

WOLFSPEED OVERVIEW



| 이태훈 부장 FSE

| DEC 1 2022

WOLFSPEED AT A GLANCE

Company Overview



241.3M
FY23 Q1 Revenue



World's First, Largest &
Only 200mm Silicon
Carbide Fab



\$1.3B Materials
Capacity Expansion



Borg Warner
\$500M Investment

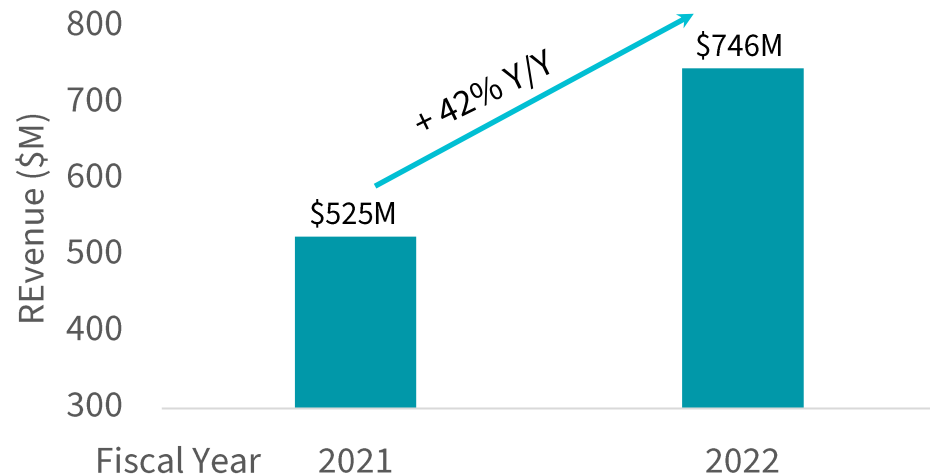


Partnership with
Jaguar Land Rover



First Fully Qualified
Silicon Carbide
MOSFET in 2011

Wolfspeed Annual Revenue (M)



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By the Numbers

#1

Producer of
Silicon Carbide
substrates

>60%

Wolfspeed makes more than
60% of the worlds Silicon
Carbide today

>90%

Wolfspeed manufactured
>90% of the Silicon Carbide
ever produced

400 years

Crystal growth team has 400
combined years of Silicon Carbide
growth experience

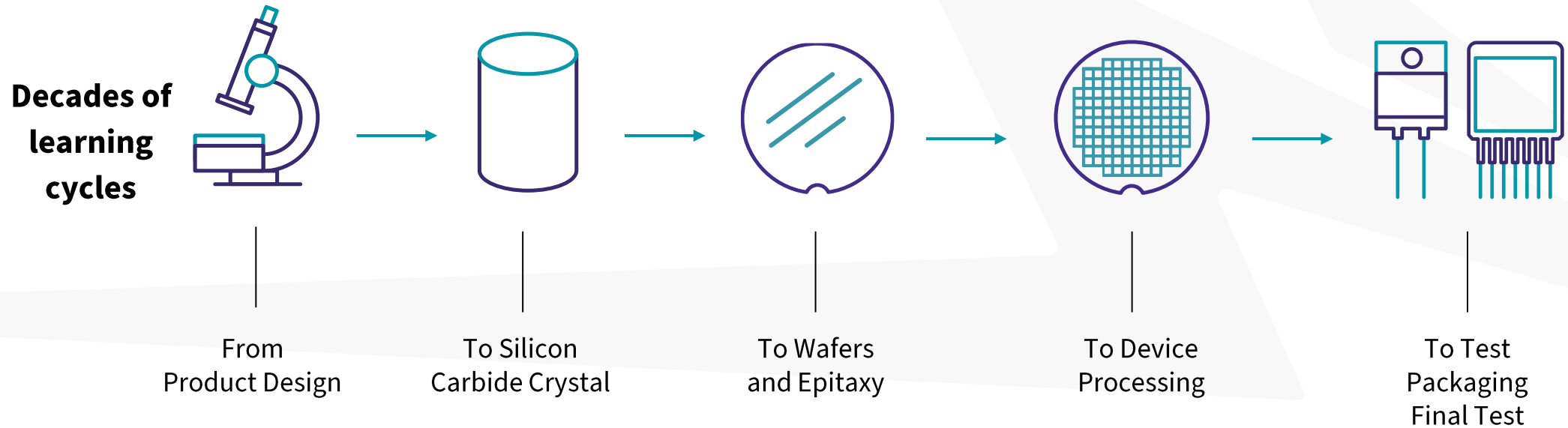
35+ years

Wolfspeed has been vertically
integrated making Silicon Carbide
semiconductors

7+ trillion

Silicon Carbide device field hours

35+ YEARS OF VERTICAL INTEGRATION BUILDS BETTER PRODUCTS



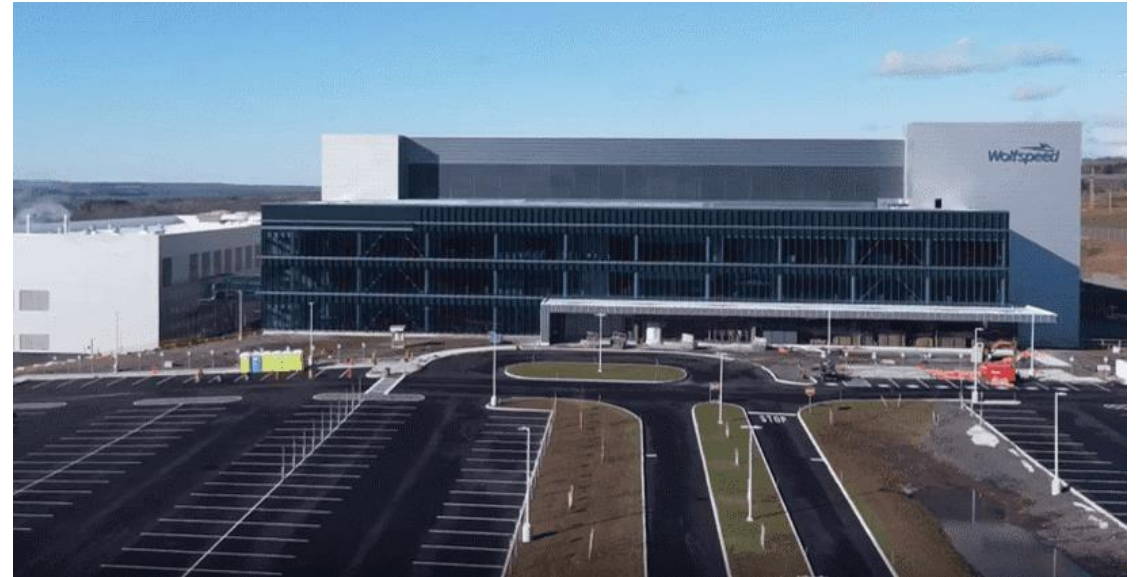
INCREASING CAPACITY TO ADDRESS STEEPENING DEMAND

LEADING THE INDUSTRY TODAY

- Wolfspeed currently produces ~ 60 % of the world's supply of Silicon Carbide.
- We are the first vertically integrated Silicon Carbide manufacturer.

