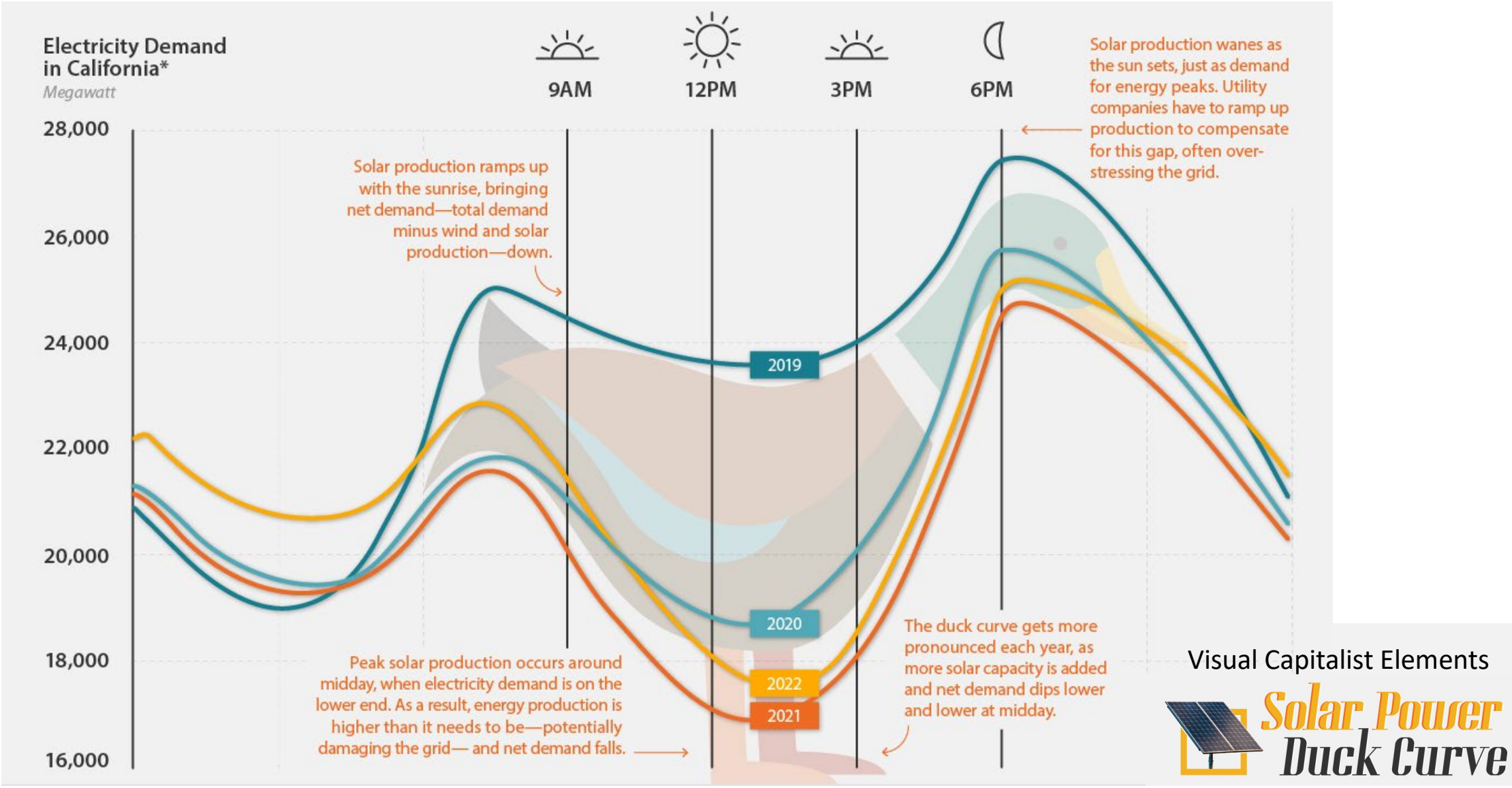

Visual Capitalist Elements

Solar Power Duck Curve

Domestic Micro-Grid with Energy Storage(s)

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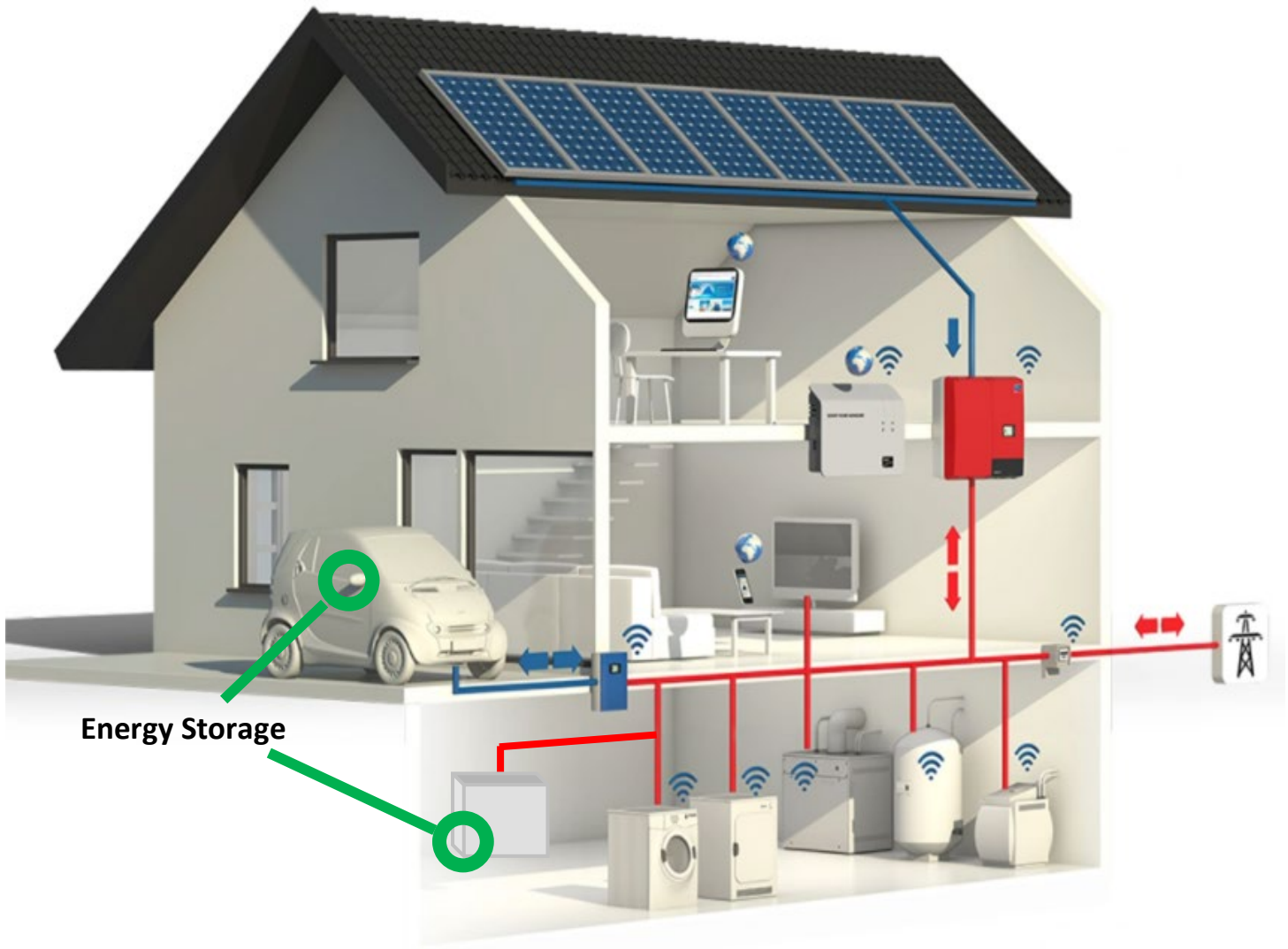


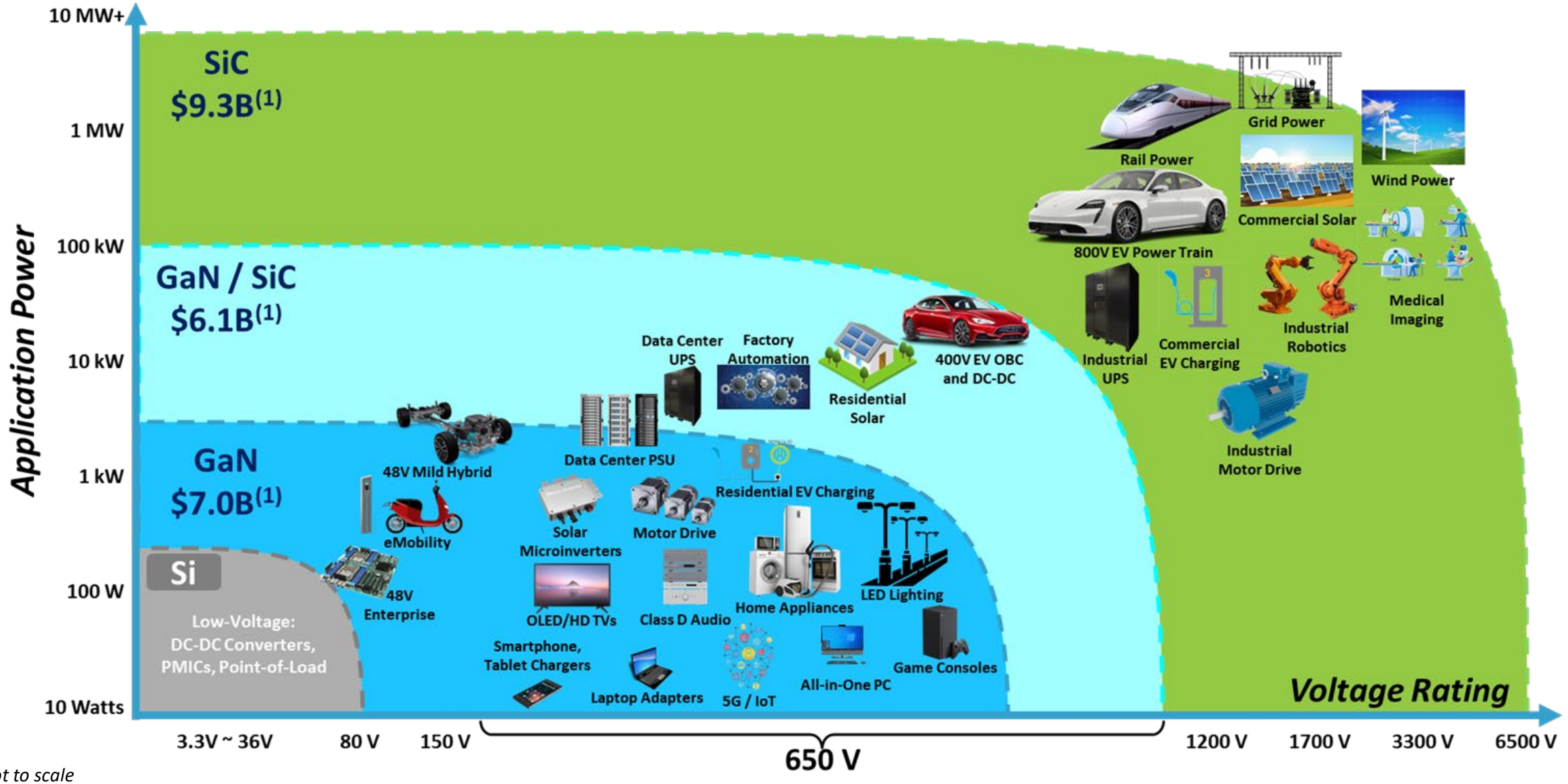
Battery Energy Storage System (BESS)

US storage/panel ‘attach rate’
+1.8x in 18 months

Energy storage available from
- Enphase
- Tesla
- Solaredge
- Toshiba
- GE, etc.