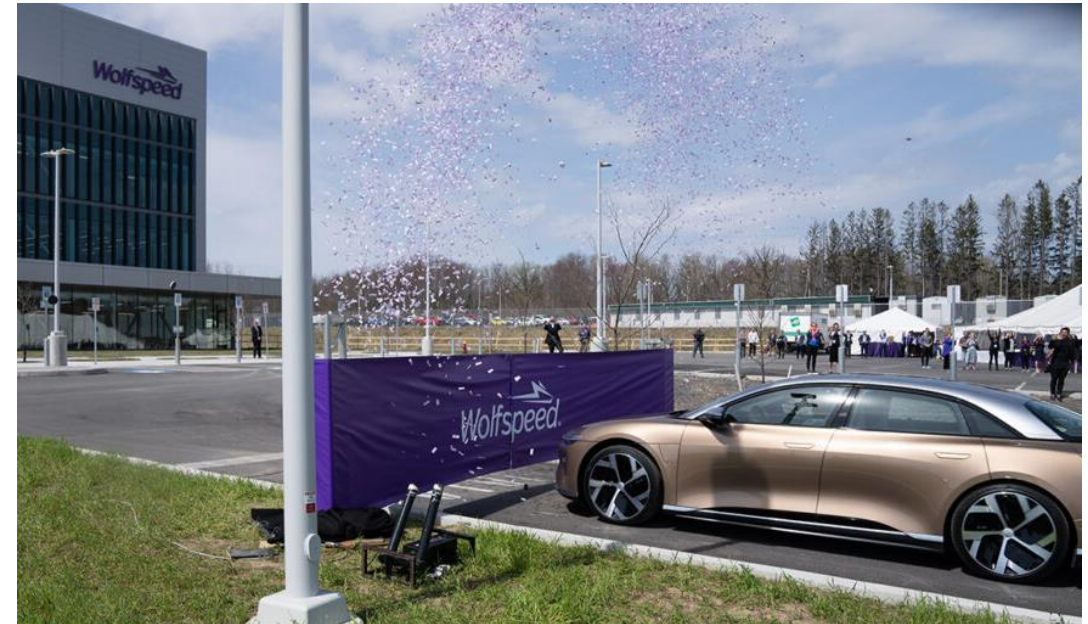
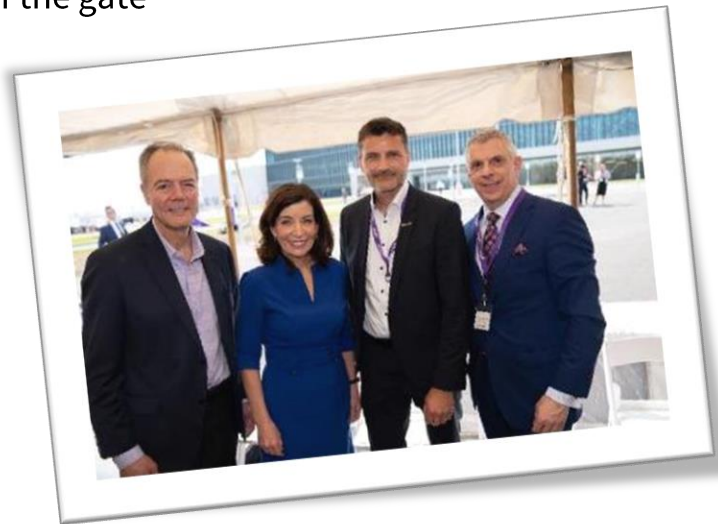
PREPARING FOR AN ELECTRIC-POWERED TOMORROW

- As of FY22 Q4 earnings call, Wolfspeed has a **2:1 CapEx to revenue** ratio.
- We are investing ~\$1 billion to support a significant increase in our production capacity.
- Additional investments will increase our materials capacity by 10x.



FIRST, LARGEST, ONLY 200mm SILICON CARBIDE FAB

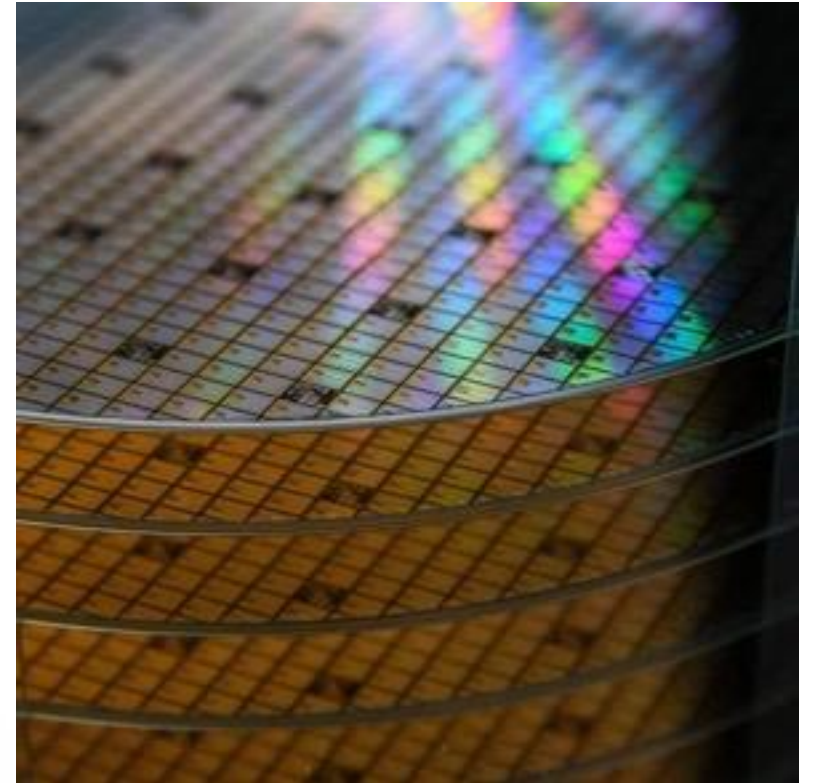
- In April 2022 we opened the doors to our Mohawk Valley wafer fab (MVF), with significant volume shipping beginning in 2023
- Qualification lots are currently in production
- Mohawk Valley is a “lights out” fab
- Automotive quality systems designed-in
- IATF certified out of the gate



A Lucid Air® powered by Wolfspeed XM3 power modules cut the ribbon at the opening ceremony.

WOLFSPEED'S MVF 200mm PROCESS IS STATE OF THE ART

- MVF is the first to adopt the overhead transport system and automated load ports in 200 mm Silicon Carbide manufacturing.
- Manufacturing systems supporting “big data” environment.
- MVF is fully automated and:
 - Reduces production touches from 10,000 to zero mitigating yield losses.
 - The Fab operates 24/7, even in the event of severe weather.
- There are few operators in the clean room; the 600 employees at MVF are tool technicians or engineers.
- The Fab has redundant power and water feeds for backup.



RECENTLY ANNOUNCED: SILER CITY FACTORY

This state-of-the-art Silicon Carbide wafer facility will:

- Increase Wolfspeed's Materials capacity by **more than 10x**
- Span **1.8 km²**(445 acres)
- Be highly-automated
- Create **1,800** new jobs by 2030
- Cover more than **92,903 m²** (1 million ft²)
- Supply our current and future fabs
- Focus on **200 mm wafers**



Architectural rendering of the new Siler City Factory

WOLFSPEED SILICON CARBIDE POWER PRODUCTS AT A GLANCE

STANDARD PACKAGE TYPES

Schottky Diodes and MOSFETs

- Up to 1700 V rating
 - Diodes: 600 V to 1700 V
 - MOSFETs: 650 V to 1700 V
- Up to 120 A current rating (package limited)
- AEC-Q101 automotive qualified products

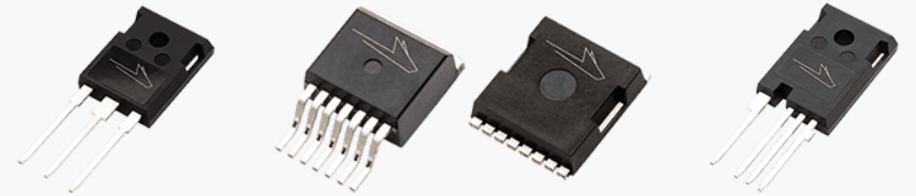
Power Modules

- Up to 1700 V rating
- Up to 760 A current rating
- AQC 324 automotive qualified modules

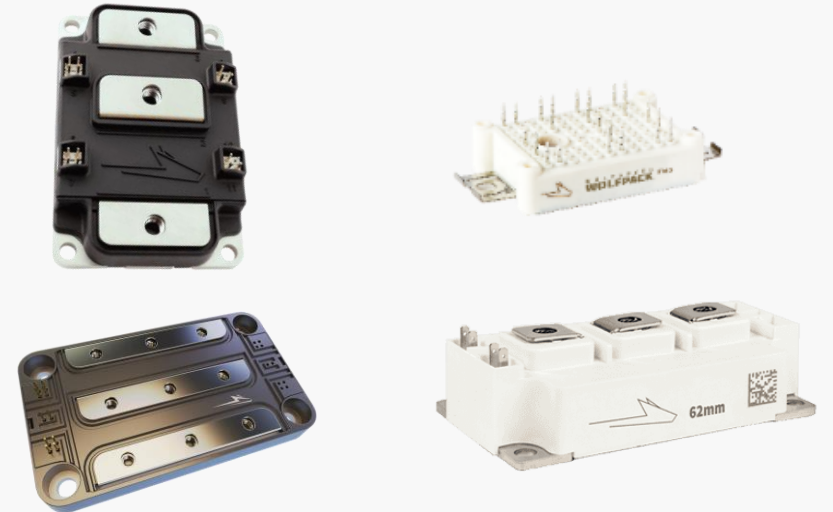
Bare Die Schottky Diodes and MOSFETs

- Up to 1700 V rating
- Up to 194 A current rating
- AEC-Q101 automotive qualified products

SCHOTTKY DIODES &
MOSFETS



POWER MODULES



WOLFSPEED DISCRETE POWER | PACKAGE GUIDE

MOSFETs →



TO-247-3
(Std. Package)



TO-247-4
(Kelvin Lead)



TO-247-4 LP
(Kelvin Lead Low Profile)



TO-263-7
(Smaller Drain Footprint)



TO-263-7 XL
(Larger Drain footprint)



TOLL
(TO-Lead Less)



U1
Top Side Cooled

Schottky Diodes →

A



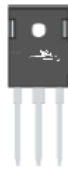
TO-220-2
(Std. Package)

D



TO-247-3
(Dual Die)

D1



TO-247-3
(Single Die)

E



TO-252-2
(Smaller Footprint)

F



TO-220-2
(No back metal)

G



TO-263-2
(Better thermals)

H



TO-247-2
(More Creepage)

I



TO-220-2 (ISO)
(Isolated metal tab)

Q



QFN 8x8
(Smallest footprint)

WOLFSPEED DISCRETE POWER | DEVICE NOMENCLATURE GUIDE

Example: C3M0060065D

C

3

M

0060

065

D

MOSFET

-	-	-	-	----	---	--	-
Production Status Prefix	Qualification Grade	Product Generation	Device Type	Typ Rdson @ 25C	Voltage Rating	Package	Product Revision
X = Experimental P = Prototype Q = Qual Vehicle BLANK = Production	C = Industrial E = Automotive	3 = 3 rd gen 2 = 2 nd gen ...	M = MOSFET	Ex: 0060 = 60mΩ	Ex: 065 = 650V	See Package Slide 2	→, 0, 1, 2... = pre-release →, A, B, C... = production

Example: E4D20120D

E

4

D

20

120

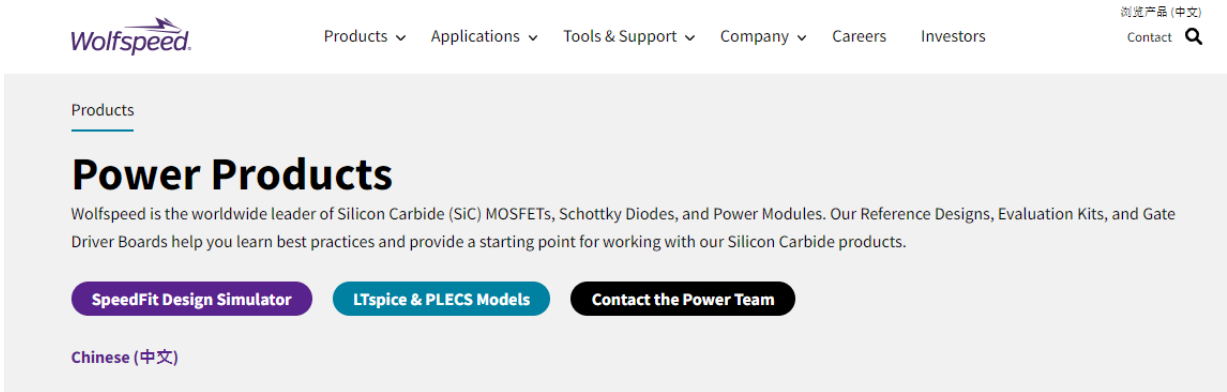
D

Schottky Diode

-	-	-	-	--	---	--	-
Production Status Prefix	Qualification Grade	Product Generation	Device Type	Current Rating	Voltage Rating	Package	Product Revision
X = Experimental P = Prototype Q = Qual Vehicle BLANK = Production	C = Industrial E = Automotive	2 = 2 nd Gen 3 = 3 rd Gen 4 = 4 th Gen 6 = 6 th Gen	D = Diode	Ex: 20 = 20A	060 = 600 V 065 = 650 V 120 = 1200 V 170 = 1700 V	See Package Slide 2	Not Currently Implemented

WOLFSPEED SILICON CARBIDE POWER PRODUCTS FINDING GUIDE

<https://www.wolfspeed.com/products/power/>



Wolfspeed

Products ▾ Applications ▾ Tools & Support ▾ Company ▾ Careers Investors

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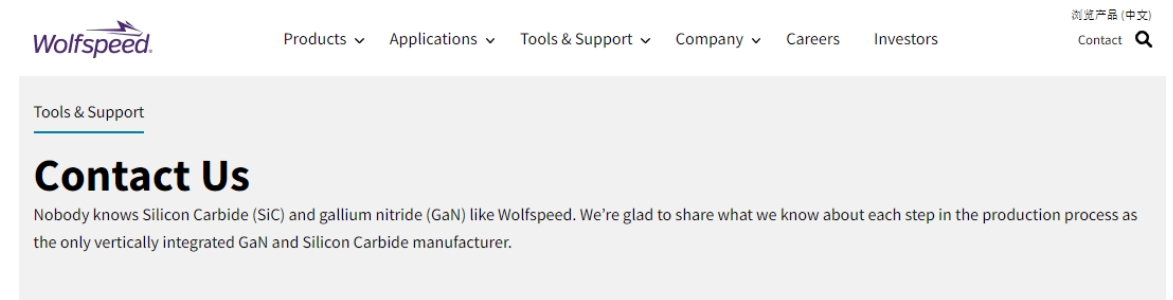
Products

Power Products

Wolfspeed is the worldwide leader of Silicon Carbide (SiC) MOSFETs, Schottky Diodes, and Power Modules. Our Reference Designs, Evaluation Kits, and Gate Driver Boards help you learn best practices and provide a starting point for working with our Silicon Carbide products.

[SpeedFit Design Simulator](#) [LTspice & PLECS Models](#) [Contact the Power Team](#)

[Chinese \(中文\)](#)



Wolfspeed

Products ▾ Applications ▾ Tools & Support ▾ Company ▾ Careers Investors

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Tools & Support

Contact Us

Nobody knows Silicon Carbide (SiC) and gallium nitride (GaN) like Wolfspeed. We're glad to share what we know about each step in the production process as the only vertically integrated GaN and Silicon Carbide manufacturer.

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[Home](#) > [Products](#) > Power Products



Discrete Silicon Carbide MOSFETs

Wolfspeed MOSFETs enable higher switching frequencies and reduce the size of components like inductors, capacitors, filters & transformers. Our Silicon Carbide MOSFETs replace silicon devices to enable lower switching and conduction losses with higher blocking voltages and avalanche capability.



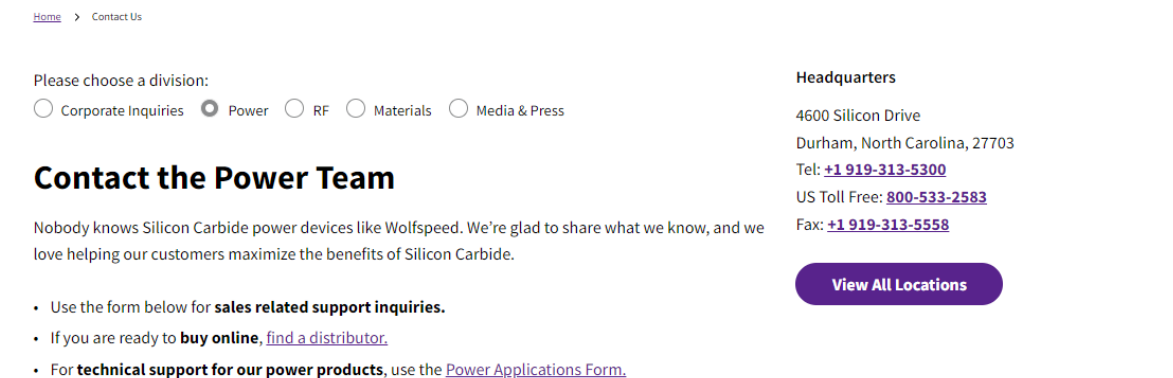
Discrete Silicon Carbide Schottky Diodes

Wolfspeed has the broadest portfolio of Silicon Carbide Schottky diodes, with more than six trillion field hours, lowest FIT rate, and 30+ years of experience in Silicon Carbide, combined with the fastest delivery times. Our diodes feature the MPS (Merged PiN Schottky) design which is more robust and reliable than standard Schottky barrier diodes.



Bare Die Silicon Carbide MOSFETs

With industry-leading low specific on-resistance over temperature, Wolfspeed's broad portfolio of bare die MOSFETs enables a system-level customization and efficiency to maximize power density. Wolfspeed offers one of the broadest Silicon Carbide power die product portfolios in the industry in terms of die layout and metallurgy for optimized module assembly.



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Please choose a division:

Corporate Inquiries Power RF Materials Media & Press

Contact the Power Team

Nobody knows Silicon Carbide power devices like Wolfspeed. We're glad to share what we know, and we love helping our customers maximize the benefits of Silicon Carbide.

- Use the form below for **sales related support inquiries**.
- If you are ready to **buy online**, [find a distributor](#).
- For **technical support for our power products**, use the [Power Applications Form](#).