Bi-directional on-board chargers in:
- Nissan Leaf
- Ford F-150 Lightning
- Hyundai Ioniq 5
- Kia EV6
- Mitsubishi Outlander PHEV, etc.

In Context: $22B 'Pure-Play' Market Opportunity[1]



Axes not to scale

1) 2026E potential, Source: Yole, DNV, IRENA, Fraunhofer ISE, IHS, Cisco, Hyperscale, Peer annual reports, Wall Street research.

August 15th, 2022: Navitas Semiconductor, industry-leader in gallium nitride power ICs, acquired GeneSiC Semiconductor, silicon carbide pioneer and industry leader

Navitas: Unique Position in Power Semis

- The only pure-play next-gen power semi company
  - 100% focus on power GaN & SiC (no one else in the world)
  - Leading-edge, industry-leading power GaN & SiC technologies
  - Fastest-growing power GaN & SiC company
- The only semi company certified CarbonNeutral™
  - Highly-efficient carbon footprint; up to 10x lower than Silicon
  - Can address over 2.6 Gtons per year by 2050
- Technology, mgmt team, capability and vision to disrupt $22B power semiconductor industry…
  - Over 300 years senior mgmt experience in power semis
  - Over 185 patents with most advanced GaN + SiC
  - Capability to impact and accelerate every clean energy segment

GaN Integration Drives Speed, Efficiency, Stability

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- *33 components*
- *250 mm² footprint*
- *External HB driver HVIC*
- *External HV bootstrap*
- *2x HV bypass diodes*
- *2x external gate drives*
- *Exposed gates*

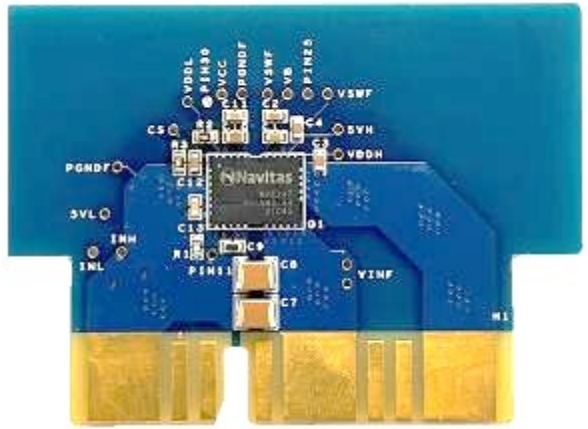
Discrete GaN Half-Bridge

61% fewer components

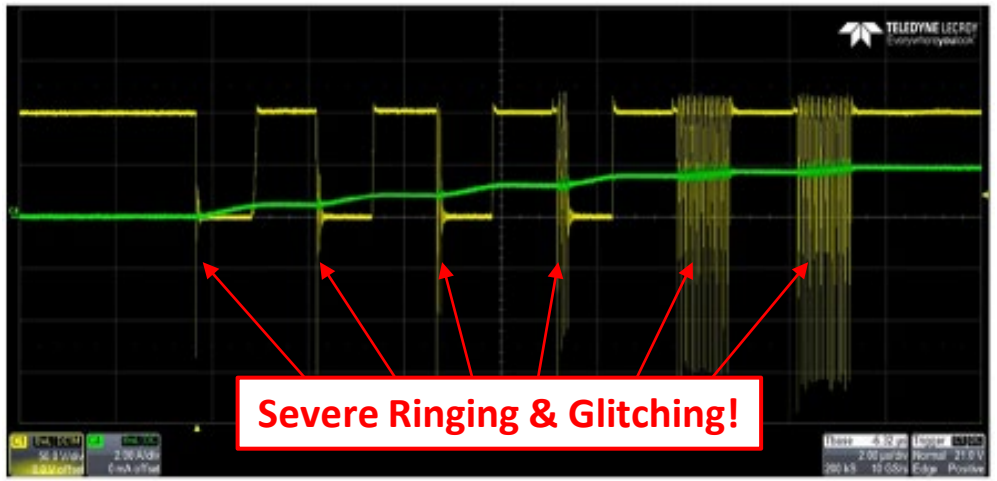
64% smaller footprint

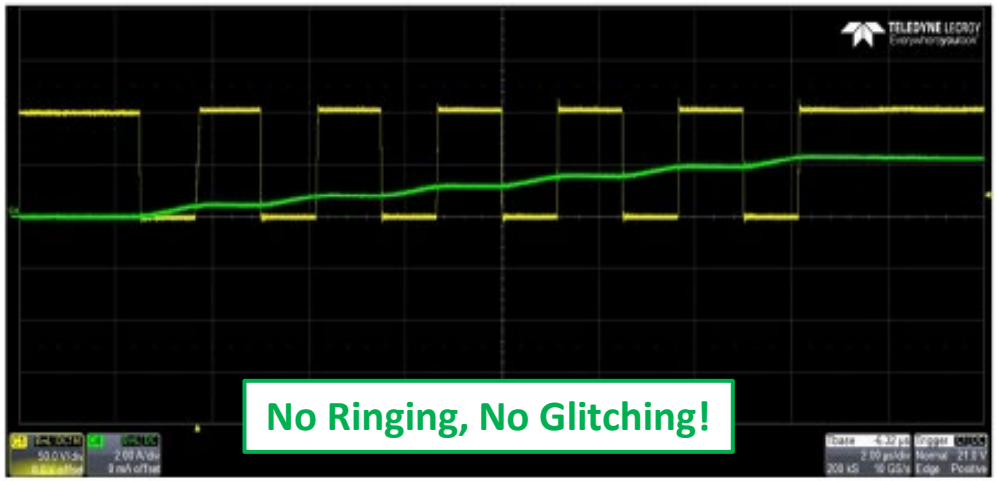
Complete integration

GaNSense Half-Bridge IC



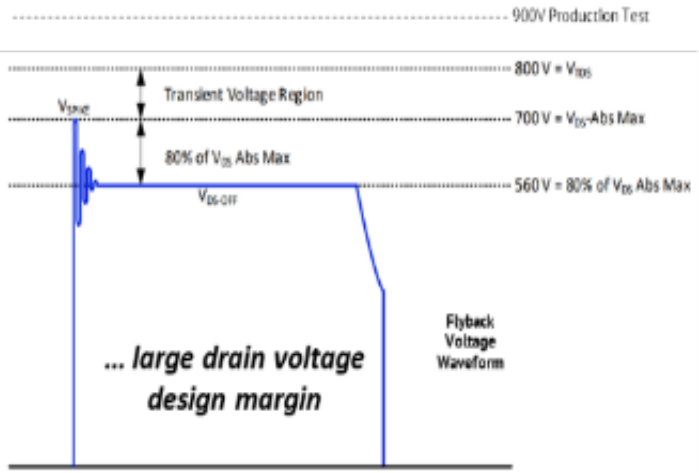
- ✓ *13 components*
- ✓ *90 mm² footprint*
- ✓ *Level shifters*
- ✓ *Bootstrap*
- ✓ *Gate drivers*
- ✓ *No exposed gates*





GaN Reliability: Driver Integration is Key

- ***Design*** for Reliability
  - Integrated drive, sensing and protection
  - Component reliability, and ***system*** reliability

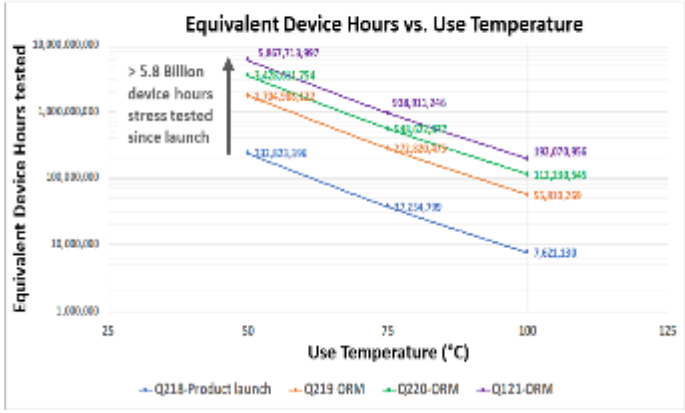


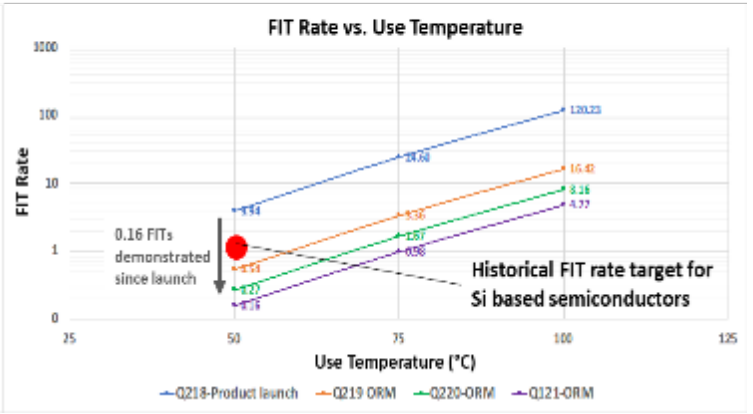
- ***Testing*** for Reliability:
  - Proprietary production test methods
  - GaN ICs tested 400% (multi-temp, high-frequency)

- ***Characterization*** for Reliability
  - Exhaustive, proactive, and unique Navitas reliability program
  - 5.8 B equivalent device hours tested(1)
  - Proprietary, highly-accelerated Op-Life, plus JEDEC, plus ELFR monitoring
  - Founder member of JEDEC JC70.1

Reliability Statistics

Calculated for High Line condition using HTOL (ZVS) results





(1) As of September 2022

Taking GaN Integration to the Next Level

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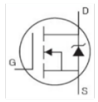
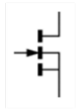
Silicon FET