Headquarters

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[View All Locations](#)



**We harness the power of Silicon Carbide
to change the world for the better**



Wolfspeed SiC 의 Heat Pump 및 Air Conditioning Solutions



: Residential & light commercial part (~ 11KW)

 **함정호** | DEC.1.2022

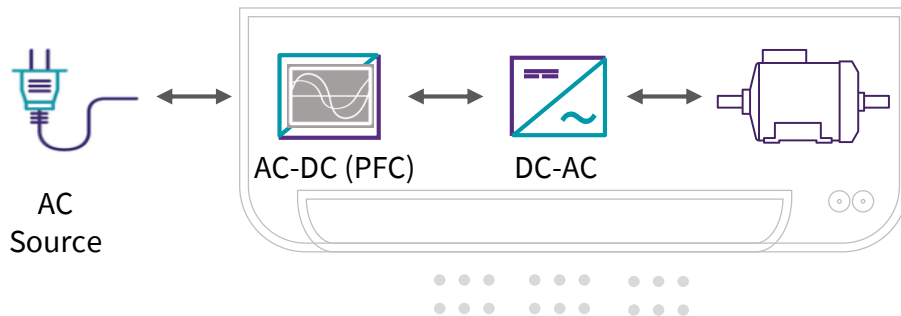
HEAT PUMPS AND AIR CONDITIONING

Key application factors:

- Meeting or exceeding efficiency standards
- Reduced cost of ownership
- Reduced audible noise

Why Silicon Carbide:

- Enables highest system efficiency: up to 2.16% system improvement by using Silicon Carbide MOSFETs & Diodes
- SCOP level increases for heat pumps
- Superior thermal performance
- Improves thermal density
- Enables less audible noise (>20kHz frequency)



>4kW Air Conditioning PFC and Compressor Drive



HEAT PUMPS AND AIR CONDITIONING IN ELECTRIC VEHICLES

Key application factors:

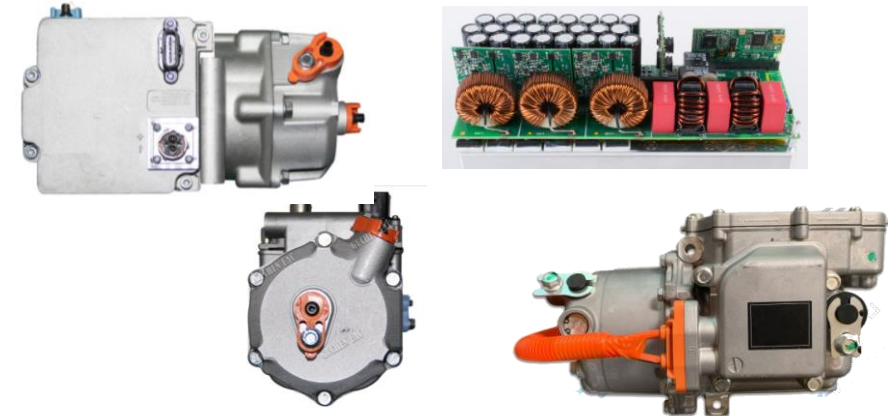
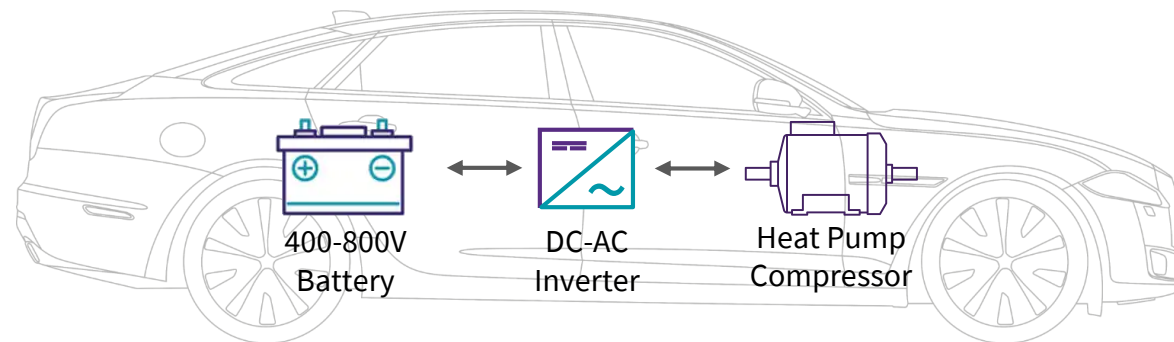
- Electronic Heat Pumps increase EV range by up to 19% in winter driving*
- 5% better efficiency under light load compared to IGBTs
- Reduced audible noise (>20kHz frequency)

Why Silicon Carbide:

- Automotive Qualified E-Series 1200 V MOSFETs
- Enables highest system efficiency
- Superior thermal performance
- Improves thermal density