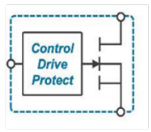
- Old, slow
- F_{SW} < 100 kHz

Discrete GaN



- External gate drive
- dV/dt sensitivity
- Layout sensitivity

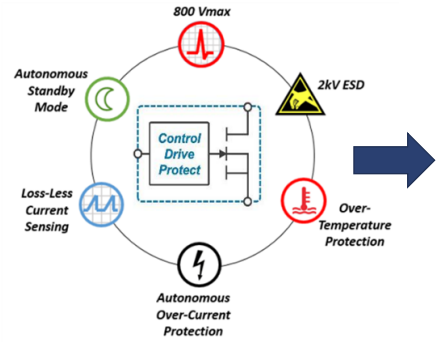
GaNFast™



Power, Drive and Protection

- ✓ Internal Gate
- ✓ Integrated Gate Drive
- ✓ Proven Robustness

GaNSense™

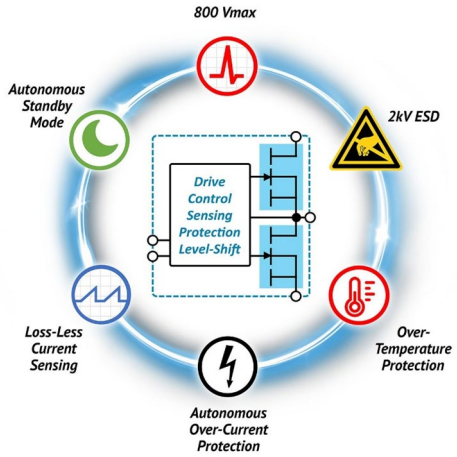


Sensing, Control

GaNFast plus:

- ✓ Autonomous Standby
- ✓ Autonomous Protection
- ✓ Loss-less Current Sensing

GaNSense Half-Bridge

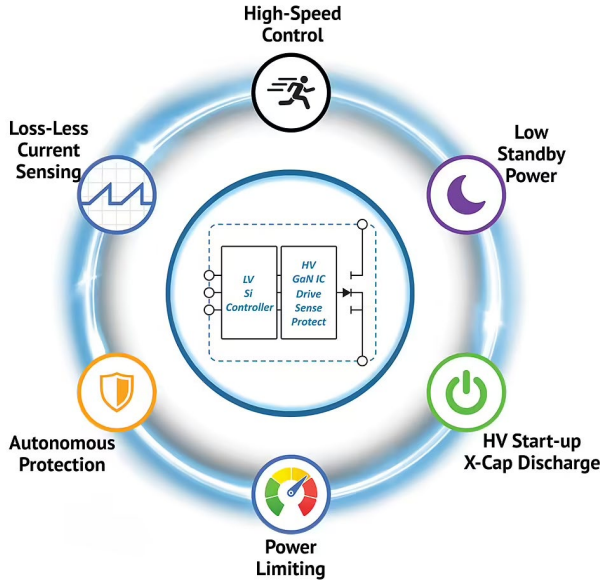


Full Half-Bridge integration

GaNSense plus:

- ✓ Highest integration
- ✓ integrated HS/LS FETs + isolation

GaNSense Control



Complete integration of GaNSense + Si Controller

GaNSense plus:

- ✓ Integrated HFQR Controller
- ✓ Fully integrated IC solution

GaNSense™ Control: Ultimate Integration

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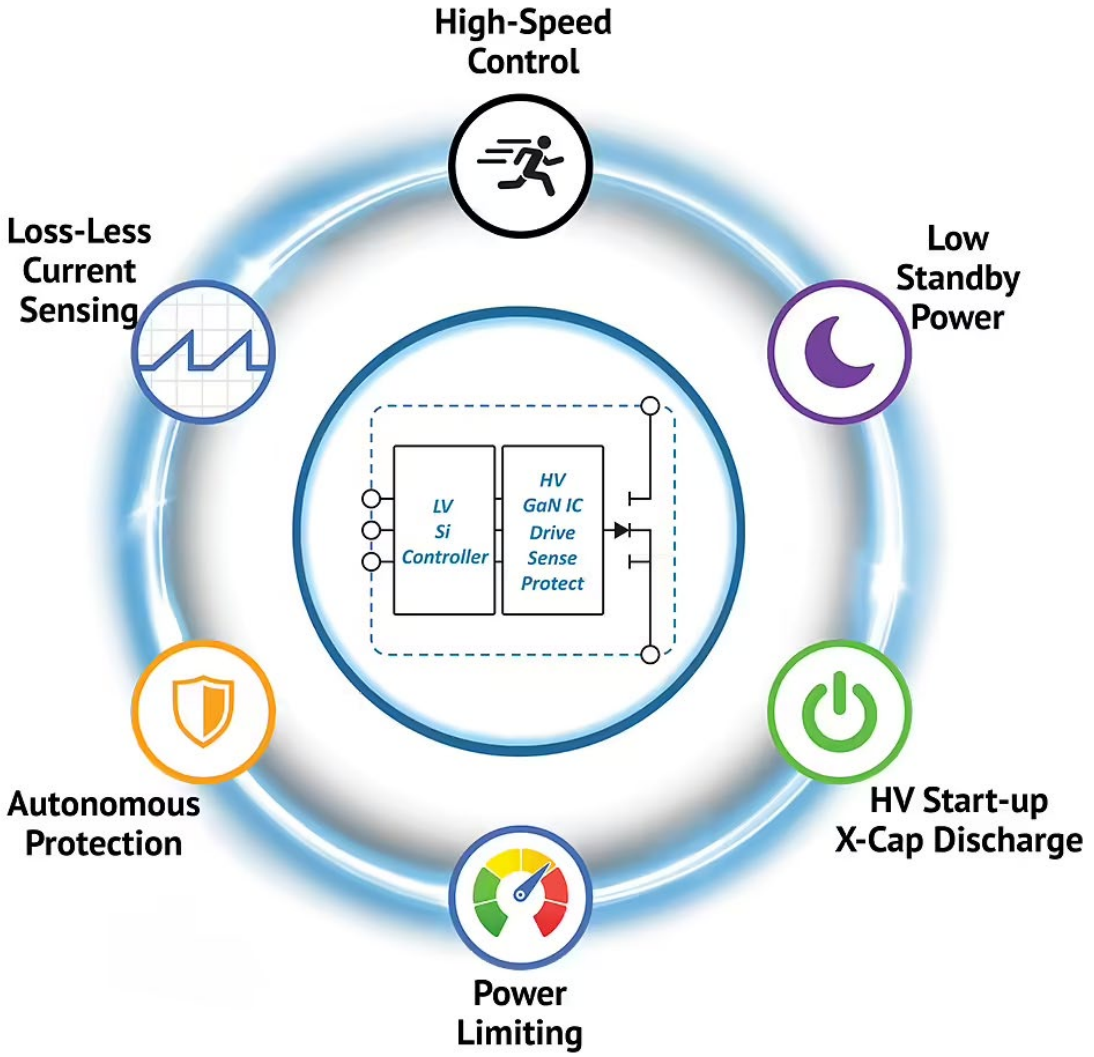


75,000,000 Shipped

Electrify Our World™

Navitas

Let's go GaNFast™


Navitas
20-YEAR
WARRANTY
GaNFast™
Navitas
GaNFast™
Power IC

GeneSiC™

Patented Trench-Assisted Planar SiC MOSFETs

Navitas

Up to 6.5 kV

Largest range of SiC FETs & diodes
(650 V to 6.5 kV)

Fast Switching

Highest efficiency hard-switch, soft-switch
(Lowest E_{ON}, E_{OFF}, E_{ZVS} losses)

Cool Operation

Lowest $R_{DS(ON)}$ at high temperature
(25% lower than industry typical)

Cool.
Fast.
Rugged.

100%-Tested Robust Avalanche

Highest published capability to handle excess energy in fault condition

Long Short-Circuit Withstand Time

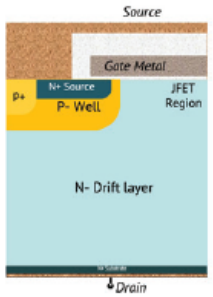
World-class survival duration in fault condition

High-Power Paralleling

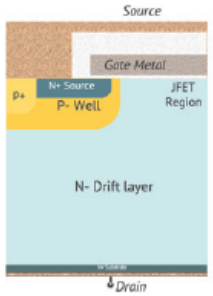
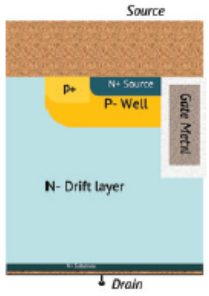
Matching currents (Stable V_{TH})

Based on Navitas testing of 1200V SiC MOSFETs vs. competitor products

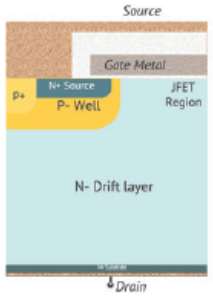
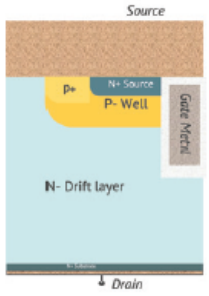
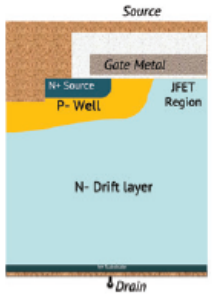
The Planar Problem

	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})