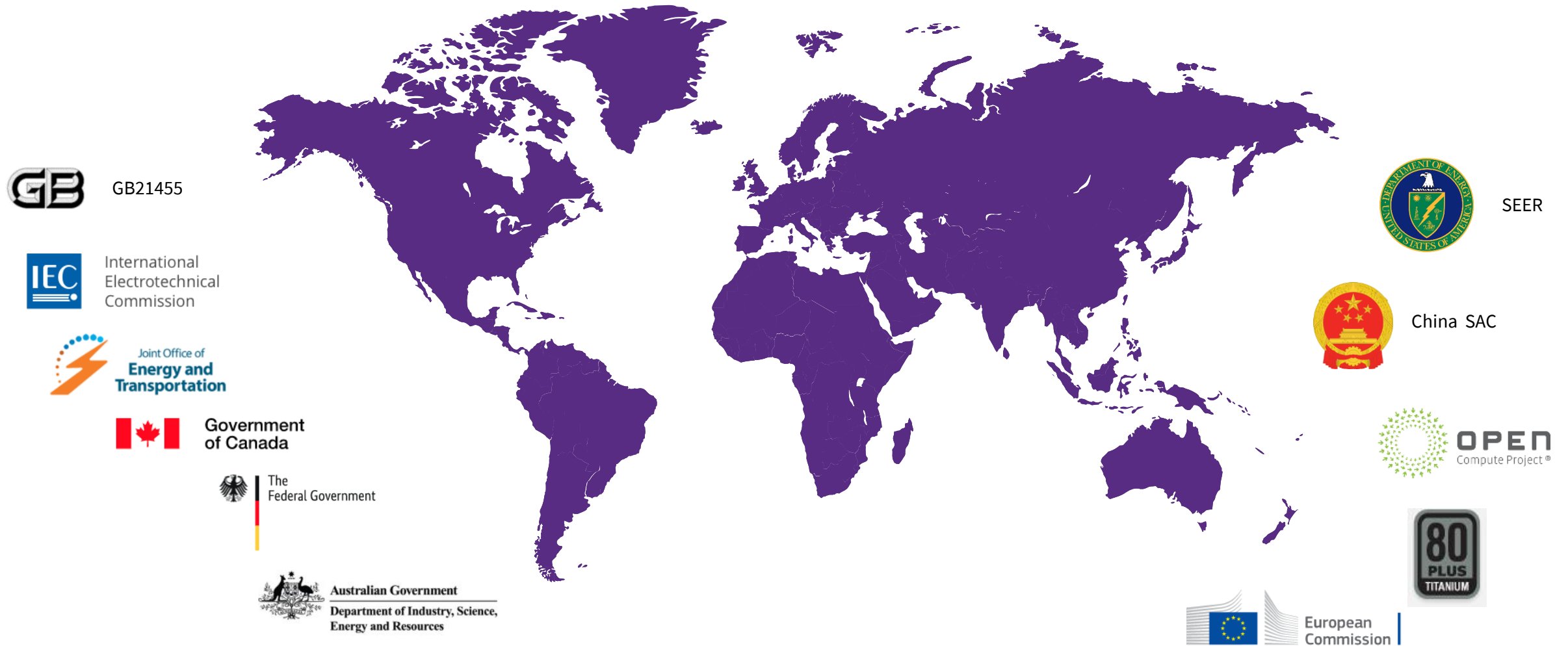


8 -11 kW E- Compressor



*<https://www.hyundaimotorgroup.com/story/CONT0000000000002995>

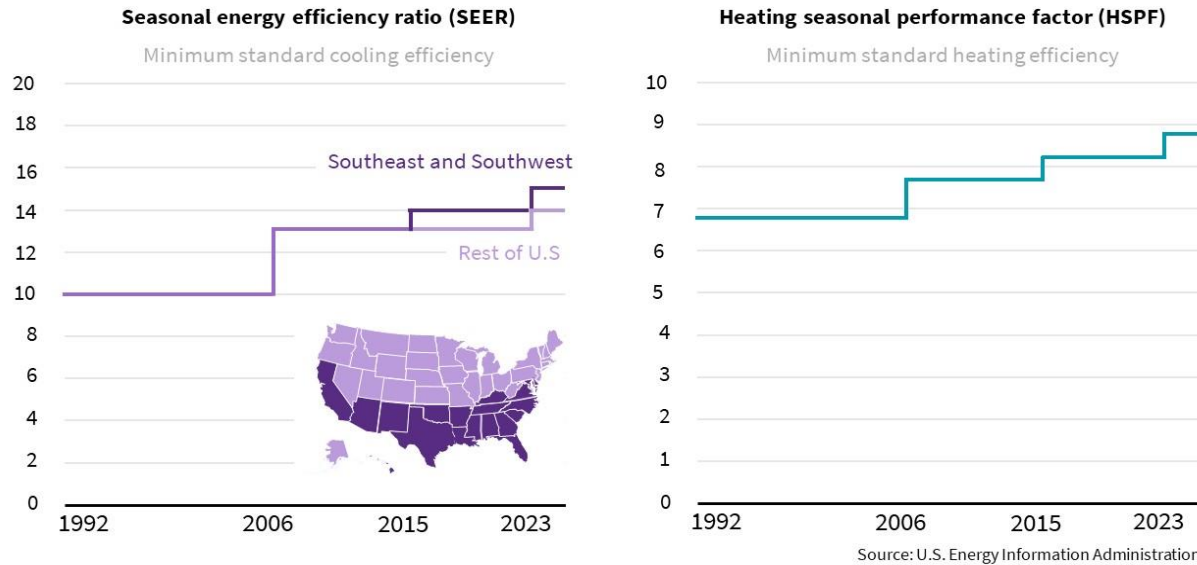
HEAT PUMP & AIR CONDITIONING EFFICIENCY STANDARDS ACROSS THE WORLD



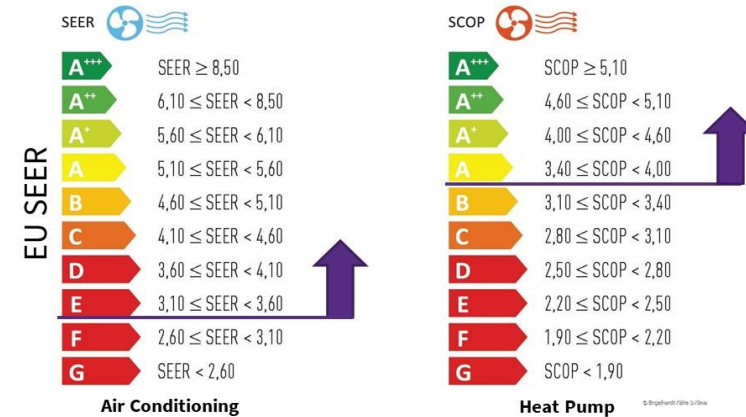
GLOBAL ENERGY EFFICIENCY STANDARDS INCREASING

American Seasonal Energy Efficiency Ratio (SEER)

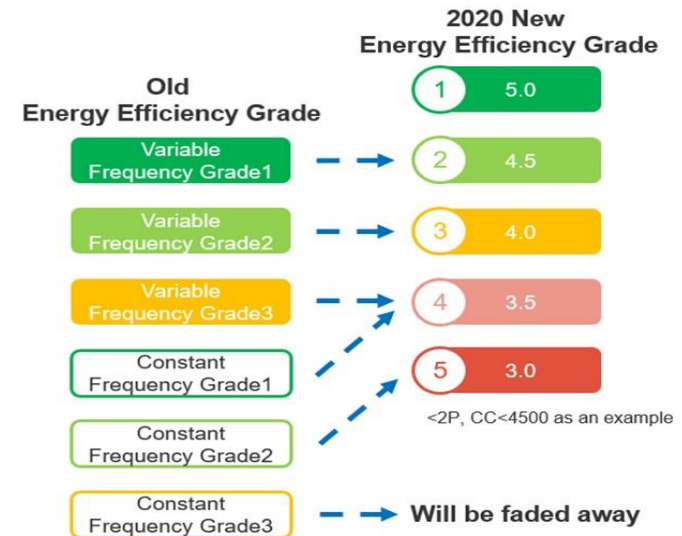
Performance standards for residential central air-conditioning equipment and heat pumps



European Minimum ESEER & Coefficient of Performance

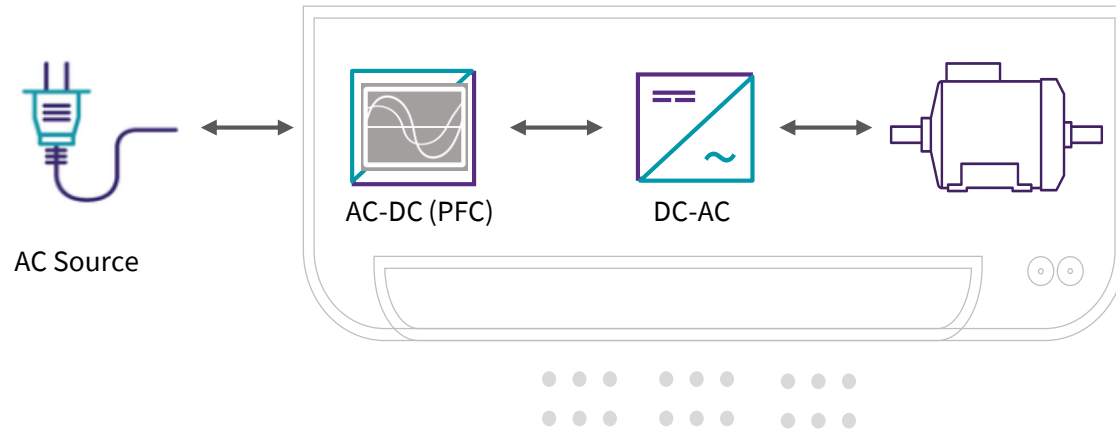


China: GB21455 Efficiency Standards



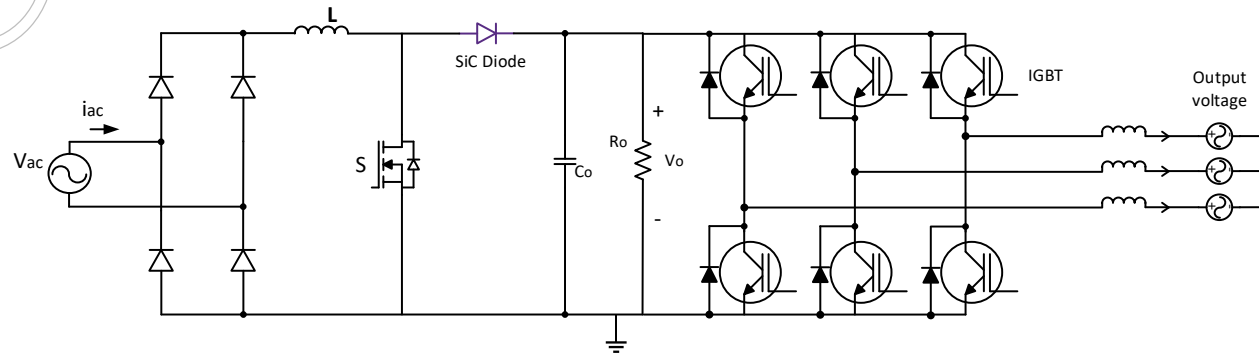
- Increased energy use and its impact on the environment are driving more stringent heating and air conditioning efficiency regulations world-wide
- American SEER ratings increasing again in 2023
- ESEER and SCOP levels are increasing in EMEA
- China's latest standards are leading the change to SiC in air conditioning now

IMPROVING EFFICIENCY WITH DROP-IN SILICON CARBIDE DEVICES



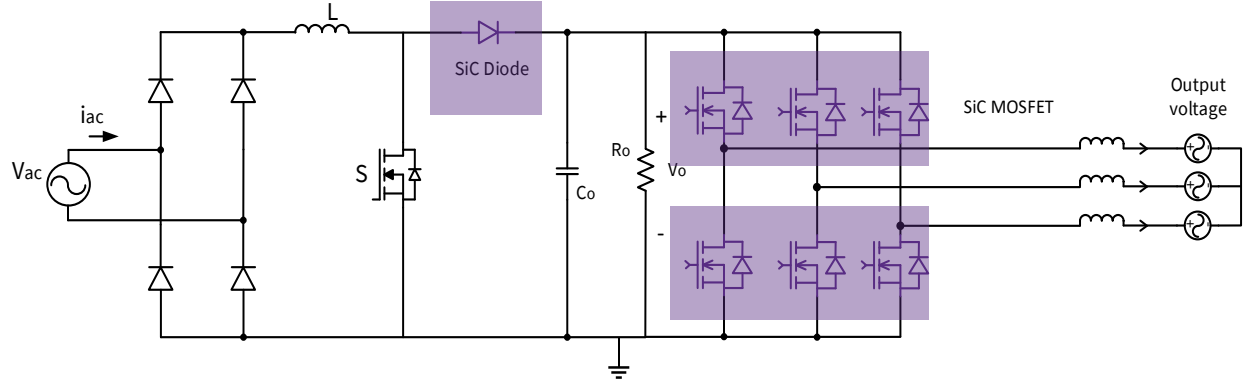
- Modeled 4kW compressor
 - 5kHz motor frequency