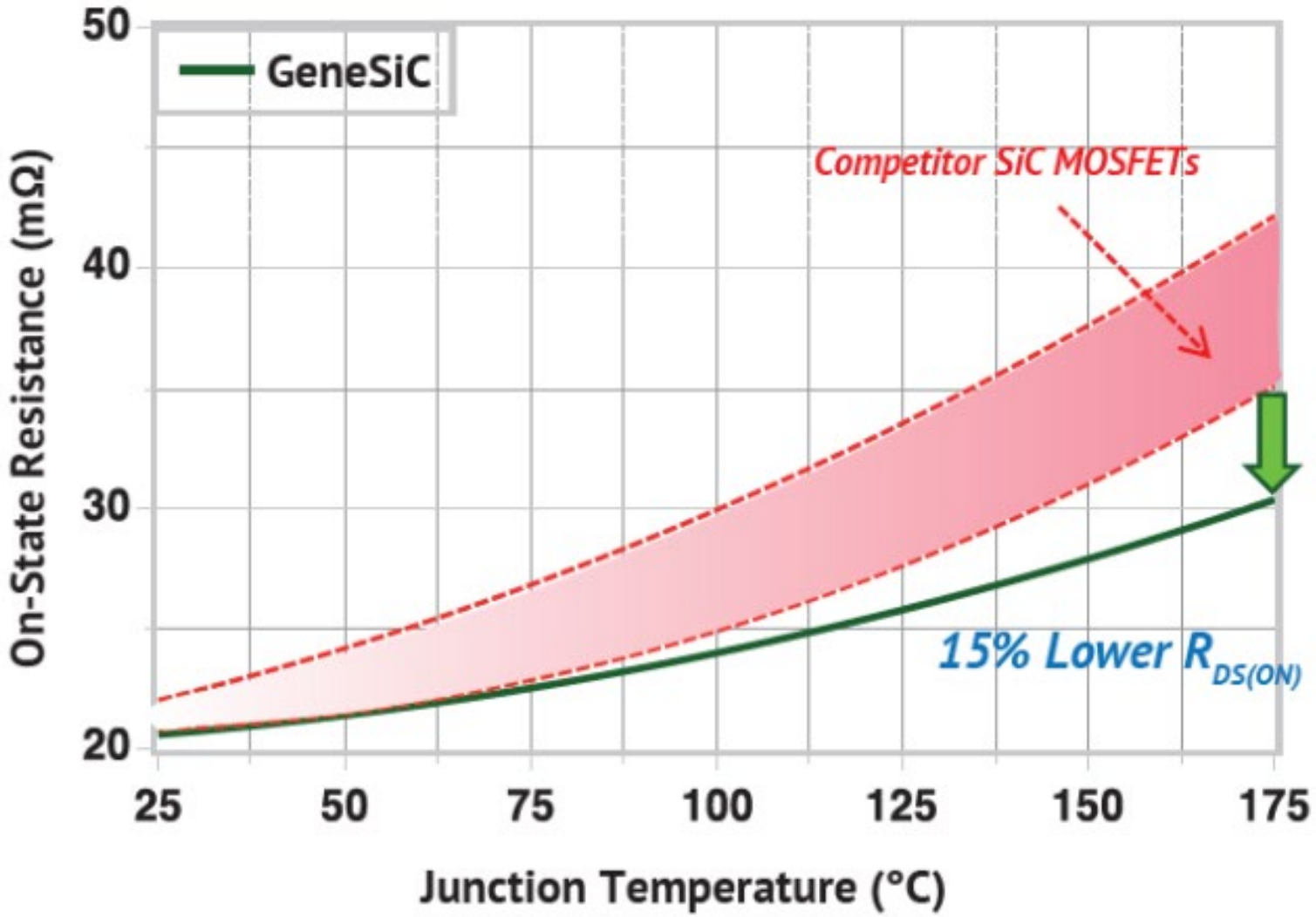
The Trouble with Trench

	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	GeneSiC
			
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})

Efficient at High Temperatures



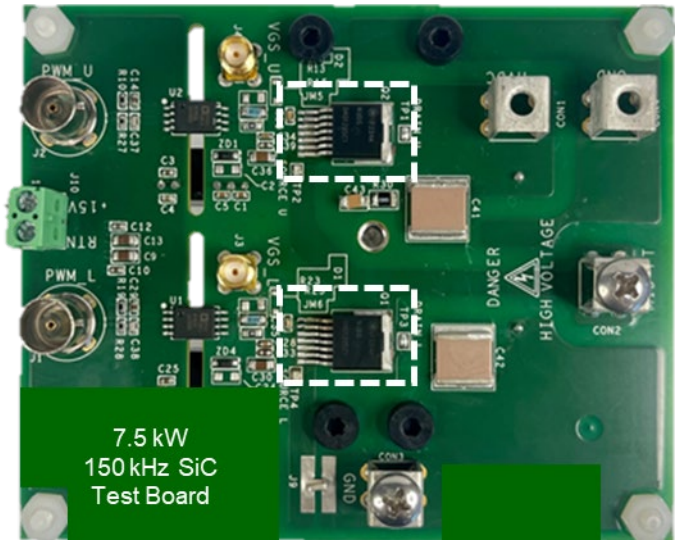
Best High-Speed, High-Temp Performance

Supplier	Resistance		Energy Loss				Figure-of-Merit *(Low number is better)*	
	$R_{DS(ON)}$ @ 25°C (mΩ)	$R_{DS(ON)}$ @ 175°C (mΩ)	E_{ON} @ 25A (µJ)	E_{OFF} @ 35A (µJ)	E_{OSS} @ 800V (µJ)	E_{ZVS} E_{OFF}-E_{OSS} (µJ)	**Hard-Switching** R_{DS} @ 175°C x (E_{ON}+E_{OFF}) (Ω-µJ)	**Soft-Switching** R_{DS} @ 175°C x E_{ZVS} (Ω-µJ)
GeneSiC	40	57	600	80	34	46	**38.8**	**2.6**
#2	40	68	600	80	40	40	46.2	2.7
#3	40	80	850	390	35	355	99.2	28.4
#4	40	71	550	150	35	115	49.7	8.2
#5	45	85	520	65	29	36	49.7	3.1

Lowest power loss at high temp, high speed = ***Highest Efficiency, Energy Savings Small Size, Light Weight, Low System Costs!***

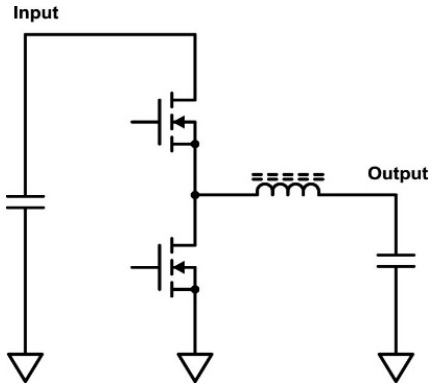
Reference 1,200V SiC FET, 40-45mΩ devices; GeneSiC = Trench-Assisted Planar G3R40MT12J; based on Navitas test result & competitive data sheet parameters.

Faster, Cooler, Longer Lifetime

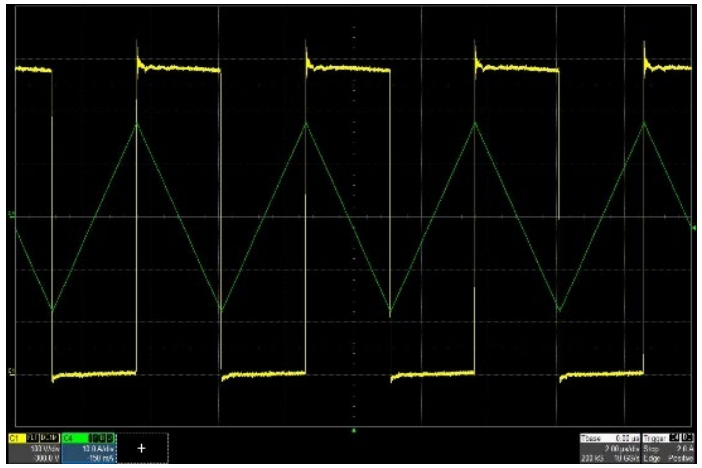


Test Board

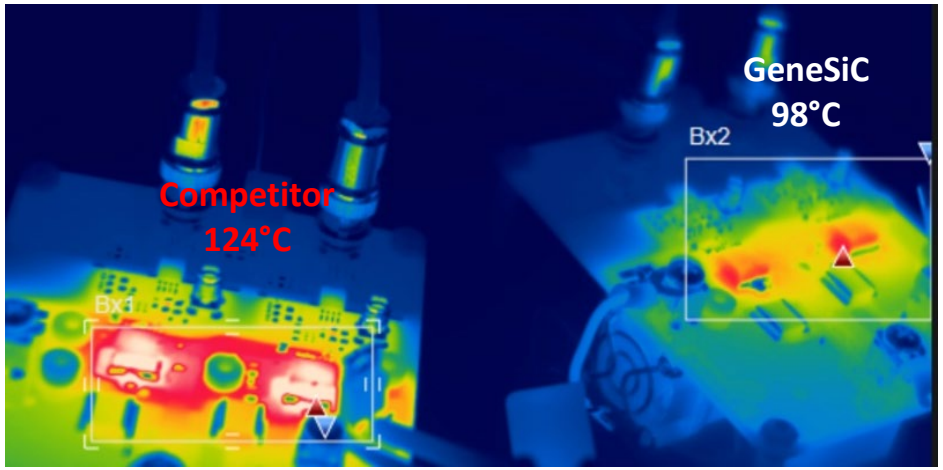
- GeneSiC trench-assisted planar FET vs. Competitor SiC FET
  - 1,200 V, 40 mΩ, D2pak in half-bridge
  - Represents 7.5 kW DC-DC converter (e.g. data center, EV)
  - 150 kHz switching = ~10x faster than Si IGBT example
- GeneSiC: **>80% energy savings (>3,000 kWh/yr) *vs* *Si IGBTs***
  -25°C cooler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

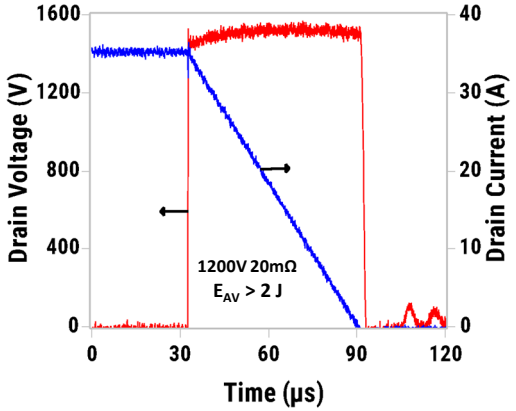


Thermal Camera

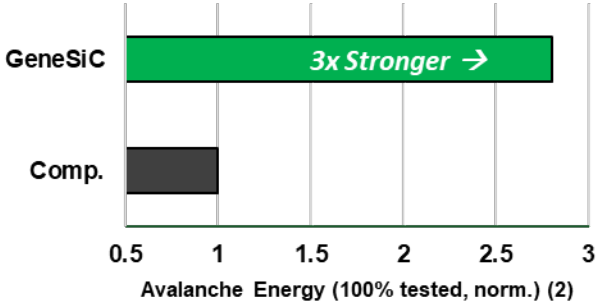
High Quality, High Reliability

100%-Tested Avalanche

Highest published capability to handle excess energy in fault condition

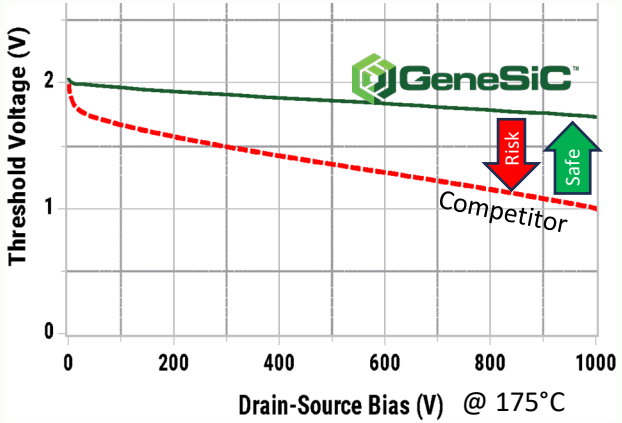


Critical in applications like motor drives to withstand unclamped inductive load (UIL) energy dump in situations like motor open-circuit (O.C.)



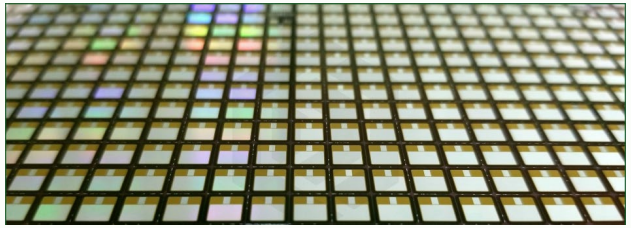
High Power Paralleling

Matching currents
(Stable V_{TH})



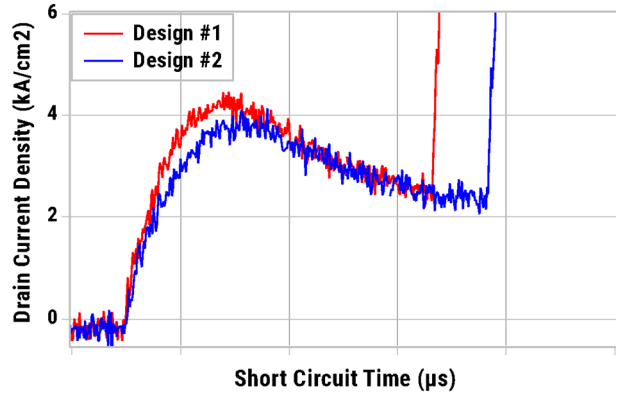
Competitor products allow threshold voltage to drop under high voltage, creating risk of turn-on error

GeneSiC packaged and bare-die FETs can be paralleled reliably for high-power applications

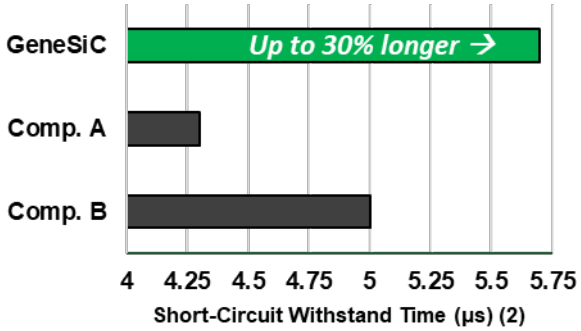


Long Short-Circuit Withstand Time

World-class survival duration
in fault condition

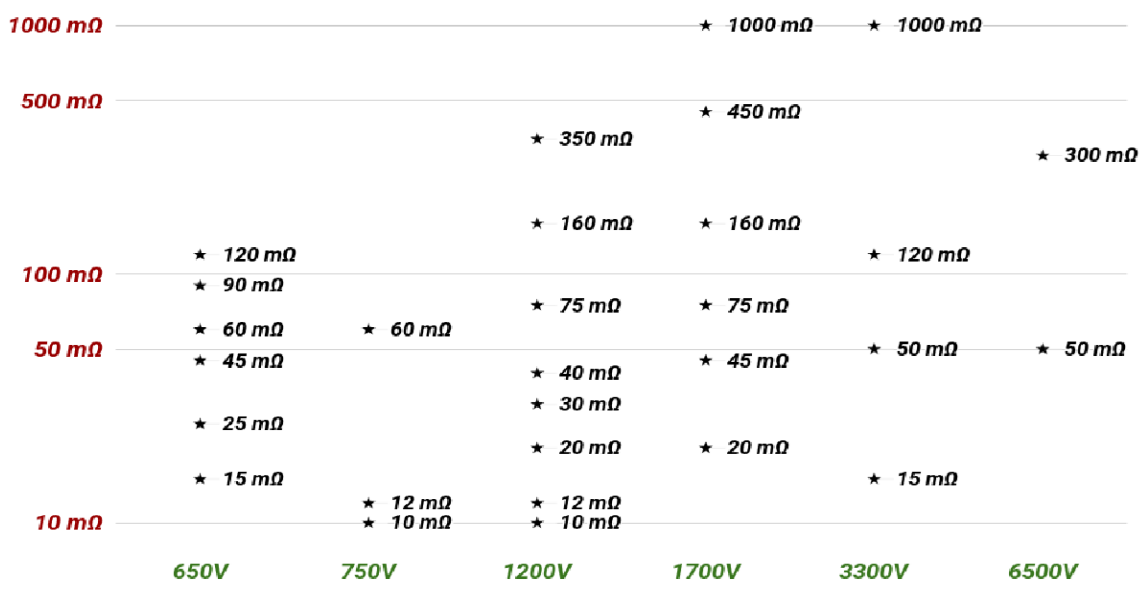


Critical to prevent failures like motor short circuit where the FET faces full voltage (V_{DD}) in ON-state.



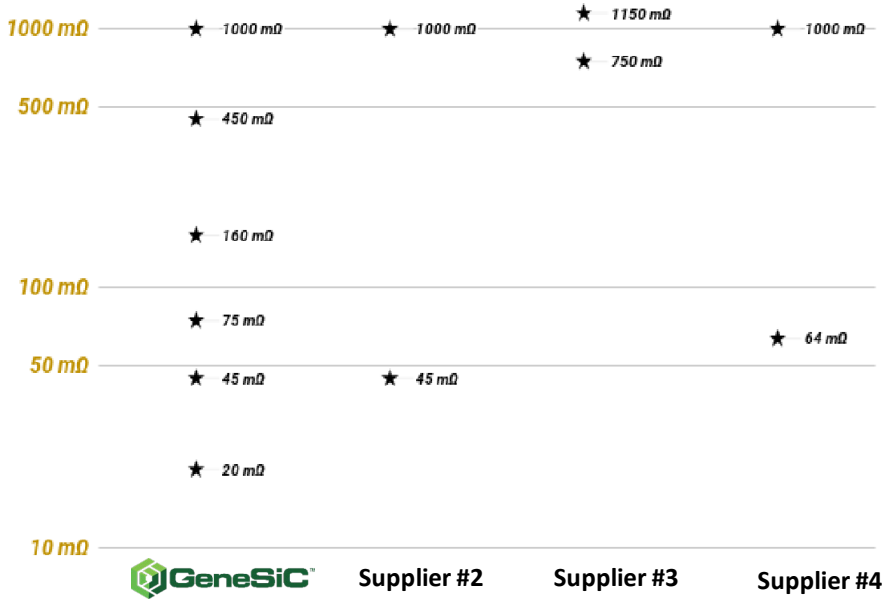
Broadest SiC FET Portfolio[1]

GeneSiC 650–6,500V Trench-Assisted Planar SiC FETs



- 50+ SiC MOSFETs, array of standard packages
- Only supplier with 650V to 6,500V SiC MOSFETs

GeneSiC Most 1,700V SiC FETs



- Broadest industry offering for 1700V SiC MOSFETs

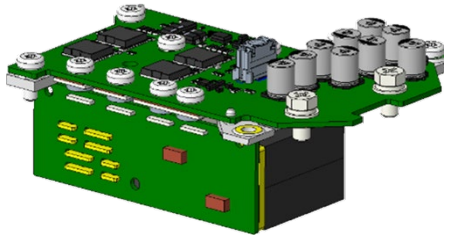
1) based on GeneSiC voltage range of production released SiC MOSFETs compared to all publicly identified voltage ranges of other SiC suppliers.

Navitas System Design Centers

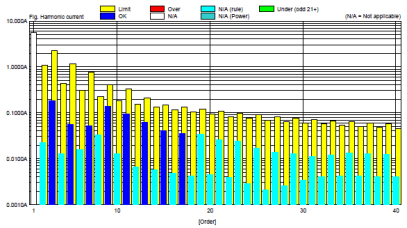
Develop *prototype* data center power supplies & EV powertrain systems, Improve component performance, and establish industry-best benchmarks

Systems

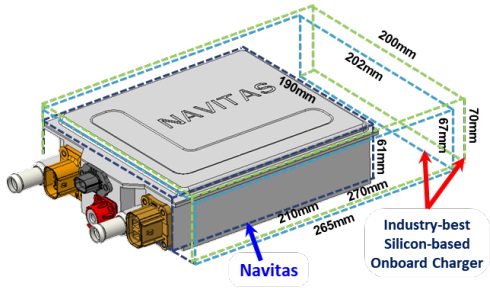
Design for Hi-F_{SW}, Hi-Efficiency, Low-Cost



Testing to enable accelerated Design-IN



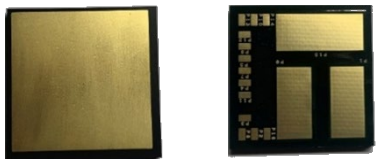
Design-IN assistance for key customers



Customer Revenue Ramp

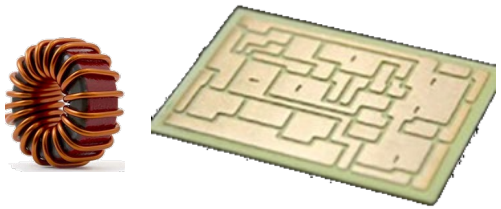
Components

Products & Packages design feedback

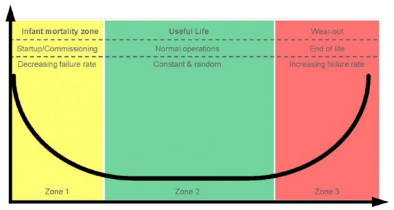


Top Bottom

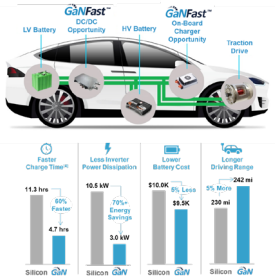
Enable low-cost, quality Ecosystem



Lifetime Reliability system-level testing



Establish Benchmarks

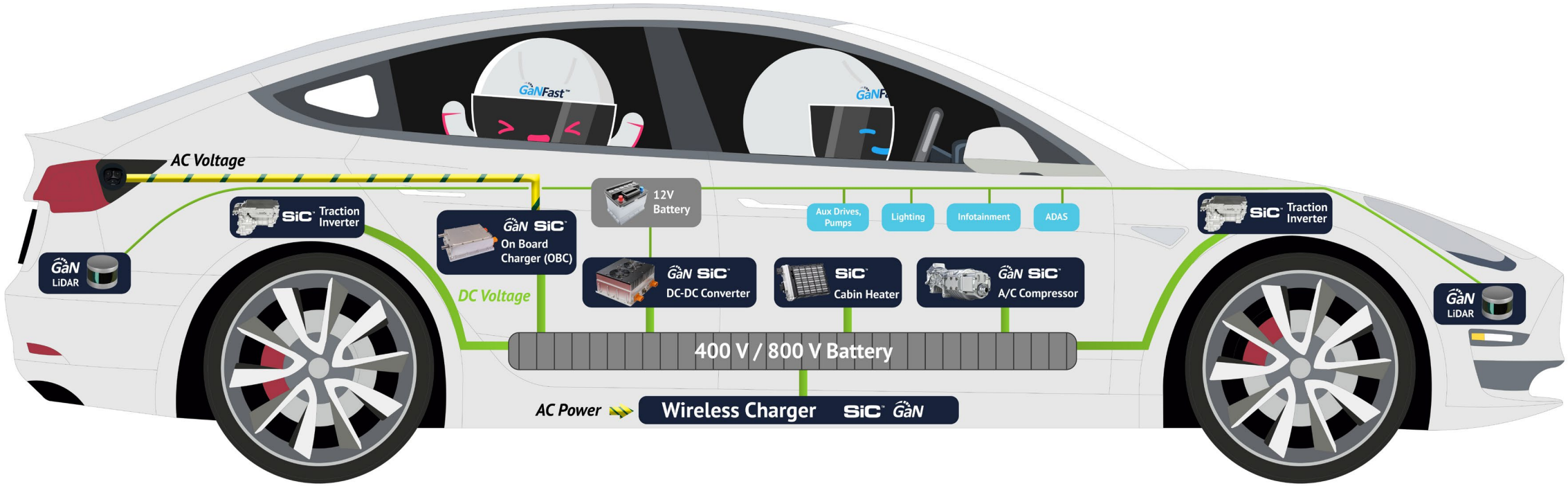


EV: On-Board

$12B/yr Potential for GaN/SiC by 2030(1)