Existing IGBT model:



ACHIEVING GREATER EFFICIENCY IS EASIER WITH SIC

4 kW, 5 kHz
frequency motor
simulation @
50% duty cycle:



Upgrading the AC-DC PFC

Upgrading the inverter

= Full Silicon Carbide solution

HOW

- Replace silicon PIN rectifier with SiC Schottky diode (multiple topologies available)

- Changing the Inverter from IGBT to SiC in same simple 6-switch configuration

- Simple drop-in replacements

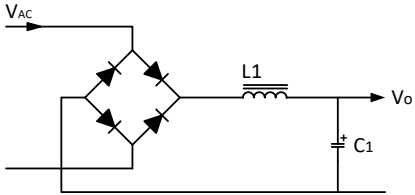
WHY

- 1.5% efficiency improvement over silicon boost PFC
- **60W reduced power consumption**

- 0.66% improvement in system efficiency over Si IGBTs
- **26W reduced power consumption**

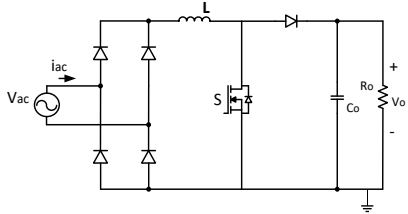
- Total reduction **in losses of 86W**
- 2.16% more efficient system

OPTIONS FOR UPDATING YOUR PFC



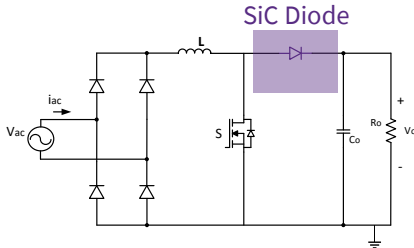
Bridge rectifier plus LC PFC

- Super simple
- Big size and heavy
- Lowest cost



Active boost PFC

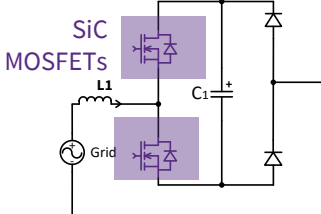
- Rectifier then boost
- Most popular to implement
- Moderate cost
- 96% efficiency



Active boost PFC with SiC diode

- Rectifier then boost
- Most popular to implement
- 96-98% efficiency

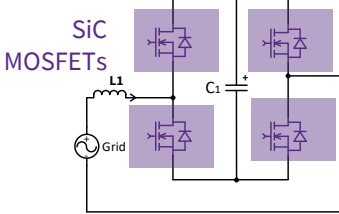
650 V SiC Diodes



Semi-bridgeless totem pole PFC

- Semi bridgeless – lower losses, high power density
- 98.9% efficiency

650V SiC MOSFETs



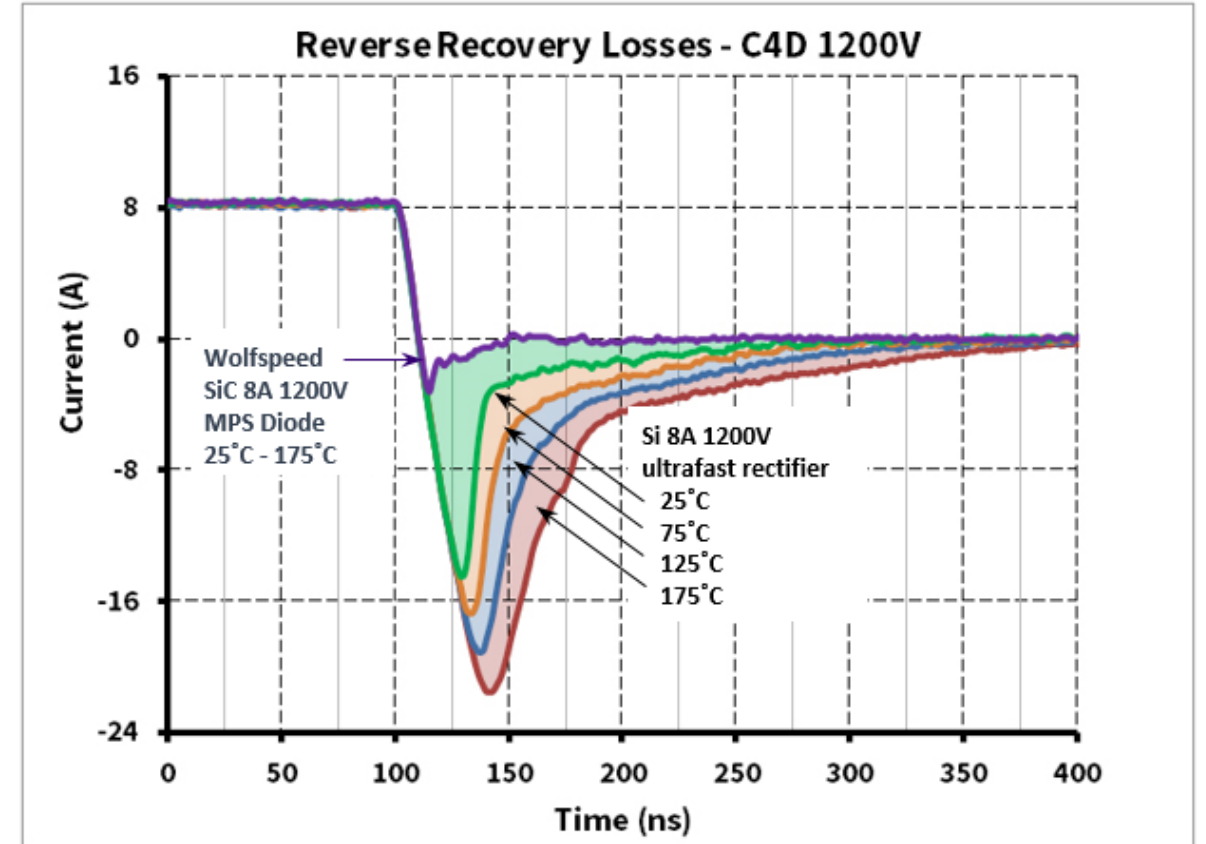
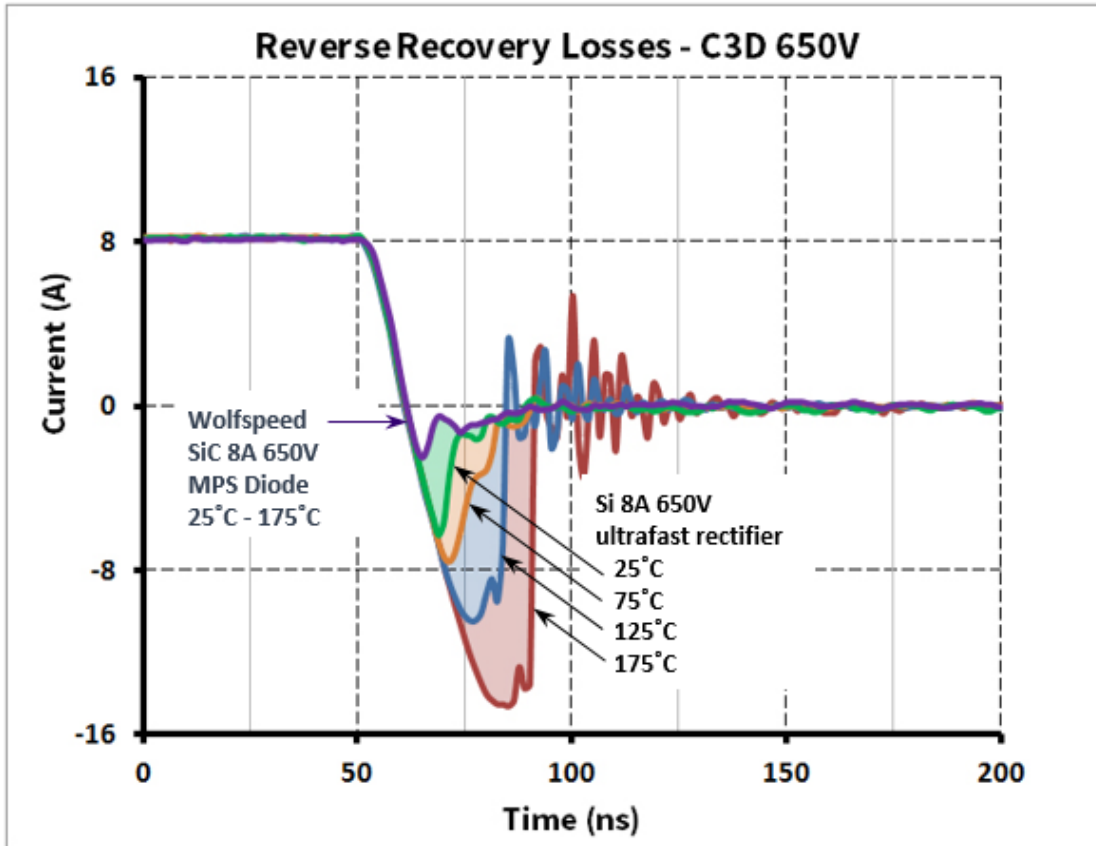
Bridgeless totem pole PFC