- ✓ OBC > $38
- ✓ DC-DC > $12
- • Traction drive >$286
- • **Total: >$330 per EV = $10.1B**

…and >$1.9B in road-side chargers



Note: Assumes 150 kW traction inverter, 100 kWh battery, $100/kWh battery cost and typical 230 mile range.

(1) Estimate 2030, 30M EV/yr, based on DNV and Navitas analysis
(2) Based on BCG Research, Yole Research and Navitas analysis.

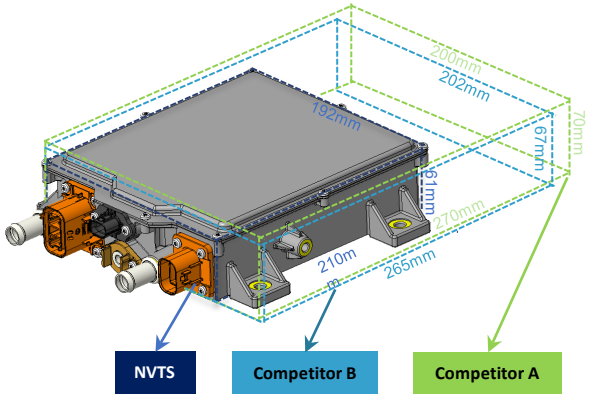
6.6kW OBC/LDC Combo (GaN only & GaN/SiC)

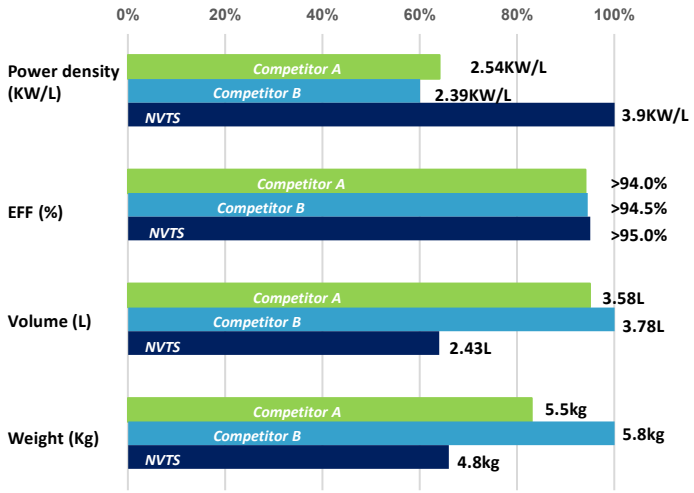
- **GaN/GaN+SiC based 6.6 kW OBC+3.0 kW DC-DC Combo**

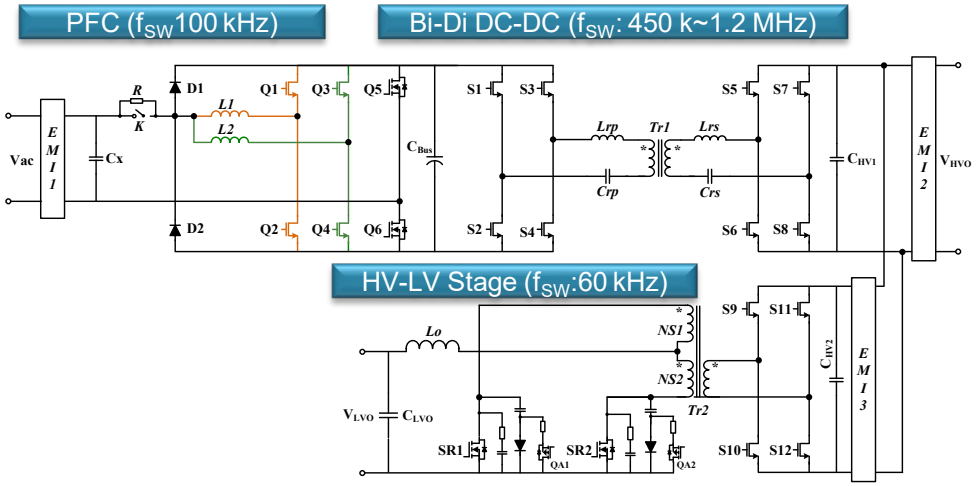
✓ Bi-6.6 kW OBC
- AC Voltage: 90 ~ 265 V_{AC} / up to 32 A
- DC Voltage: **470~860 V, 500~860 V full load**
- Power: 6.6 kW charge, 6.0 kVA discharge
- Efficiency : > 95.0% @ full load

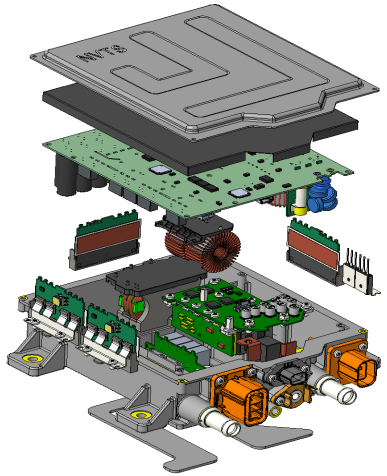
✓ 3.0 kW DC-DC
- LV DC Voltage: 9~16 V

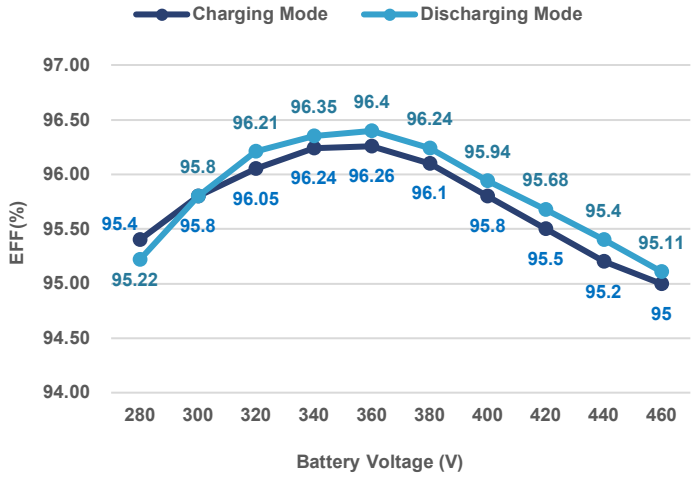
✓ Dimension: 210 x 192 x 61 mm (<2.5 L)
✓ Cooling: -40~65 ˚C liquid-cooled
✓ Others: IP 67, CAN interface





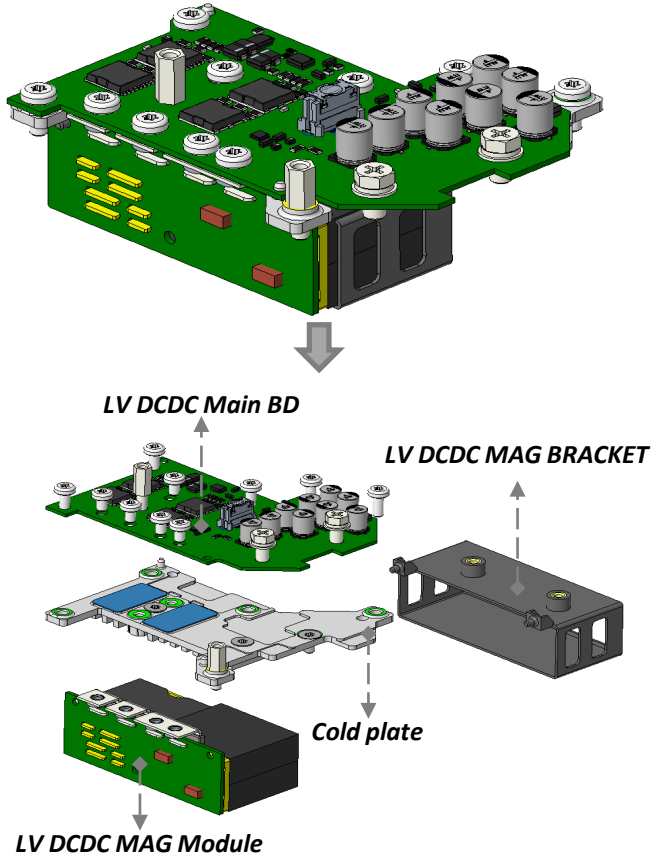


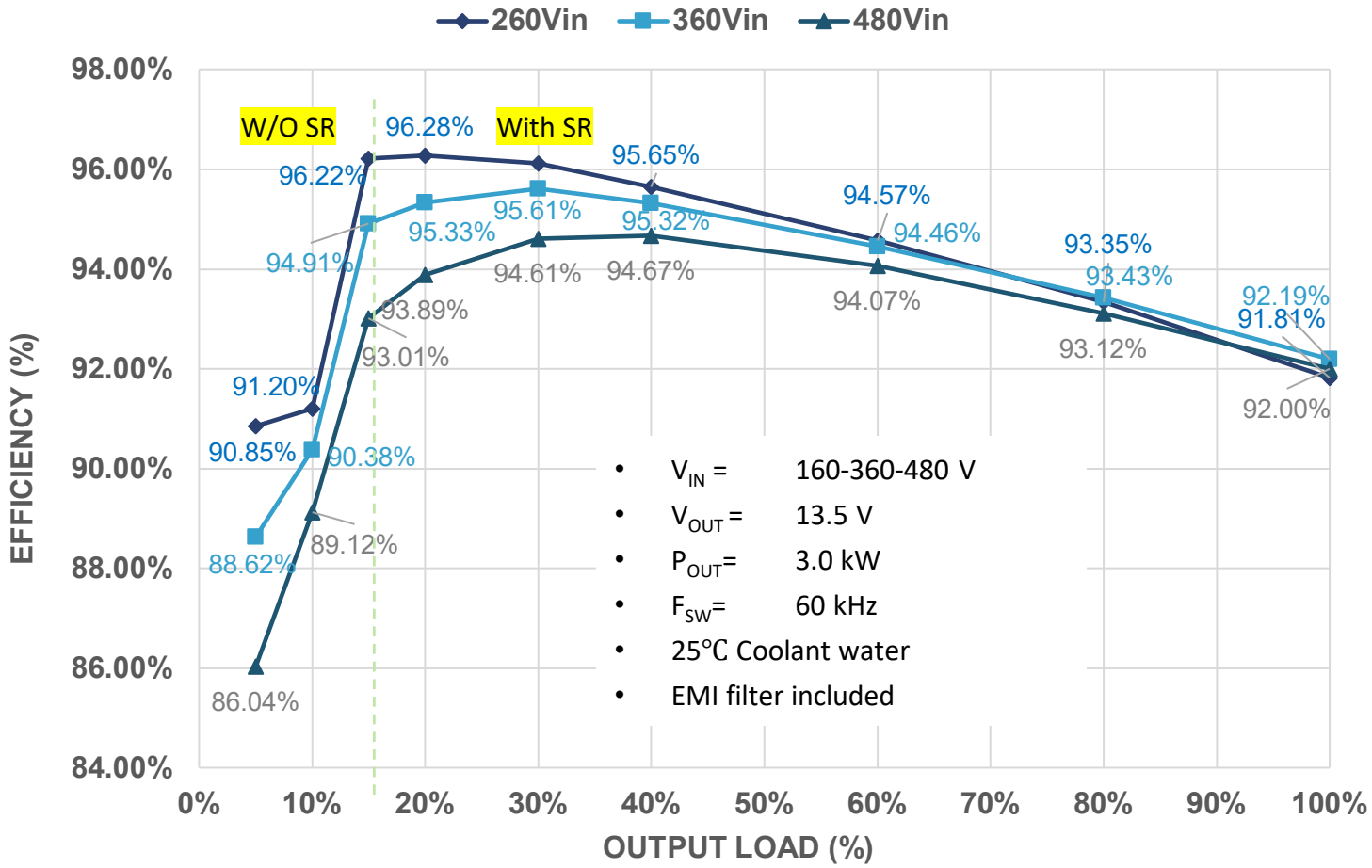




3 kW LDC Efficiency

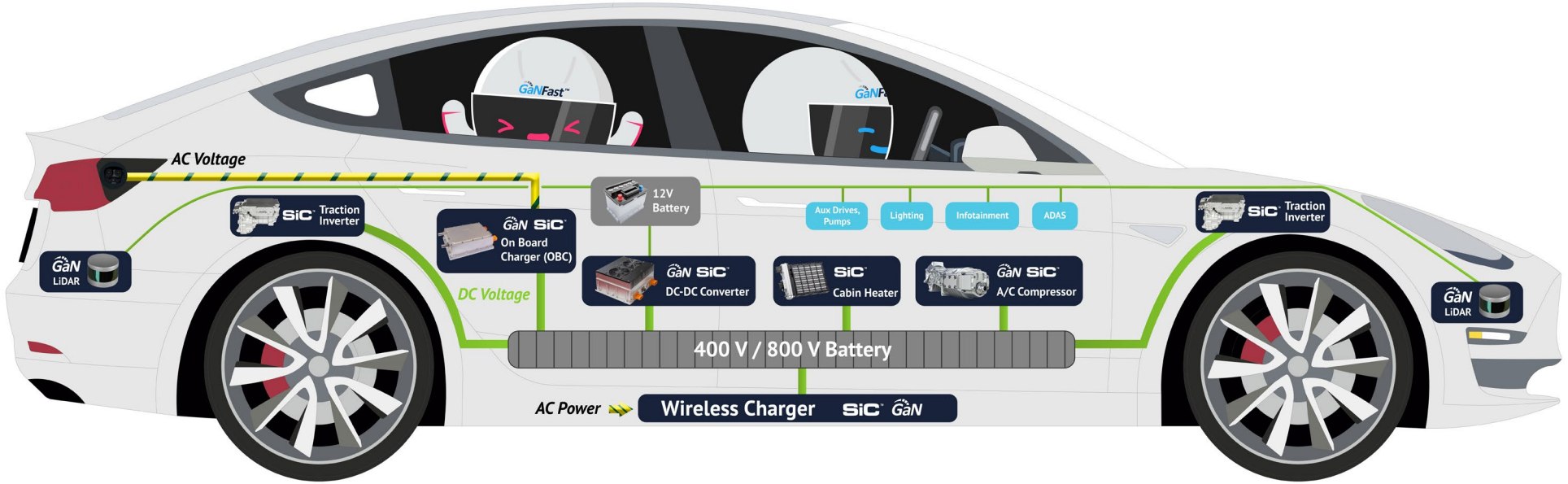
- Exploded 3D View of LV DC-DC Assembly





EV: Roadside

- *Level-3 ultra-fast chargers, up to 350 kW*
- *New architectures increased working bus voltage from 1,000 to 1,500V*
  - *Increase power density*
  - *Simplify designs*
  - *Improve efficiency, reliability and system cost*
- *1,500V bus needs up to 3,300V SiC device capability, to cover main and auxiliary power*



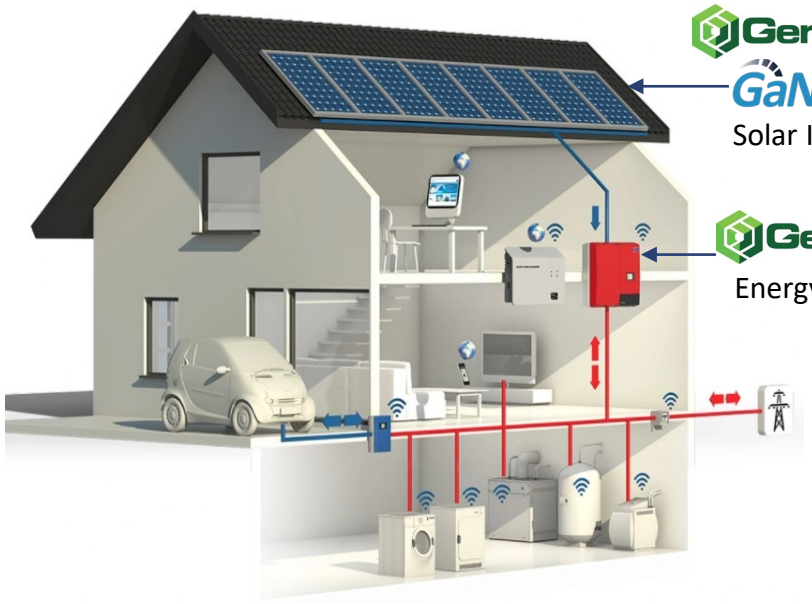
"10-80% charge in only 18 minutes!"(1)

(1) Level 3 800V 350 kW DC charger 10-80% in 18 minutes for Genesis GV70 SUV


ZEEKR
VREMT
ZEEKR VREMT - Navitas Semiconductor
Next-Generation Power Semiconductor Joint Lab
Navitas
Navitas
GaNFast
Power IC
Navitas
GeneSiC
Power

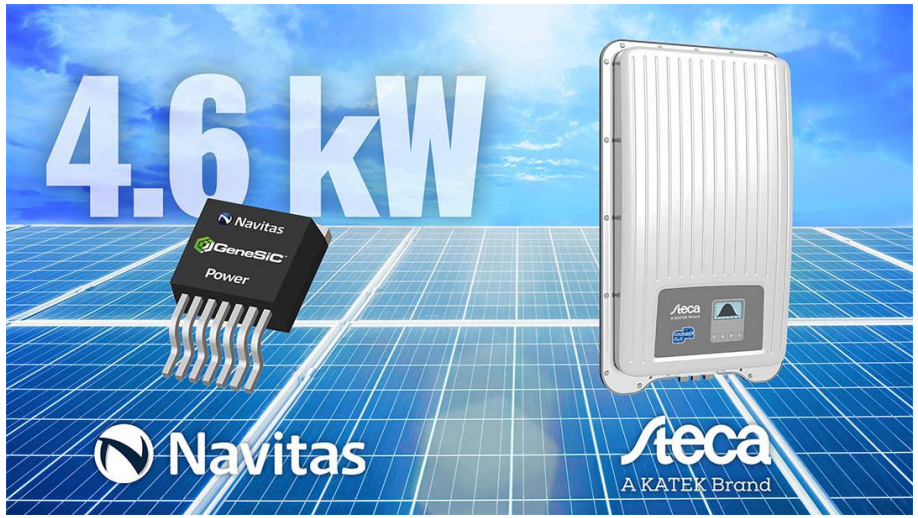
GaN + SiC for Solar & Energy Storage

Navitas



GeneSiC GaNFast™ Solar Inverters

GeneSiC Energy Storage



25°C cooler with GeneSiC

Market Potential (2)

- Residential Micro >$1.4B (GaN)
- Residential String >$1.0B (SiC)
- Commercial String >$1.0B (SiC)
- Energy Storage >$1.25B (SiC) *(50% attach rate)*

Total = >$4.65B

20 Customers in Development, Production

Advanced Energy, Alpha power solutions, ENPHASE, solaredge, GROWATT, CHINT, GOODWE, steca A KATEK Brand, SUNGROW Clean power for all, EXIDE TECHNOLOGIES, KACO new energy.