- Bridgeless – lower losses, high power density
- 99.2% efficiency

650 V SiC MOSFETs



SIC DIODES ENABLE MAGNITUDES LOWER REVERSE RECOVERY LOSS

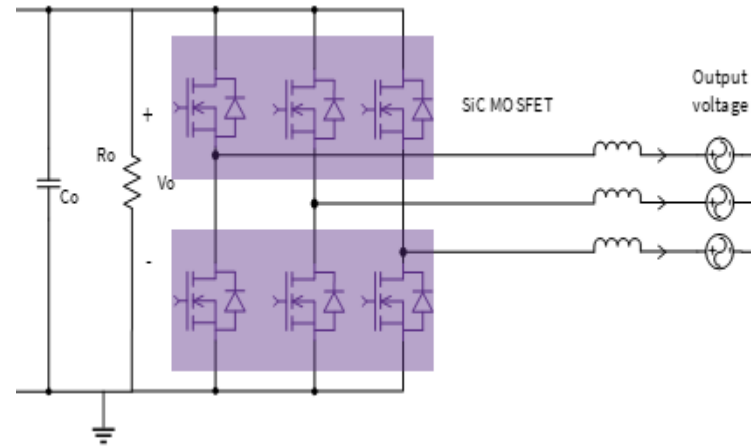


- SiC Schottky ~zero reverse recovery charge (Q_{RR}) replace high-loss silicon PIN diodes
- Schottky losses are capacitive and not temperature dependent for more stable performance

MOTOR DRIVER LOSSES FOR IGBT VS. SILICON CARBIDE MOSFET – 5/16KHZ

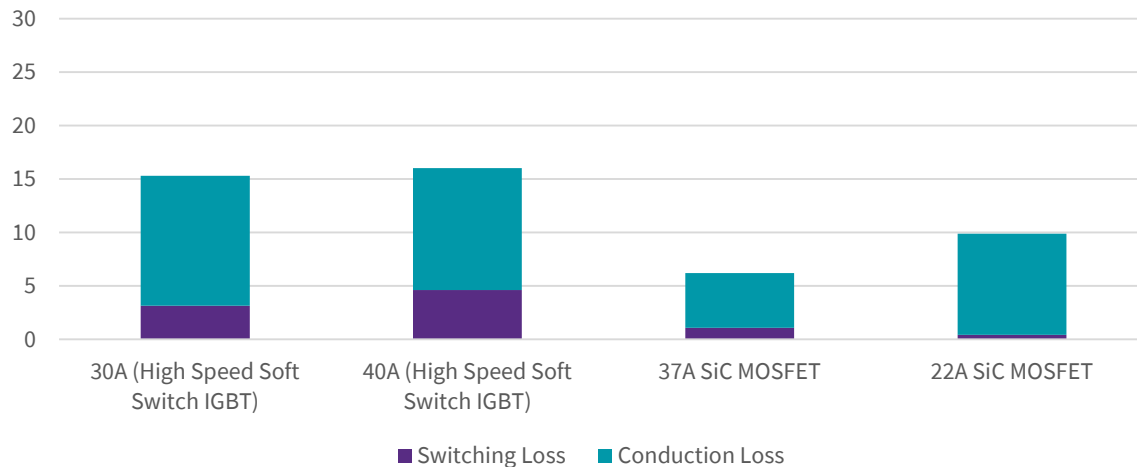
- SiC is the choice to meet higher efficiency level while achieving a smaller, lighter, quieter systems
- As frequency is increased, SiC advantage widens
- Larger rated IGBTs only improve efficiency until switching losses dominate
- Alternatively, a designer can use SiC based system to:
 - Increase system power output at a given efficiency
 - Improve thermal performance... maybe remove a fan
 - Increase system reliability and lifetime

Motor Driver Test Conditions



Power Factor	0.9
Frequency	5/16 kHz
Power Level	4 kW
Duty Cycle	50%
Vout	240 V
Vdc_link	400 V

Switching Losses at 5kHz



Switching Losses at 16kHz



SILICON CARBIDE SOLUTION PAYBACK = 195 DAYS

Payback rate scenario:

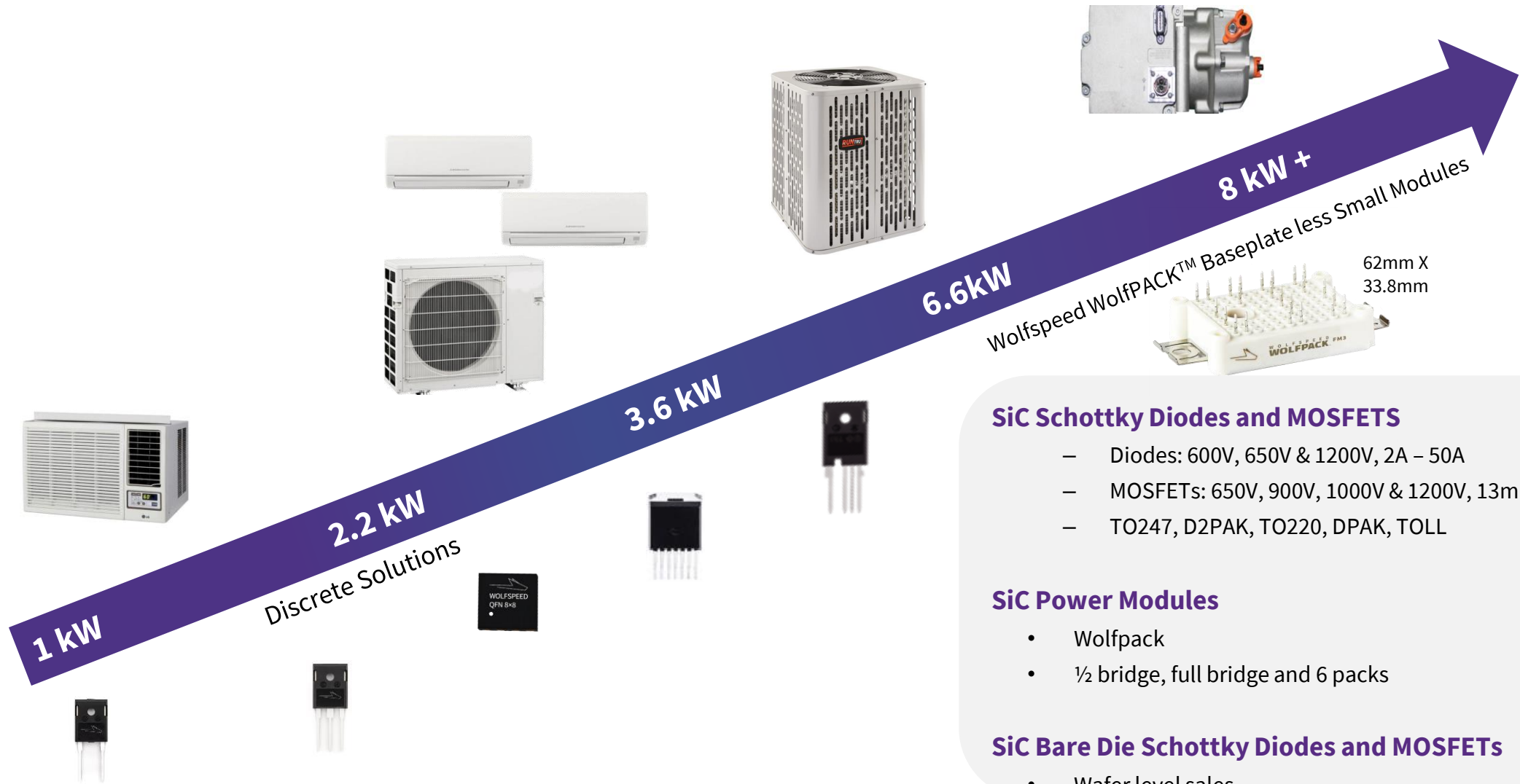
- You replace competitive 650-V IGBTs in your unit with Wolfspeed 650-V SiC MOSFETs. This drop-in solution is more expensive up front.
- You use your unit for 15 years, saving a total of **2,838 kWh**
- With SiC's efficiency, you would only have to run your unit for **195 days** to be paid back for making the switch from IGBTs to SiC.

The total cost of ownership for moving to SiC:

Rated Power	4000	W
Expected Efficiency Improvement	2.16	%
Power Savings	86.4	W
Hours/day operating	6	Hours
Duty Cycle	50%	
kWh/year usage	4380	kWh
kWh/year savings	189.2	kWh
Electricity cost	0.64	Euro/kWh
Annual Operating Cost	2803	Euro
Annual Savings	121.1	Euro

*Electricity cost = Germany's rate as of November 2022.