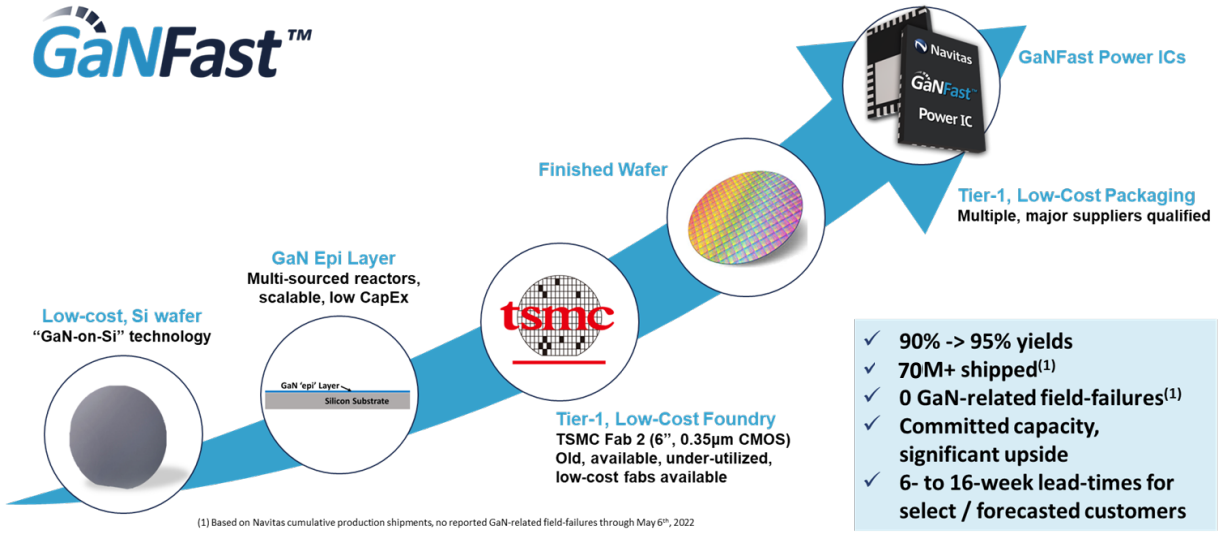
Navitas Strength & Opportunities

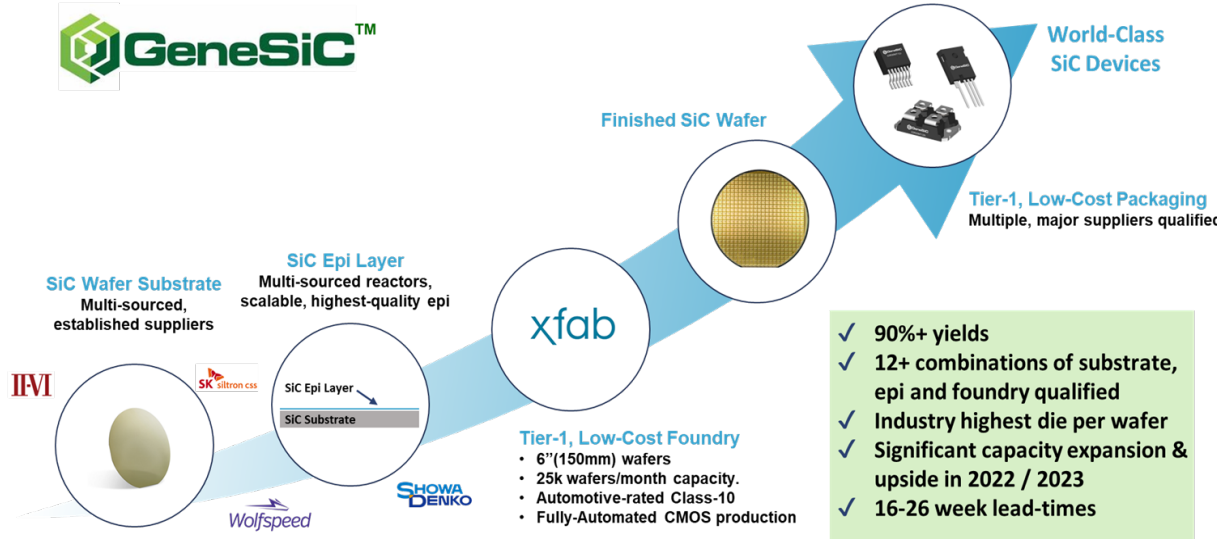
- Solar up 3x 2022-2027, more capacity than natural gas by 2026, coal by 2027
- Inflation Reduction Act: >$50B to solar, storage and wind
- Bus voltages rising to 1,500V – matches GeneSiC 3,300V capability

(1) Navitas est. 6.2 kW residential installation with silicon inverter at 97.5%, GaN at 98.5% efficiency.
(2) Market estimates for 2030, based on DNV and Navitas analysis

High Capacity, 50% Shorter Lead-times(1)

Navitas





- Tier-1 foundry partners, excellent manufacturing support
- High yields, low costs, flexible supply chains
- Long-term capacity agreements: GaN up 3x, SiC up 5x starting in 2023
- 50% shorter lead-times than industry typical

1) Industry lead-times per Jefferies Equity Research, August '22

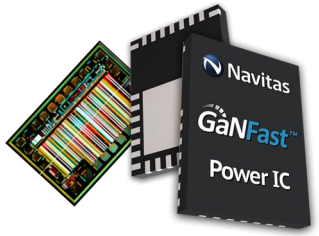
Leader in Sustainability: 150,000+ tons CO_2 Saved! (1)

Navitas

February '22 First GaN sustainability report based on global standards.

Every GaNFast™ IC saves

4 kg CO_2



- **4x-10x** lower component CO_2 footprint than silicon
- **28% lower** lifetime CO_2 footprint for chargers / adapters
- **Accelerates** transition from ICE to EV by **3 years**, saving **20%/yr** of road-sector emissions by 2050
- GaN + SiC save up to **6 Gton / year** by 2050

May '22 World's first semiconductor company CarbonNeutral® certified

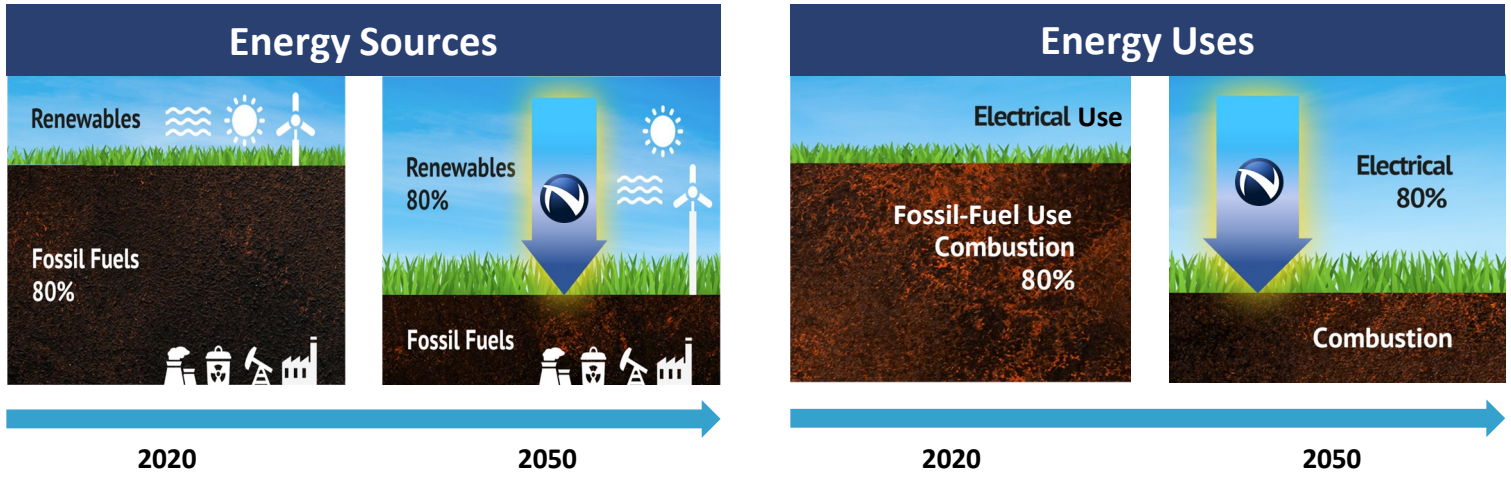
August '22 First 100,000 tons CO_2 saved

October '22 Recognized for industry-leading sustainability reporting

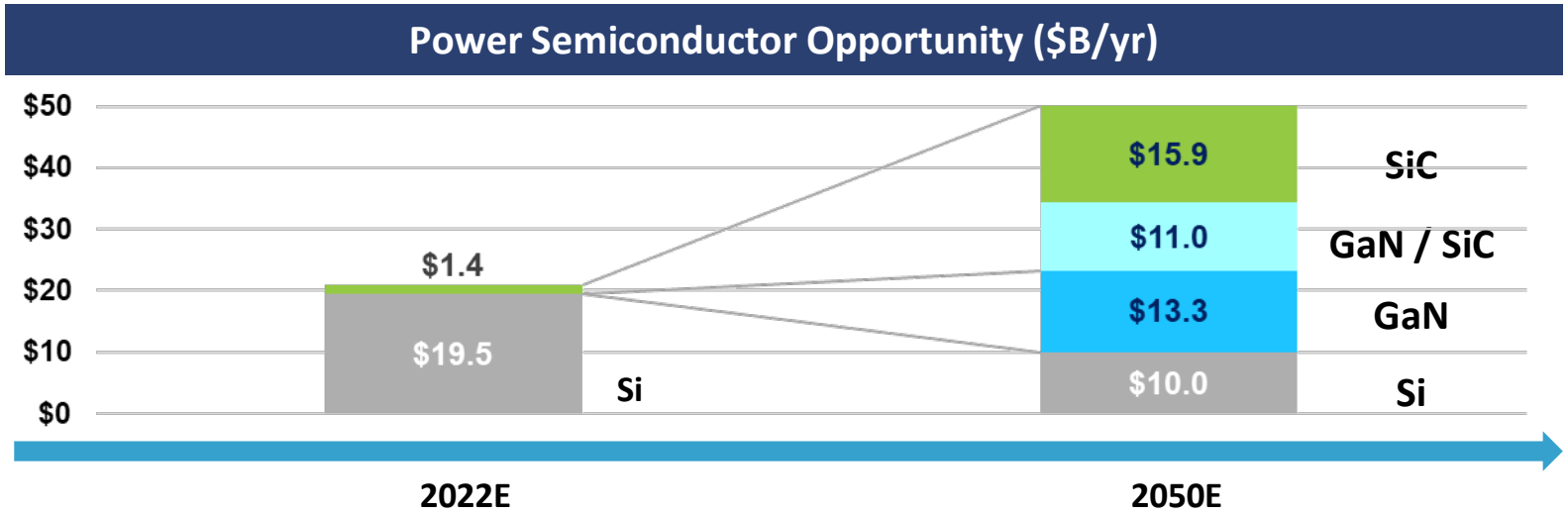
(1) Navitas estimates based on Earth-Shift Global, DNV life-cycle analysis, market growth. See 2021 Sustainability Report for more details. CO_2 saved as of March 2023

Mission: Electrify Our World™

Energy sources and uses are being electrified…



…creating a $40B GaN + SiC opportunity by 2050



Fossil-fuel vs renewable ratios adapted from IRENA 2020 "Global Renewables Outlook".
Shift required to meet "Transforming Energy Scenario, 9.5 Gton target in 2050", per Paris Agreement's 1.5°C rise.
Market opportunity $ from Yole Développement, 2020 and Navitas analysis.

Electrify Our World™

From:

20 W Mobile fast-chargers to
20 kW EV on-board chargers to
20 MW Grid-tied systems

Navitas GaNFast power ICs and GeneSiC power FETs and diodes drive efficiency, power density and lower system costs