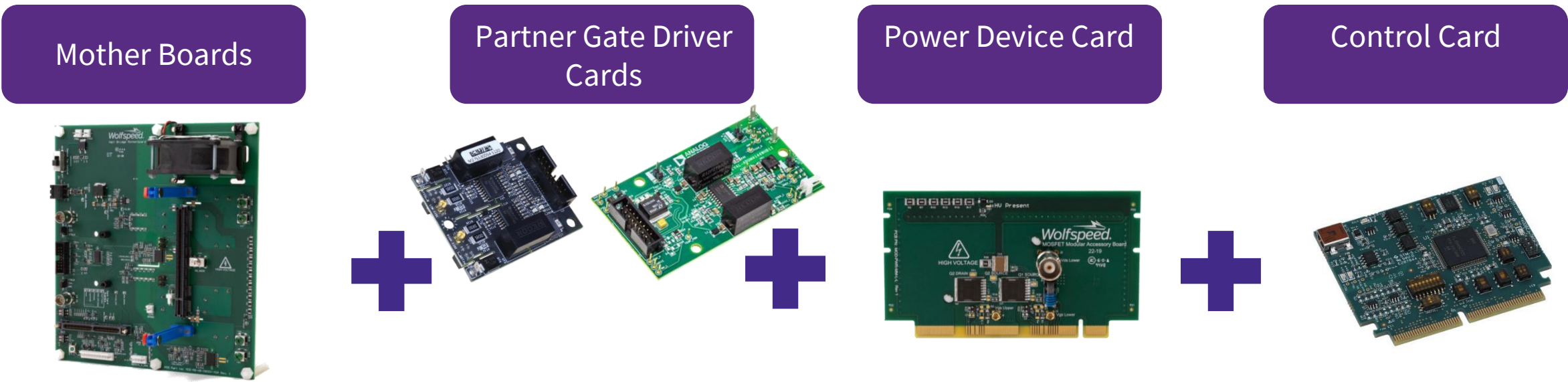
WOLFSPEED SILICON CARBIDE POWER CONTINUUM



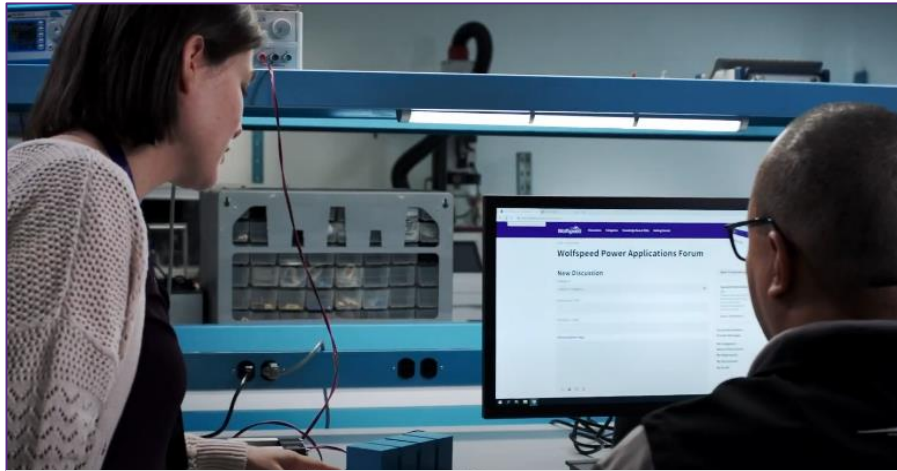
QUICKLY EVALUATE SILICON CARBIDE WITH SPEEDVAL KIT™

New discrete device evaluation platform launching January 2023

- Single test platform to support almost all discrete devices
 - 600 →1200V SiC MOSFETs and Schottky diodes
- Freedom to select from a range of gate drivers from industry leading partners
 - Analog Devices, Skyworks, Texas Instruments, Broadcom, NXP, MPS
- Ability to run additional topologies
- Can utilize MOSFET daughter cards and/or gate driver daughter cards for rapid prototyping

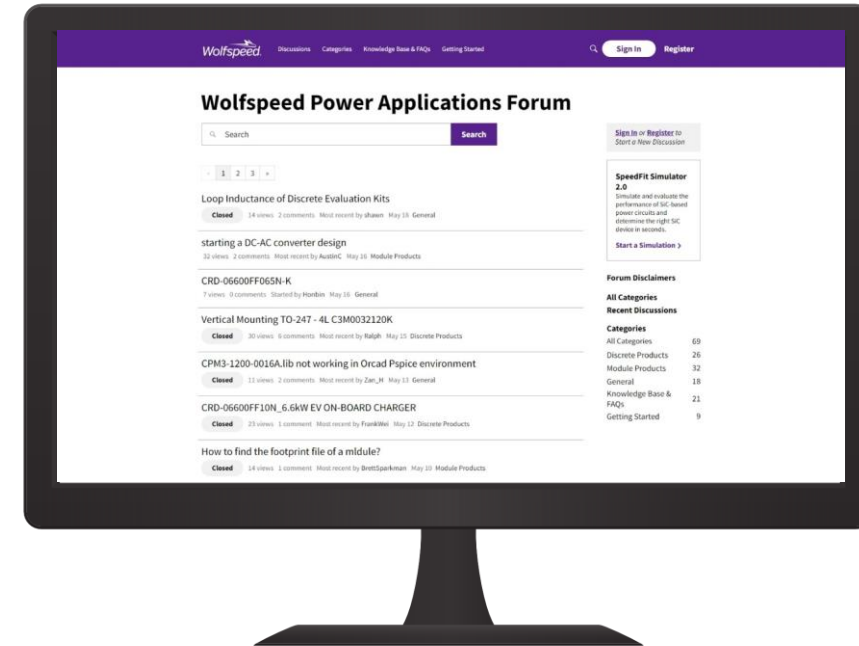


WOLFSPEED POWER APPLICATIONS FORUM



New support platform launched January 2022

The Wolfspeed Power Applications forum allows you to connect directly with Silicon Carbide applications engineers. Join our community and participate in technical dialogue that will help you advance your design. Access our knowledge base, ask technical questions in a community forum or reach us through private chat.



Power Applications Forum
forum.wolfspeed.com

Knowledge Center

Discussion

Private Chat

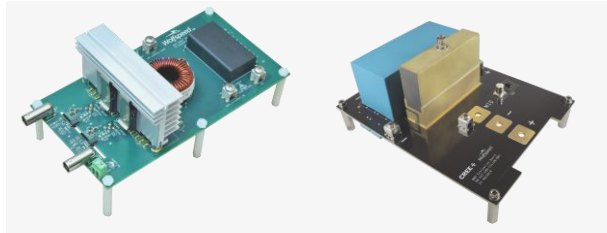
WOLFSPEED DESIGN SUPPORT TOOLS

Enabling faster and easier design with Wolfspeed Silicon Carbide



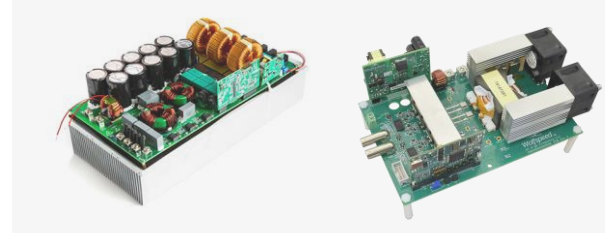
Power Applications Forum

[Learn more](#)



EVALUATION KITS

Reduce design resource investment and enable fast characterization of Silicon Carbide discrete and module packages.



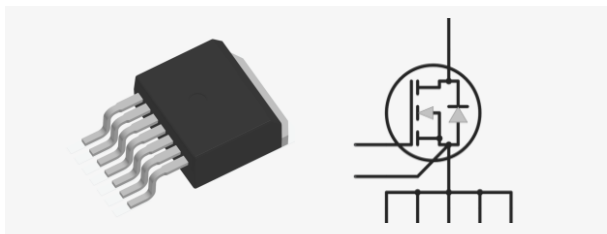
REFERENCE DESIGNS

Create rugged and reliable systems using Reference Designs and Demo Boards designed for power applications from 2.2kW up to 600kW.



GATE DRIVER REFERENCE DESIGNS

Quickly understand and implement our designs into your end-system with companion gate driver evaluation tools.



CAD MODELS, SYMBOLS AND FOOTPRINTS

OrCAD, Altium, Eagle, KiCad formats



SPEEDFIT™ 2.0 DESIGN SIMULATOR

Accelerate the design process with the industry's most comprehensive system-level circuit simulator for Silicon Carbide power applications.



LTSPICE & PLECS MODELS

Simulate quickly and accurately with our library of LTSpice and PLECS models.



We harness the power of Silicon Carbide

